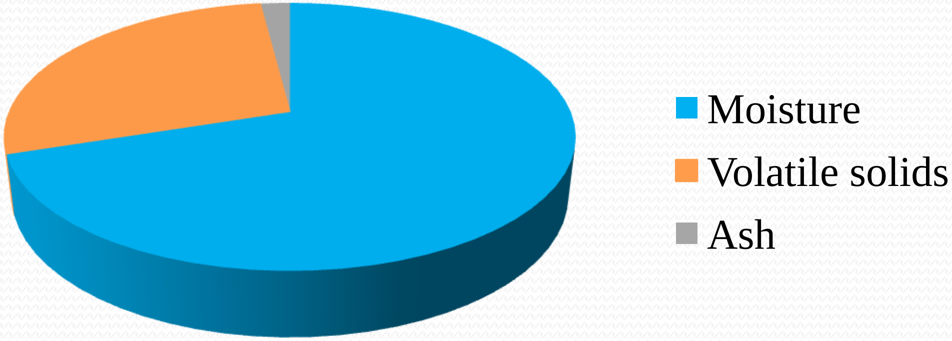
Anaerobic digestion: Terminology and benefits

Total Solids, Volatile Solids

- Total Solids (TS)= Dry matter content of substrate
  - Inverse of moisture content
  - one of the most variable parameters between substrates
  - water
- 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
  - $CH_4+2O_2 \rightarrow CO_2+2H_2O$
  - 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 = BOD_5)
- 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)/m^3/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

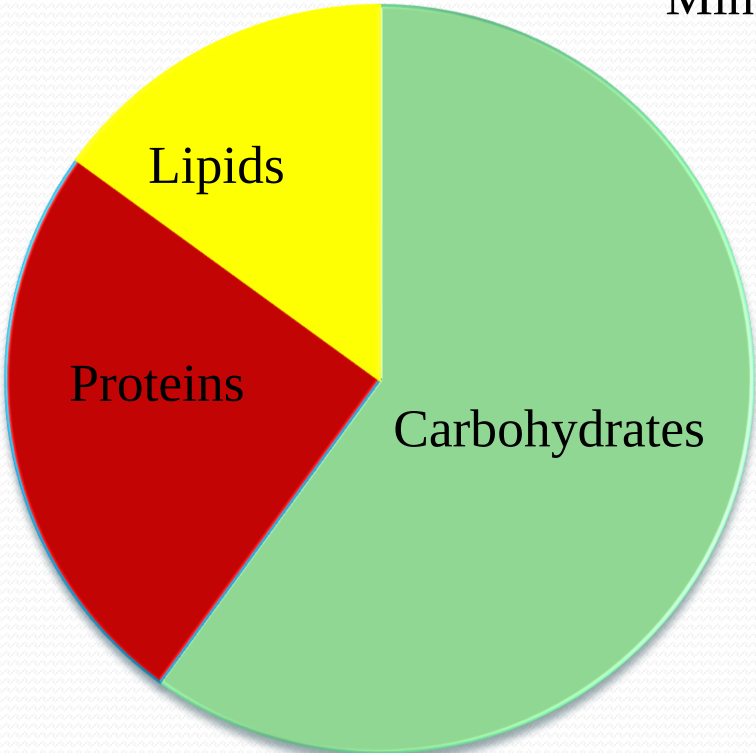
- Critical parameter
- Optimum 7.0, acceptable 6.0-8.0
- Methanogens cannot function at low pH
- Ammonia toxicity above 8.0
- pH can be maintained through addition of buffering agents (sodium bicarbonate, etc.), if required
- Dependent upon alkalinity of feedstock

