Opportunities and Challenges Related to Anaerobic Digestion of Food Waste

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AGRICULTURAL & BIOLOGICAL ENGINEERING

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UF | IFAS
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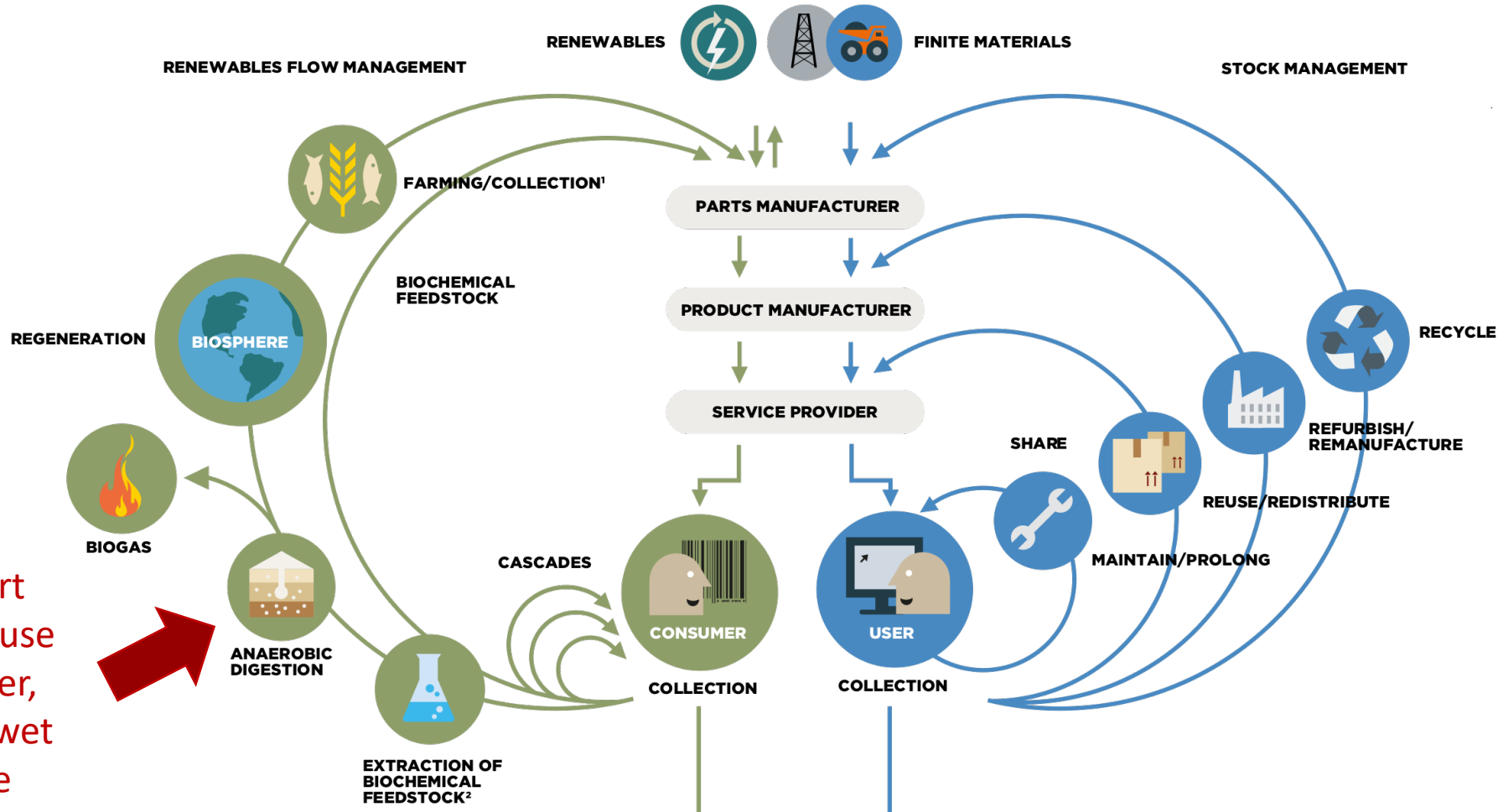
Anaerobic Digestion (AD) is recognized as beneficial process within the Circular Bioeconomy

AD can support recovery and reuse of carbon, water, nutrients from wet organic waste



1 Hunting and fishing
2 Can take both post-harvest and post-consumer waste as an input

SOURCE
Ellen MacArthur Foundation
Circular economy systems diagram (February 2019)
www.ellenmacarthurfoundation.org
Drawing based on Braungart & McDonough, Cradle to Cradle (C2C)

ELLEN MACARTHUR FOUNDATION

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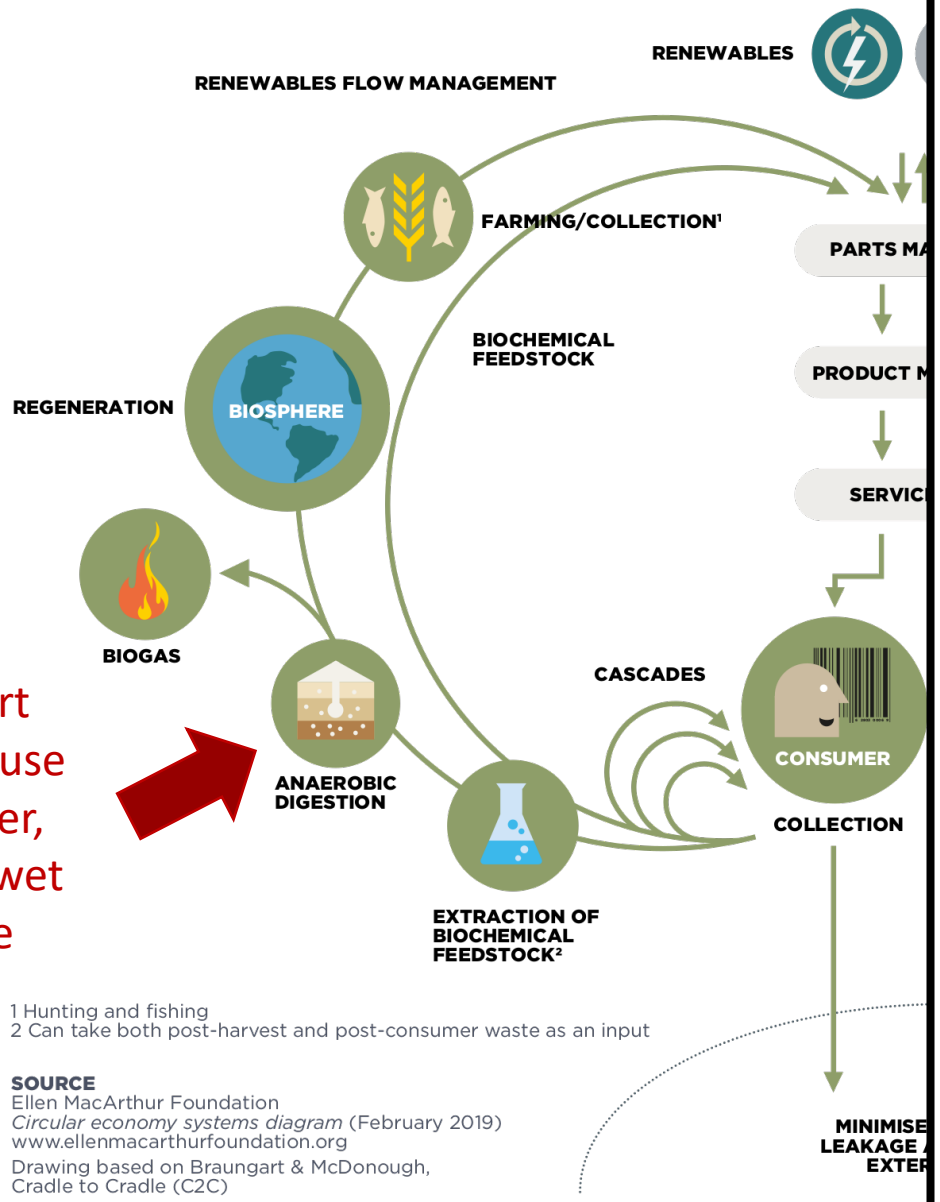
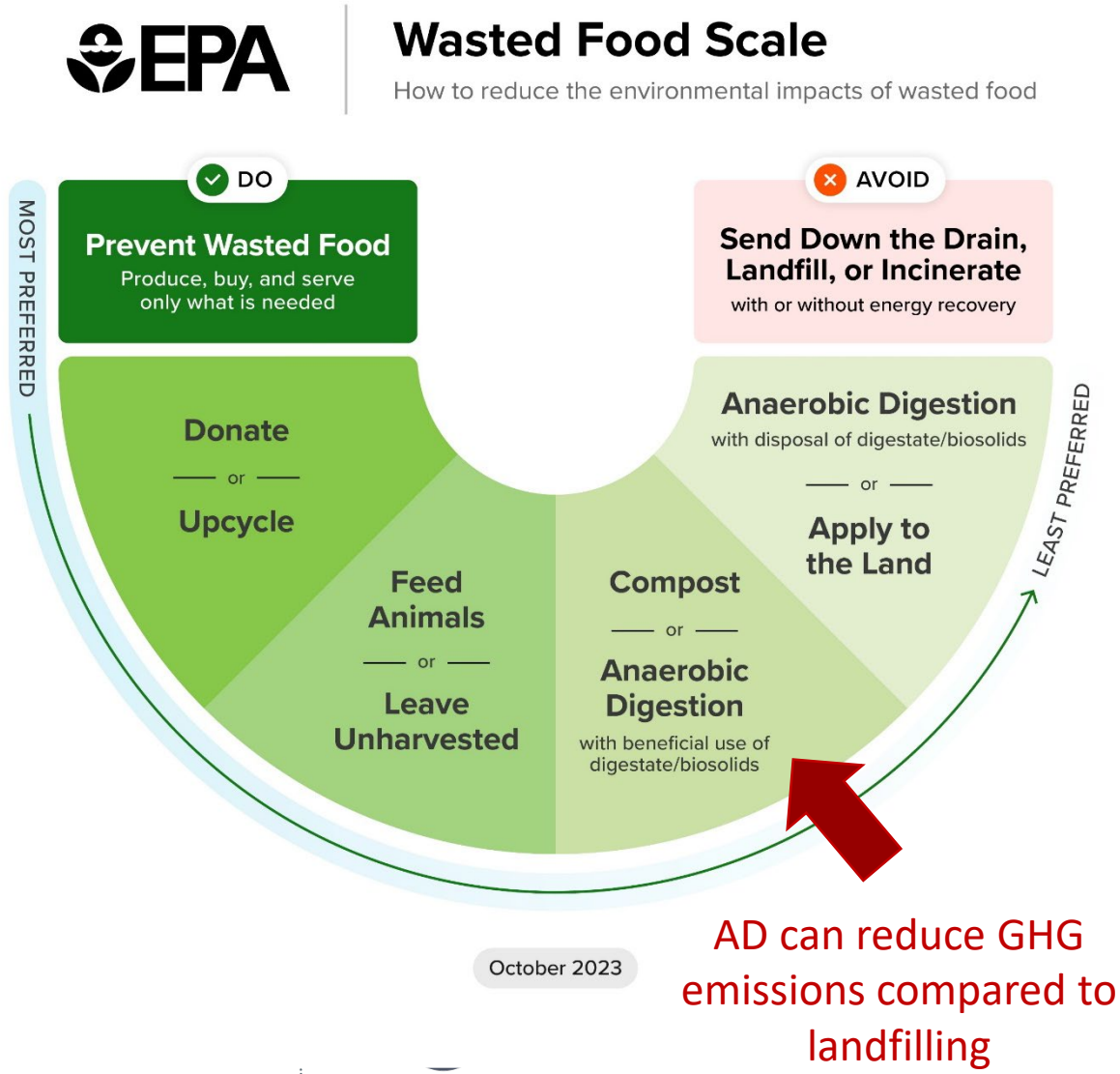
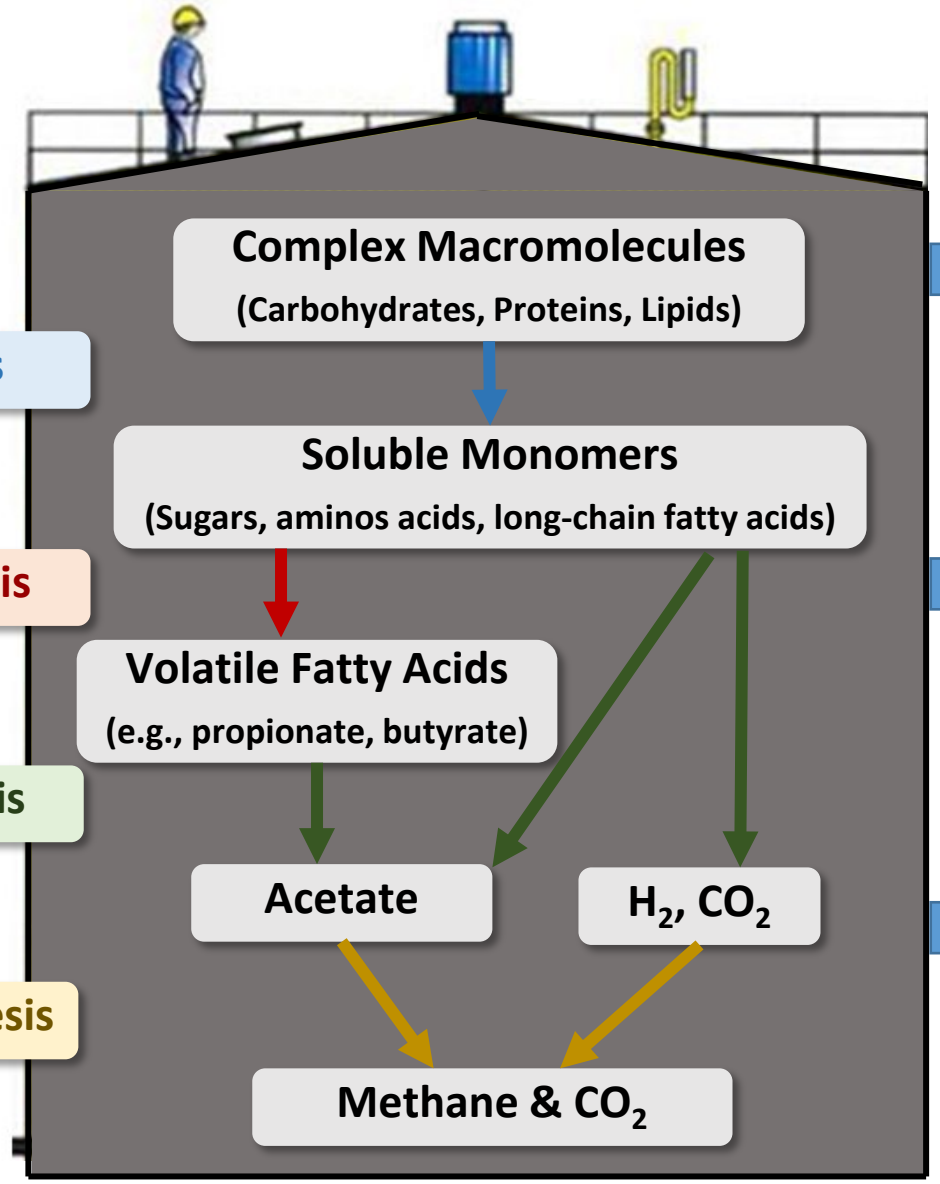




