Re-engineering Carbon Cycling for Resource Recovery from Waste Streams

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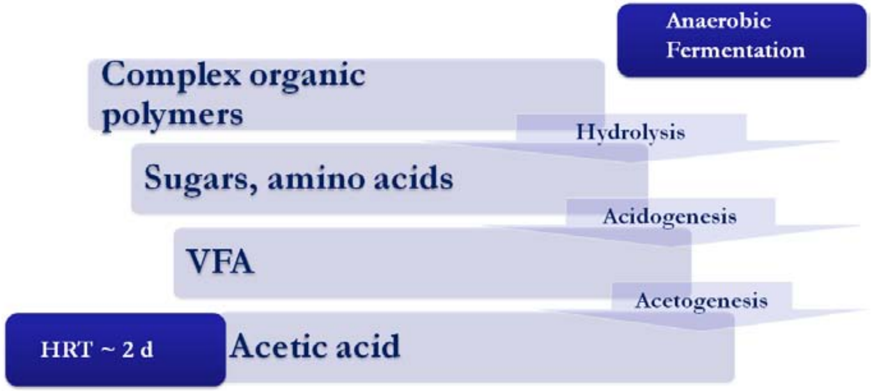
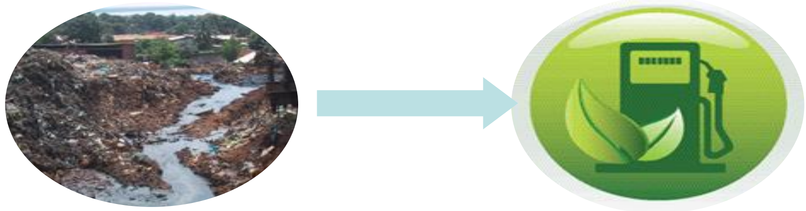
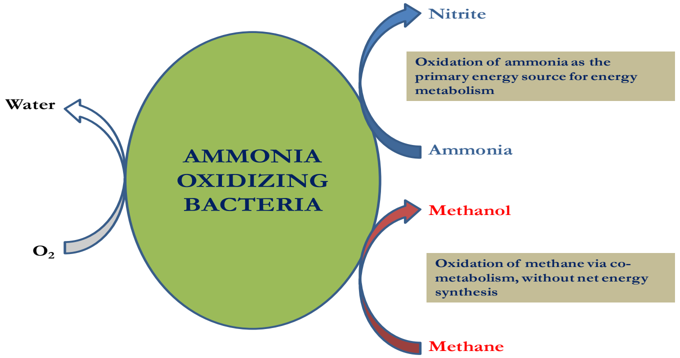
This presentation focuses on



Foundation for resource recovery through anaerobic C-conversions



Options for carbon recovery to fuels and chemicals (think beyond CH_4)



Resource efficient options for wastewater treatment and sanitation

Anaerobic Digestion

Complex organic polymers

↓ Hydrolysis

Sugars, amino acids

↓ Acidogenesis

VFA

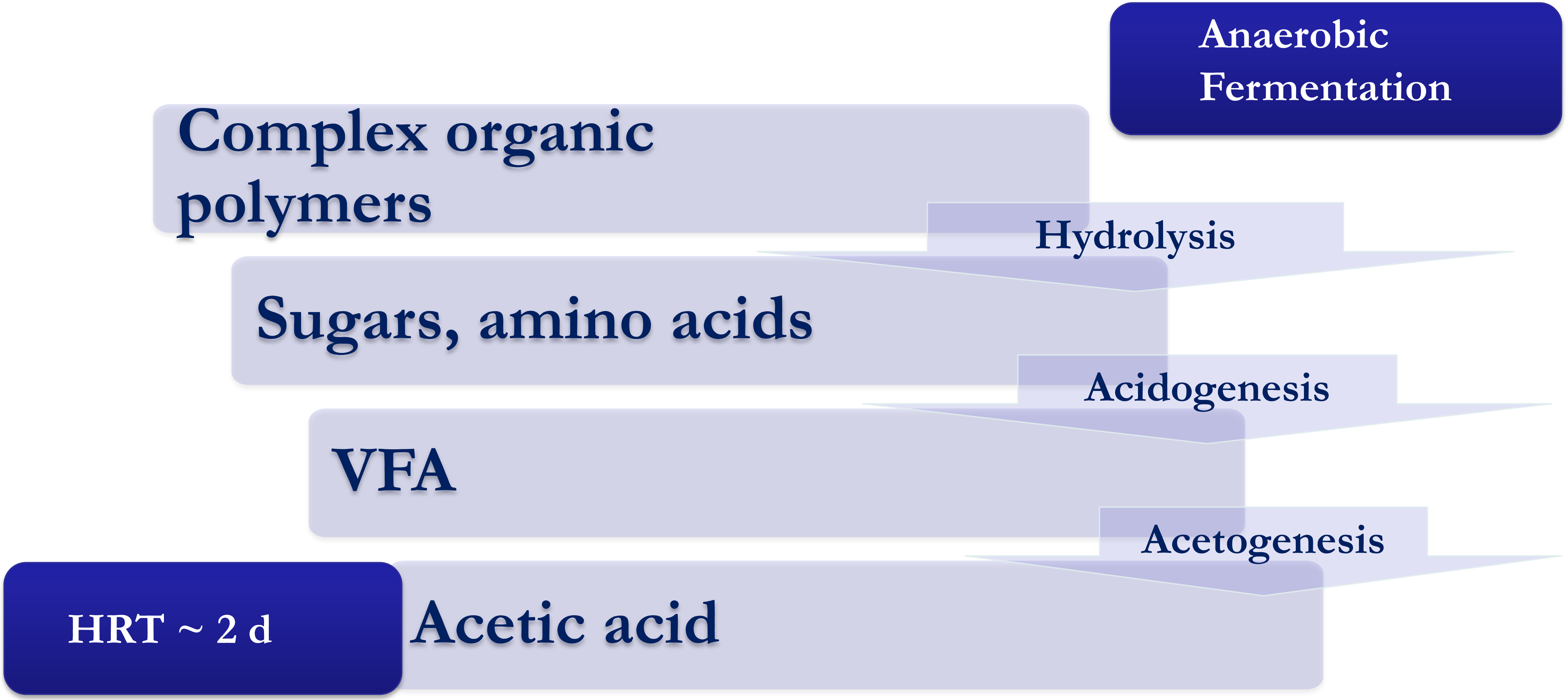
↓ Acetogenesis

Acetic acid

↓ Methanogenesis

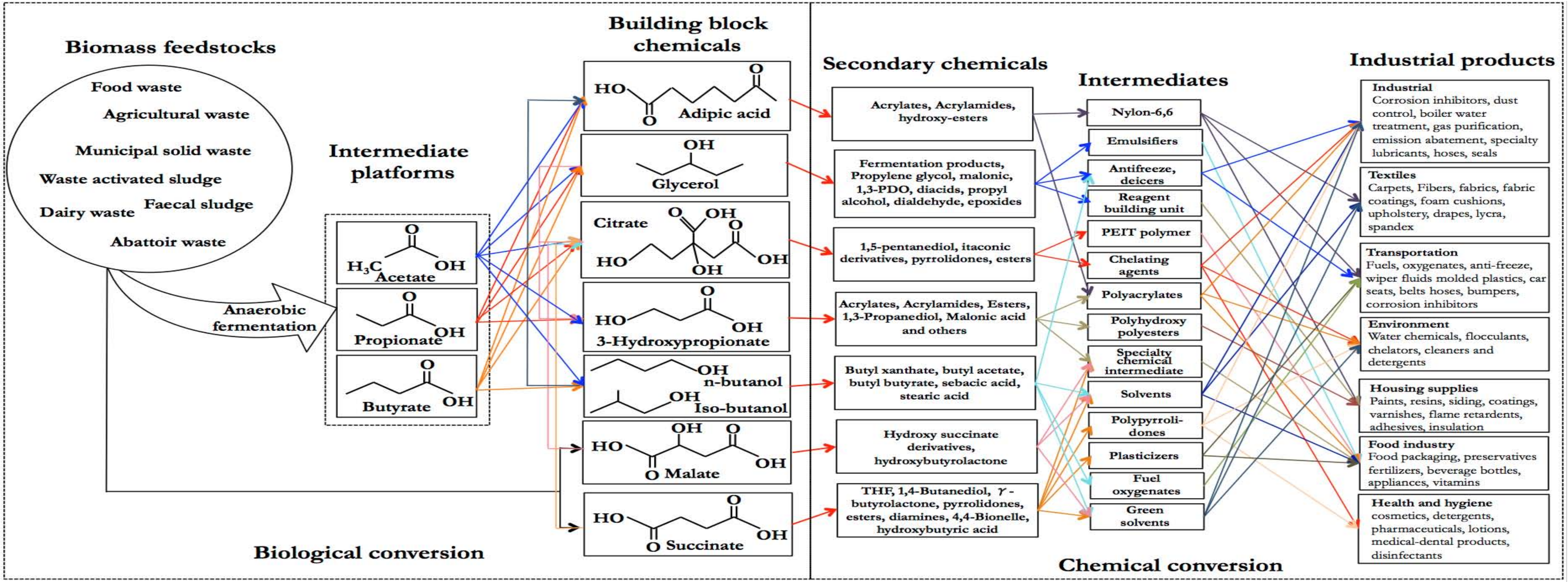
Methane

HRT > 10 d



- Fermentation (still using mixed microbial consortia) is more advantageous than just anaerobic digestion
- Fermentation can be incorporated into existing digestion processes