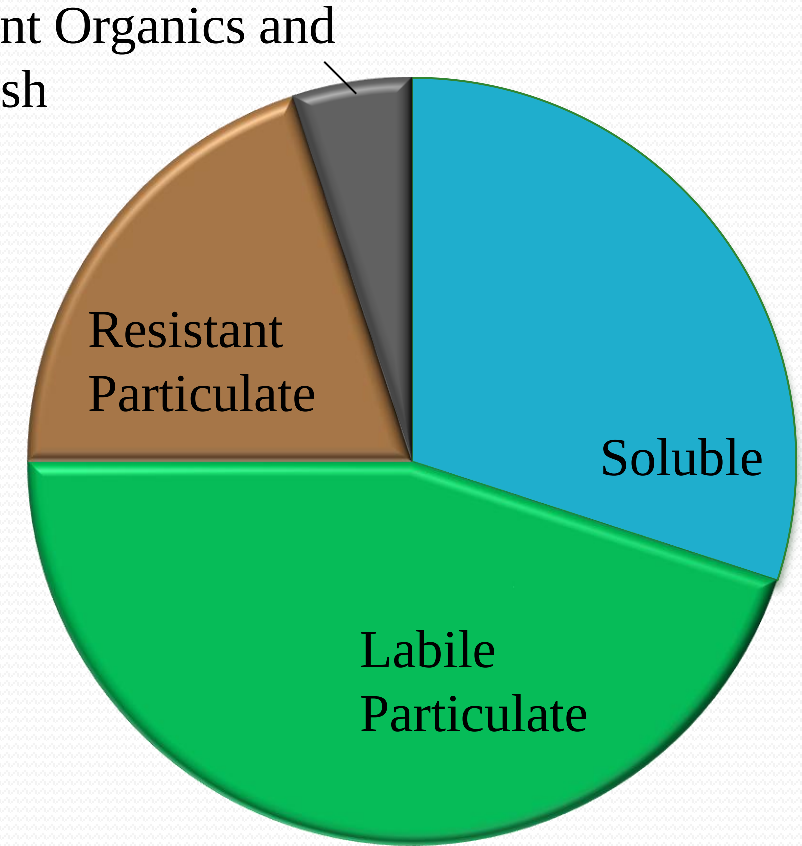
Acidification

- 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

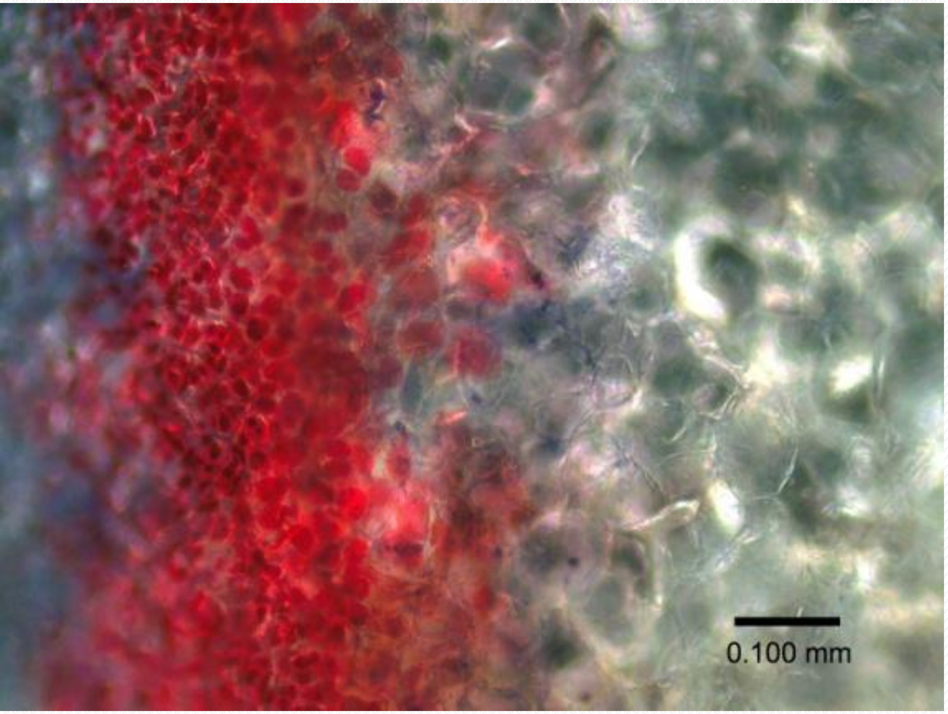




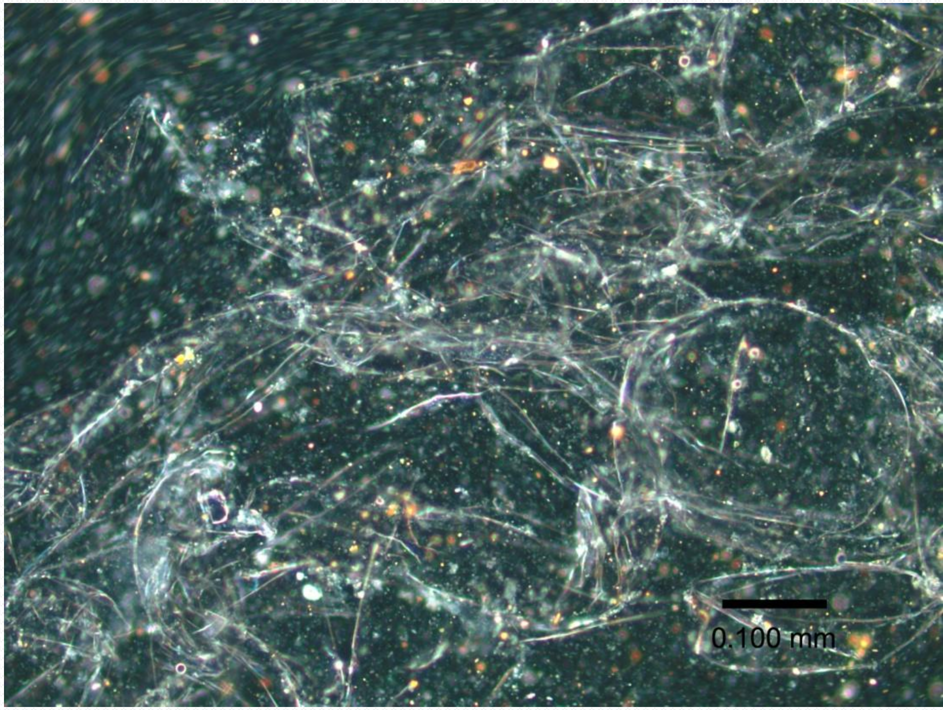
Pretreatment can increase kinetics

- For some substrates and digesters, kinetics are determined by hydrolysis rate
- Total organic matter (TCOD) fractioned 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