AD can reduce GHG emissions compared to landfilling

Anaerobic Digestion is a balance of microbes working together to covert organics to biogas

Four Phases:



Products:

Biogas (60% CH_4, 40% CO_2)
- Combined Heat and Power
- Renewable Natural Gas
- Compressed Natural Gas

AD Intermediates
- Volatile Fatty Acids
- Acetate

Digestate
(nutrients)

Liquid Fraction
- Potential fertilizer
- Significant NH_4^+ content

Solid Fraction
- Soil Amendment
- Pelletize/Incinerate

Examples of Commercial Scale Digesters

Saerbeck Bioenergy Park, Germany

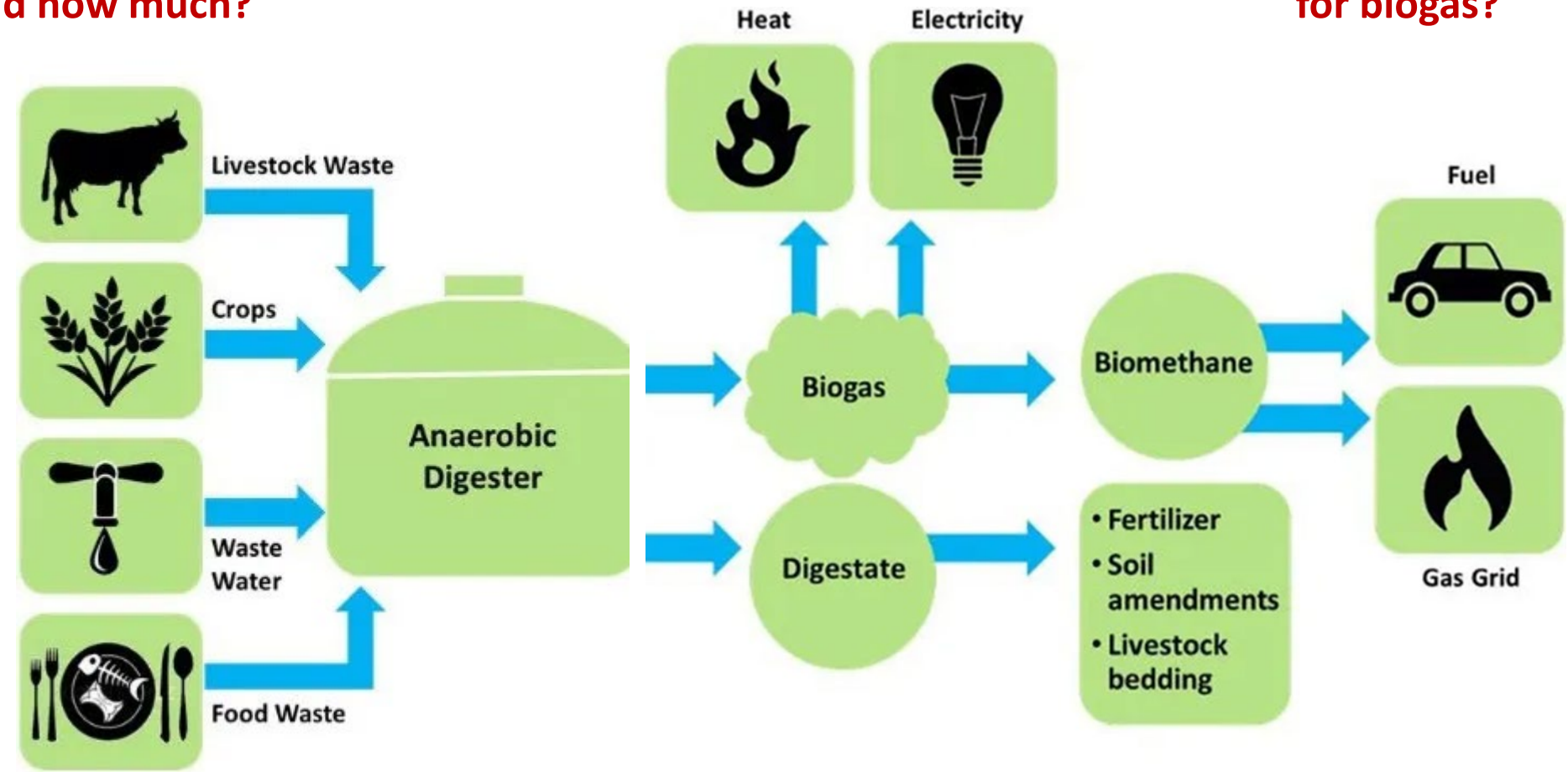
Alliance Dairy Trenton, Florida

Bigadan Copenhagen, Denmark

The Three Questions…

(1) What will the feedstock be and how much?

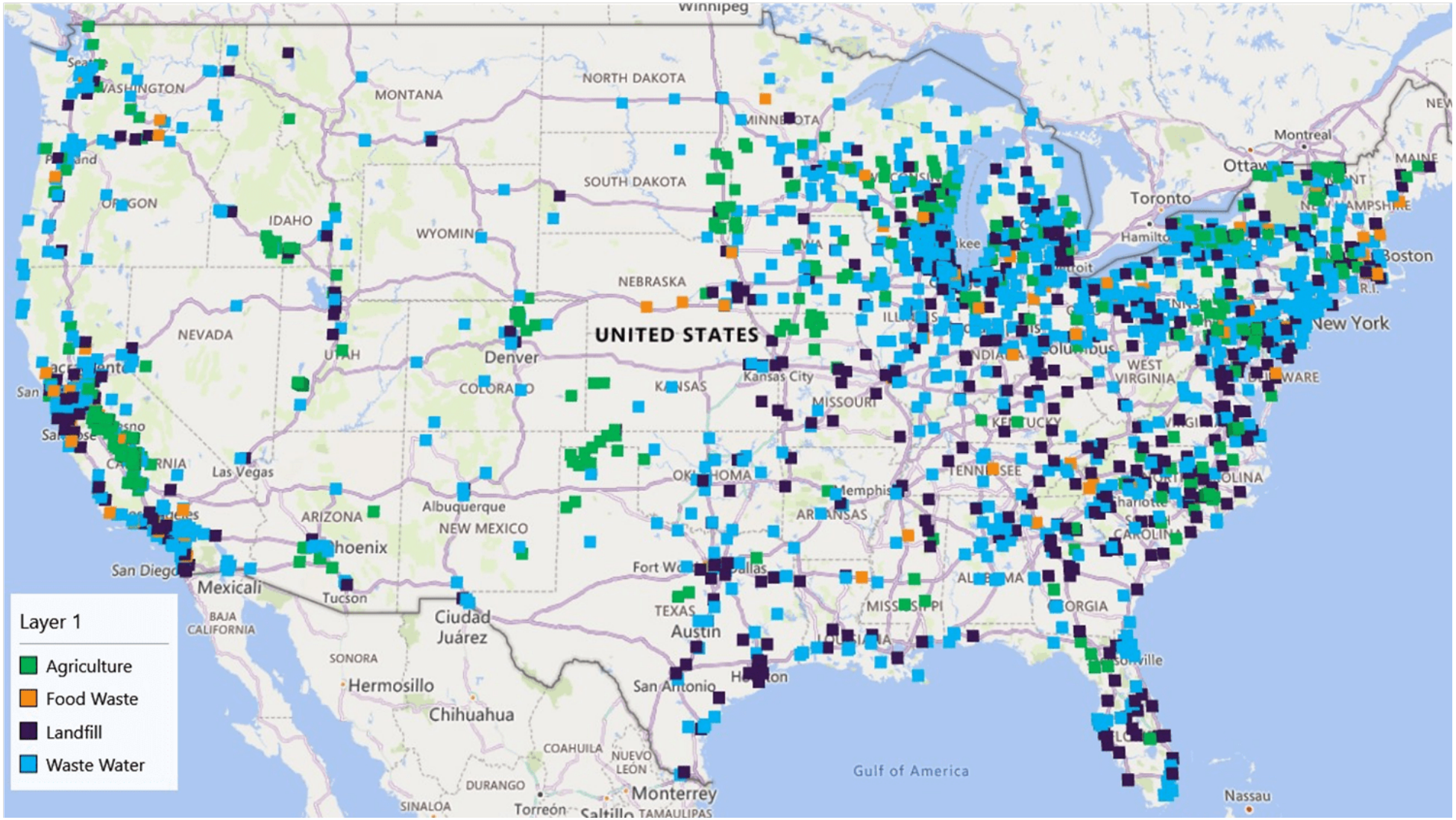
(2) What is the market/value for biogas?



(3) What is market/management options for digestate?

Image adapted from Anaerobic Digestion Process (Sara Tanigawa, EESI).

Anaerobic Digestion (AD) in the U.S.



