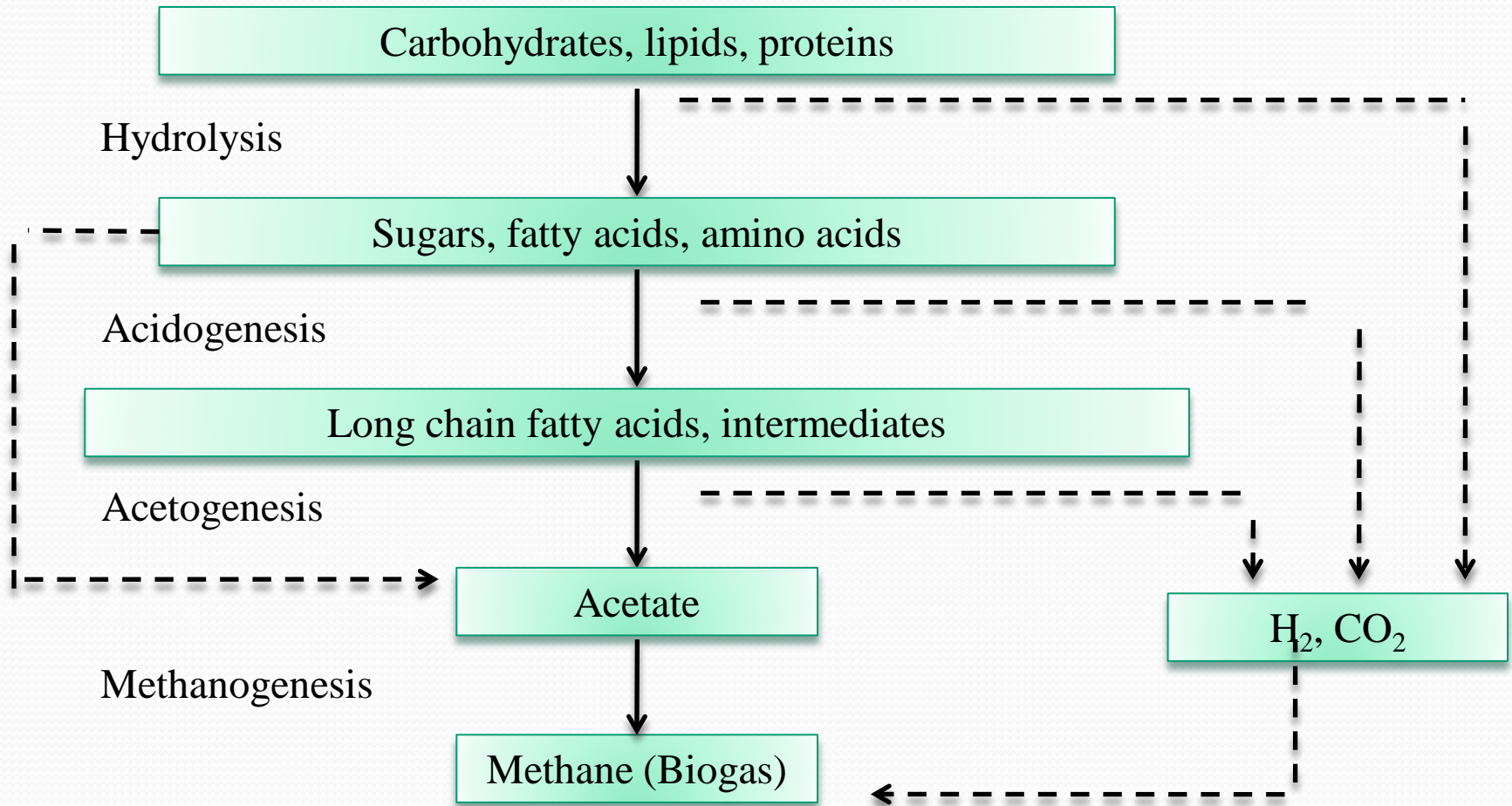


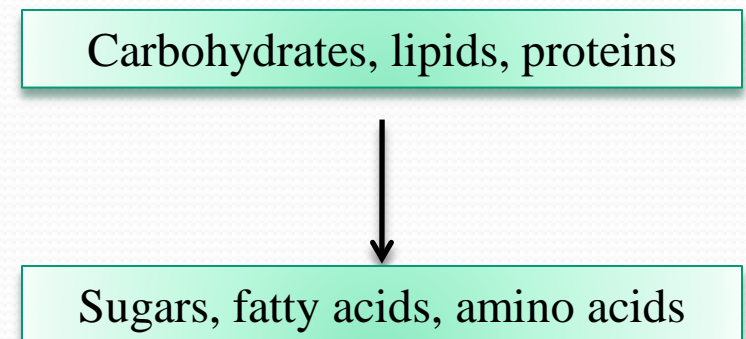
Anaerobic digestion: Terminology and benefits

Microbiology Review



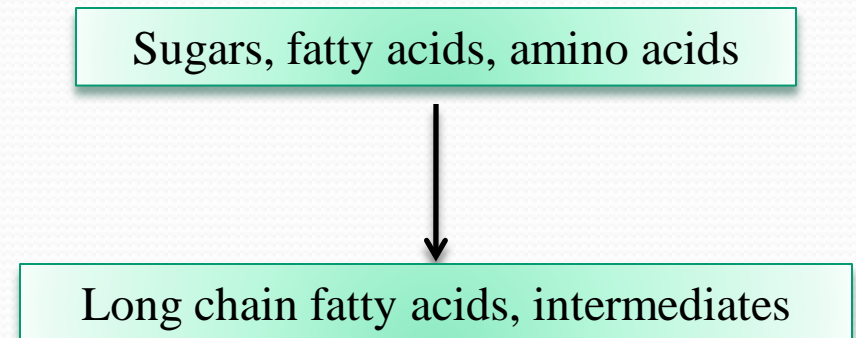
Hydrolysis

- Large molecules breakdown into simple monomers
- Facilitated with extracellular hydrolytic enzymes
 - Different enzymes for different molecules (lock and key)
- Includes a wide variety of bacteria, fungi, and protists



Acidogenesis

- Organic monomers are converted into organic acids
- Occurs through anaerobic fermentation
- Many different organic acids are produced including acetate
- Acidogens are also frequently responsible for hydrolysis
- Often the fastest step
 - Can cause acidification



Acetogenesis

- Organic acid intermediates are converted into acetate
- Occurs through anaerobic respiration
- Two main groups of bacteria
 - Homoacetogens – less common in AD
 - Obligate hydrogen-producing acetogens (OHPA)
- OHPA must produce H_2 to produce acetate, which leads to syntrophy with methanogens