Fermentation as a platform for resource recovery



I. Strategies to increase carboxylic acid production from anaerobic fermentation of food waste

Variables tested (T=35^{o}C)

- Organic loading rate
  - 10 and 25 kg COD/m^3-day
- pH
  - 6.5, 7.0, 7.5, 8.0, 9.0
- Solids retention time
  - 2 d, 4 d, 6 d

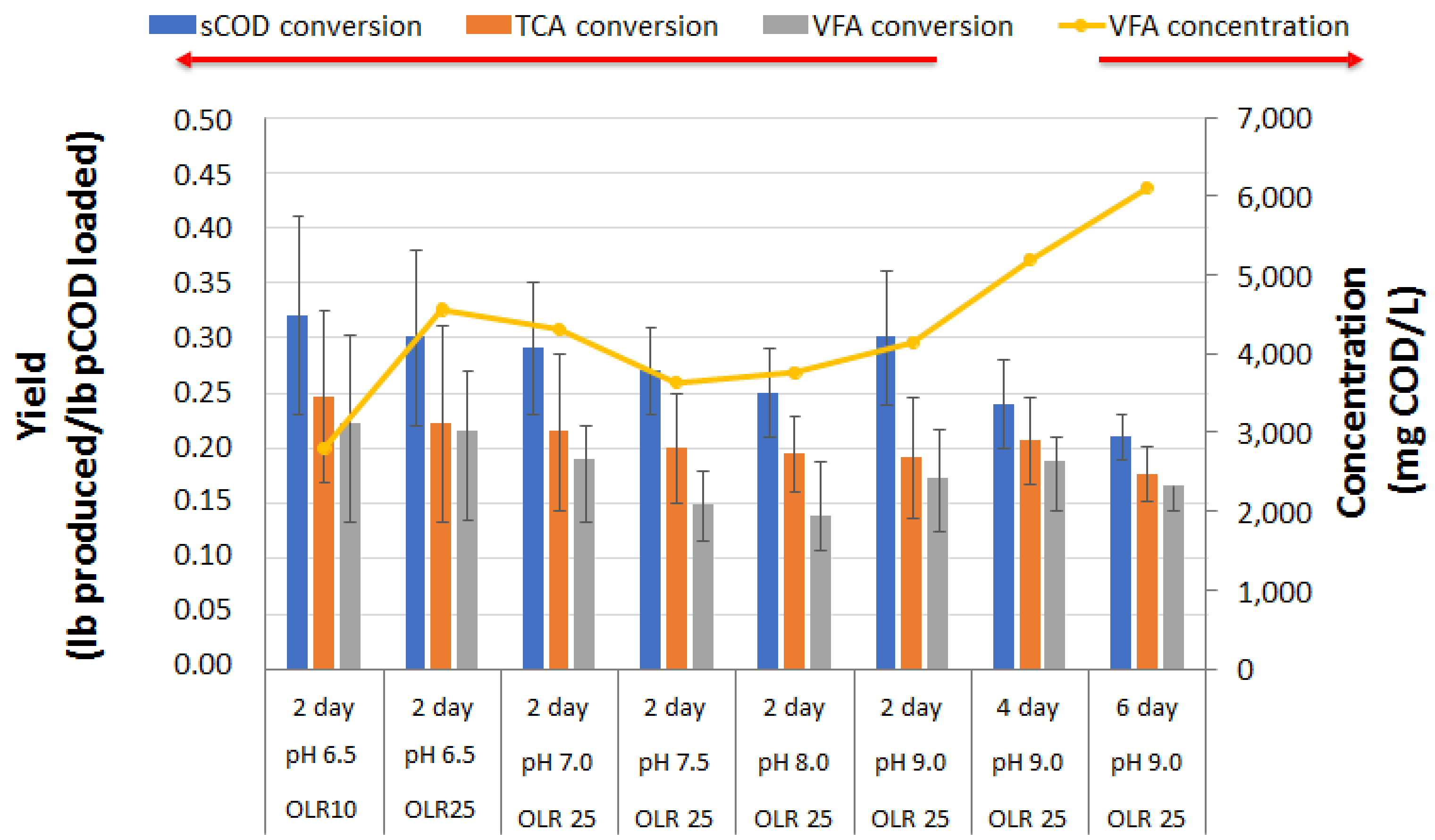
Performance indicators

- sCOD yield
- Total carboxylic acid yield
- VFA yield
- TCA concentration
- VFA concentration

$$Yield = \frac{Effluent\ (sol) - Influent\ (sol)}{pCOD_{in}}$$

Pavlakis *et al.*, unpublished

Fermentation experiments were focused on defining strategies to maximize TCA and VFA production



No difference in yield for OLR 10 vs OLR 25

…but VFA concentrations are higher in OLR25

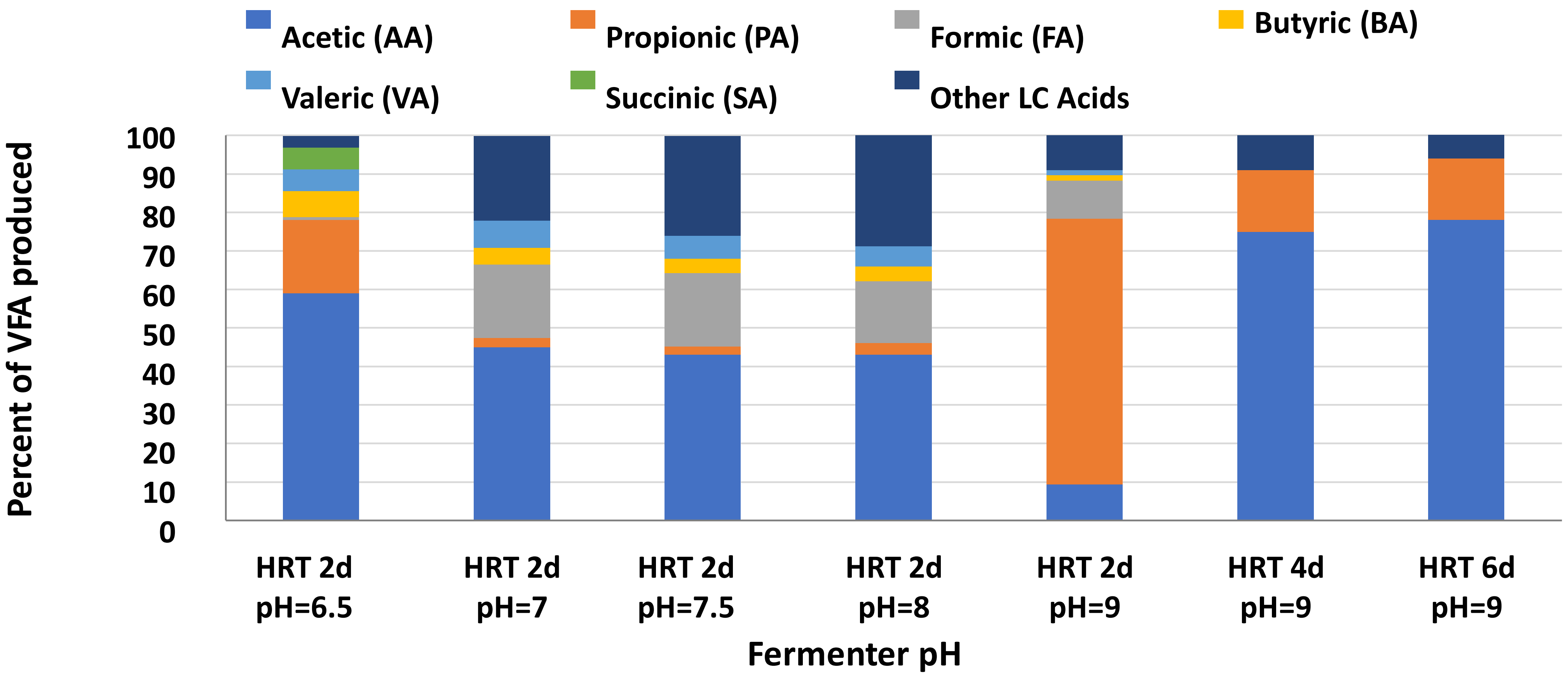
Fermentation at higher pH did not improve yield or effluent concentrations