According to American Biogas Council:

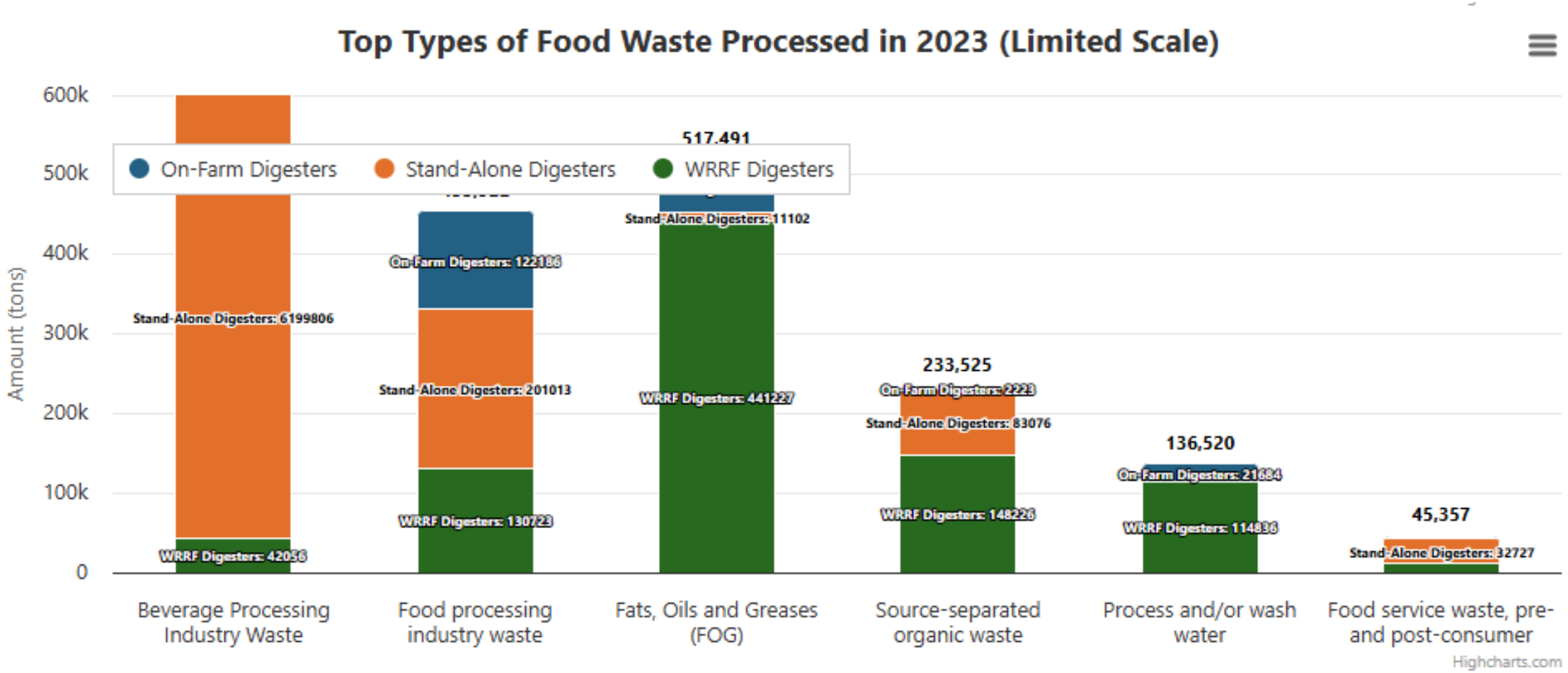
2,500 AD sites in U.S.

- 609 on farms
- >1,180 at WRRFs
- 113 food waste
- 583 landfill gas

Germany has nearly 10,000 operating digesters

[Biogas Industry Market Snapshot | American Biogas Council]

Currently Anaerobic Digestion of post-consumer food waste is limited



[Anaerobic Digestion Facilities Processing Food Waste in the U.S. (2022 & 2023) | US EPA]

Most post-consumer food waste is sent to landfills due to AD challenges

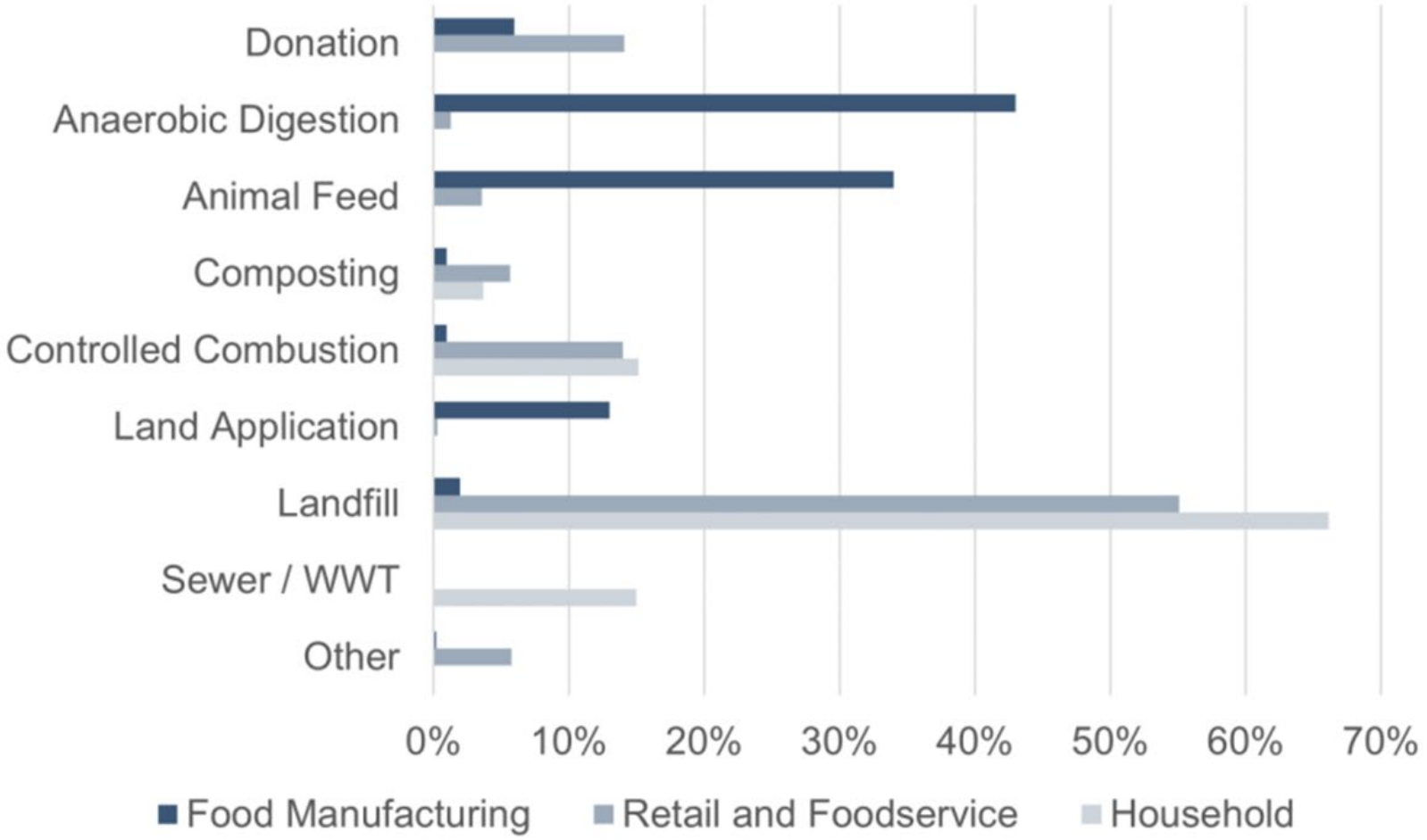


FIGURE 1-1. PERCENTAGE OF WASTED FOOD MANAGED BY EACH PATHWAY, BY SECTOR IN WHICH THE WASTED FOOD IS GENERATED

Challenges related to AD:

(1) Food Waste Variability

(2) High Capital Costs

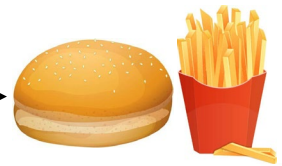
(3) Digestate Management

(Part 2) From Field to Bin: The Environmental Impacts of U.S. Food Waste Management Pathways (epa.gov), 2023