Methanogenesis

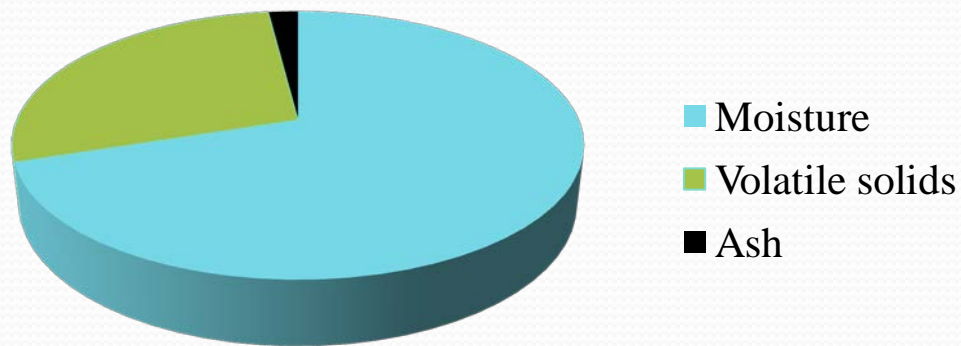
- Acetate or CO_2 and H_2 are reduced to methane.
- Acetoclastic methanogens utilizes acetate
 - *Methanosarcina* sp. and *Methanosaeta*
- Hydrogenotrophic utilizes CO_2 and H_2
 - Live in syntrophy with OHPA by consuming H_2 and allowing production of acetate

Important factors of AD

- Total Solids/Volatile Solids
- Chemical Oxygen Demand
- Biochemical Oxygen Demand
- Biochemical Methane Production
- Organic Loading Rate
- Hydraulic Retention Time
- Temperature
- pH
- Acidification
- Substrate Composition
- Pretreatment

Total Solids, Volatile Solids

- Total Solids (TS)= Dry matter content of substrate
 - Inverse of moisture content
 - One of the most variable parameters between substrates
- Volatile Solids (VS)= Combustible proportion of TS, organic matter
- Non-volatile Solids (Ash)= Inorganic material (Minerals, salts), does not contribute to methane



COD (Chemical oxygen demand)

- Chemical oxidant used to completely oxidize substrate
- Color indicator used to determine oxidant consumed
- Represents organic carbon in substrate
- Stoichiometrically related to methane potential
 - $\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}$
 - Therefore 1 g COD = 0.35 L methane @ STP
- COD represents the theoretical maximum methane produced from a substrate
- More accurate estimation than VS

BOD (Biochemical oxygen demand)

- Similar to COD, but uses aerobic microbes to oxidize substrate
- Measures oxygen consumed during process
- Requires several days (commonly 5 days = BOD₅)
- More realistic representation of microbially-available organic material
- Used widely in aerobic treatment to determine aeration requirement

BMP (Biochemical methane potential)

- Assay developed as correlative test of BOD in anaerobic systems
- Determines actual methane production
- Accounts for non-biodegradable materials in feedstock (i.e. lignin)
- Measures kinetics of methane production



Organic loading rate (OLR)

- Rate at which feedstock is fed to the digester
- Units in kg VS (or COD)/m³/day or g VS (COD)/L/day
- Dependent on feedstock, reactor type, microbial population, temperature
- Too low= Unnecessarily large reactor (\$\$\$)
- Too high= Overload reactor, acidification (i.e. rate of acidogenesis exceeds rate of methanogenesis)

Hydraulic Retention Time (HRT)

- Turn-over rate in digestion (i.e. amount of time substrate remains in active volume)
- Optimized for highest biogas/reactor volume ratio
- Too high= Unnecessarily large reactor (\$\$\$)
- Too low= Reduced biogas output, washout microbes

Temperature

- Anaerobic metabolism more sensitive to temperature than aerobic
- Three primary temperature ranges
 - Ambient: 10-25° C (50-77 °F)
 - Mesophilic: 25-45 °C (77-113 °F)
 - Thermophilic: 45-60 °C (113-140 °F)
- Different microbial ecology at each temperature range
- Biogas output is greater at higher temps, but not linearly
- Each range has optimum temp for that microbial population

pH

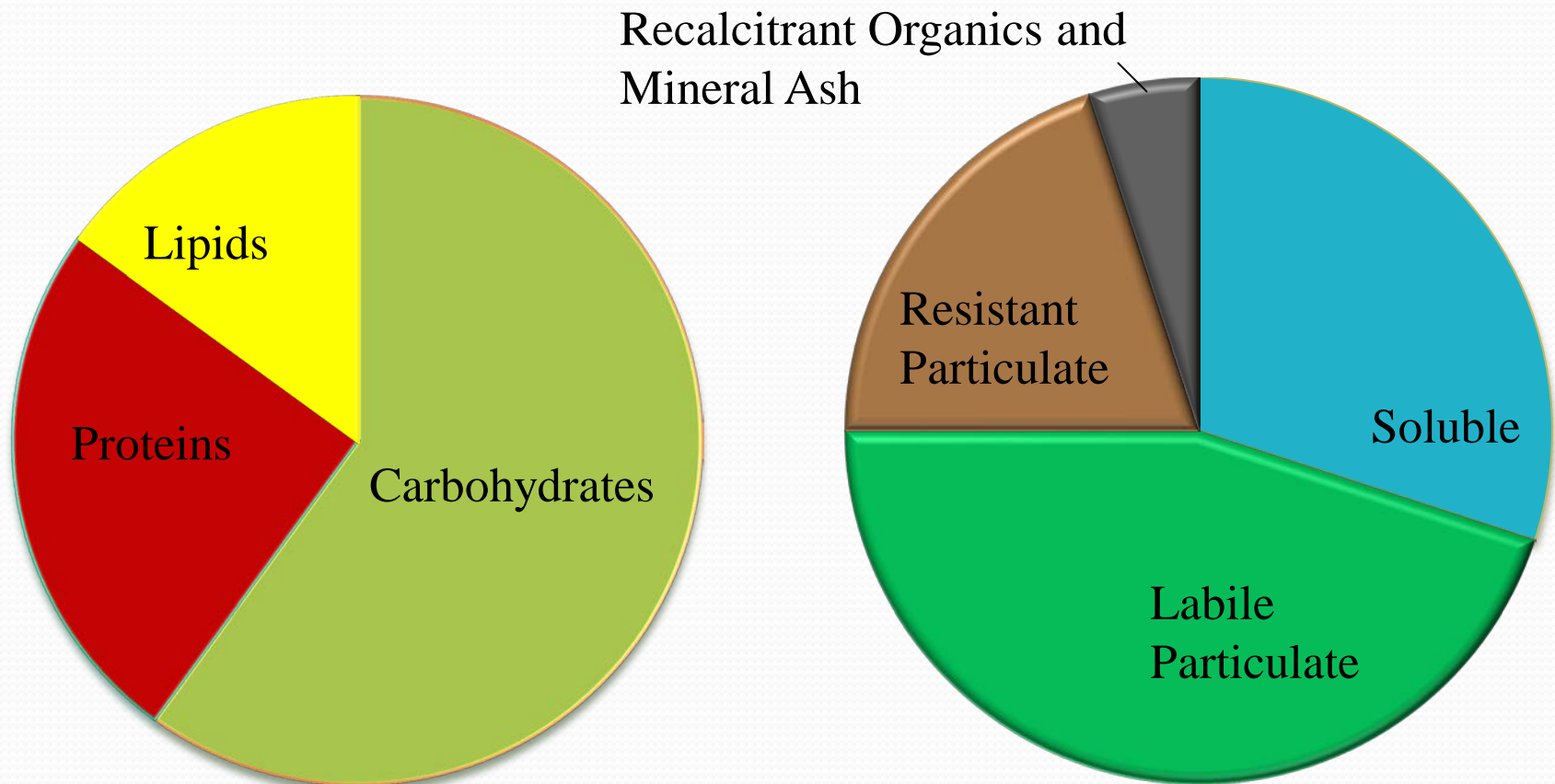
- Critical parameter
- Optimum 7.0, acceptable 6.0-8.0
- Methanogens cannot function at low pH
- Ammonia toxicity above 8.0
- pH can be maintained through addition of buffering agents (sodium bicarbonate, etc.), if required
- Dependent upon alkalinity of feedstock and population of methanogens