Increasing fermenter SRT at alkaline pH increased effluent VFA concentrations and fractions

Non-TCA sCOD needs to be characterized to expand valorization options

Pavlakis *et al.*, unpublished

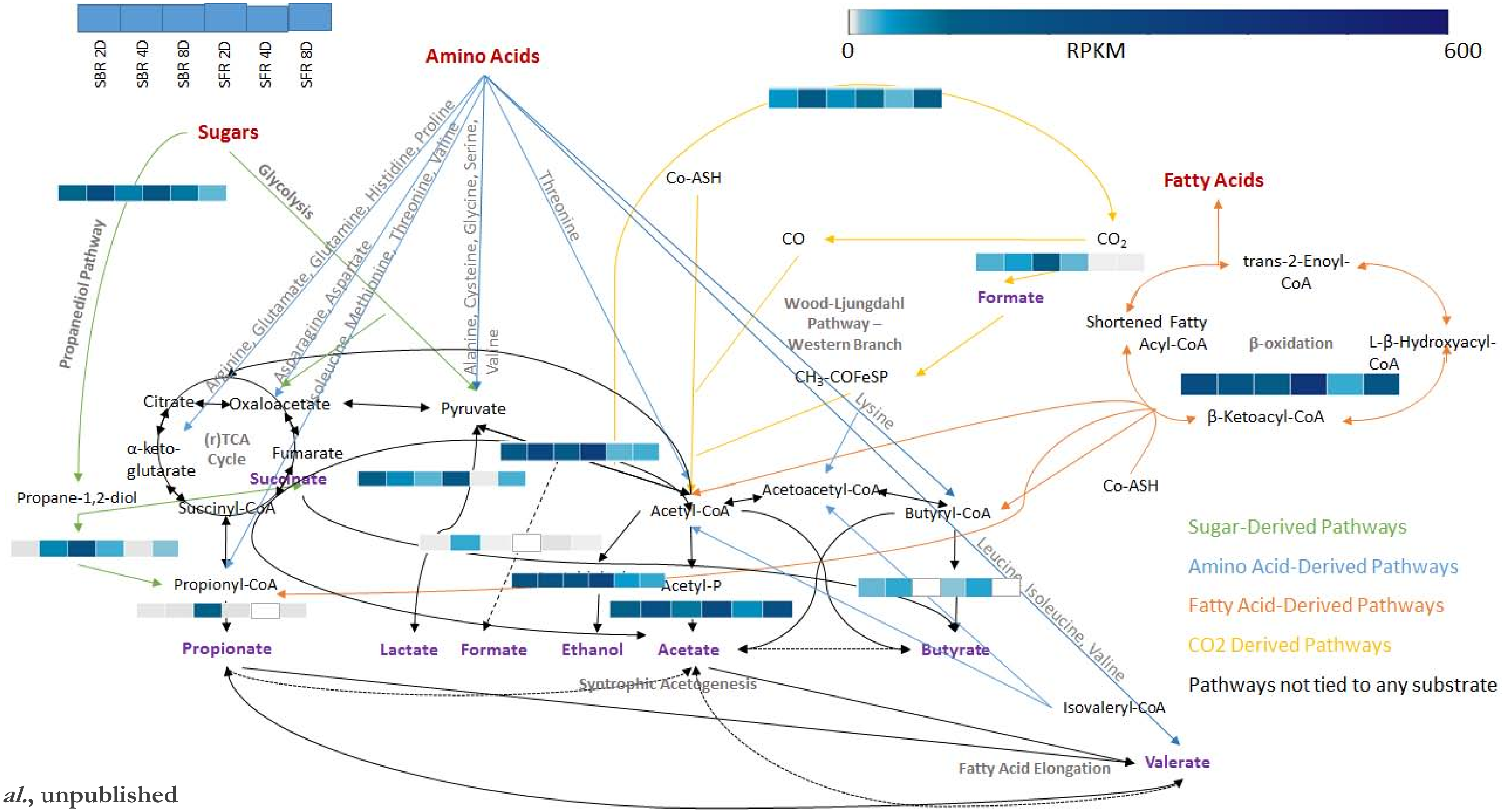
Elevated pH and SRT increased selectivity for acetate production



Pavlakis *et al.*, unpublished

Impact of configuration on function and metabolism

Complement of pathways present in anaerobic fermentation processes



Annavajhala *et al.*, unpublished

Challenges and opportunities

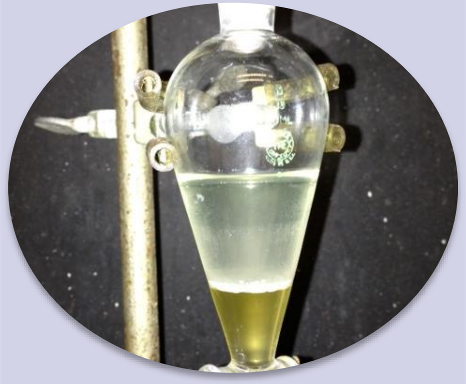
- Anaerobic fermentation is a fairly flexible process (feed composition, operating strategies)
  - Optimization possible through appropriate process engineering
- Feedstock pre-processing
  - Homogenization, pre-hydrolysis
- VFA separation
  - Low tech – elutriation (washing)
  - Membrane separation, pervaporation and more
- VFA speciation and concentrations for downstream conversion
  - 100% purity not entirely essential

II. Organic feedstocks to lipids and more

Organic feedstock

Anaerobic fermentation to produce volatile fatty acids (VFA)

