Mechanical pretreatment for enhanced food waste solubilization and anaerobic digestion

Ryan Graunke
Interdisciplinary Ecology Seminar
February 1, 2011

Advisor: Dr. Ann C. Wilkie
Soil and Water Science Department

BIOENERGY AND SUSTAINABLE TECHNOLOGY LABORATORY

Food waste: a global problem produced locally

- 32 million tons produced annually in the US
- 1.7 million tons generated annually in Florida
  - Currently only 1% is recycled

Food waste is everywhere

- Grocery stores
- Supermarkets
- Restaurants
- Schools
- Hotels
- Prisons
- Households
- Food processors

Food waste audits at local schools and restaurants

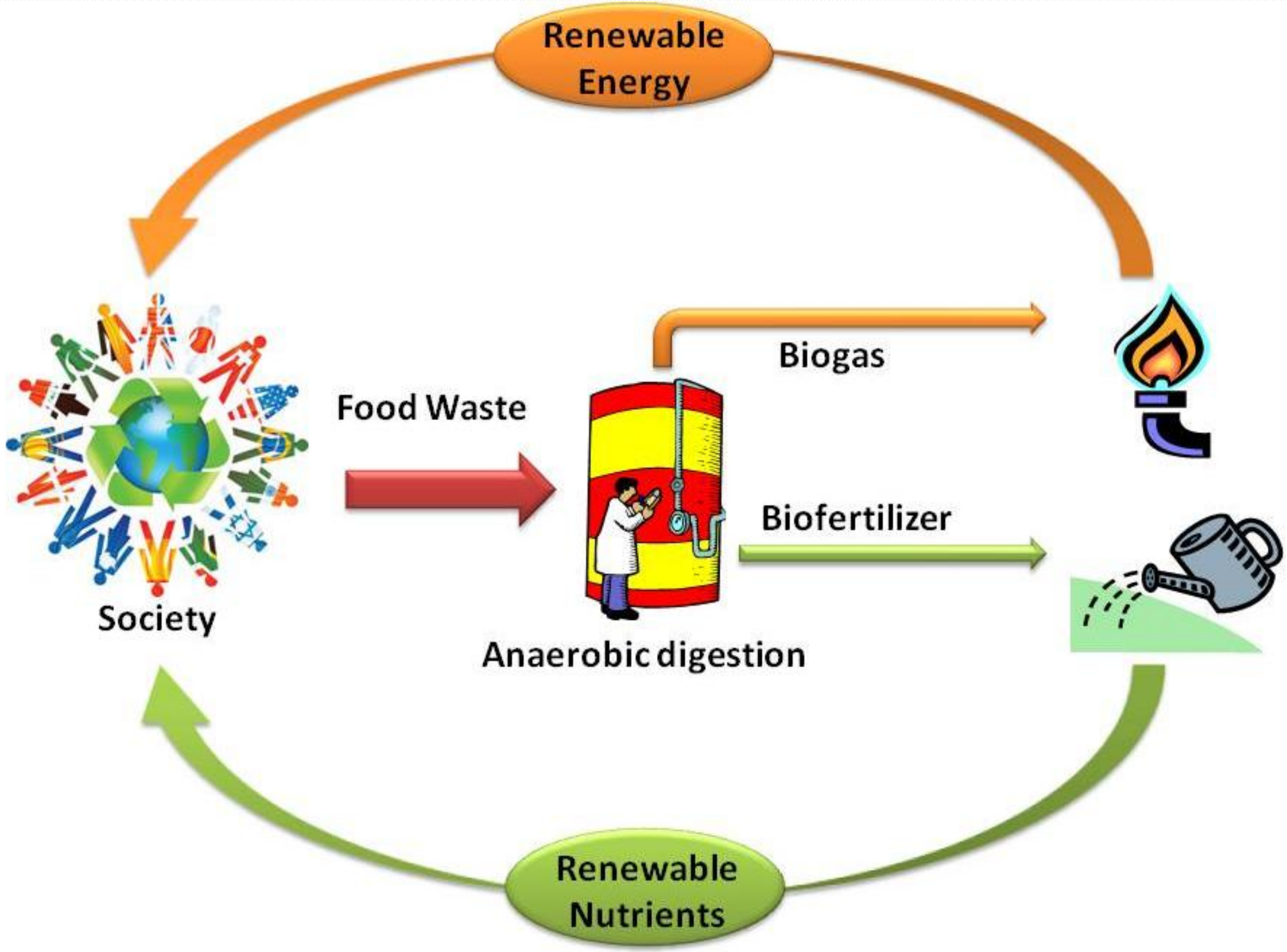
	Schools	Restaurants
Daily per capita food waste	30 – 83 g	75 – 187 g
Annual per capita food waste	5 – 15 kg	21 – 56 kg
Daily food waste/location	8 – 37 kg	20 – 56 kg
Annual food waste/location	2 – 7 Mg	7 – 17 Mg

Problems with landfilling food waste

- Methane emissions
- Leachate problems
- Transportation
- Land requirement
- Nutrient lock-up
- Aesthetics (odors, vermin)

Florida has a 75% recycling goal by 2020

Closed-loop food waste diversion



Anaerobic digestion of food waste

- Anaerobic digestion is the microbial decomposition of organic material to methane under anaerobic conditions
- Digesters harness natural microbial consortia, which also occur in wetlands, lakebeds, and ruminant animals