Acidification

- In anaerobic digestion organic acids are produced through acidogenesis, and drives pH lower
- Consumption of acids through methanogenesis keeps pH in balance
- If acidogenesis exceeds methanogenesis, acidification can occur
- Decrease in pH further inhibits methanogens, driving pH even lower (in a positive feedback loop)
- Slow recovery after sustained drop in pH

Kinetics and substrate composition

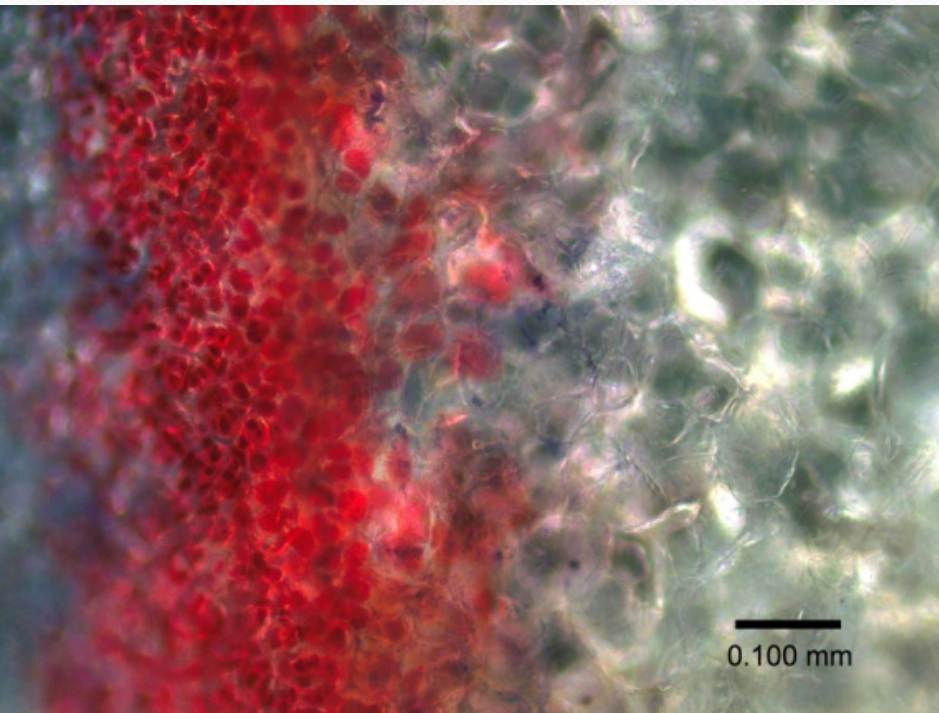
- Type of materials in substrate determines digestion kinetics



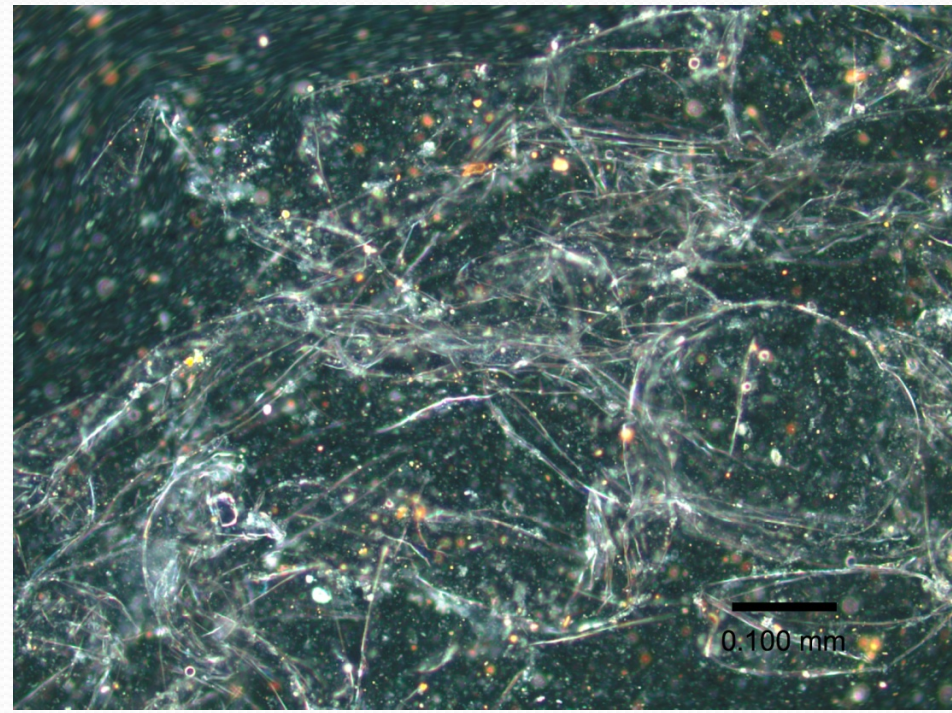
Pretreatment can increase kinetics

- For some substrates and digesters, kinetics are determined by hydrolysis rate
- Total organic matter (TCOD) fractionated between particulate matter (PCOD) and soluble matter (SCOD).
- Only SCOD can be assimilated by microbes
- Hydrolysis converts PCOD to SCOD.
- Pretreatment can enhance solubilization by:
 - Releasing endogenous SCOD
 - Increasing availability to hydrolytic enzymes