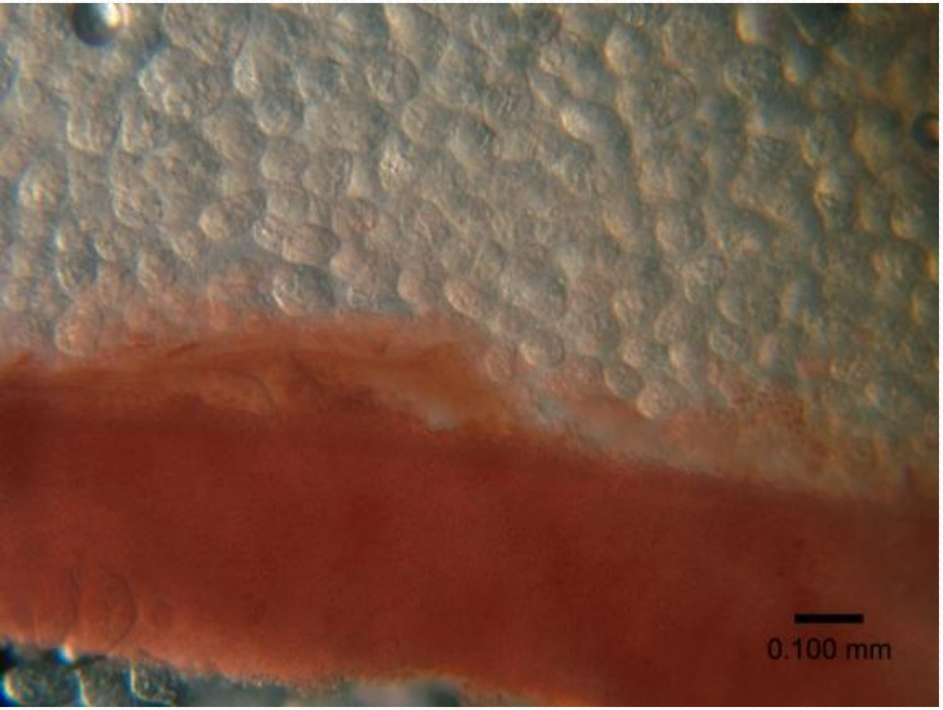


Before grinding

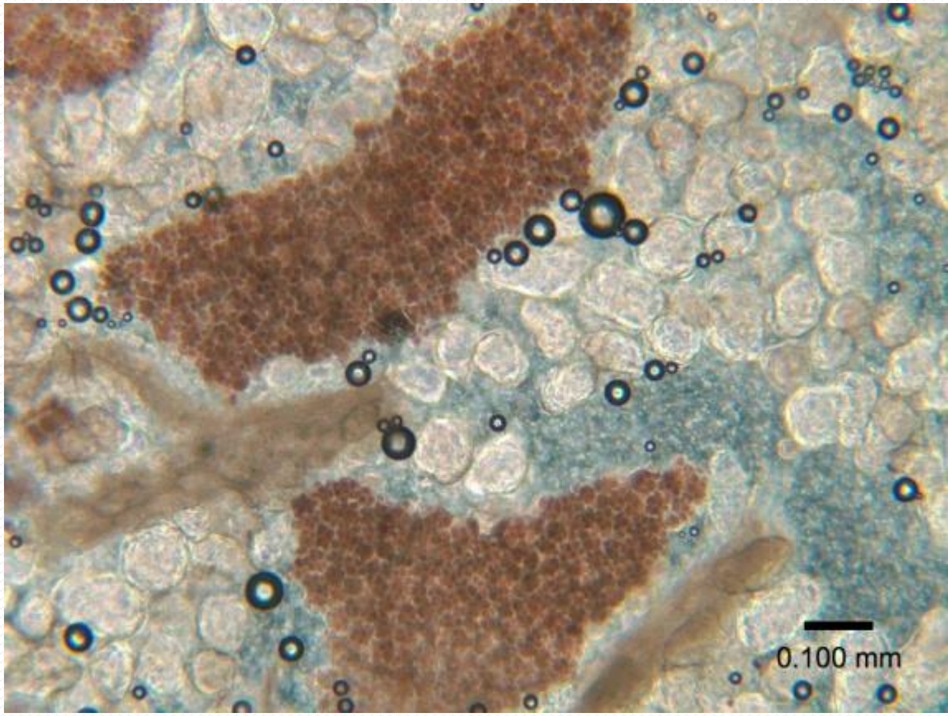


After grinding

Pretreatment of bean