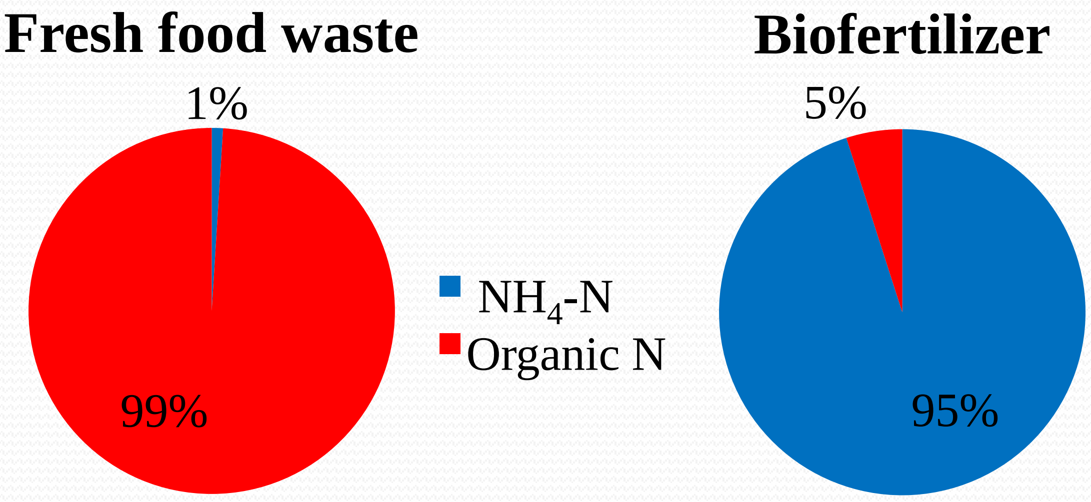
Digesters: all shapes and sizes

Food waste to energy

- Biogas: a methane-rich gas produced from organic material
- Used as an alternative to natural gas for:
  - Cooking
  - Heating
  - Electricity
  - Vehicle fuel

Food waste to fertilizer

- Nutrients converted to plant-available form
- Liquid fertilizer – can be used in fertigation systems
- Organic replacement for synthetic fertilizer



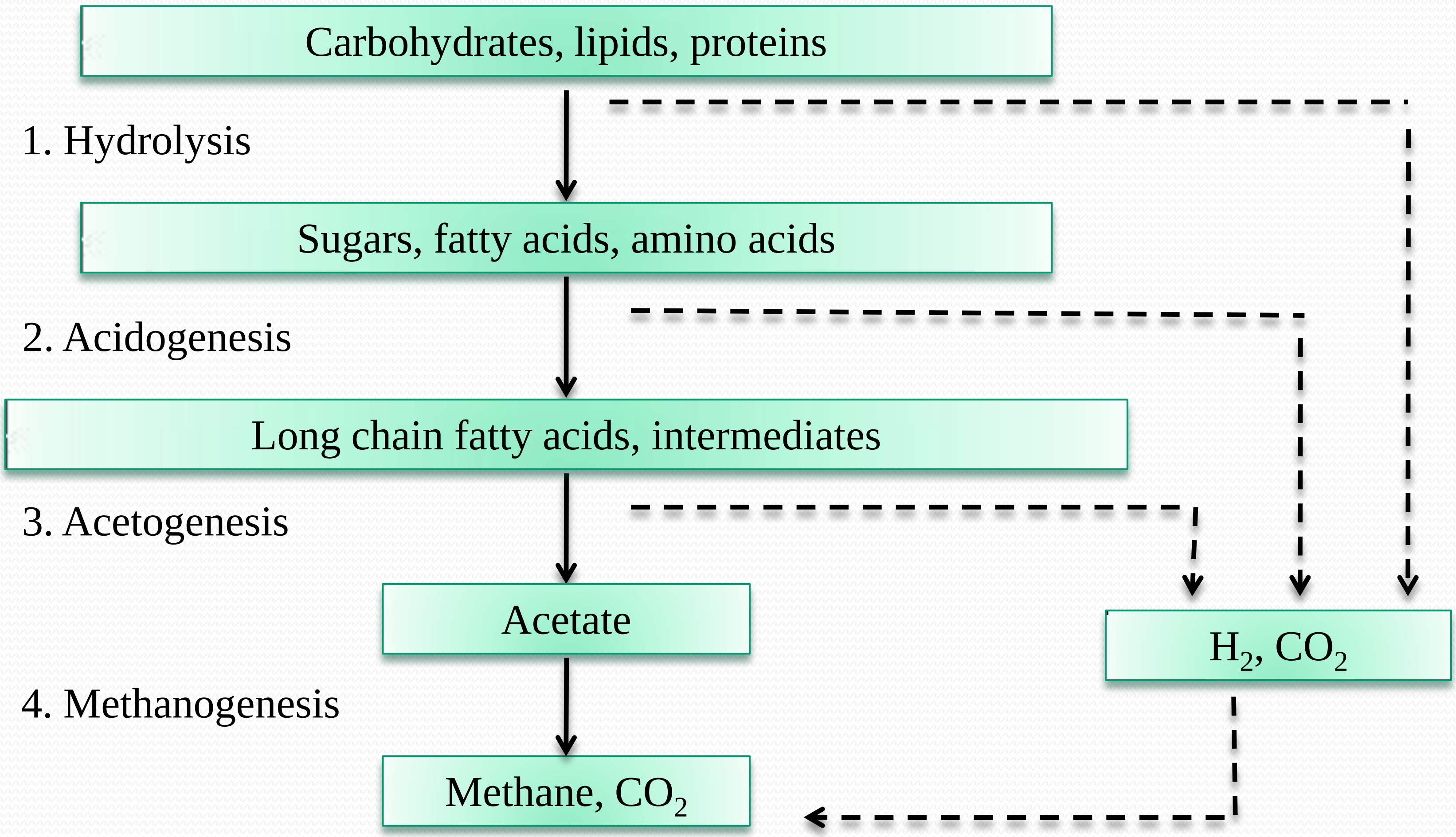
Bioresources available in Florida's food waste