Pretreatment of apple

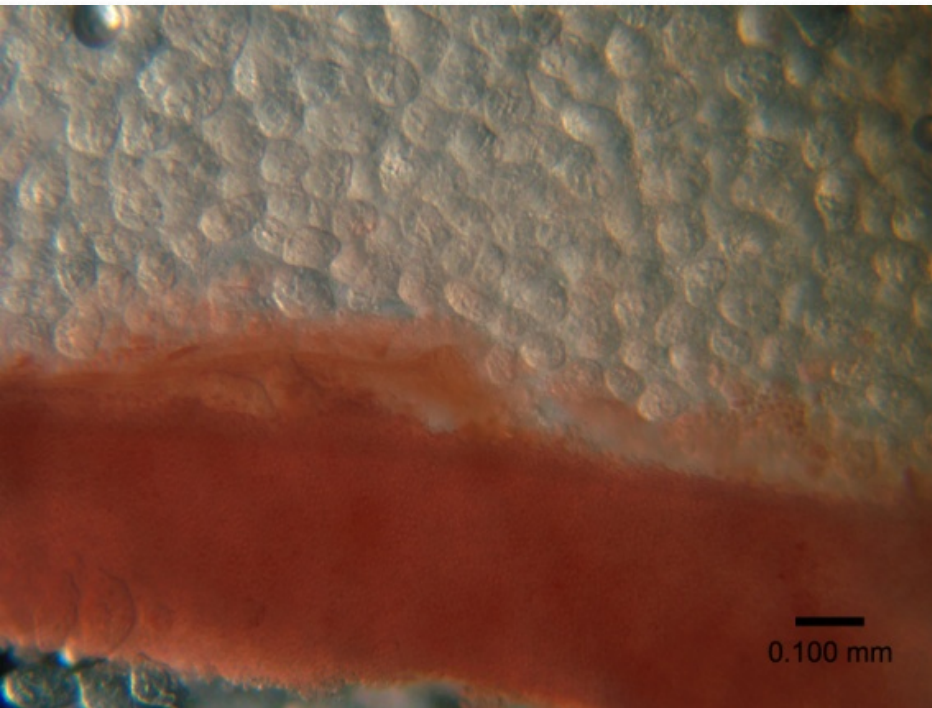


Before grinding

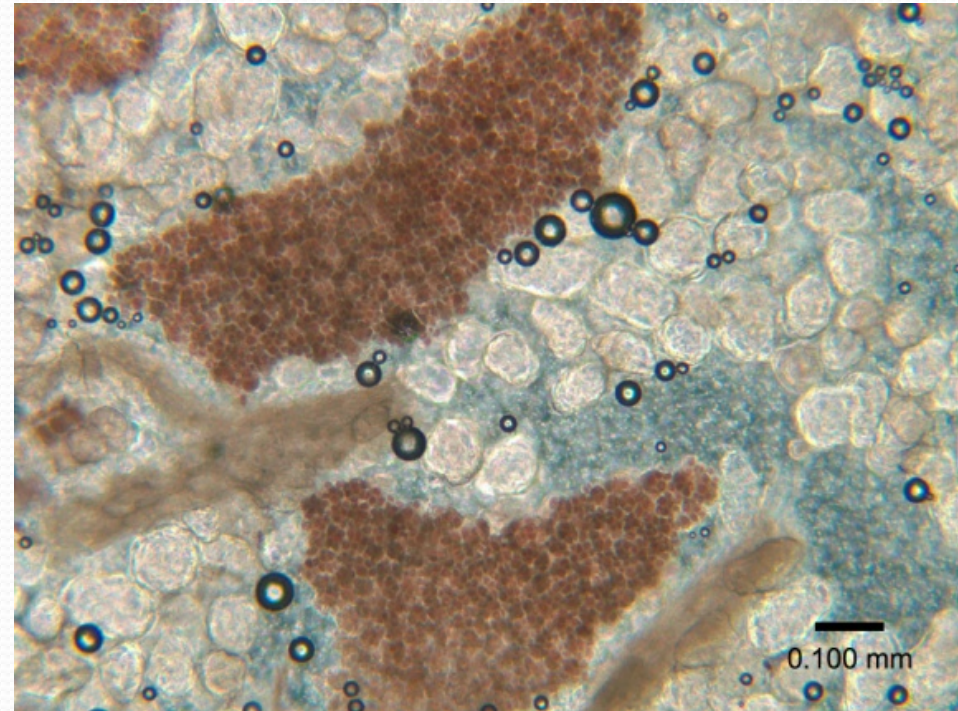


After grinding

Pretreatment of bean

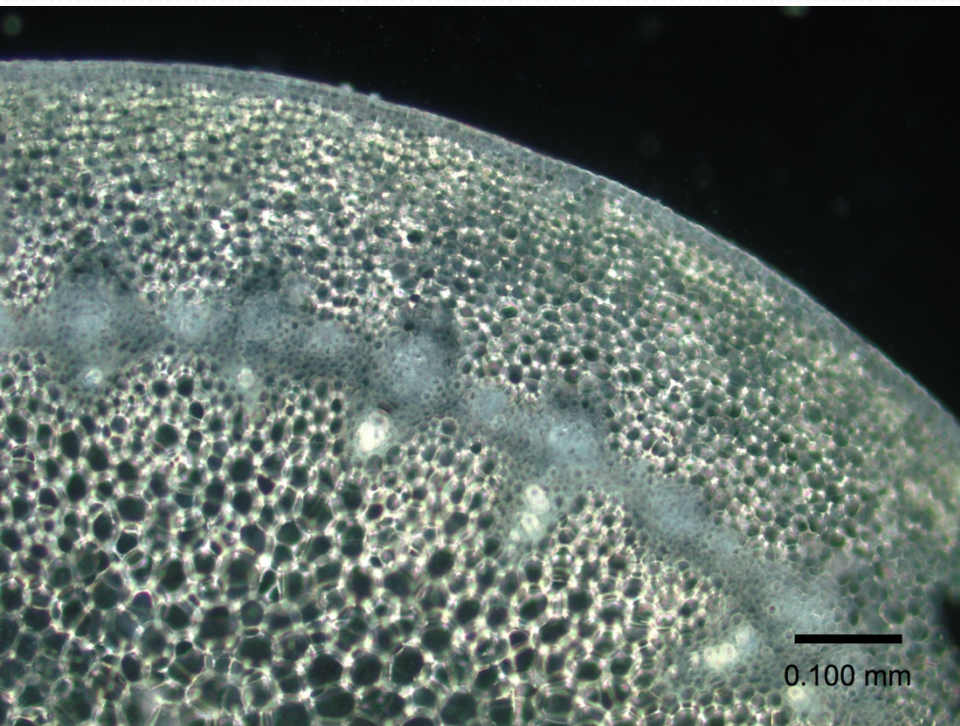


Before grinding

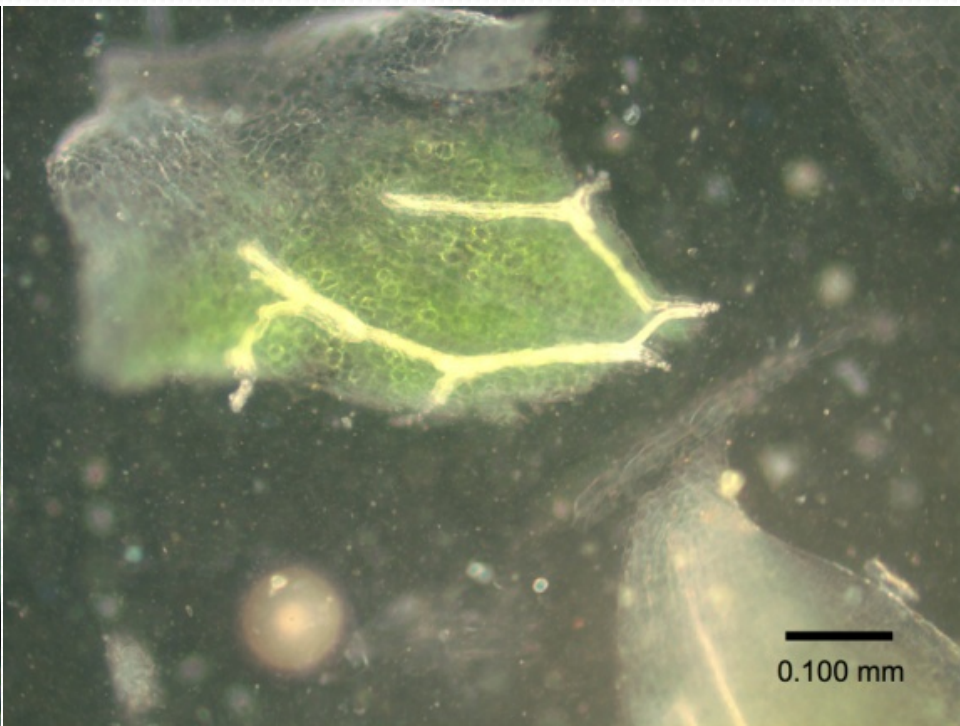


After grinding

Pretreatment of broccoli