Challenge 1: Food Waste Variability will impact methane yield and stability

Carb:Protein:Lipid

Baseline: 60:20:20

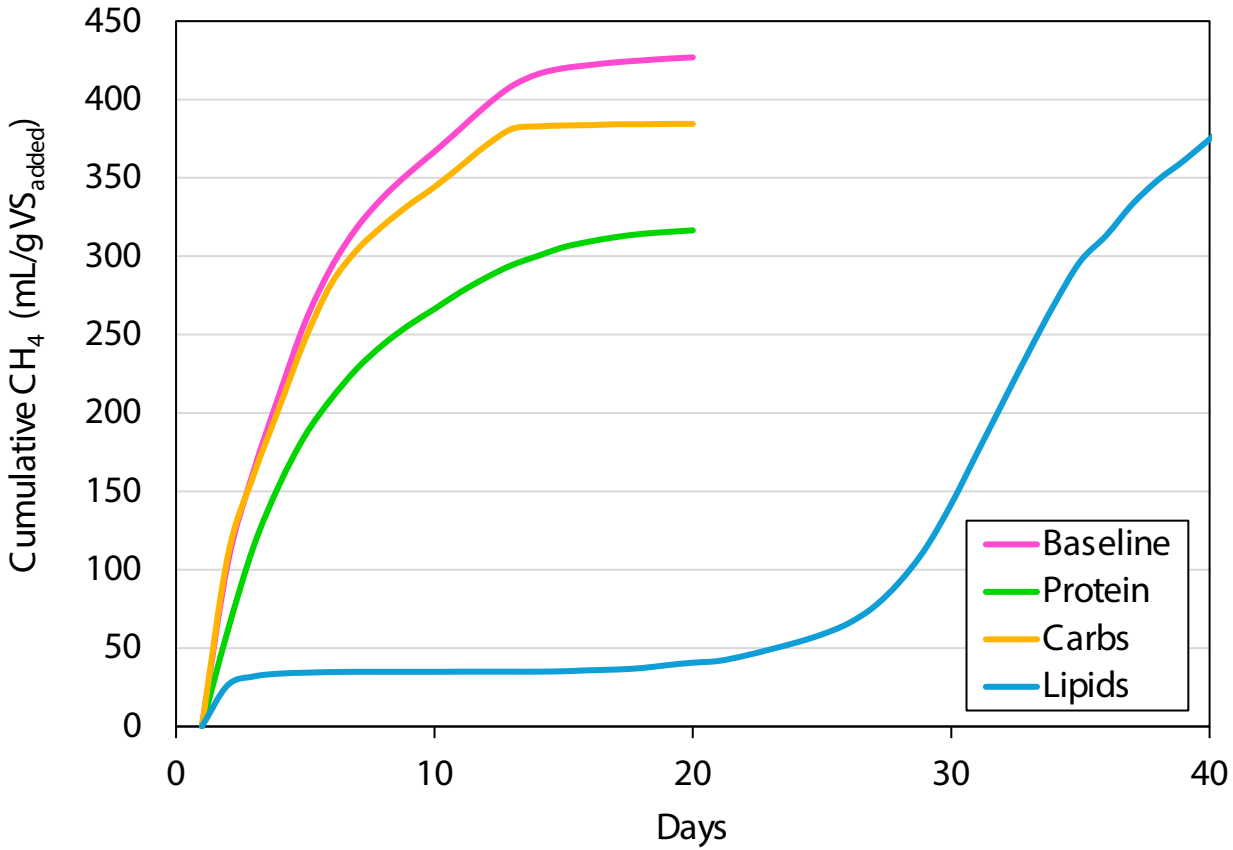


High Carb: 75:20:5

High Protein: 30:60:10

High Lipid: 40:5:65

Theoretical ranking: **Lipid > Carb > Baseline > Protein**



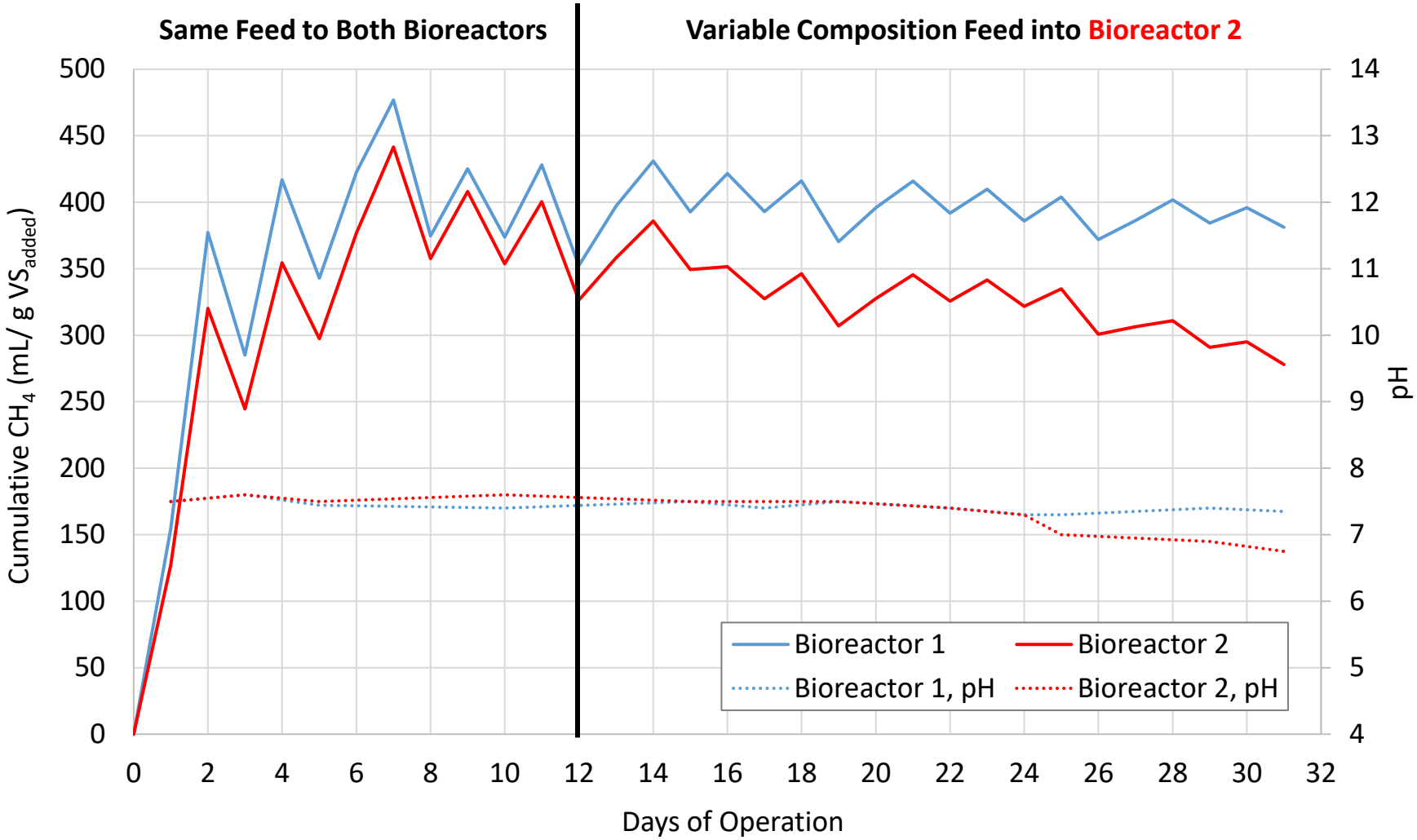
Chloe Hughes and
Elizabeth Perkins

Undergraduate Students

We found:

- **Baseline condition produced higher methane**
- **High lipid condition experienced extensive lag period**

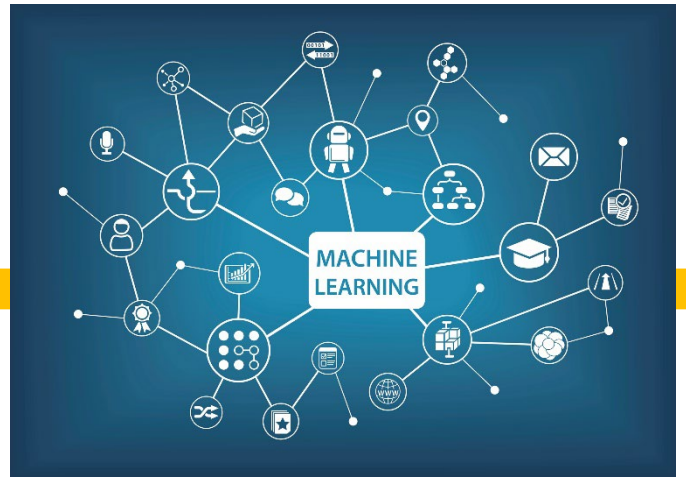
Challenge 1: Food Waste Variability will impact methane yield and stability



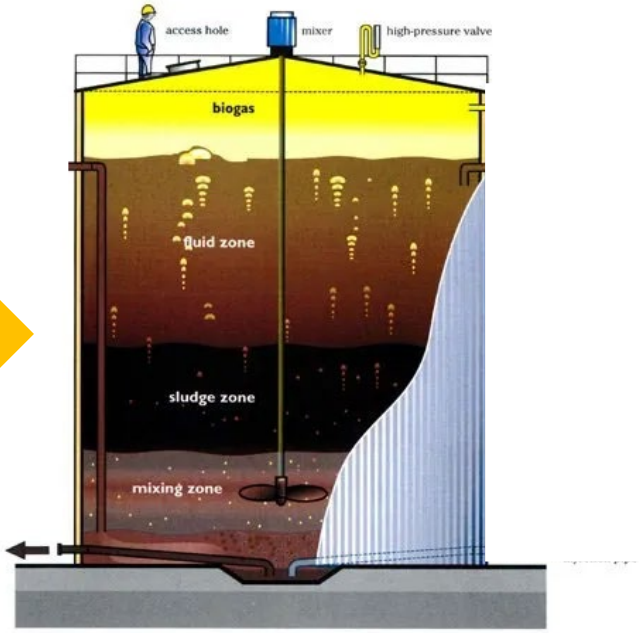
15 L working volume
Temp: 37°C
HRT: 30 days
OLR: 1 g VS/L/day

Prior Hinkley Project: Developing a Machine Learning Predictive Model for AD

Food Waste Composition



AD Process Outcomes



Dr. Nikolay Bliznyuk
Associate Professor

Dr. Jithran Ekanayake
Former PhD student

Camil Coss-Flores
Undergraduate

Machine Learning Model Development

1. Literature Review

Web of Science Database w/ key words:

"anaerobic digestion" AND "food waste" AND:
"household" or "consumer" or "restaurant"

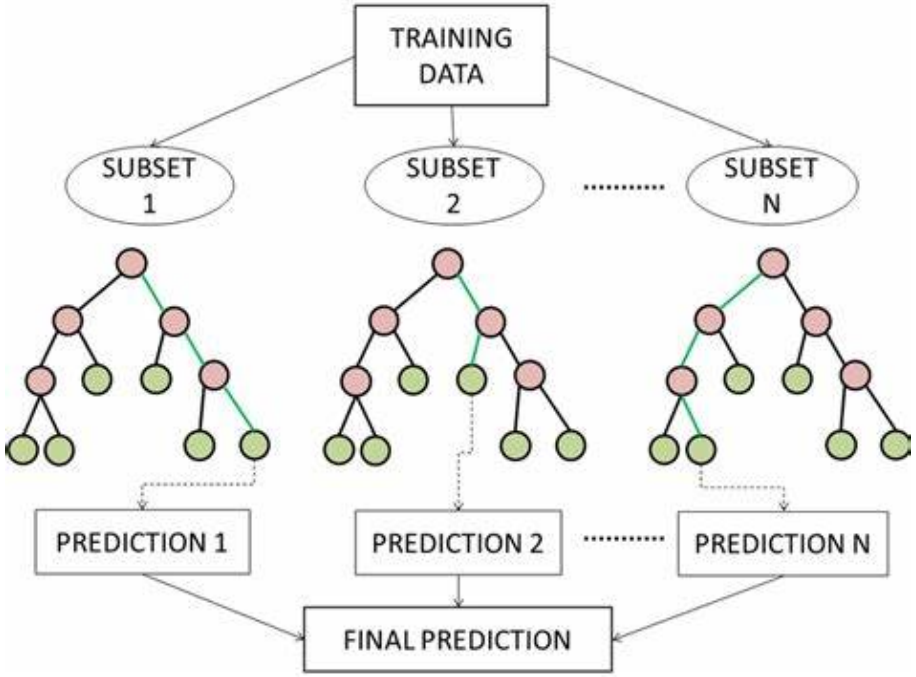
Round 1 = 100 records
Round 2 = 202 records, focused on feedstock macromolecules

16 predictor variables identified

Variable Type	Categorical	Numerical
Feedstock Characteristics	- Feedstock Source	- Volatile Solids (VS) (% w/w) - Total Solids (TS) (% w/w) - VS/TS (%) - Carbohydrate Content (% TS) - Protein Content (% TS) - Lipid Content (% TS) - Feedstock C/N
Operating Conditions	- Reactor Type - Pretreatment Type	- Solid Retention Time (days) - Number of Process Stages - Digester Volume (L) - Hydraulic Retention Time (days) - Organic Loading Rate (g-VS/L-d) - Temperature (C)

2. Random Forest Regression

- Dataset was imputed and split into training (80%) and testing (20%) datasets using k-fold cross validation
- RandomForestRegressor method available in the Python Machine Learning Library, sci-kit learn, was used to build a regression tree with all predictors, without prescreening