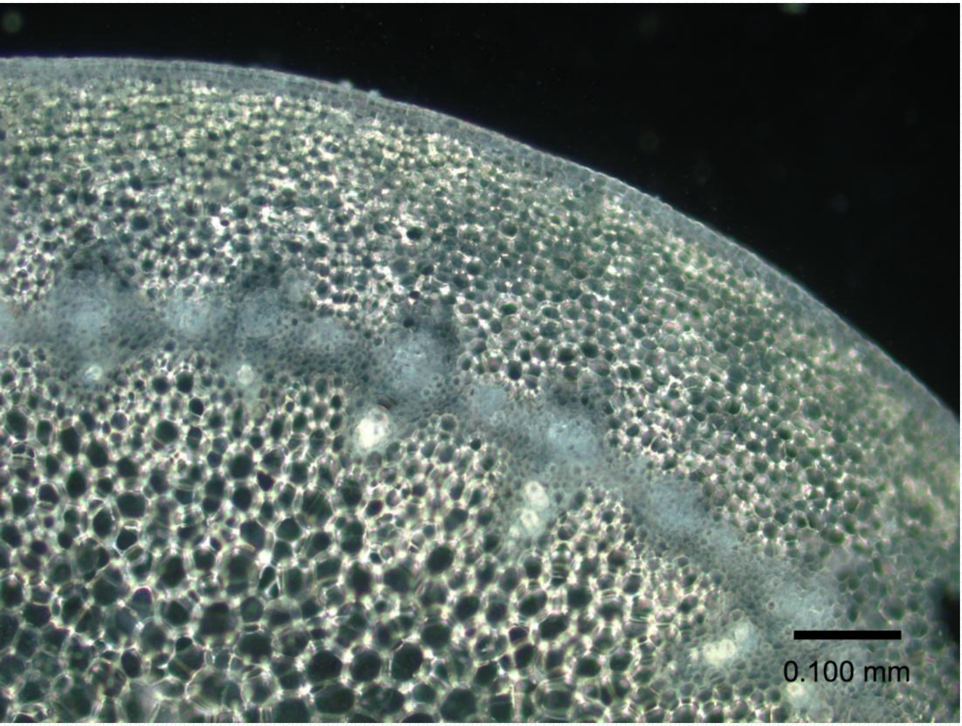


Before grinding

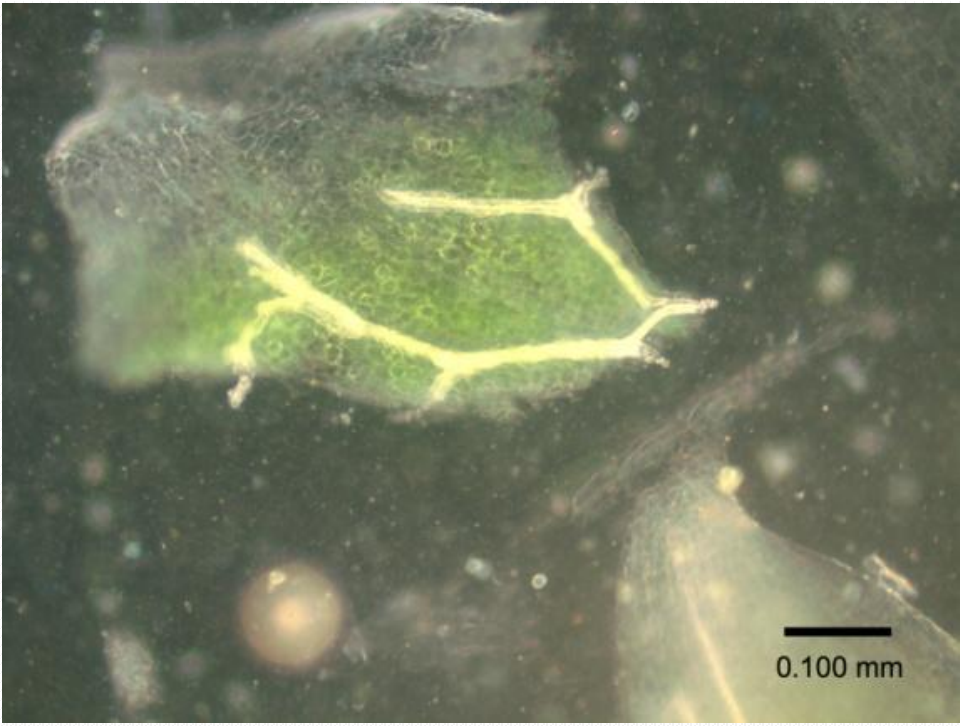


After grinding

Pretreatment of broccoli

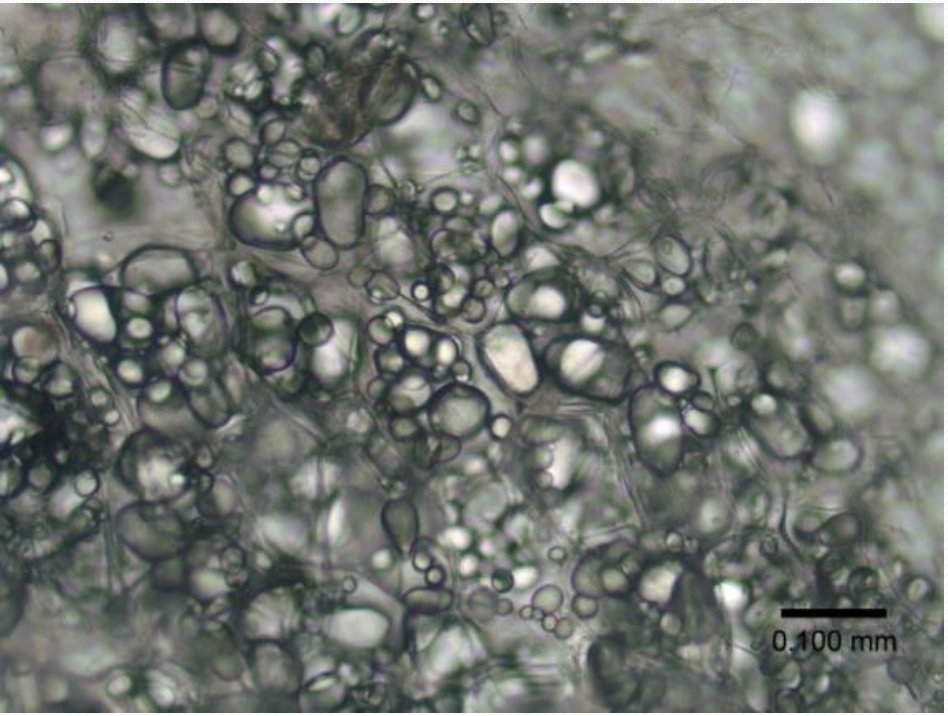