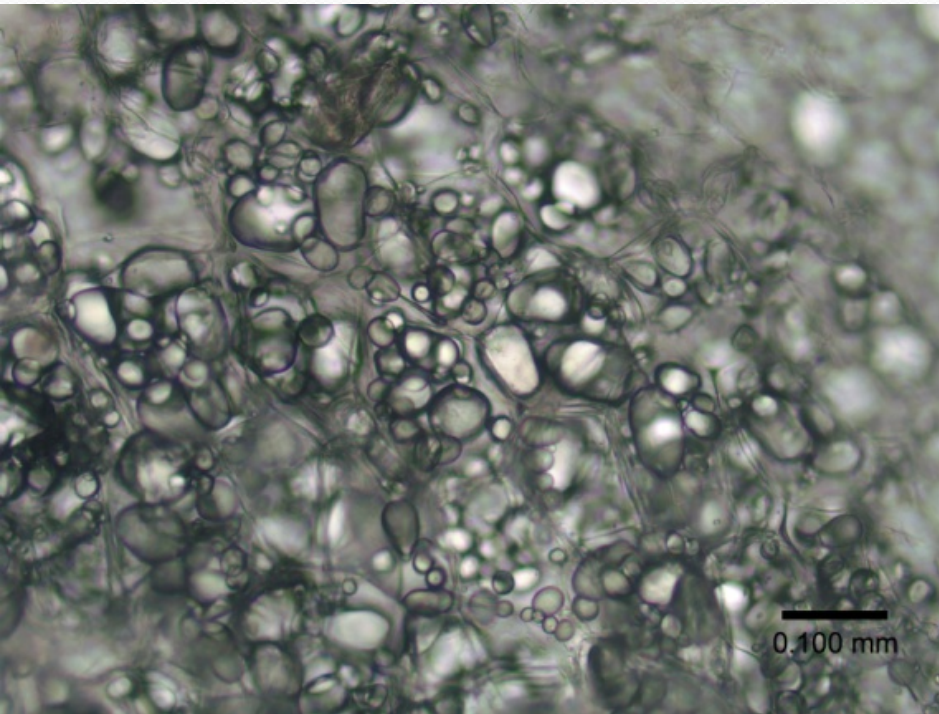


Before grinding

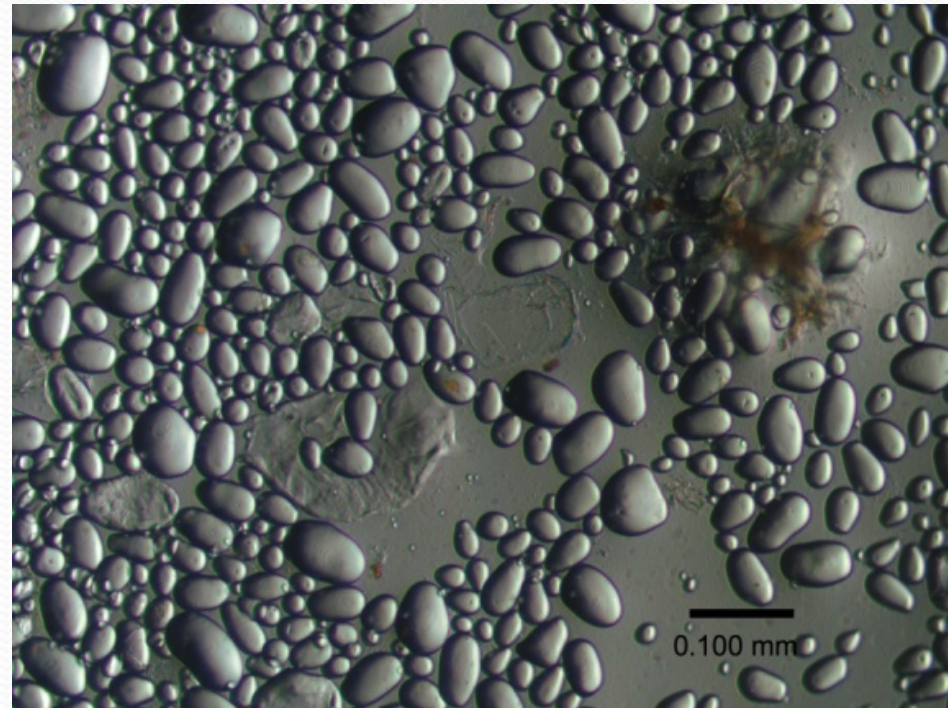


After grinding

Pretreatment of potato



Before grinding



After grinding

Different digester types

- Batch vs. continuous
- Wet vs. dry
- Two phase digestion
- CSTR
- UASB
- “Bag” digester
- Covered lagoon
- “Egg-shaped” digester