- 1.7 million tons of food waste per year could generate:
  - 189 million m^3 of methane
  - 14,300 Mg of nitrogen
  - 2,100 Mg of phosphorous

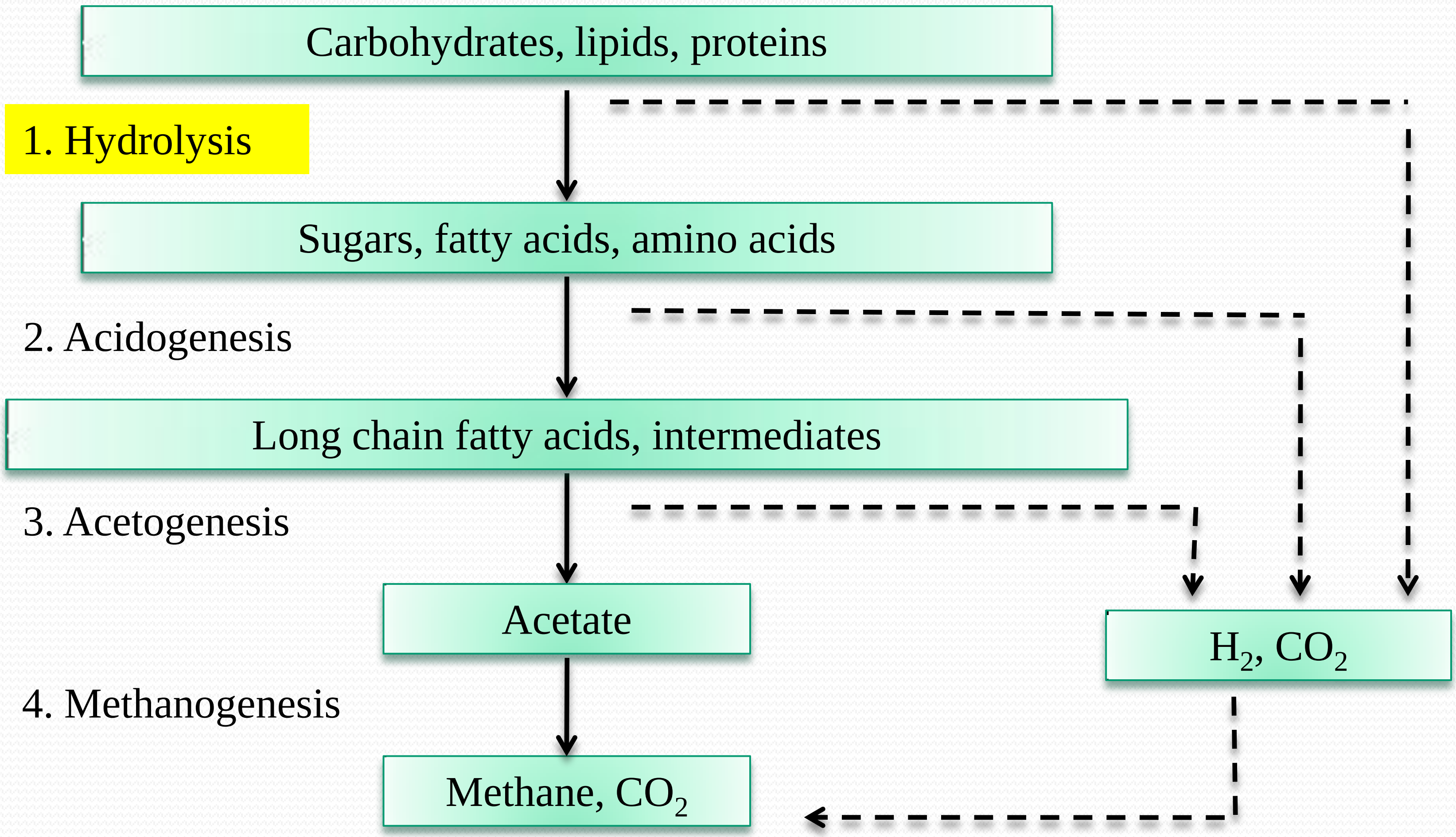
So what are we waiting for?

- While food waste digestion is possible, optimization is key to implementation
- Food waste is different substrate than manure or wastewater
- The rate of digestion is limited by hydrolysis
- Improving hydrolysis will facilitate food waste digestion.