Convert VFA to lipids

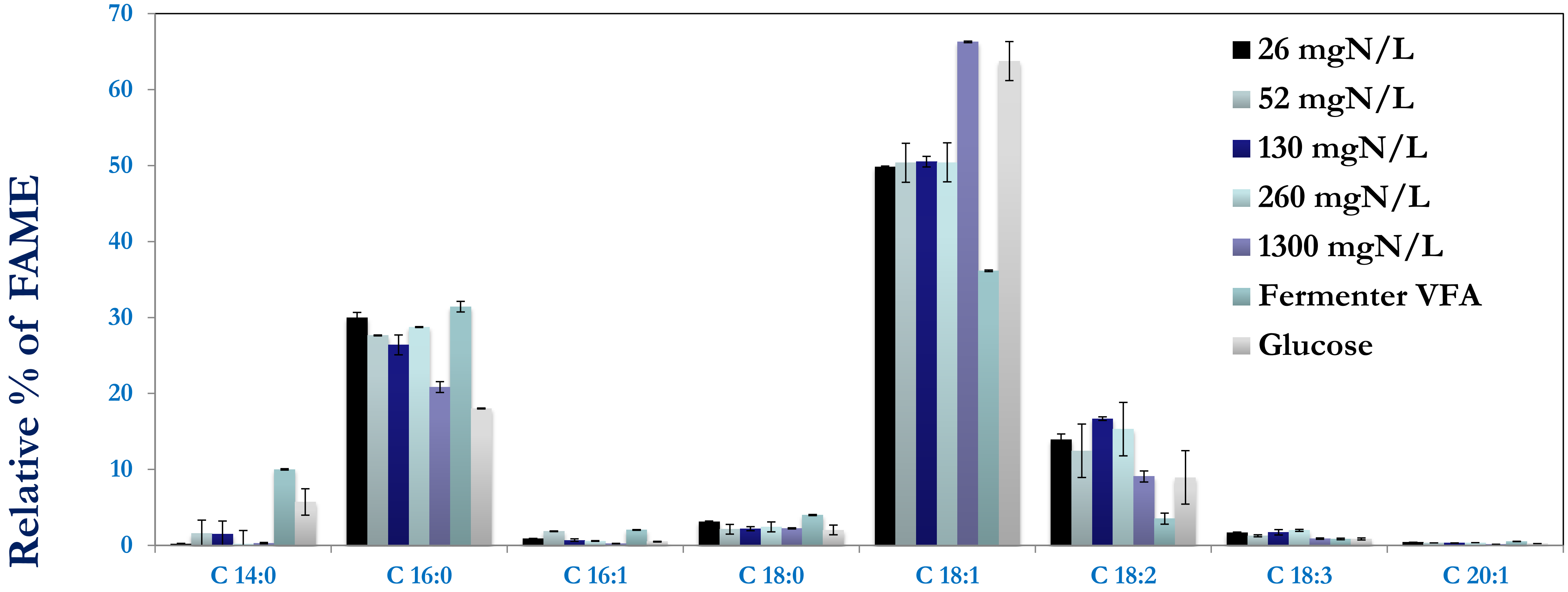


Harvest and extract lipids

Convert lipids to …

☑

Composition of lipids accumulated by *Cryptococcus albidus*

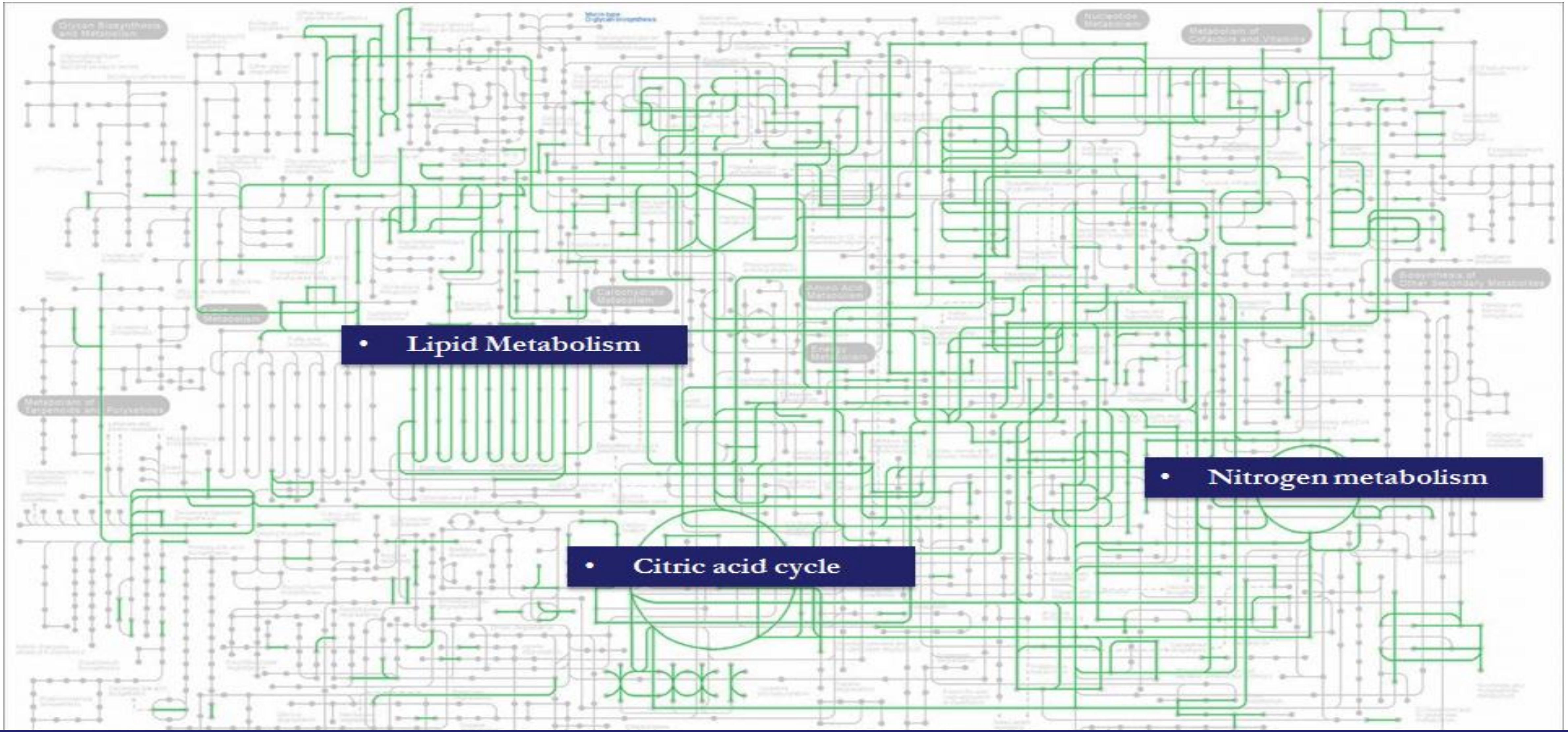


Major fatty acids accumulated are palmitic (C16:0), oleic (C18:1), and linoleic acid (C18:2)

Most similar to palm oil

What else can *C. albidus* accumulate (or do)?

Under what conditions?



Total size ~ 25 Mbp, Genbank accession number LKPZ 00000000.1

Vajpeyi and Chandran, 2016

Challenges and opportunities

- Potential to enhance product yield and rate
  - Process engineering
  - Genetic manipulations
  - Impact of co-culturing bacteria and yeast
- Cell separation and extraction
  - Re-utilization of chemicals
- Re-utilization of 'waste' biomass (?)
  - Digestion
  - Co-processing with other biomass
  - Nutrient extraction

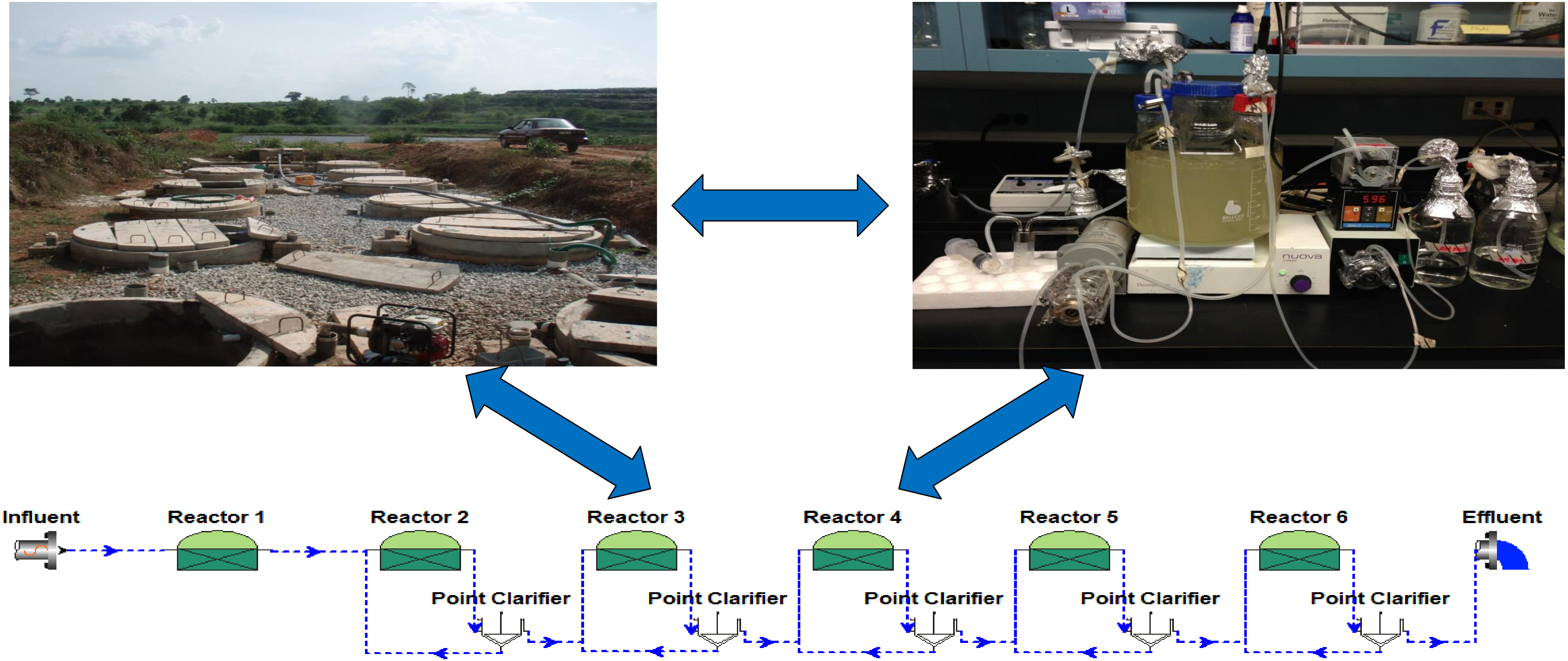
III. A. Internal use of VFA for enhanced BNR