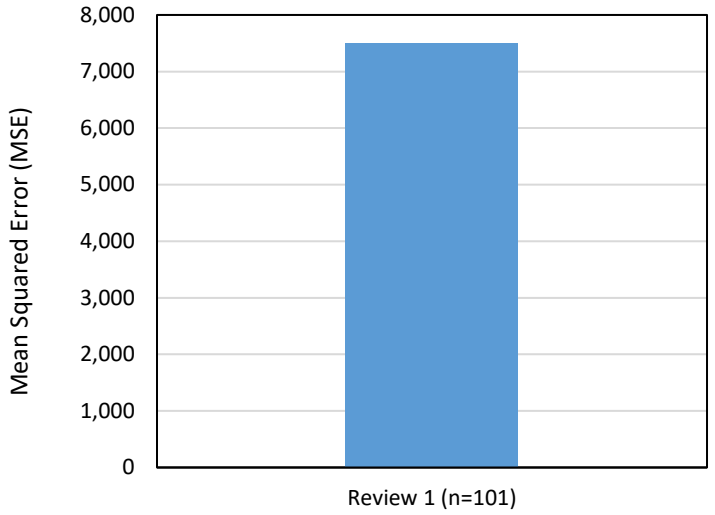


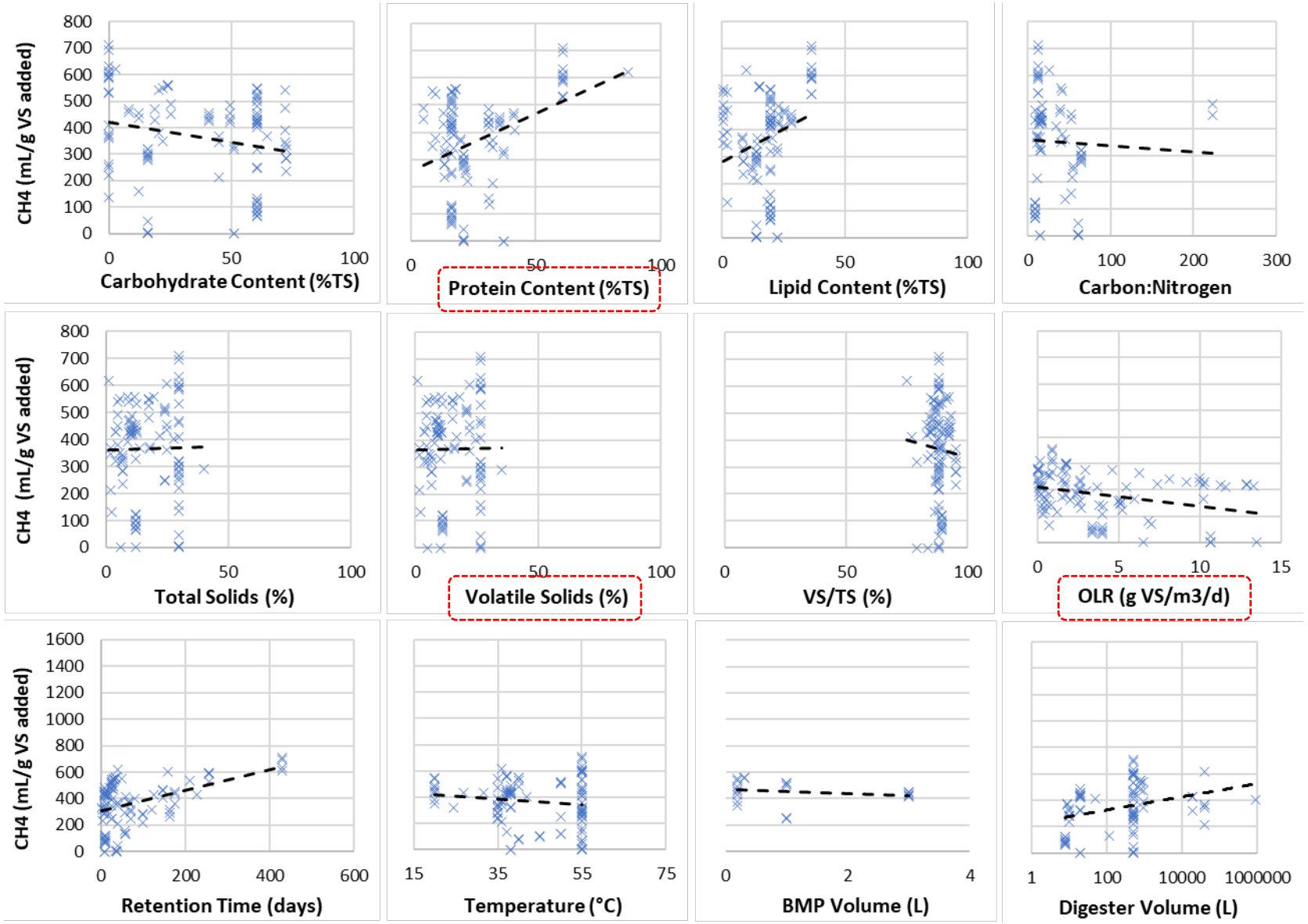
Random Forest using initial dataset (n=101) resulted in high mean squared error

Key predictor variables included:

- **Protein Content**
- **Organic Loading Rate**
- **Volatile Solids**

More data needed to improve predictability

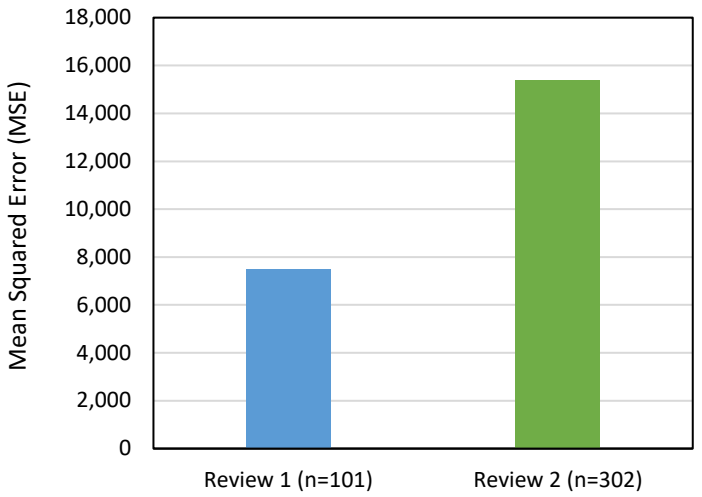


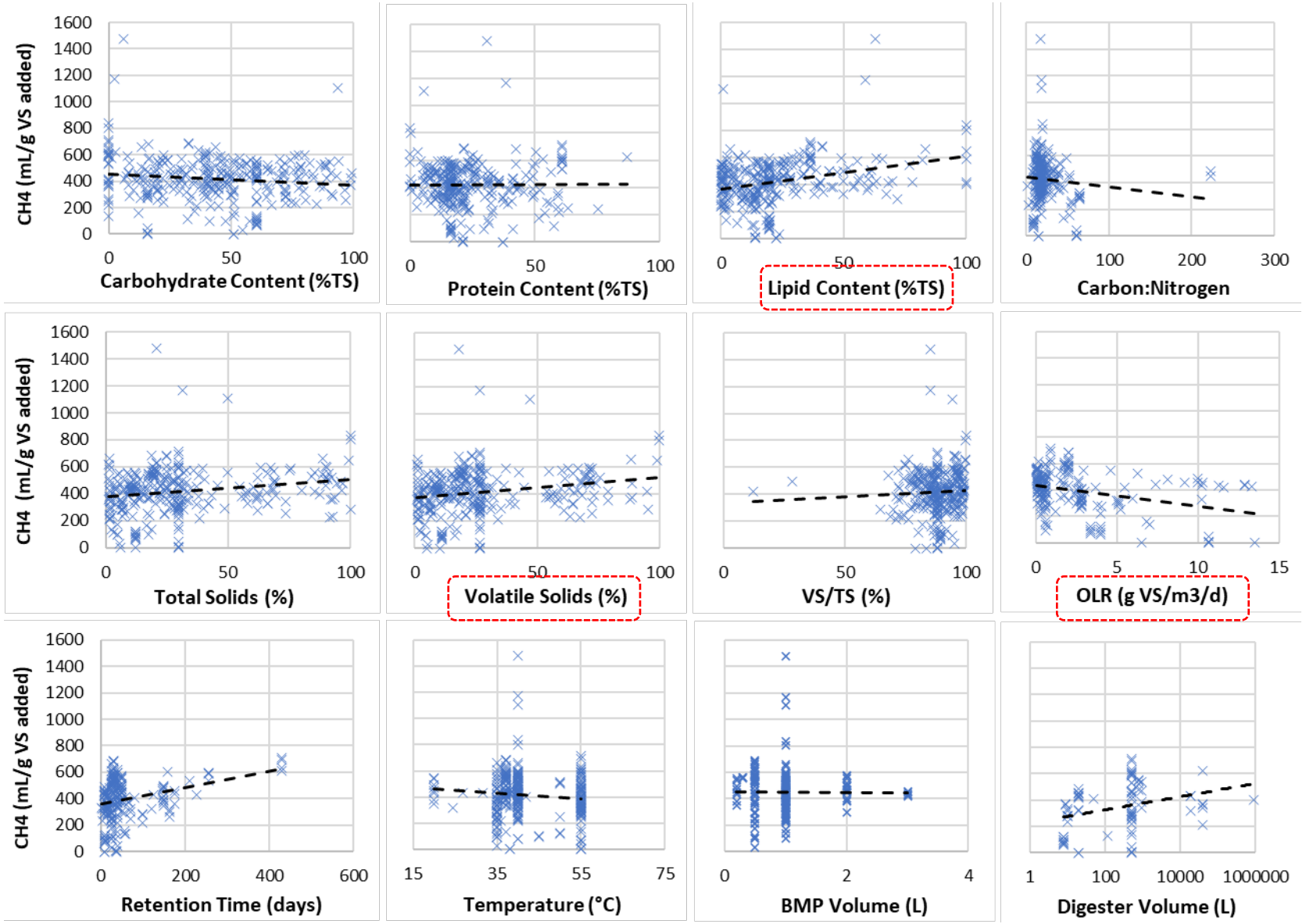


Expanded dataset (n=302) resulted in even higher mean squared error

Key predictor variables included:

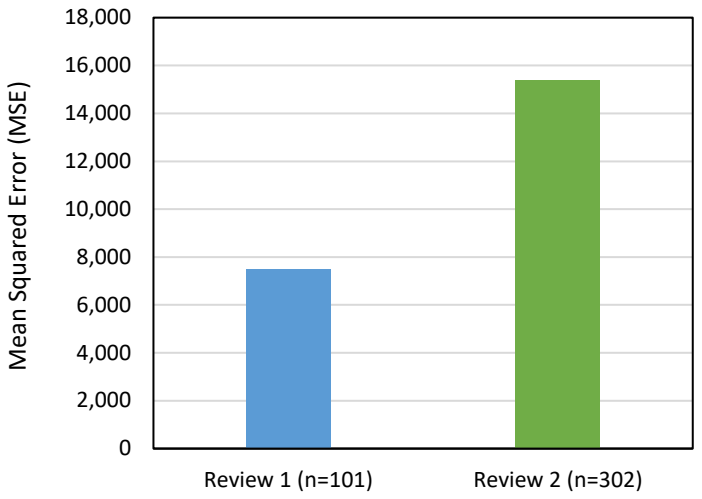
- **Lipid Content**
- **Organic Loading Rate**
- **Volatile Solids**

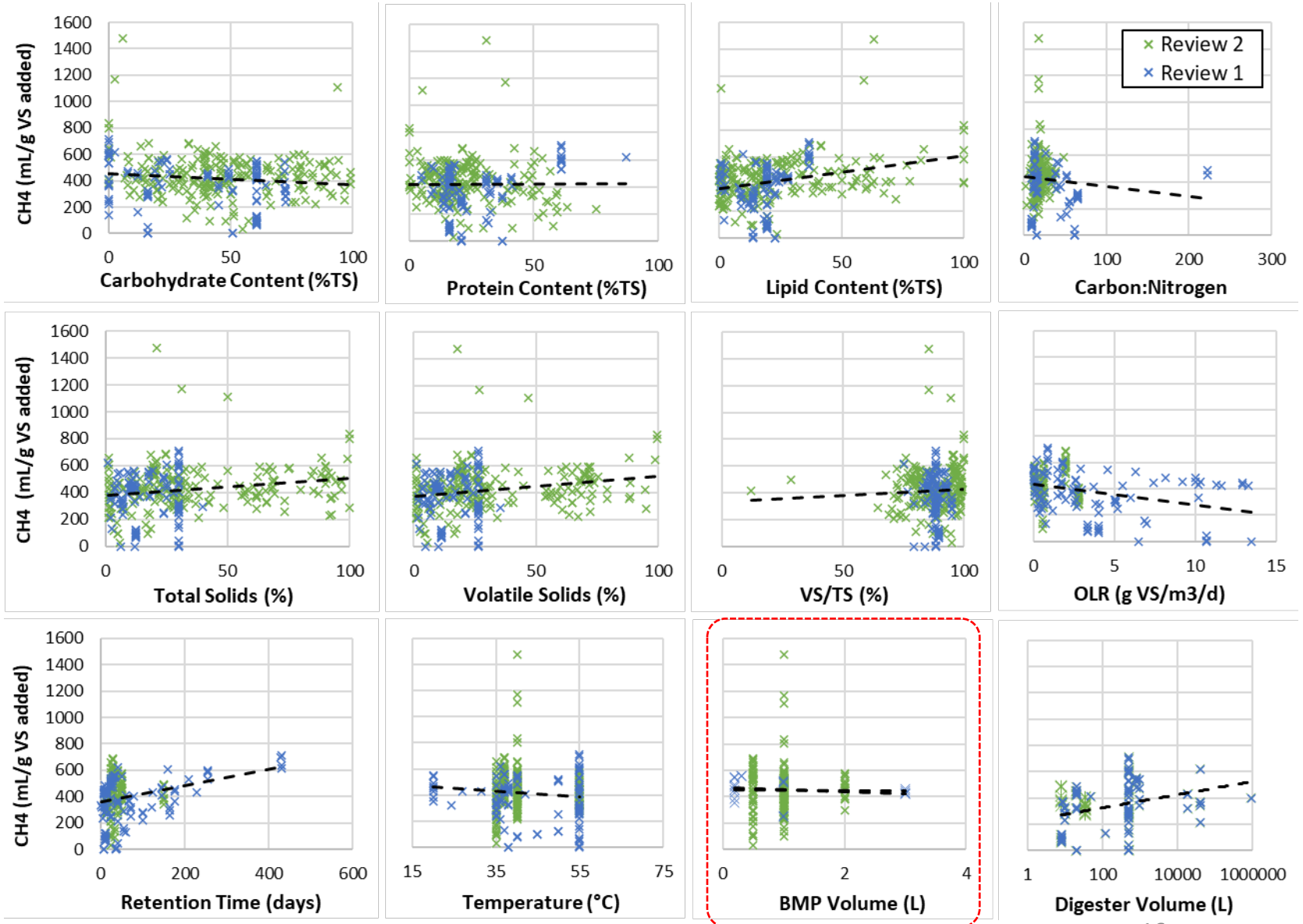




Expanded dataset included more small scale (≤ 3 L) biomethane potential data

- **BMP literature had more description of feedstock characteristics**
- **Small scale BMP testing may not represent realistic and/or predictable outcomes**