Mixed microbial metabolism



Mixed microbial metabolism



Hydrolysis of organic macromolecules

- Microbes require organic molecules to be solubilized for assimilation to occur
- Hydrolysis is facilitated by extracellular enzymes produced by microbes in the digester

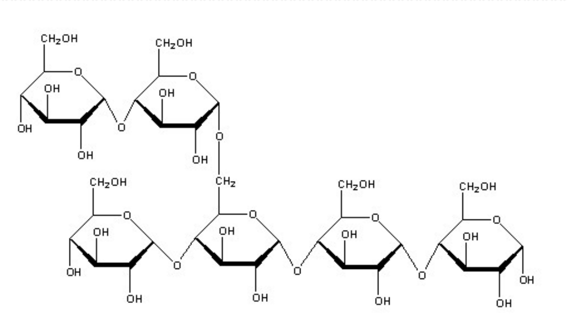
Carbohydrates, lipids, proteins

↓ 1. Hydrolysis

Sugars, fatty acids, amino acids

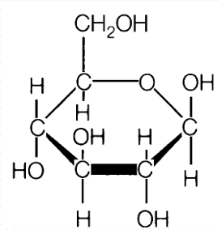
Hydrolysis of organic macromolecules

- Different microbes and enzymes hydrolyze different macromolecules

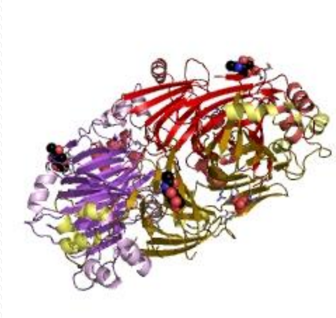


Starch

Amylase

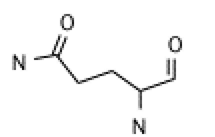


Glucose

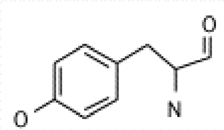


Legumin

Protease

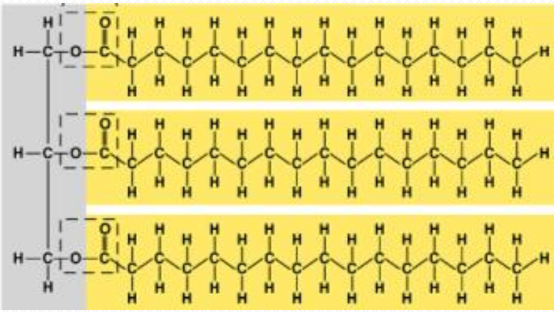


Glutaminyl



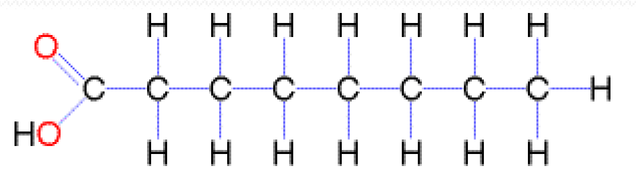
Tyrosyl

Amino Acids



Triglyceride

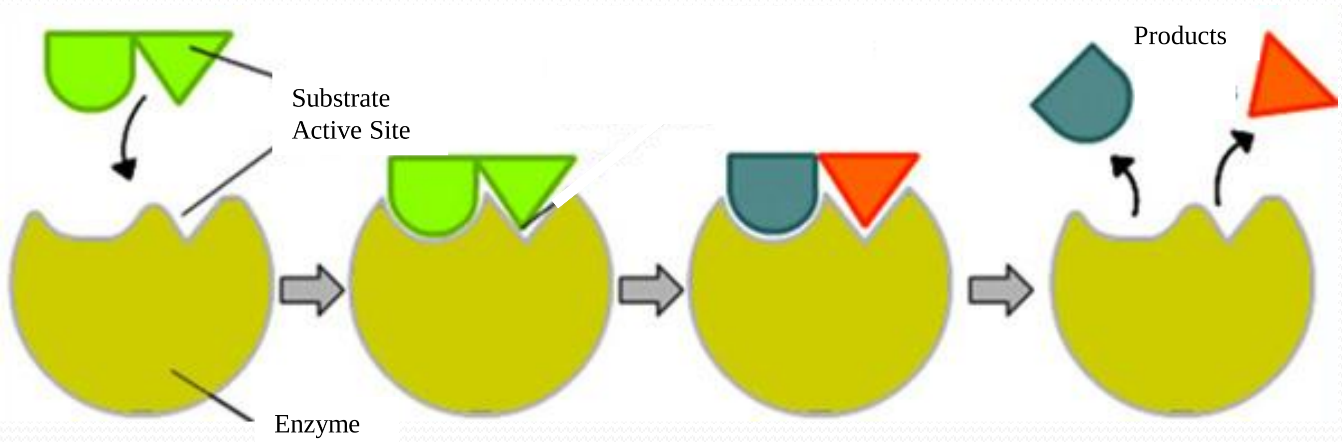
Lipase



Fatty Acid

Hydrolysis of organic macromolecules

- Enzymes function through a lock-and-key mechanism



How to improve hydrolysis

- Various methods have been studied to enhance food waste hydrolysis through pretreatment
  - Freezing/thawing
  - Heating (150°C)
  - Enzyme cocktails
  - Ball milling
- These methods are expensive and energy intensive
- Practical mechanical pretreatment may be more feasible

Research question

How does mechanical pretreatment impact the anaerobic digestion of food waste?