Dual-Phase Digestion and Fermentation of AS

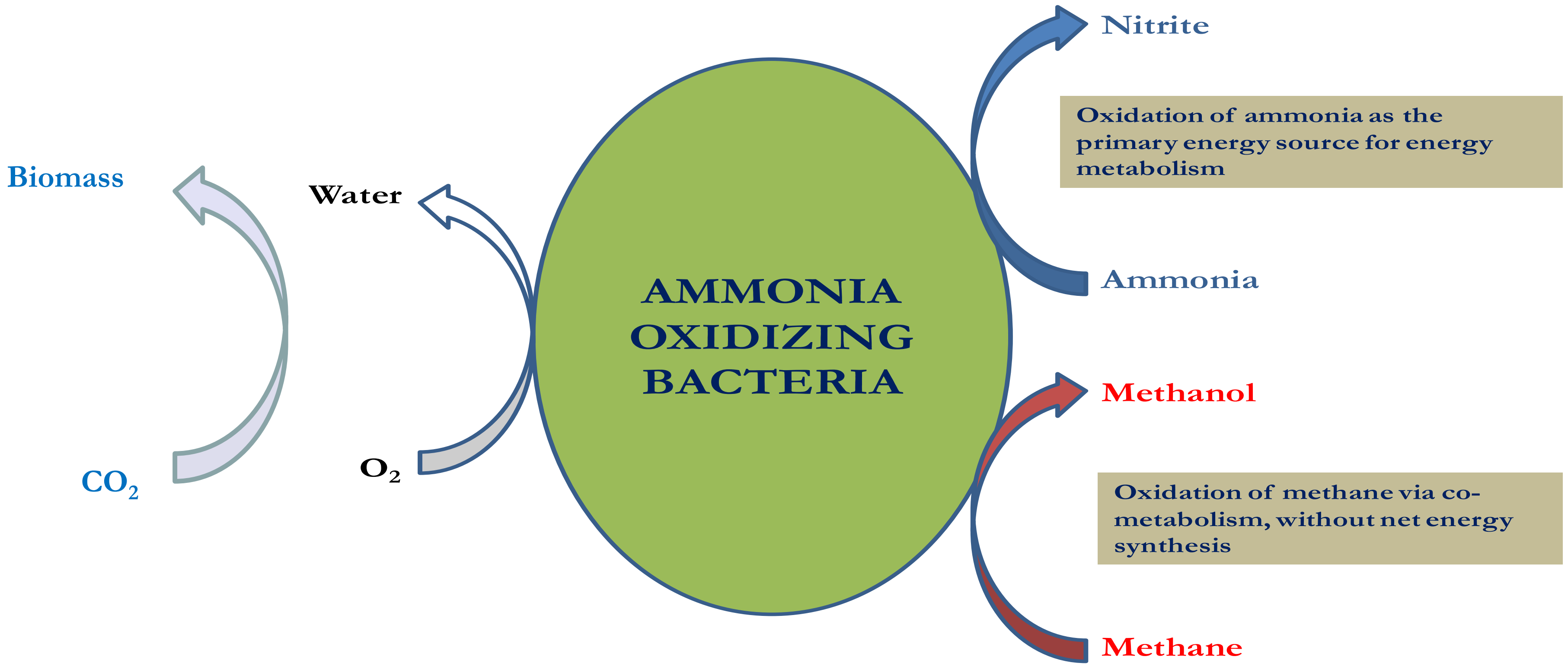
PDS fermentation and storage at 26th Ward WPCP in New York City, 2002

- Fermentation of PDS to produce VFA
  - Used mainly for denitrification
  - Kinetics higher than MeOH

III. B. Faecal Sludge to Biodiesel in Kumasi, GH

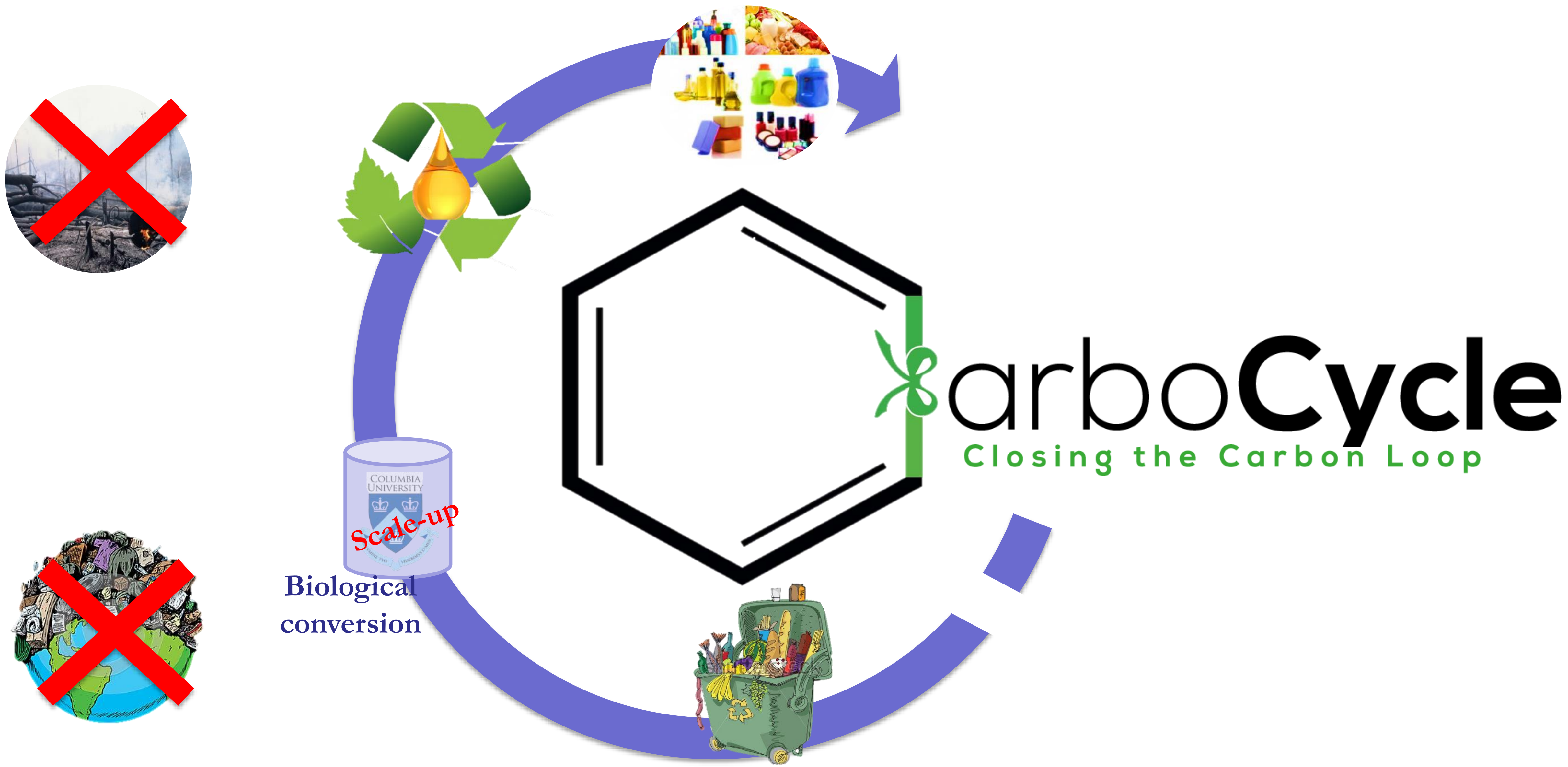


III. C. From Greenhouse Gas to Green Fuel

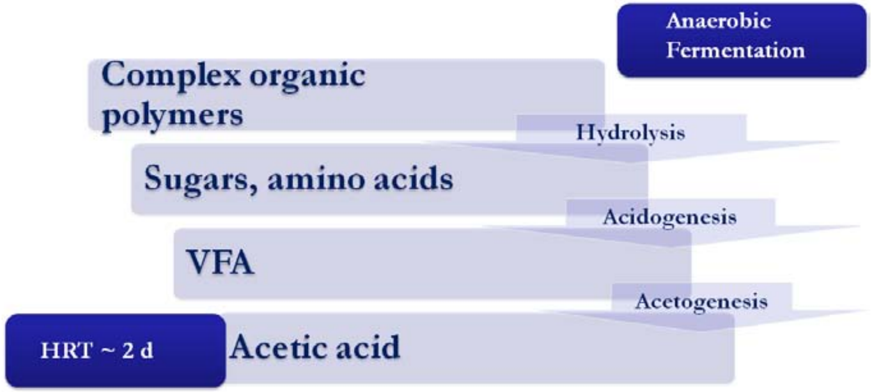


- Concomitant oxidation of CH_4 and CO_2 fixation
- Prospect of combining C &N cycles