Batch vs. continuously fed

- Batch – Digester loaded once, emptied once fully degraded
- Continuously fed – Digester loaded on a continuous basis, effluent produced at each loading

Wet vs. dry digestion

Wet

- Used for high moisture feedstocks
- Allows pumping of material
- Generally faster than dry digestion

Dry

- AKA high solids digestion
- Used for high solid materials (e.g. MSW)
- Leachate recycling usually employed
- Typically a batch system

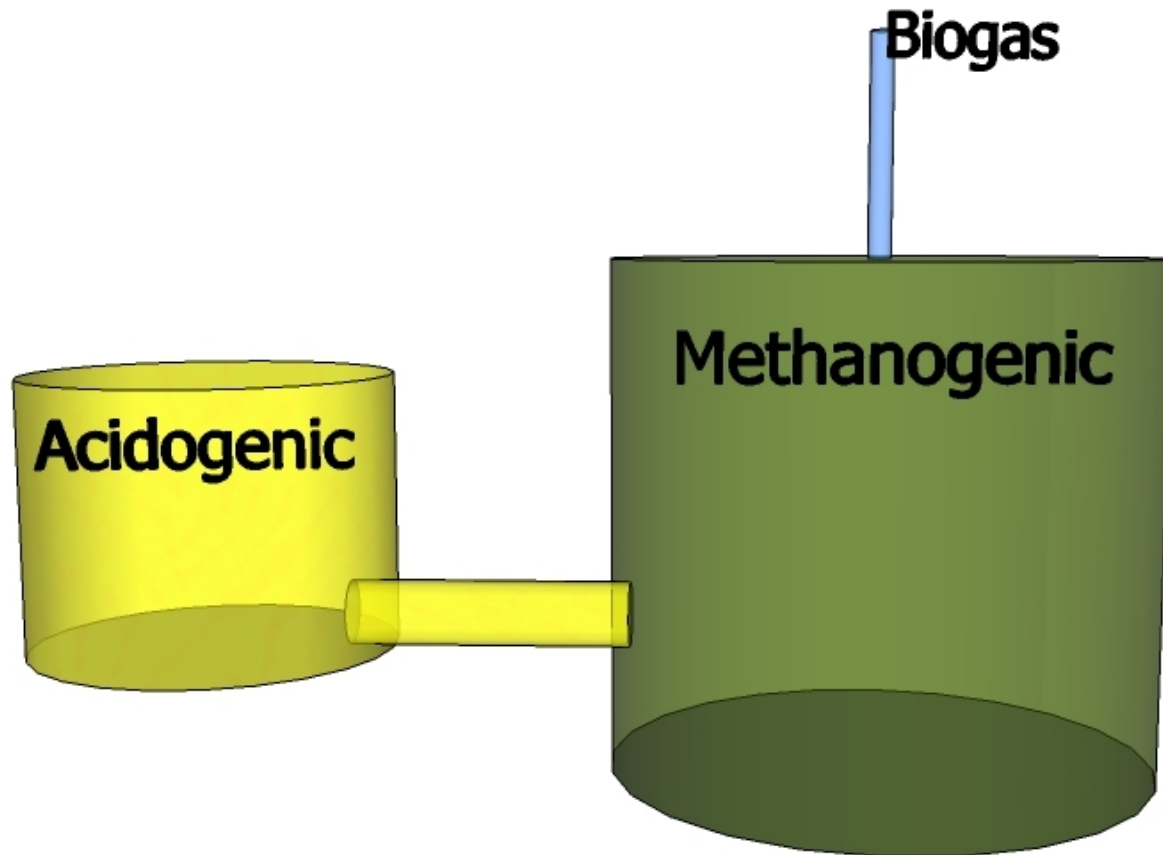
Food waste can go either way



Two phase digestion

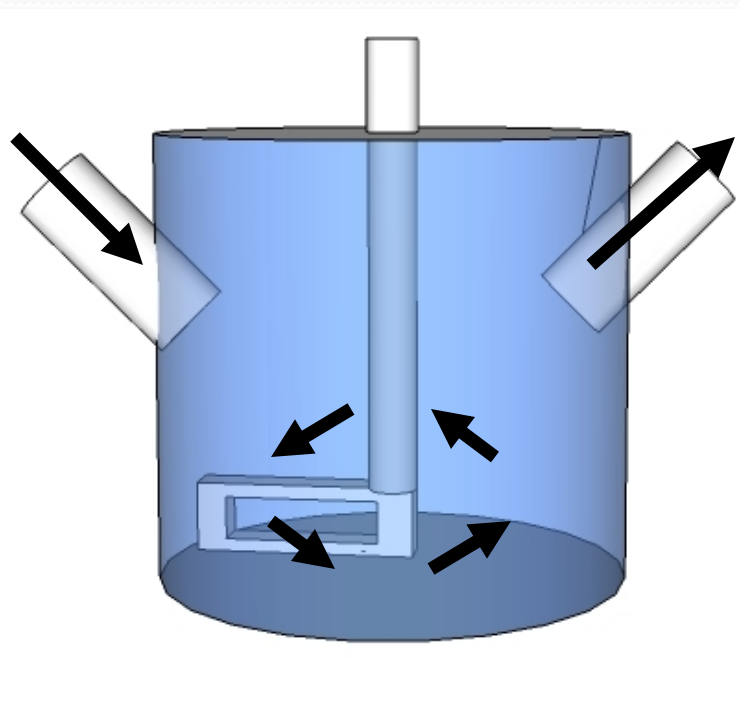
- Single phase- all in one reactor
- Two phase- acidogenesis and methanogenesis separated
- Benefits
 - Increased over-all efficiency (short HRT of acidogenic reactor)
 - More pH control of methanogenic reactor