Hypothesis: Low-tech mechanical pretreatment will improve solubility and therefore methane production

Objectives

1. Determine solubilization kinetics of pretreated food waste
2. Measure impacts of pretreatment on methane production

Development of methodology

Key parameters

- Chemical oxygen demand (COD) – measures organic strength of substrate
  - Total COD (TCOD) – COD of particulate and soluble material
  - Soluble COD (SCOD) – soluble organic matter; available for microbial growth
  - Solubility – SCOD/TCOD%

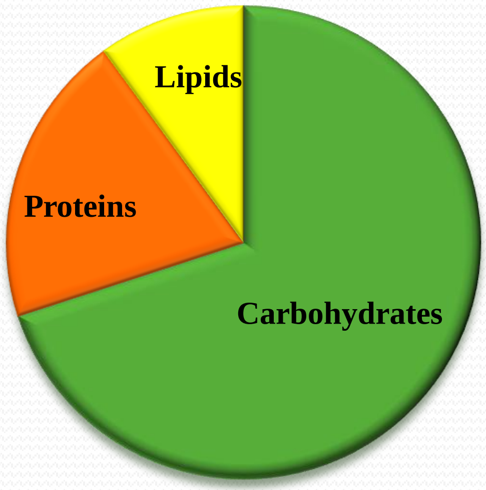
Development of methodology

1. Develop standard food waste as a representative substrate for experimental replication
2. Select hydrolytic enzymes to measure substrate availability for enzymatic hydrolysis after pretreatment
3. Choose suitable mechanical pretreatment method

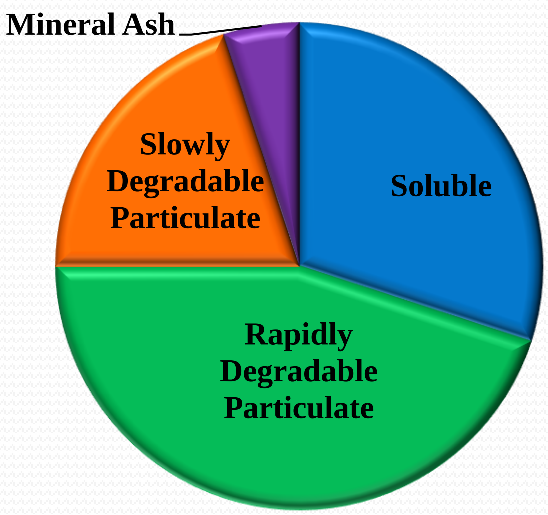
1. Standard food waste

- Food waste is highly variable and heterogeneous
- Moisture content range: 45%-90%
- Standard food waste must capture this heterogeneity, while representing "real" food waste

Macromolecule Composition



Degradability composition



1. Standard food waste

Represents different organic macromolecules

Food type	% (wet weight)	Macromolecule type
Apple	24	Carbohydrate – sugars, pectin
Potato	24	Carbohydrate – starch
Bread	20	Carbohydrate – starch
Broccoli	12	Carbohydrate – cellulose
Beans	12	Protein
Cheese	8	Protein, fat

1. Standard food waste

Represents actual food waste

Parameter	Standard food waste	School cafeteria waste (n=33)	Restaurant dining waste (n=50)
Moisture	70.1%	52.9 – 75.3%	43.9 – 92.2%
VS/TS[a]	95.4%	80.2 – 95.8%	70.1 – 97.8%
TCOD[b]	318.3	302.3 – 580.0	78.8 – 787.5
Total nitrogen[c]	3.08%	2.07 – 7.01%	1.04 – 5.59%
Total phosphorus[c]	0.32%	0.29 – 1.4%	0.10 – 0.56%

a: volatile solids/total solids
b: g COD/kg wet weight
c: dry matter basis

2. Measure enzymatic hydrolysis

Commercial digestive enzyme cocktail selected due to efficacy and suitability for experimental use

Enzyme	Macromolecule targeted	Concentration (per 0.25 g)
Amylase	Carbohydrates (starch)	12,000 DU[a]
Cellulase	Carbohydrates (cellulose)	200 CU[b]
Lactase	Carbohydrates (lactose)	850 ALU[c]
Pectinase	Carbohydrates (pectin)	50 Endo-PGU[d]
Protease	Proteins	42,000 HUT[e]
Lipase	Lipids	500 FCC-LU[f]

a: Dextrinizing units
b: Cellulase units
c: Acid Lactase units
d: Endo-polygalacturonidase Units
e: Hemoglobin Units in a Tyrosine base
f: Food Chemical Codex - Lipase Units

3. Mechanical pretreatment selection

- Mechanical pretreatment method should be practical for a restaurant, school, or grocery store
- Manual meat grinder selected for ease of use and uniformity of pretreatment
- In-sink food disposal also tested

Objectives

1. **Determine solubilization kinetics of pretreated food waste**

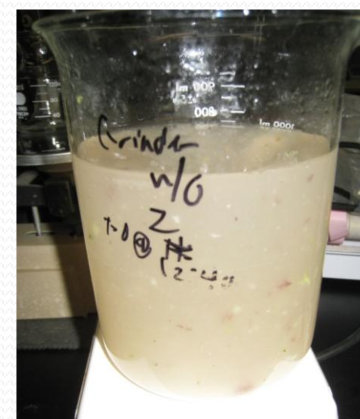
2. Measure impacts of pretreatment on methane production

Objective 1: Solubilization kinetics

- Developed assay to determine solubilization over time
- SCOD measured as a proxy for hydrolysis
- Mechanical pretreatment vs. intact food waste
- Enzymes added to measure substrate availability
- Buffer added to prevent acidification