Before grinding



After grinding

Pretreatment of potato



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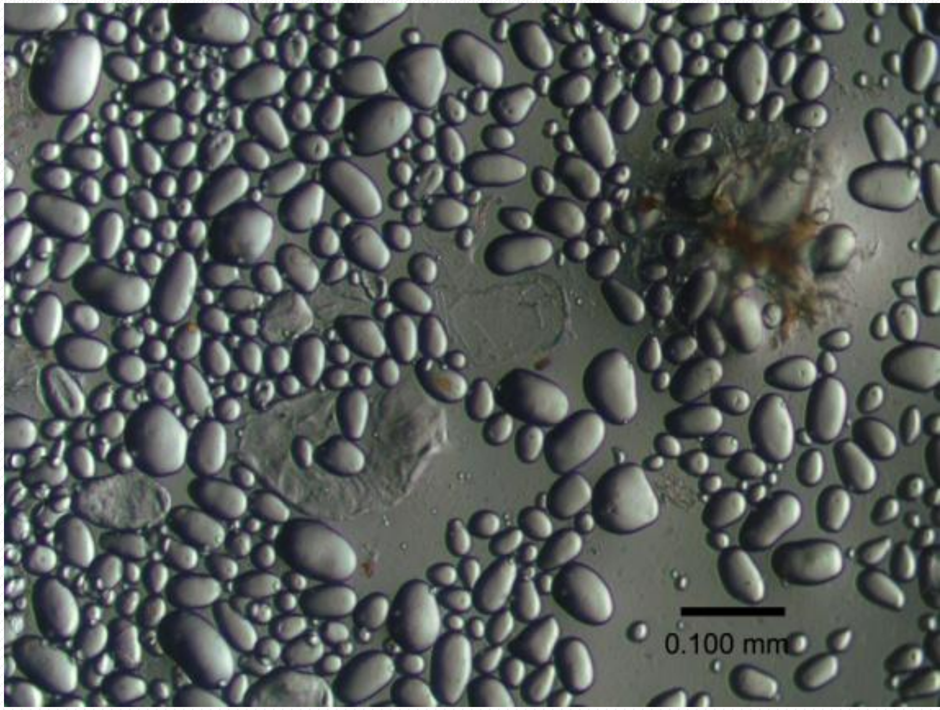