Two phase digestion



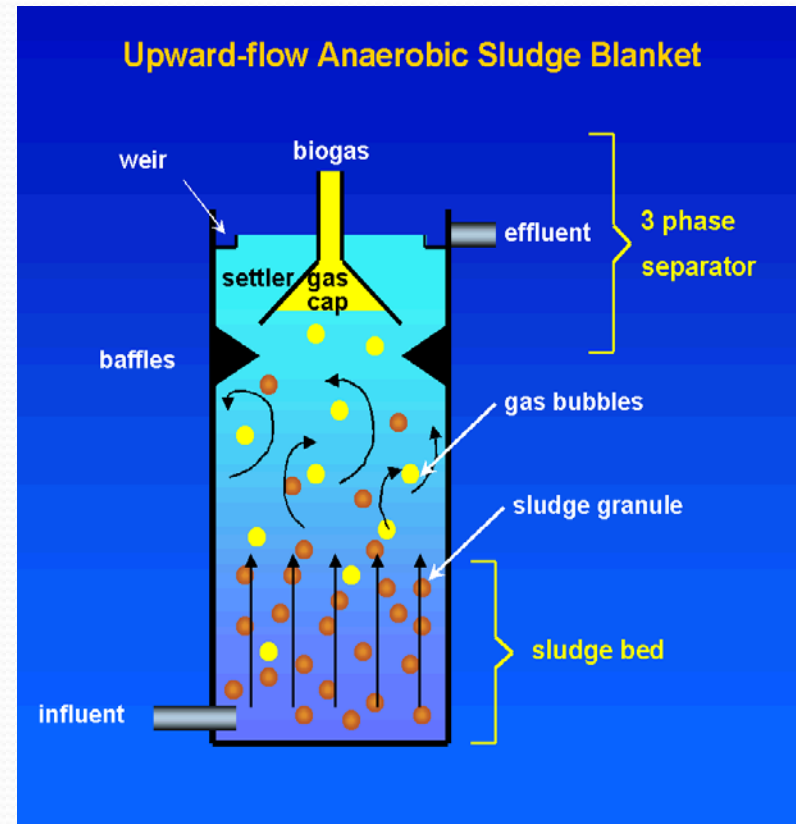
CSTR

- Continuously-Stirred Tank Reactor
- Simple, common design



UASB

- Up-flow Anaerobic Sludge Blanket
- Employs methanogenic granular sludge
- Ideal for wastewater digestion



“Bag” digester

- Low materials and infrastructure input
- Ideal for developing nations



Covered lagoon

- Plastic cover over new or existing manure lagoon
- Plumbing on and through cover captures biogas
- Convert existing infrastructure into a digester



“Egg-shaped” digester

- Shape optimized for footprint space, sludge accumulation, mixing, and heating
- Generally used for activated sludge digestion



Fixed Film Reactor

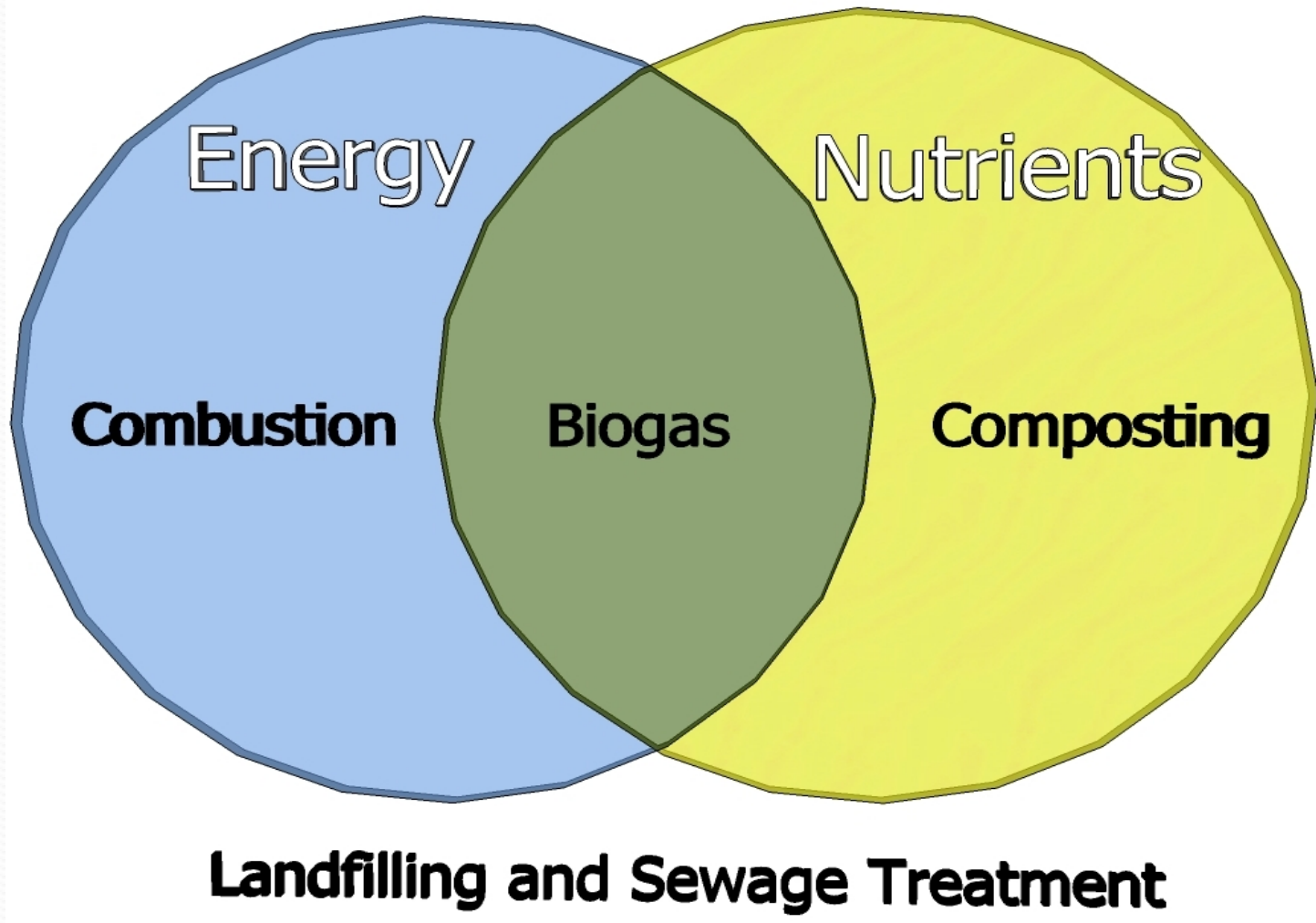
- Fixed media increases microbial population and microbe/substrate interactions
- Microbes form biofilm on media
- Higher methanogenesis= low HRT, high OLR, and decreased reactor size