Taher and Chandran, ES&T, 2013
WE&RF Paul Busch Award, 2010

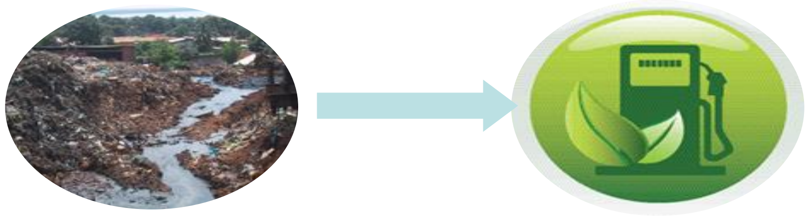

COLUMBIA UNIVERSITY
Scale-up
Biological conversion
arboCycle
Closing the Carbon Loop

Concluding remarks



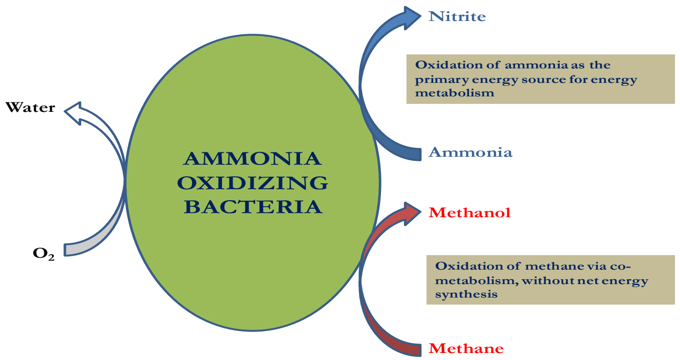
Channeling anaerobic C-conversions through SC-FA offers attractive flexible prospects for resource recovery

Detailed understanding in conjunction with reductionist approaches needed to advance implementation



Wide variety of endpoints (chemicals, fuels..) possible

Disrupting or complementing conventional pathways to biofuels



Links to other applications needed and possible

Resource efficient options for wastewater treatment and sanitation

Discussion

Shashwat Vajpeyi, Medini Annavajhala, Justin Shih, Ato Fanyin Martin, Edris Taher, Yu-Chen Su, Huijie Lu, Vladimir Baytshtok, Jorge Santodomingo, Vikram Kapoor

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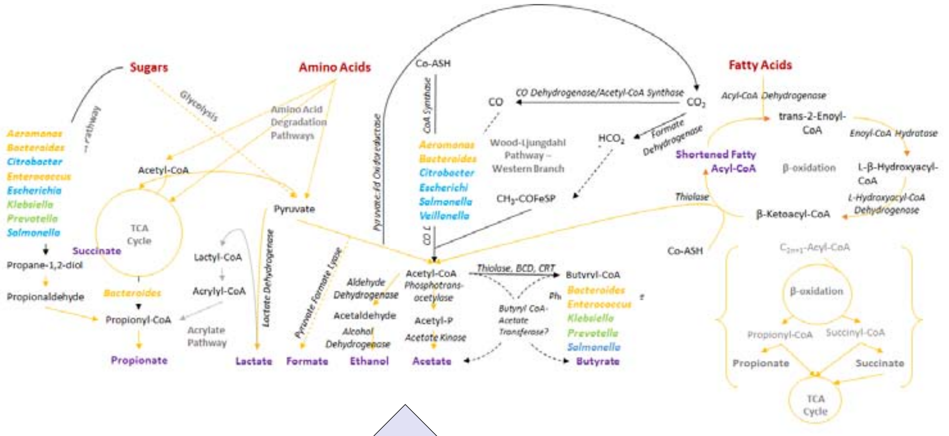
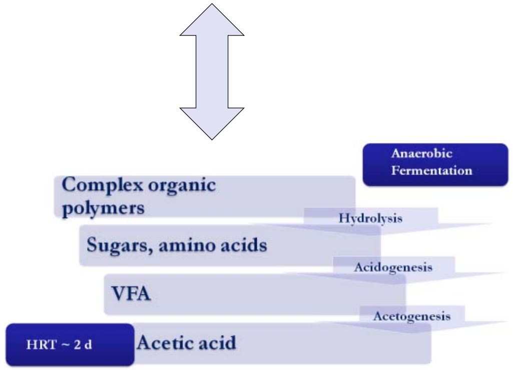
Significance

- As we attempt to move away from ‘digestion’ or ‘fermentation’ towards carbon recovery and biorefining, we need more structured information
- It becomes beneficial to link
  - Process configurations and operating conditions with microbial ecology, metabolic function
    - and in turn with product yield and speciation
  - Feedstocks (can import or mine added ones) with products

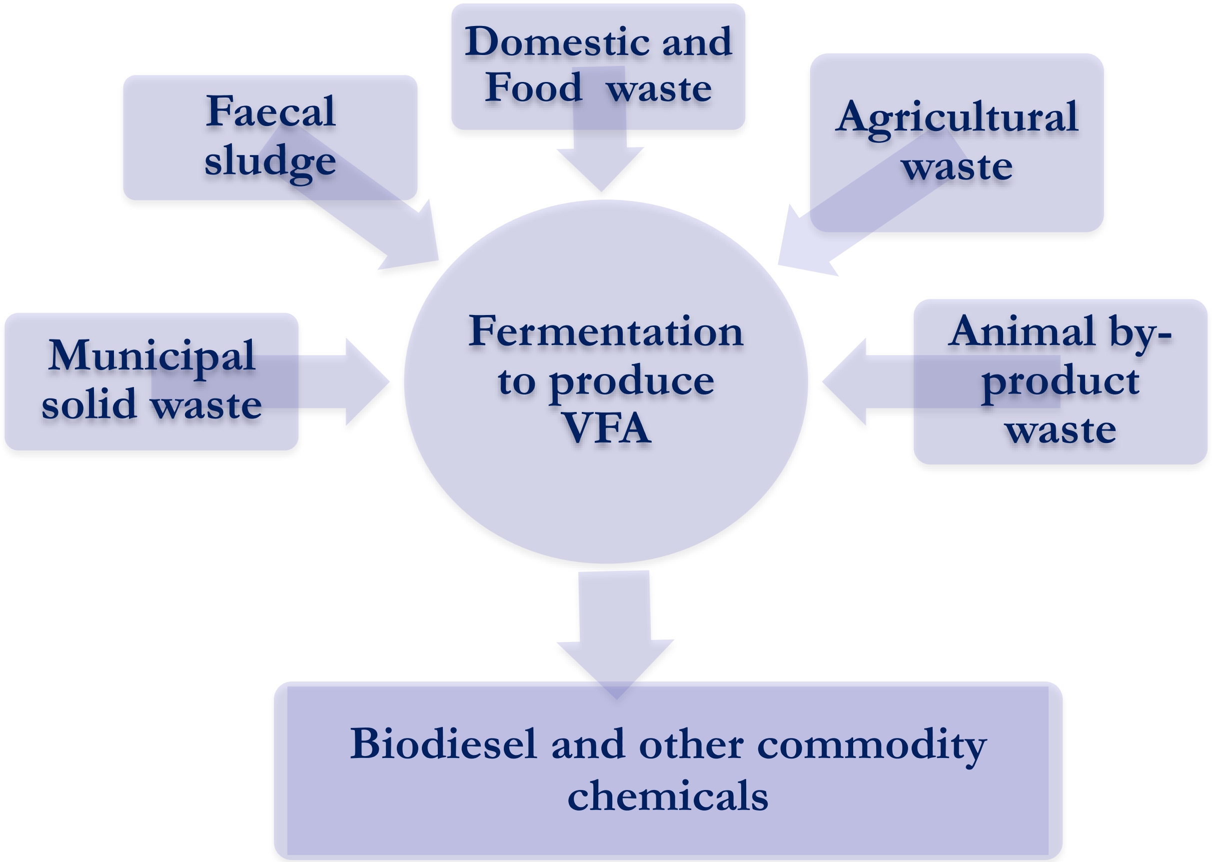


- Next steps
  - Which pathways are active? mRNA, protein expression
  - At what rate? ^{12}C or ^{13}C metabolite tracking