After grinding

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

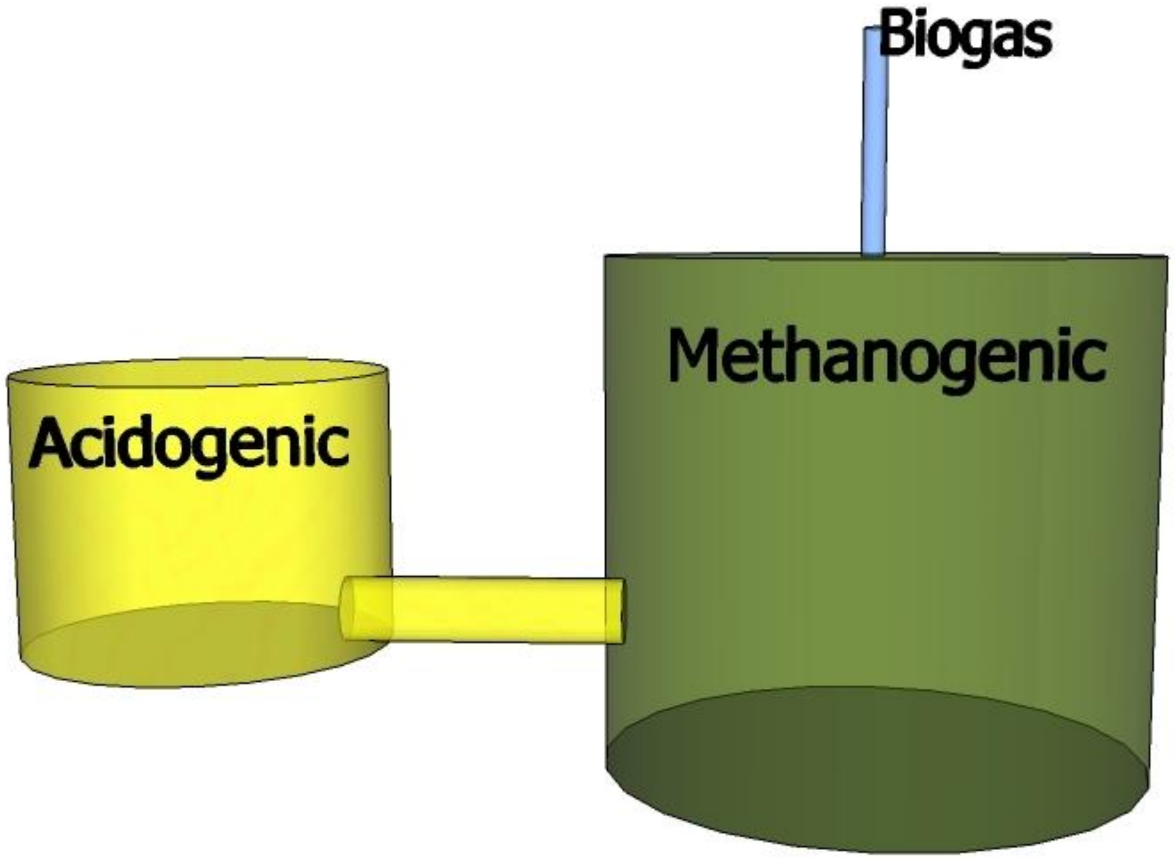
- AKA high solids digestion
- Used for high solid materials (e.g. MSW)
- Leachate recycling usually employed
- Typically a batch system

Food waste can go either way

Two phase digestion

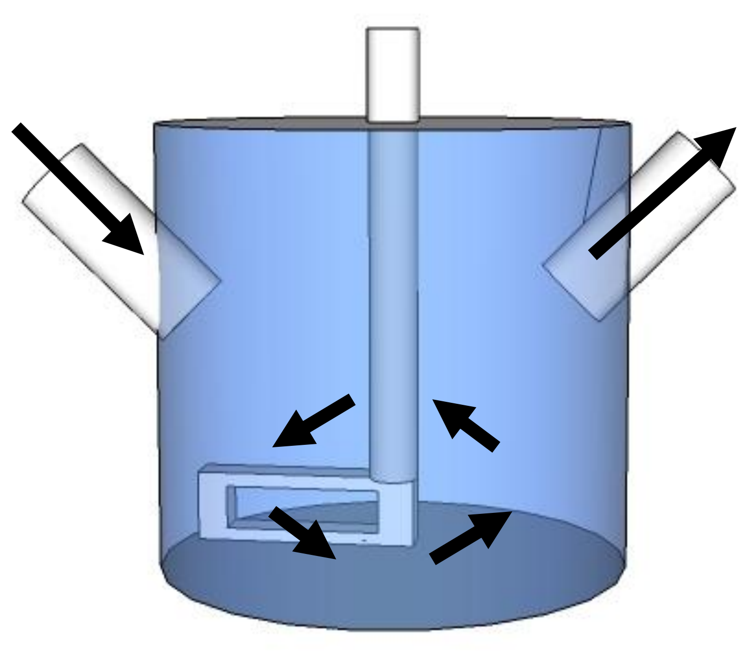
- Single phase- all in one reactor
- Two phase- acidogenesis and methanogenesis separated
- Benefits
  - Increased over-all efficiency (short HRT of acidogenic reactor)
  - More pH control of methanogenic reactor