Benefits of biogas

- Sustainable energy
- Sustainable nutrients
- Scalable and local
- Reduces pathogens
- Waste diversion

Benefits of Biogas

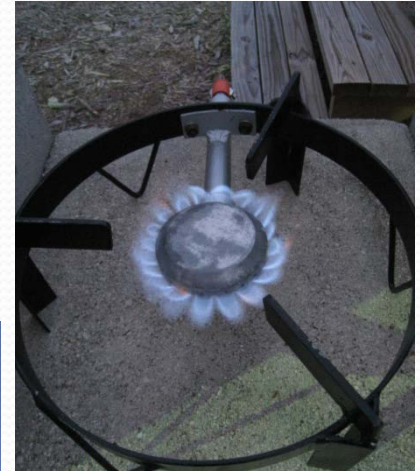


Sustainable energy

- Carbon neutral
 - Combats global warming
- Captures energy from waste
 - No need for energy crops
- Offsets fossil fuel use
 - Stretches energy reserves

Sustainable energy

- Uses of biogas
 - Cooking
 - Heating (water/air)
 - Electricity
 - Gas lighting
 - Vehicle fuel
 - Hydrogen fuel cells



Sustainable nutrients

- Nutrients converted to plant-available form
- Nutrient content depends on feedstock (e.g. high protein=high N)
- Can be injected into existing fertigation systems
- Avoids need for spreaders
- Can be diluted to concentrations



Sustainable nutrients

- Reduces use of synthetics
 - Synthetics= fossil fuel derived
- Reduces cost of organic fertilizer
- Increased organic production
- Keeps nutrients within productive cycle
- Reduces runoff/ eutrophication
- Ideal for small farms implementing organic agriculture
- Facilitates urban agriculture

Scalable and local

- Applicable to small farm or large city
- Biogas produced on-site or at centralized digester



Reduces pathogens

- Anaerobic bacteria out-compete pathogens
- Huge benefit for human waste and manure



Escherichia coli



Salmonella typhimurium

Diverting waste from aerobic treatment

- Problems with aerobic treatment
 - High aeration energy input
 - Loss of nutrients
 - Transportation of biosolids



Diverting waste from landfills

- Problems with organics in landfills
 - Take up space
 - Increased leachate problems
 - Release of methane
 - Lock-up nutrients
 - Cause odor and vermin problems
 - Transportation



Landfill gas vs. biogas

- Landfill gas

- Slow, passive process
- Gas contaminated with many pollutants
- Transportation of waste to landfill
- Feasible option for existing landfill

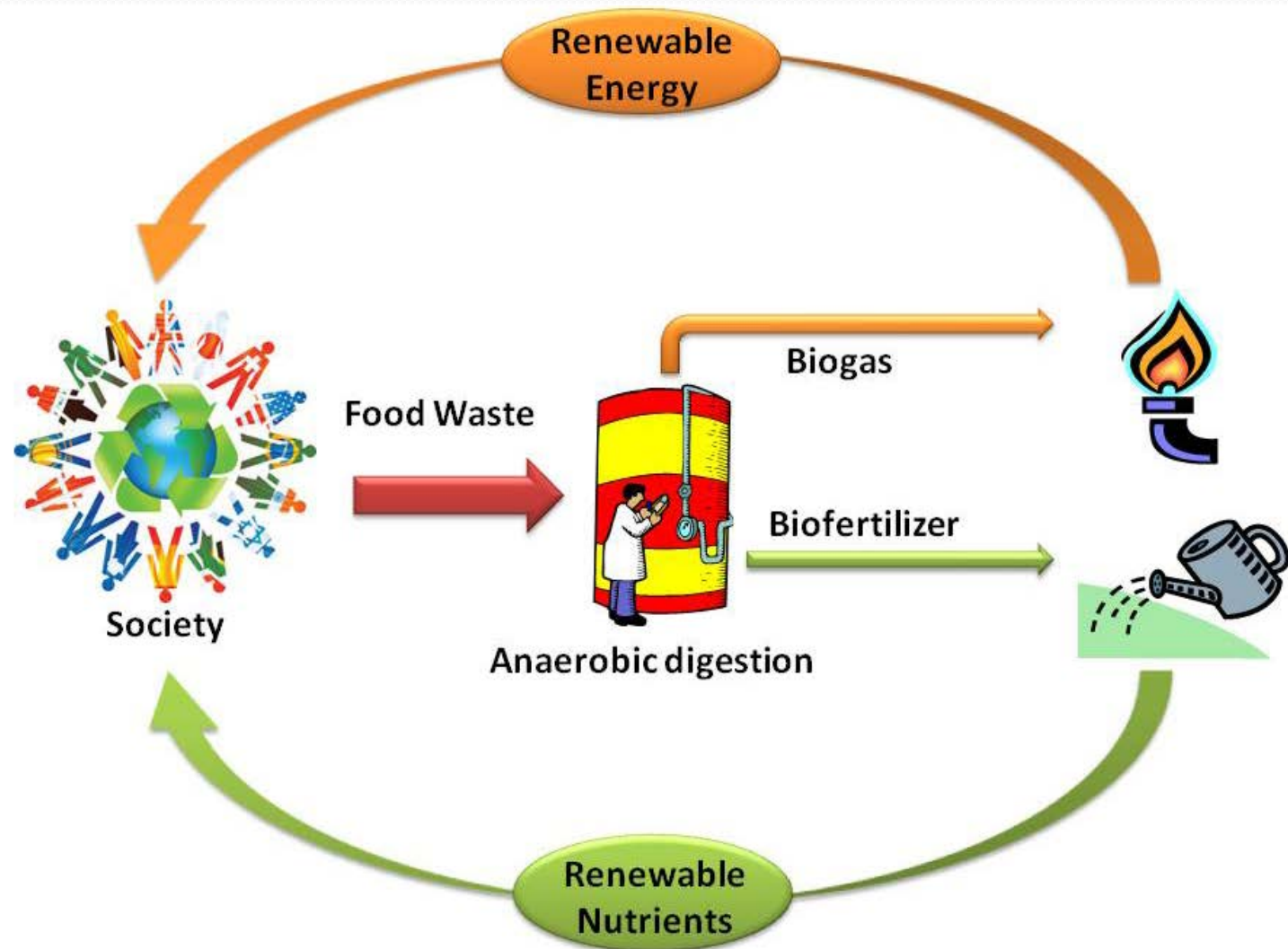


- Biogas

- Fast, active process
- Gas significantly cleaner
- Energy AND nutrients
- Can be produced throughout community
- Saves landfill space



A closed-loop cycle





Questions?