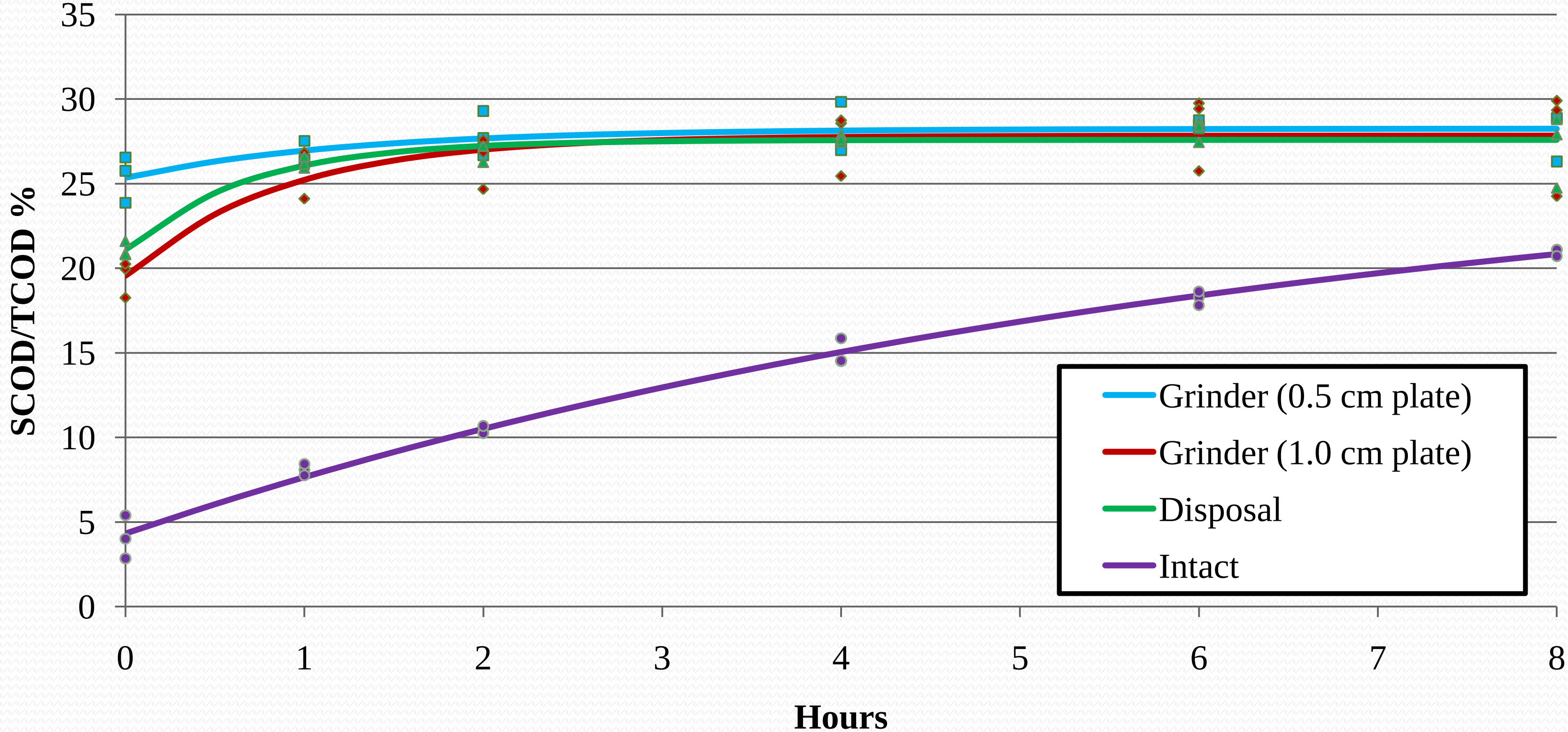
Intact food waste

Pretreated food waste



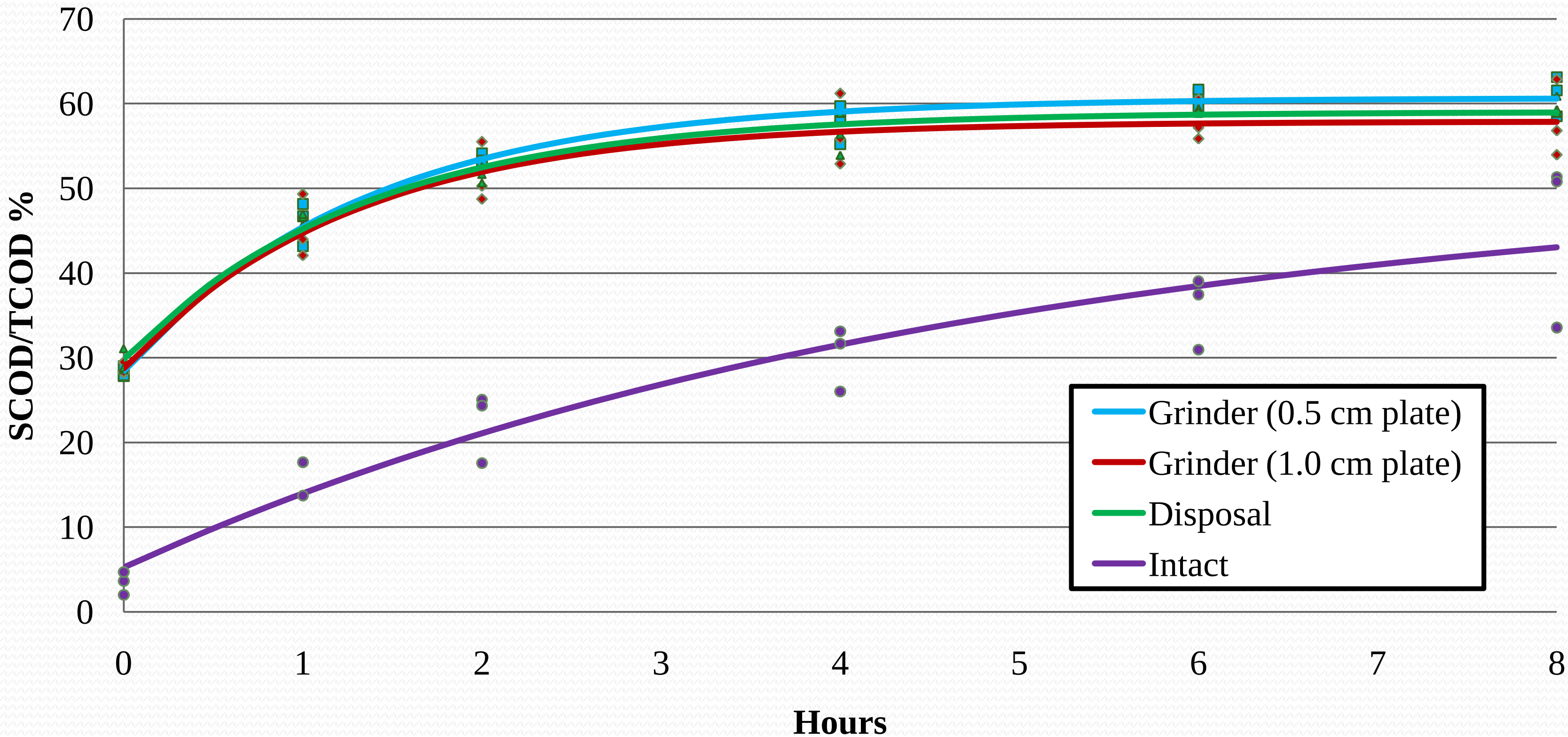
Solubilizing food waste

Solubilization without enzymes



- Pretreatment: 28% solubilization within 2 hours
- Intact food waste: 20% solubilization at 8 hours
- All pretreatments showed similar solubilization

Solubilization with enzymes



- Pretreatment: 60% solubilization within 4 hours
- Intact food waste: 40% solubilization at 8 hours
- Pretreatment significantly increased substrate availability