Two phase digestion



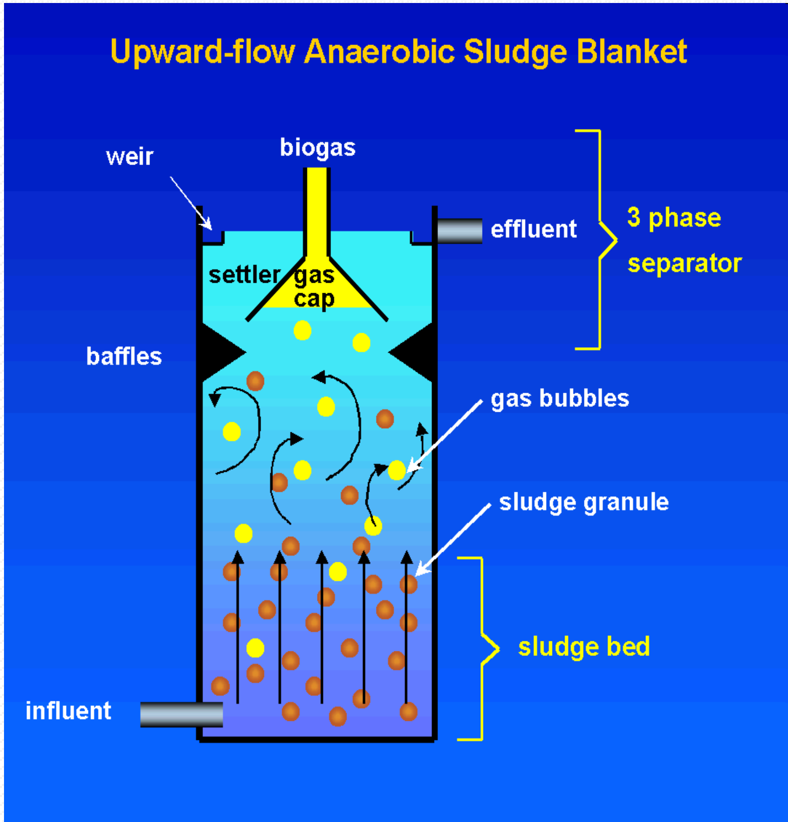
CSTR

- 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

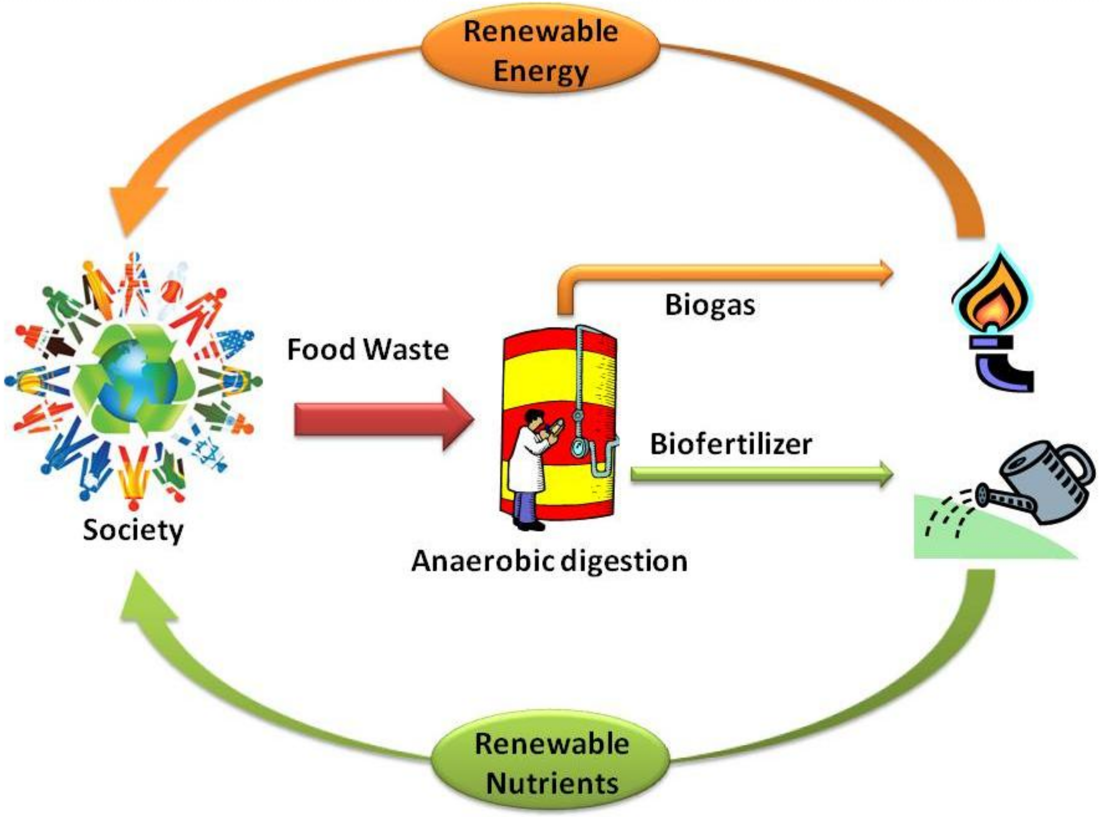
- Shape optimized for footprint space, sludge accumulation, mixing, and heating
- Generally used for activated sludge digestion