- Not needed for every case
  - Reductionist approaches needed to enhance translation

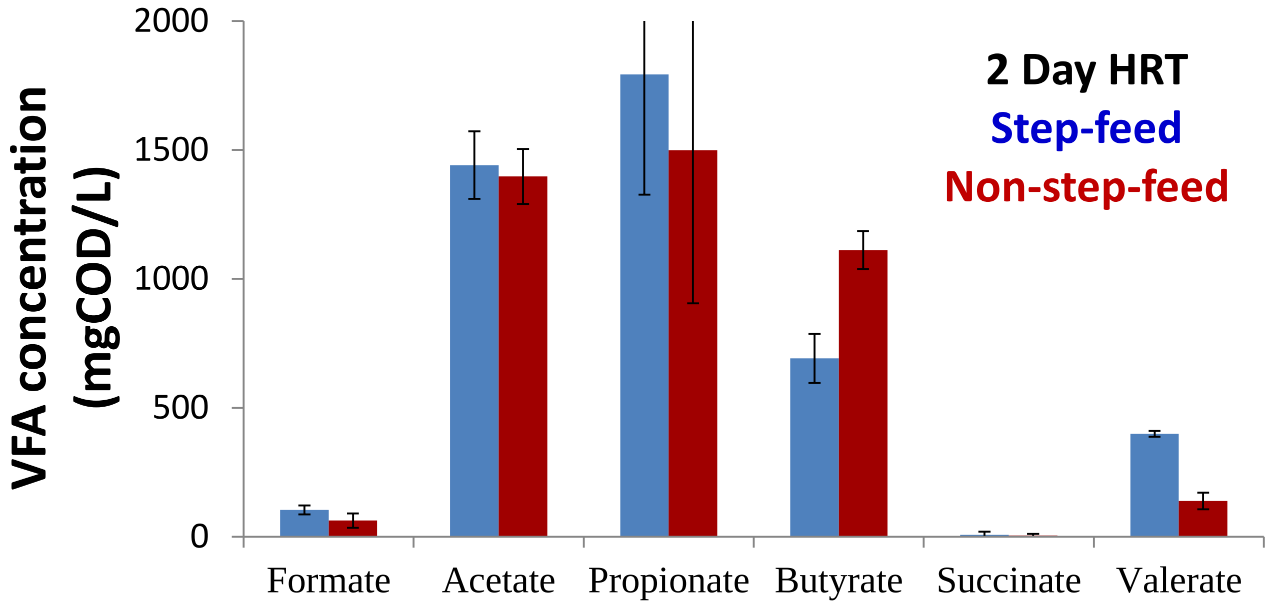
Significance

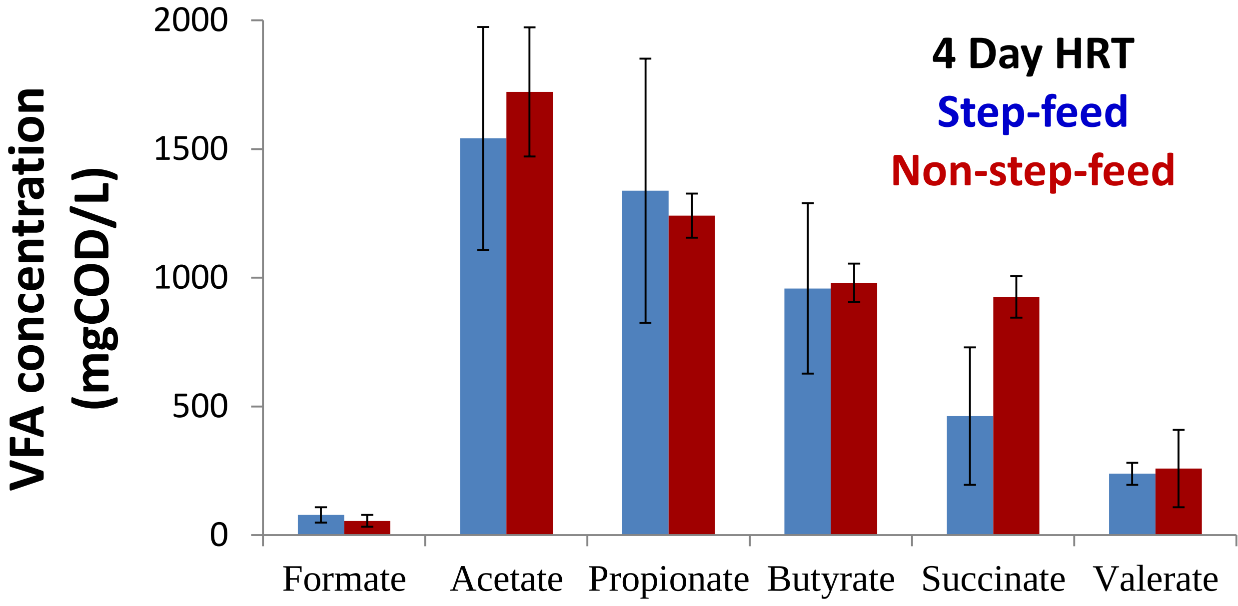


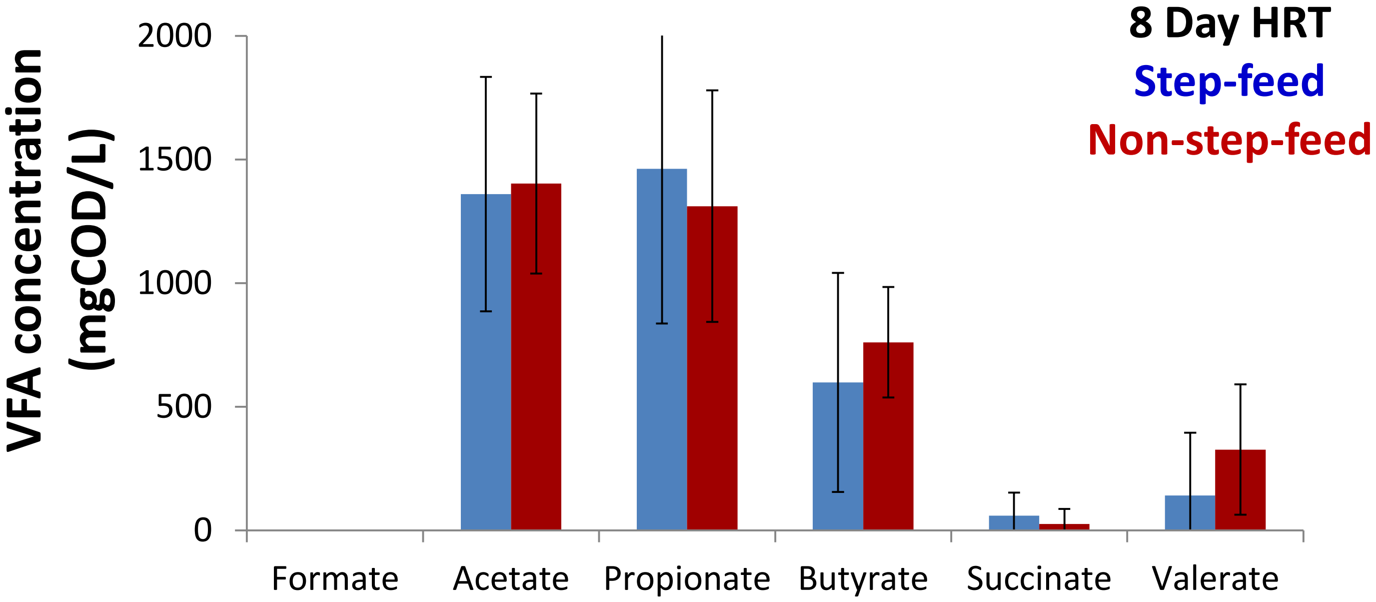
Novel and flexible platform to convert a variety of organic 'waste' streams to biodiesel or other lipid based commodity chemicals

Not reliant upon inherent lipid content- other organic classes can be converted to lipids

- For biodiesel as the preferred end point, reliance upon agricultural outputs is reduced or eliminated
- Links clean water production with energy and chemical recovery
- Process enhancements through fundamental understanding of the biological platform
- Cost?