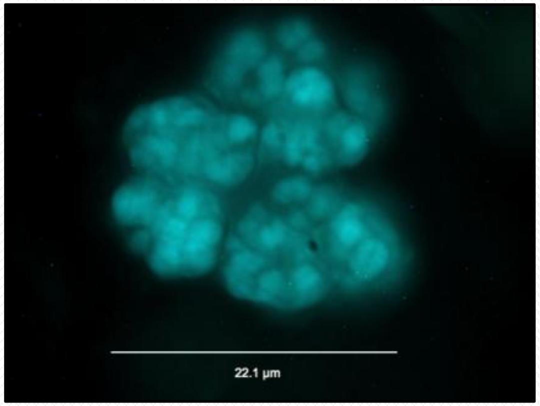
Objectives

1. Determine solubilization kinetics of pretreated food waste

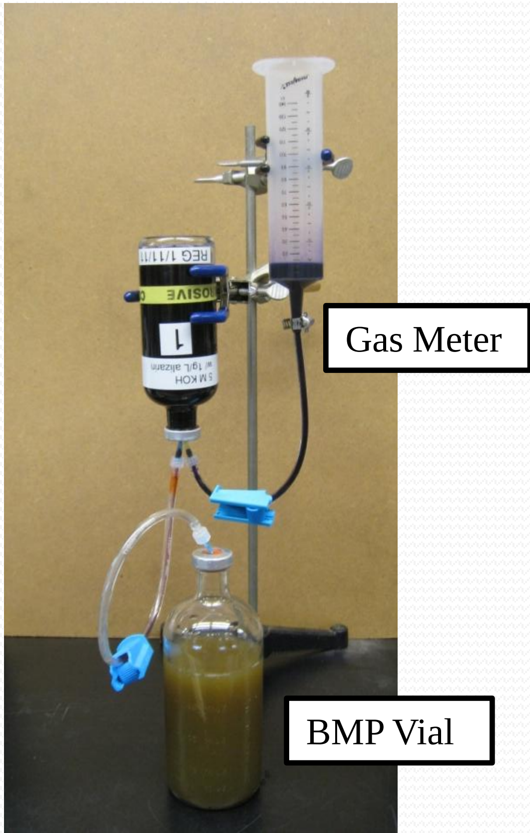
2. **Measure impacts of pretreatment on methane production kinetics**

Objective 2: Methane production

- Biochemical methane potential (BMP) assay
- Batch assay measures ultimate methane yield of a substrate
- Inoculated with methanogenic culture
- Measures microbial methanogenesis



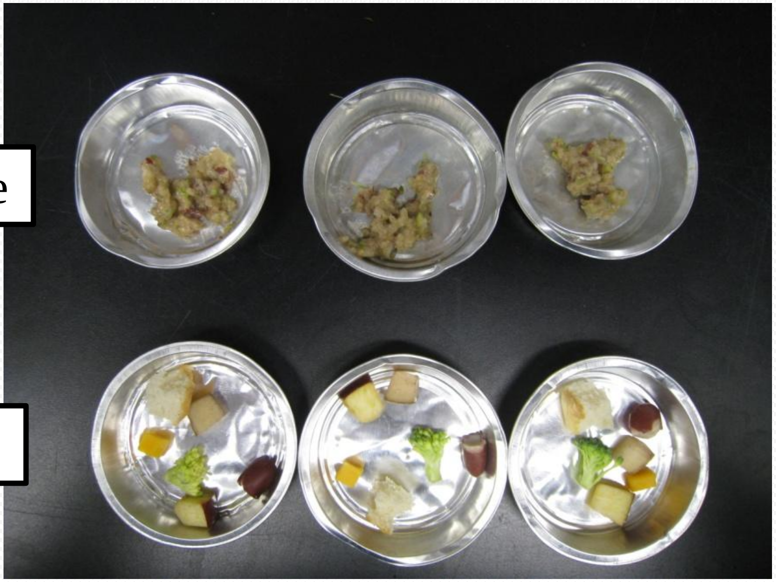
Methanosarcina sp.