Fixed Film Reactor

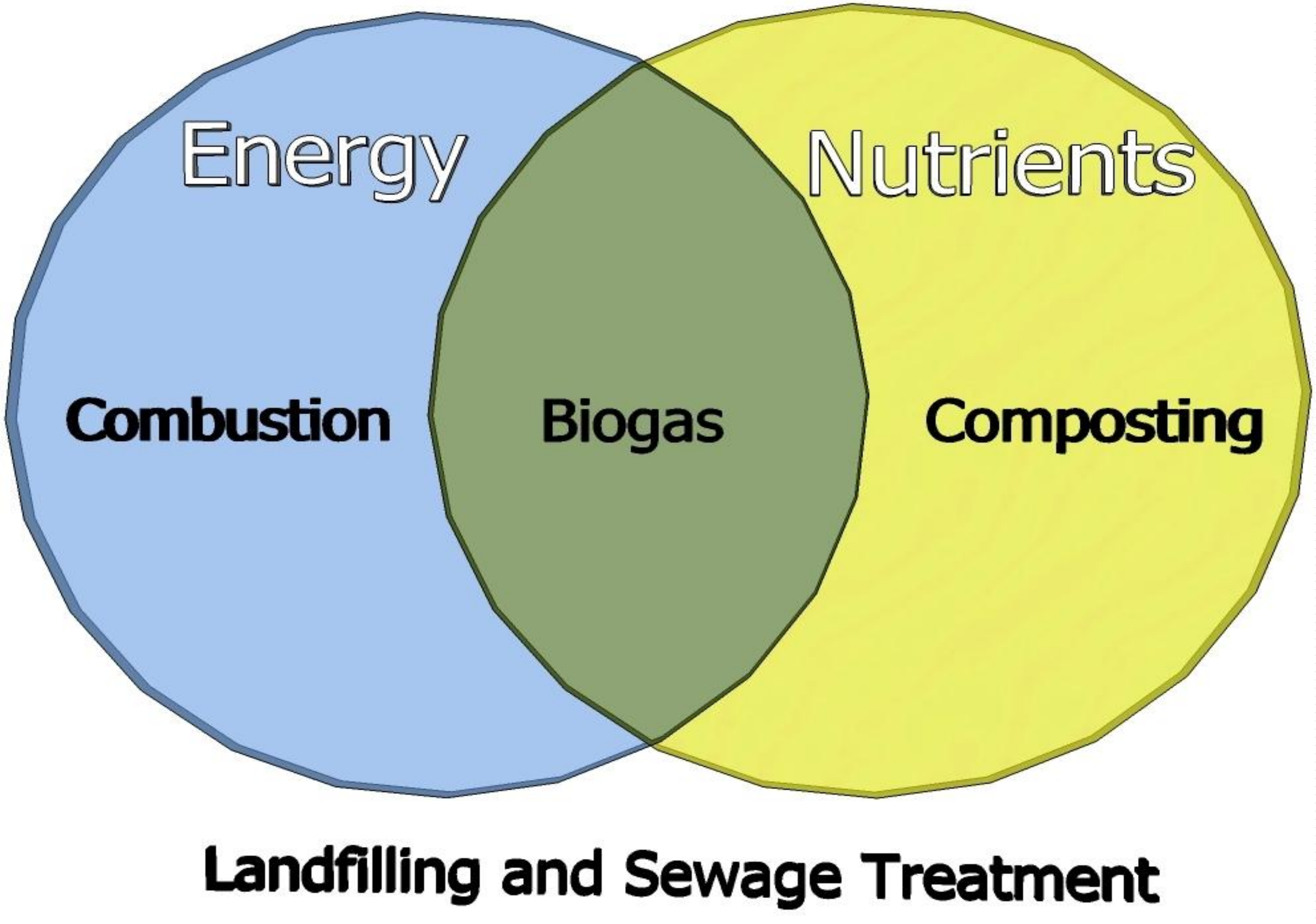
- Fixed media increases microbial population and microbe/substrate interactions
- Microbes form biofilm on media
- Higher methonogenesis= low HRT, high OLR, and decreased reactor size

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

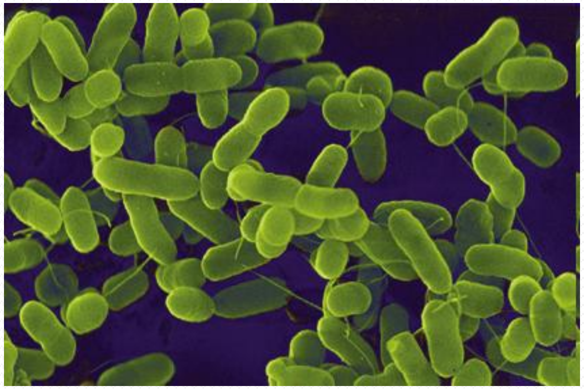
- Reduces use of synthetics
    - Synthetics= fossil fuel derived
- Reduces cost of organic fertilizer
- Increased organic production
- Keeps nutrients within productive cycle
- Reduces runoff/ eutrophication
- Ideal for small farms implementing organic agriculture
- Facilitates urban agriculture

Scalable and local

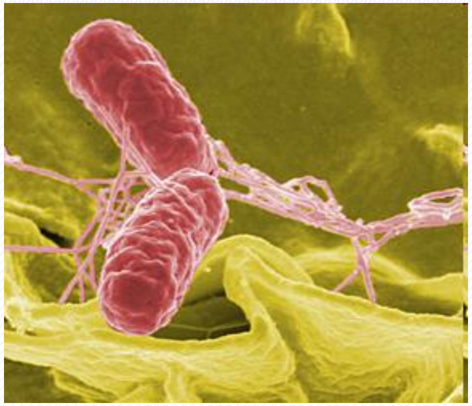
- Applicable to small farm or large city
- Biogas produced on-site or at centralized digester
- Sustainable energy in nations

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

Questions?