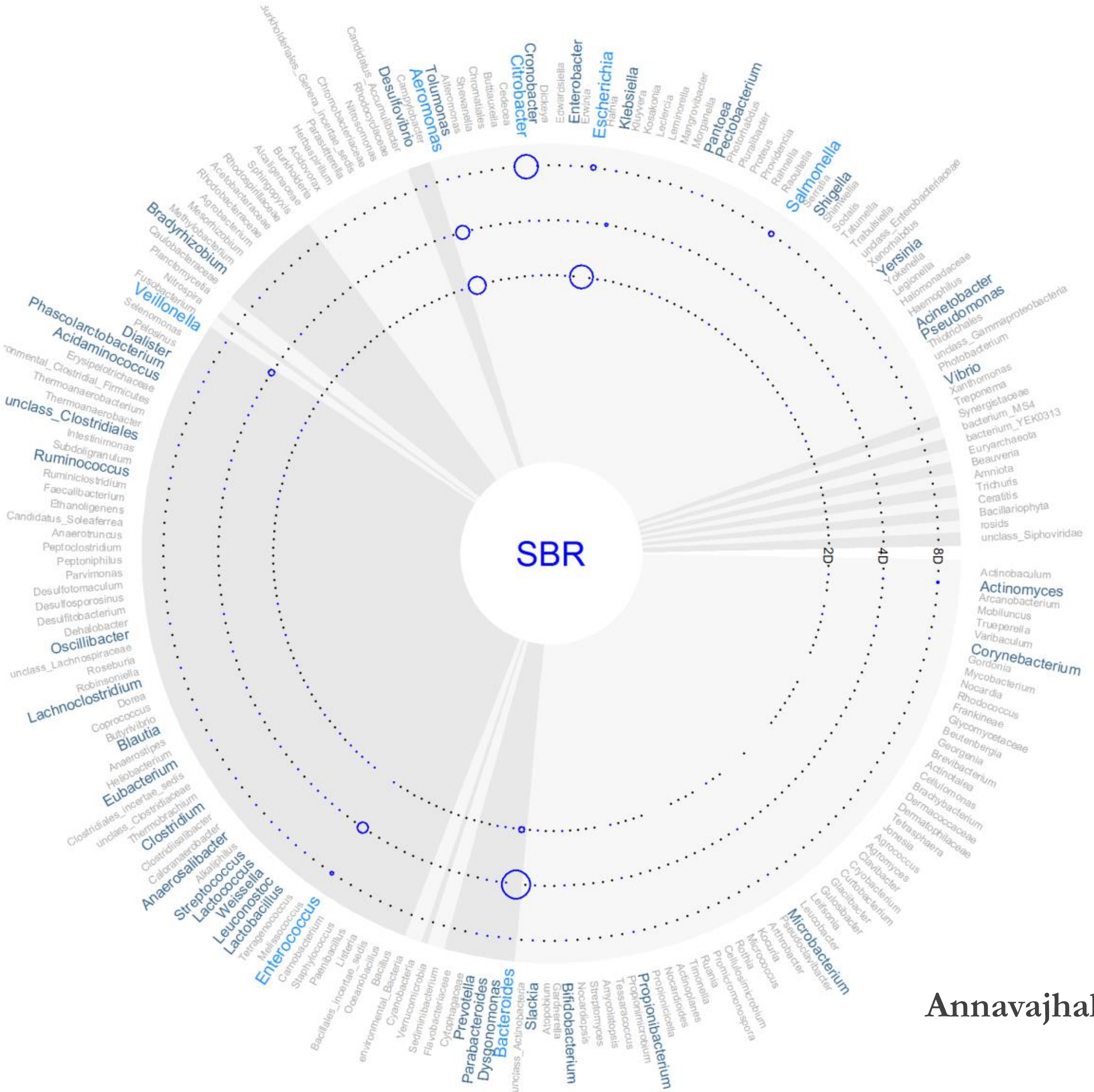


- Largely similar VFA speciation and yields observed across HRTs
- Acetate, propionate and butyrate were the dominant VFA

Insights from fermentation experiments

- Increasing OLR can increase TCA concentrations – potentially limited by pCOD hydrolysis
- Increasing pH and SRT can boost acidogenesis
  - Tradeoff could be increased CH_4 production
- Maximizing hydrolysis and acidogensis requires an effective strategy to separate products from reactants

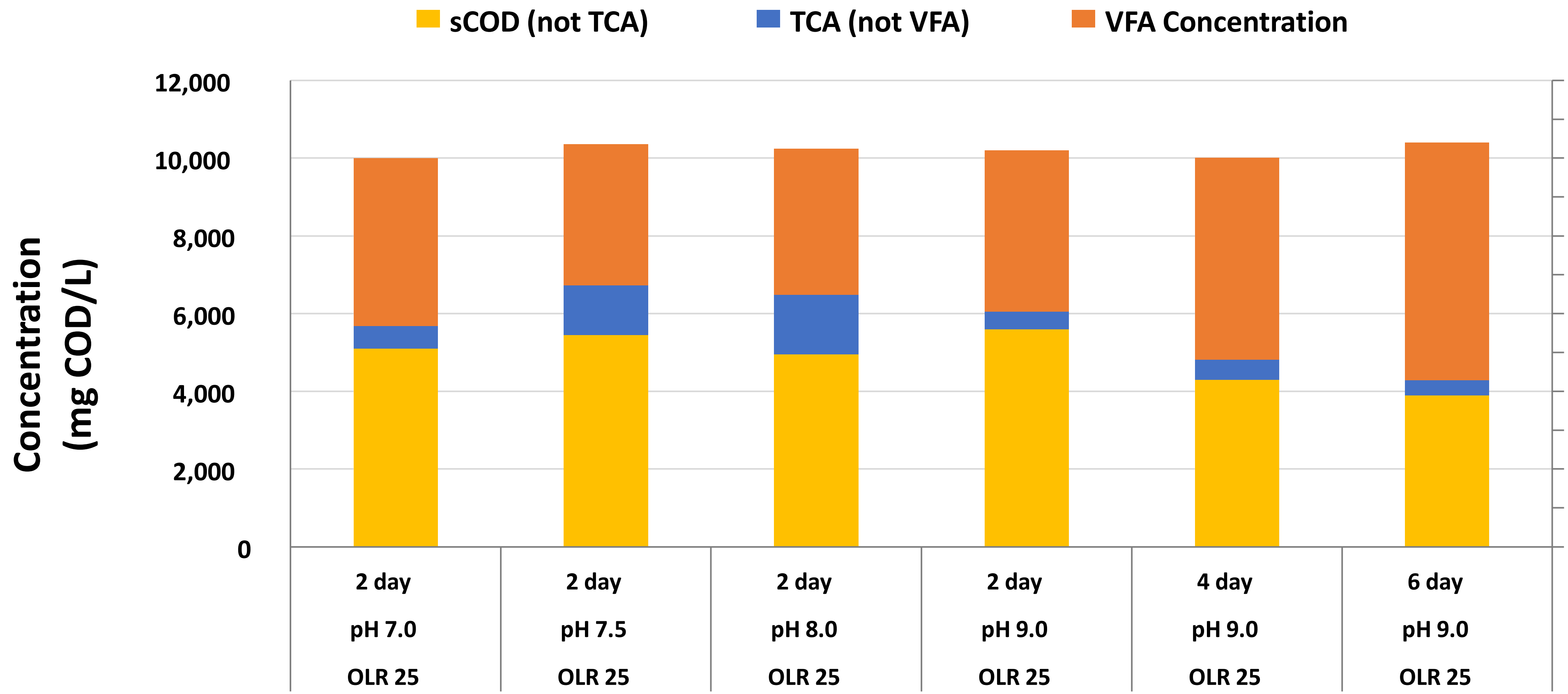
Impact of configuration on community structure



Annavajhala *et al.*, unpublished

Comparison of microbial community profiles in SBR and SFR at 8d, 4d, and 2d HRT; genera included have been assigned >= 50 reads per million (RPM) for at least one HRT; dark blue or green color indicates assignment of >= 1,000 RPM; light blue or green color indicates assignment of >= 50,000 RPM; dot size scaled to RPM values; shading reflects phylum-level relationships

Acidogenesis improved at elevated pH and SRT



Non-TCA sCOD needs to be characterized to expand valorization options

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