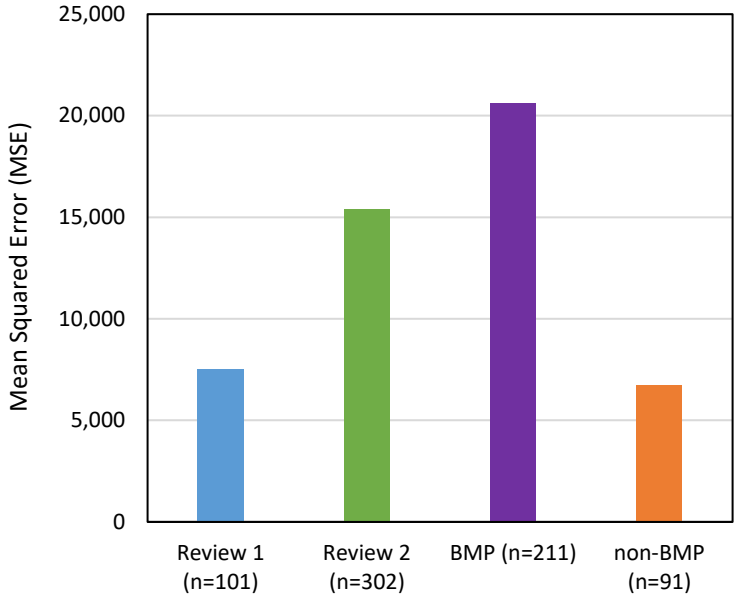


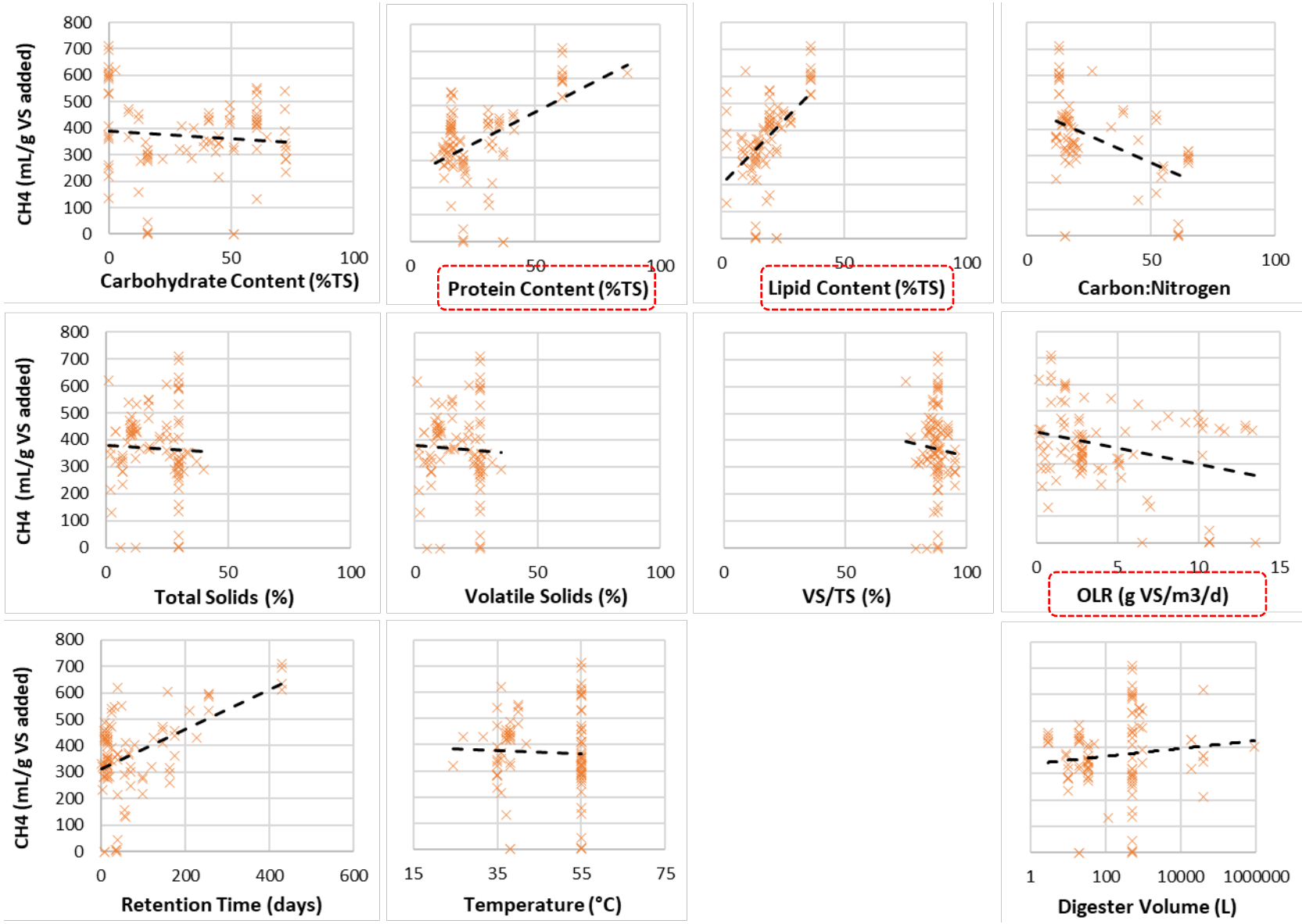


Removing BMP data resulted in lowest MSE – More data needed to improve

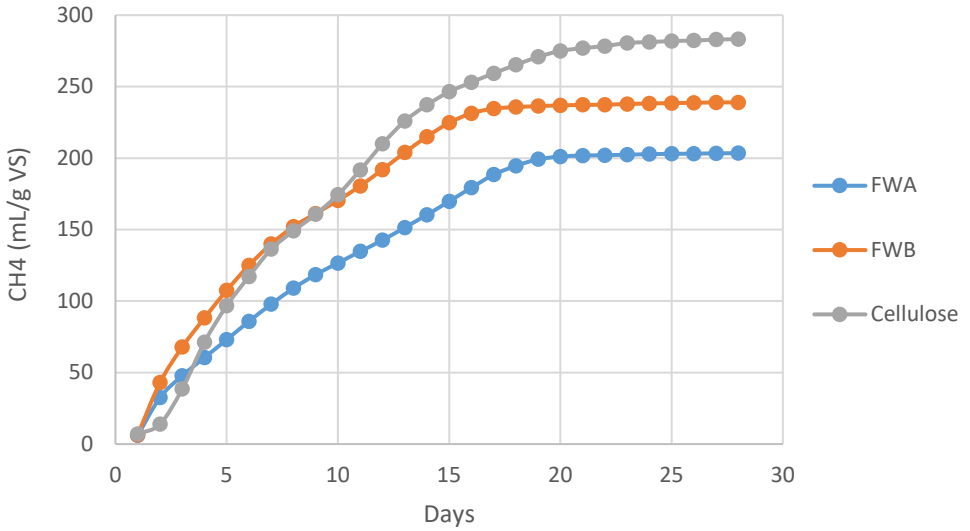
Key predictor variables included:

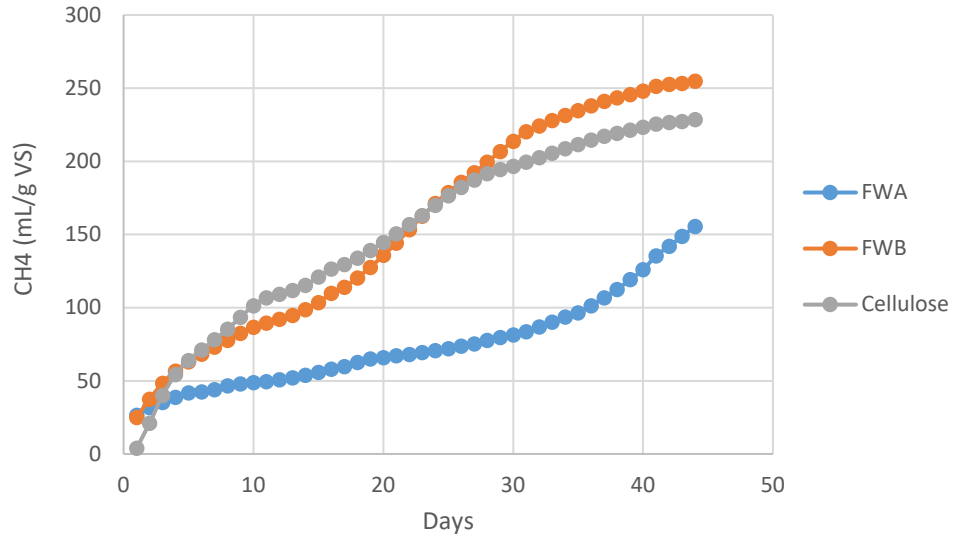
- **Lipid Content**
- **Protein Content**
- **Organic Loading Rate**





On-going Hinkley Project – Data collection from actual food waste





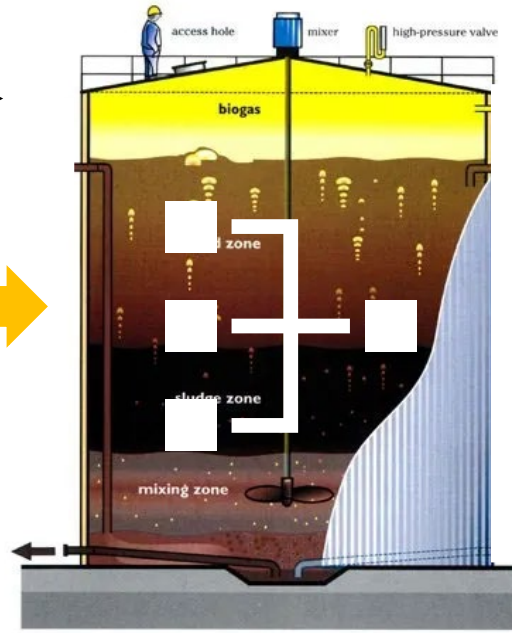
Long term goal: To develop a dynamic process control system

Food Waste

Visible Near Infrared (VNIR) Scanning

Real time composition data informs AD model

ML Predictive AD Model

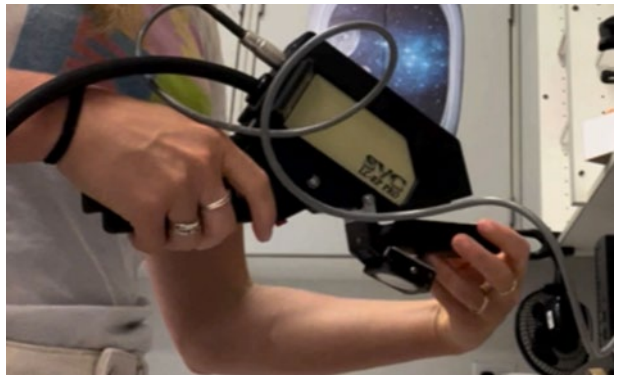


Feed and operational adjustments informed by AD model

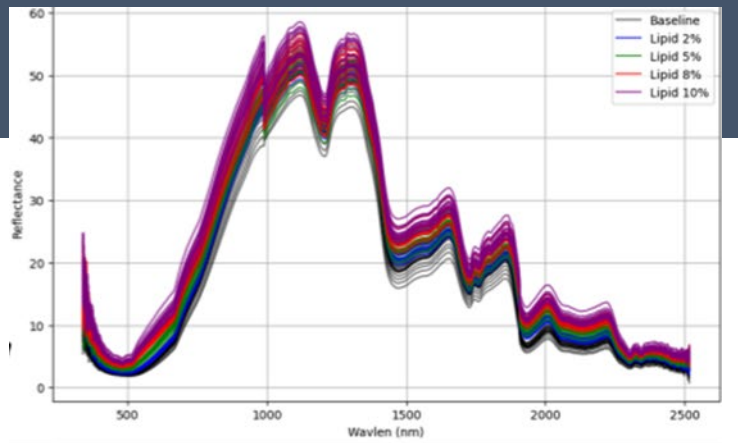
Using VNIR to characterize food waste composition