Objective 2: Methane production

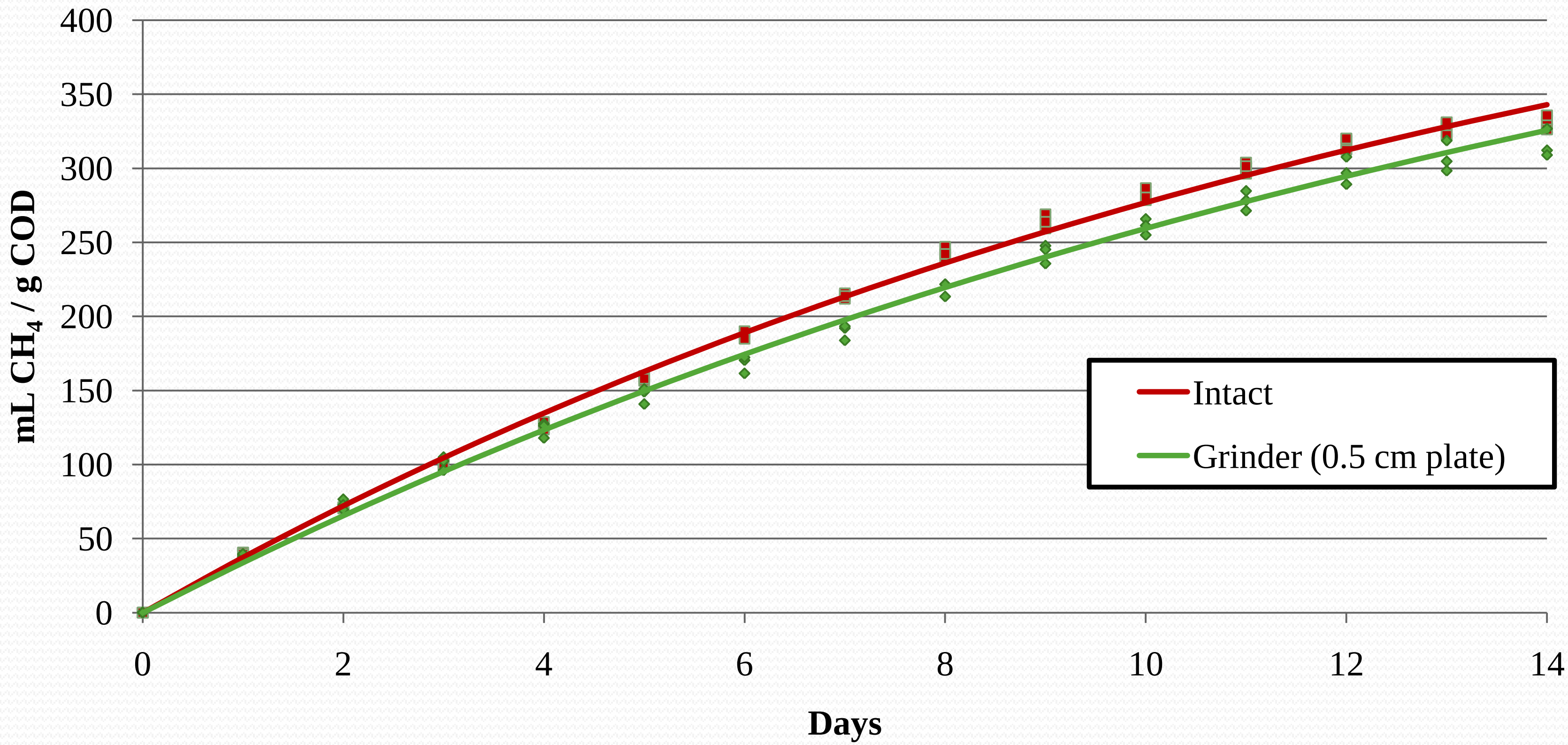
- Pretreated food waste (meat grinder) vs. intact food waste
- Flushed dairy manure used as an inoculum
- Digested at mesophilic temperature (35°C)
- Methane generation measured daily

Pretreated food waste



Intact food waste

BMP Methane Production



- Both pretreated and intact food waste reached nearly 100% conversion within 14 days
- Intact food waste slightly greater than pretreated food waste
- May be due to accumulation of organic acids through increased acidogenesis

Conclusions

- Mechanical pretreatment results in significantly faster solubilization than intact food waste

- Pretreatment did not lead to faster methane production
  - May be limited by slower methanogenic rate in BMP assay

- Therefore a high-rate digester (e.g. fixed film or two-phase) could be coupled with mechanical pretreatment to take full advantage of increased solubilization

Acknowledgements

I would like to thank:

- Dr. Ann C. Wilkie - Advisor
  Soil and Water Science Department

Committee Members

- Dr. George Hochmuth
  Soil and Water Science Deparment
- Dr. Kimberly Moore
  Environmental Horticulture Department

This work is funded by a grant from the Hinkley Center for Solid and Hazardous Waste Management.

Questions?

Contact:
reg1214@gmail.com

Website:
http://biogas.ifas.ufl.edu/foodwaste