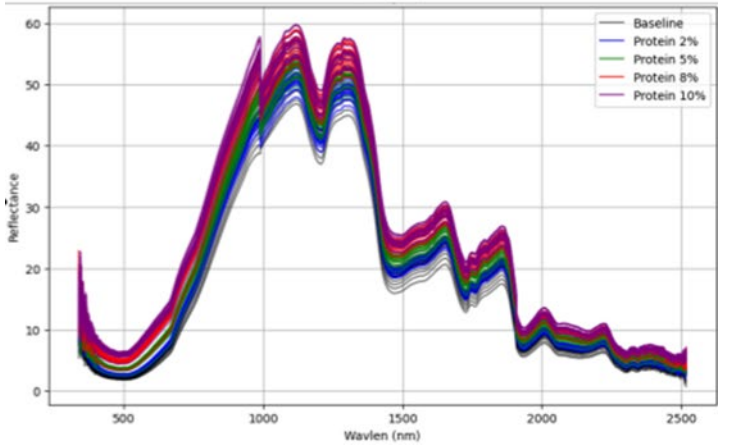
Spiked dried food waste samples with model compounds:

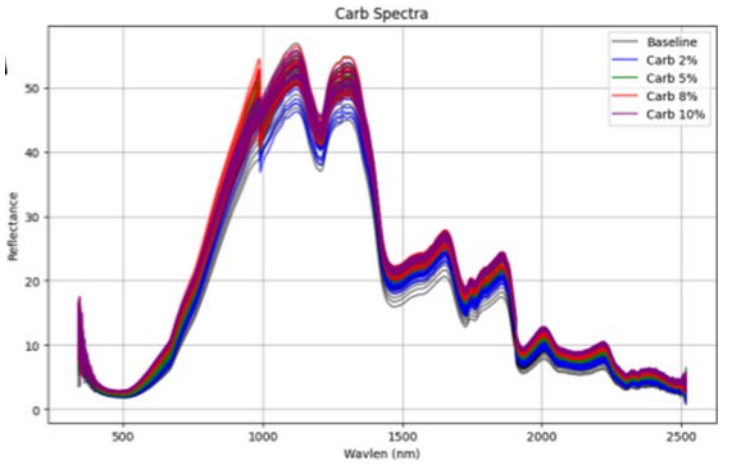
- corn starch (carb)
- collagen (protein)
- Triglyceride (lipid)



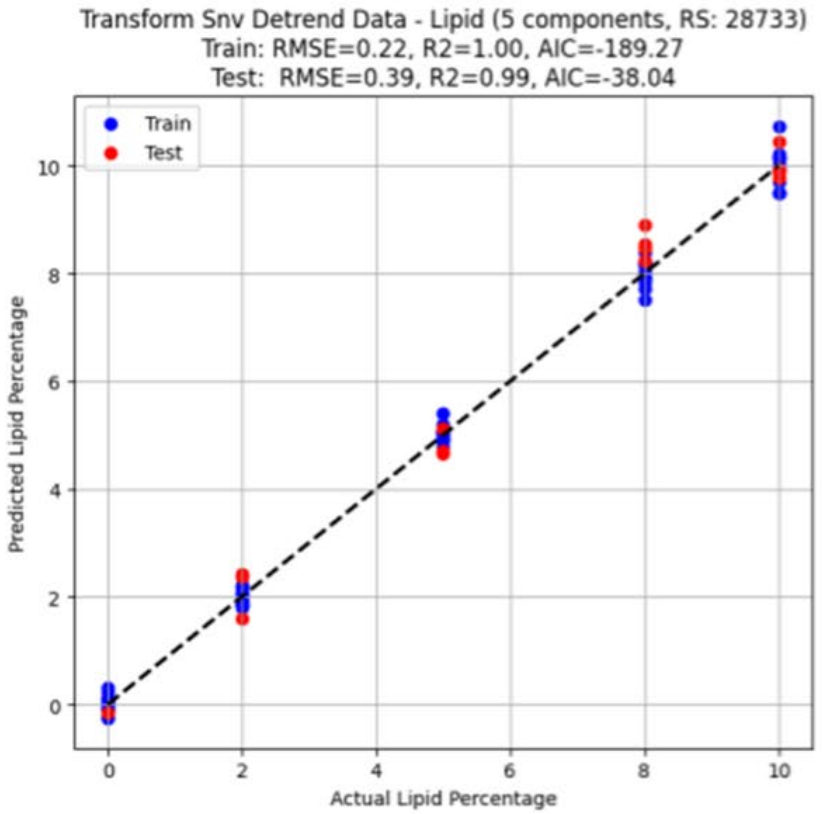
Collected VNIR spectral data (340-2500 nm) of spiked food waste samples



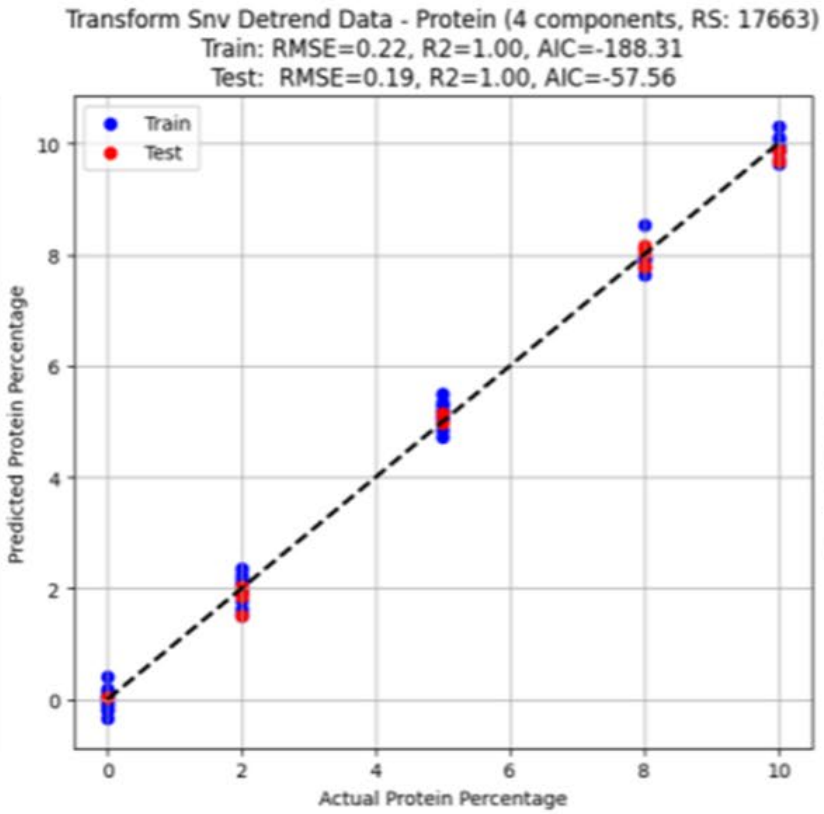




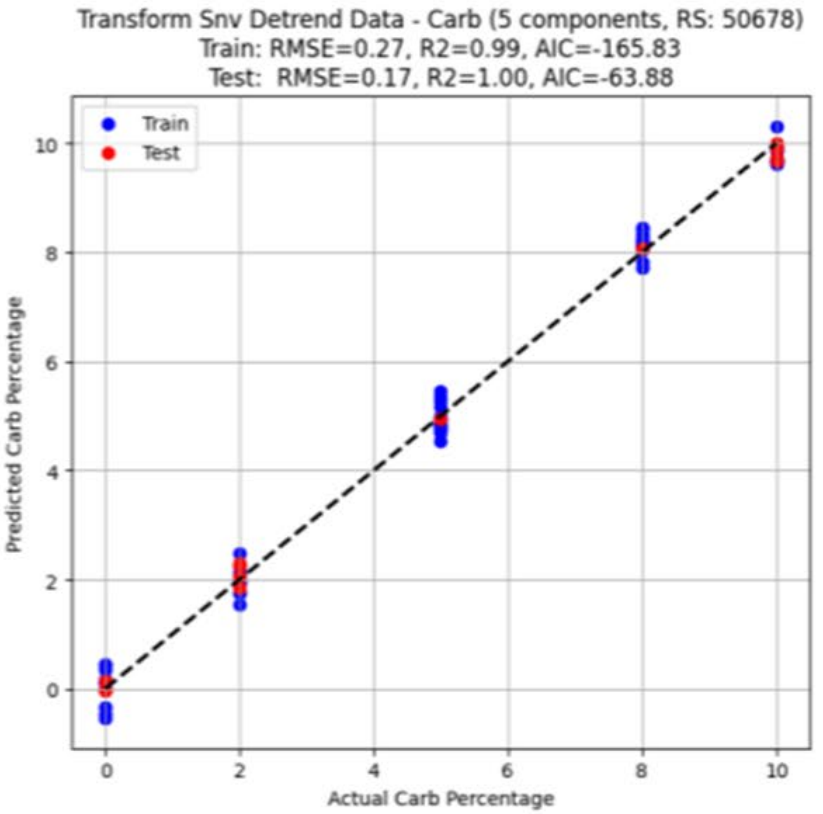
Lipid



Protein



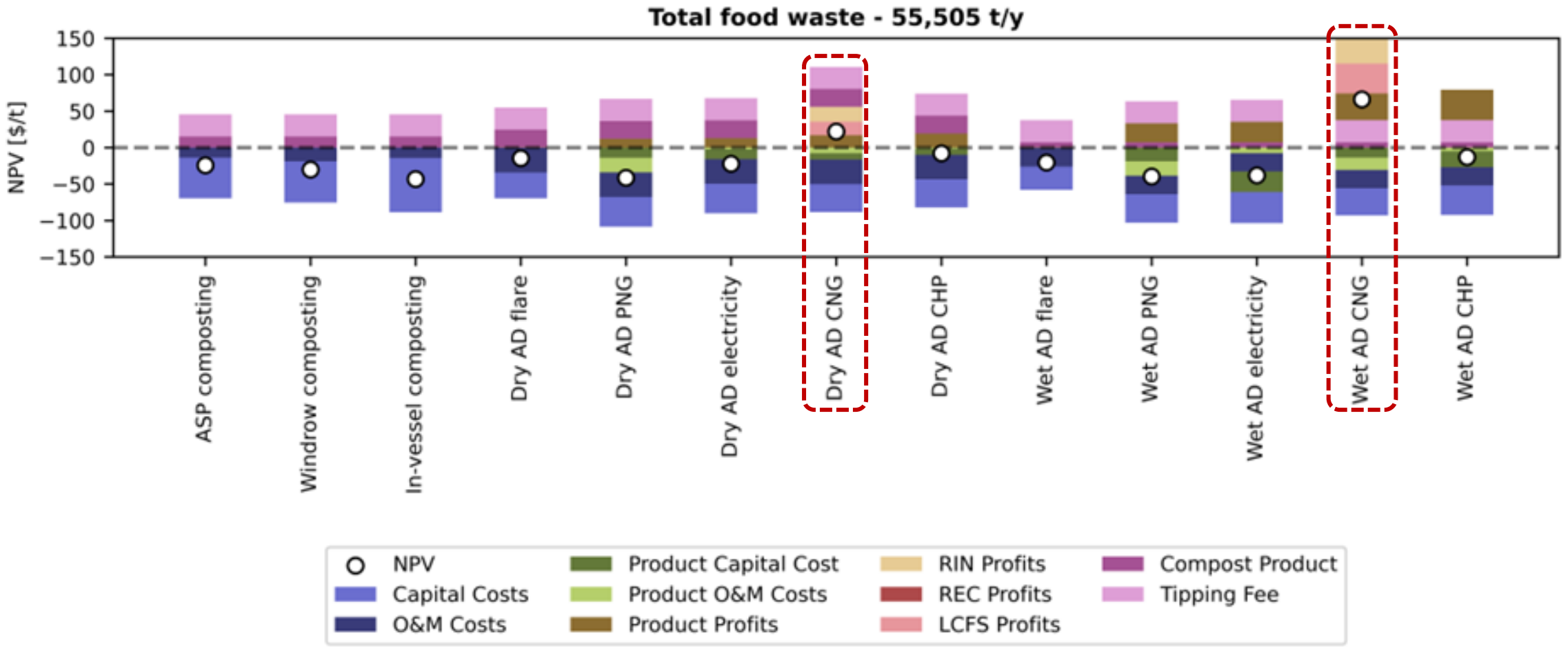
Carbs



Macromolecule	n	RMSE	R^2
Lipids	5	0.39	0.99
Protein	4	0.19	1.00
Carbs	5	0.17	1.00

Ryan Lam
MS Graduate

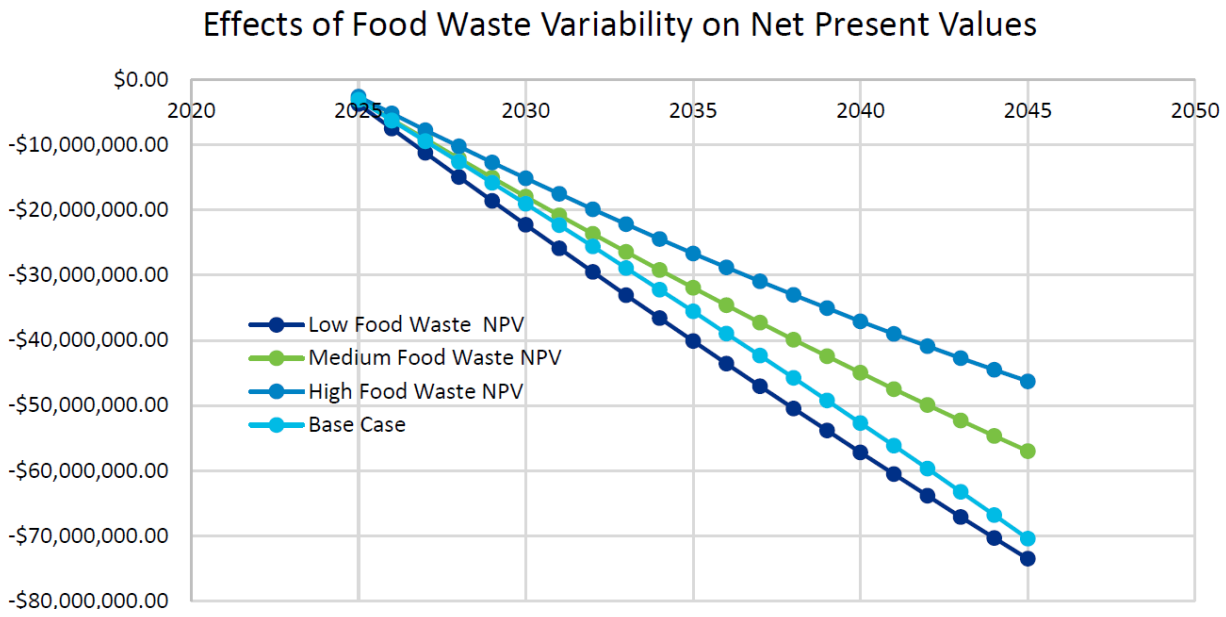
Challenge 2: Economic Viability



Initial results from NREL analysis for the City of Gainesville estimating net present value (NPV) for community food waste composting and anaerobic digestion (AD) scenarios with various biogas upgrading options: PNG = Pipeline Renewable Natural Gas, CNG = Compressed Natural Gas, CHP = Combined Heat and Power.

City of Gainesville AD Feasibility Study

Co-digestion:

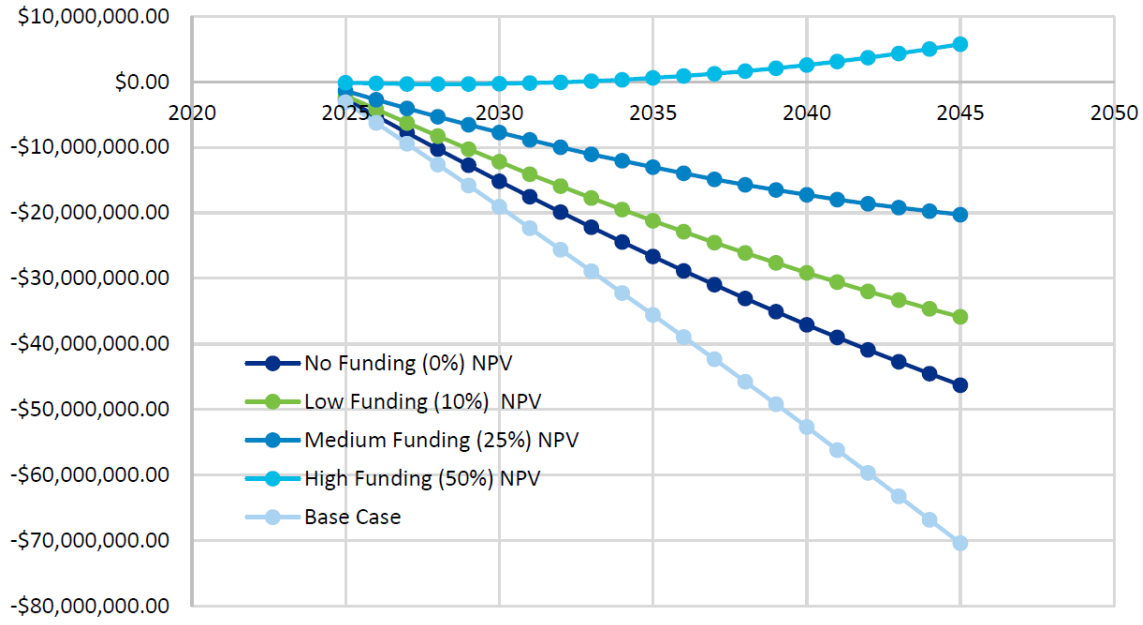


Low feedstock availability will reduce economic viability

Zero Waste Ordinance:

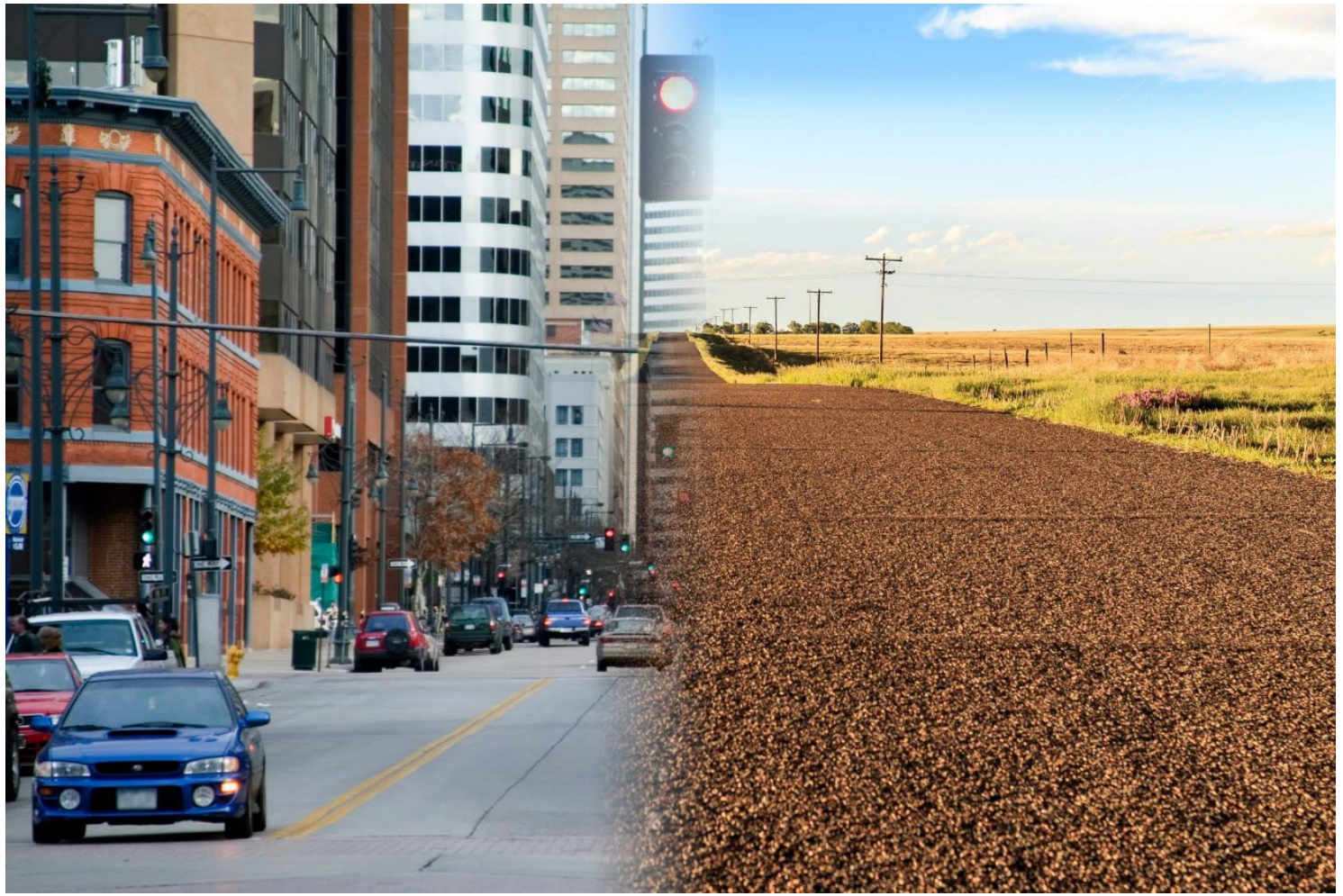
EFFECTIVE: 6/1/2023

Commercial establishments that generate one cubic yard of food waste or more per week shall separate food waste from the waste stream and collect food waste in containers that are separate from garbage and recovered materials.



Grants or other funding needed to generate value

Challenge 3: Digestate Management



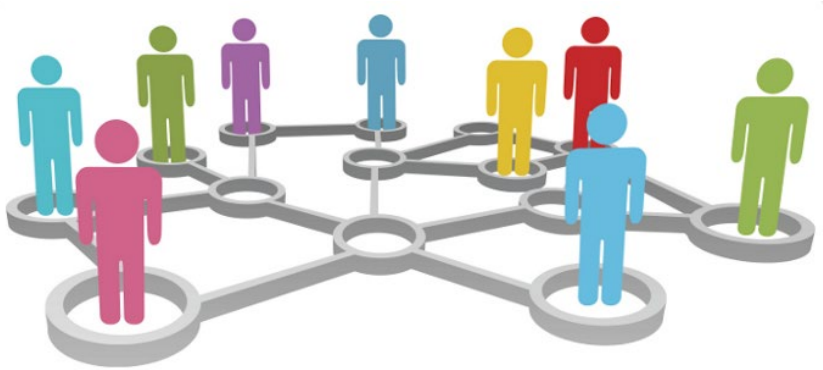
- Must make beneficial use of digestate (water and nutrients)
- Digestate dewatering/drying may be necessary
- Solids can be land applied, composted or upgraded to higher value product
- Partnerships/agreements need to be established

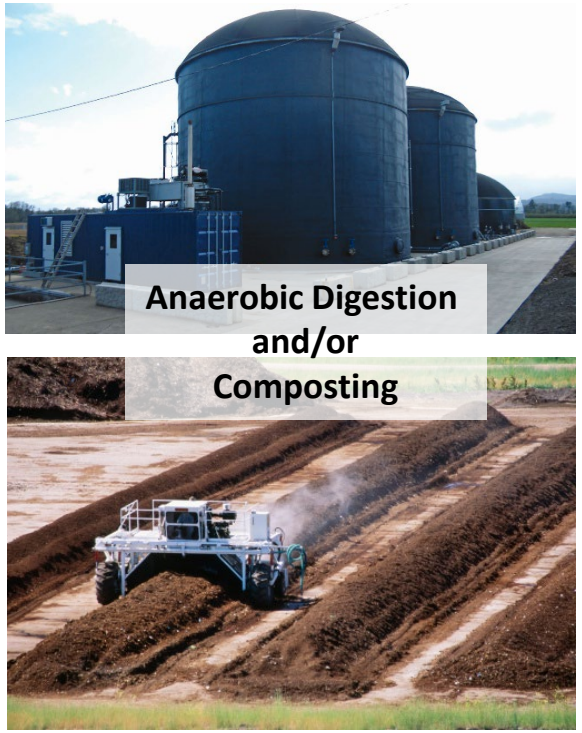
Current Hinkley Project:

Evaluating Barriers to Adoption of Sustainable Food Waste Management

Interviewing Stakeholders:

- Policy Makers and Solids Waste Managers
- Restaurant Owners
- Composters





Identify barriers and opportunities including education/outreach

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Family Youth and Community Sciences

Thank you!

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USDA

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