Anaerobic Digestion

Microbiological perspective

What is anaerobic digestion?

- Microbial degradation of organic waste under anaerobic conditions
- Ubiquitous, naturally-occurring process
- Found in swamps, hydric soils, landfills, rumens

Discovery of methane

- Alessandro Volta discovered methane in 1776 through studying swamp bottoms
- This video demonstrates how the power of methane was first discovered.
  - Volta experiment at Rutgers

How does AD work?

- Consortia of bacteria and microbes work in a serial reaction that leads to production of methane
- Products of one phase are feedstocks for the next
- Overall process only as fast as its slowest step

Anaerobic metabolic processes

- All metabolism requires electron donor (reducer) and acceptors (oxidizer)
- Aerobic organisms use oxygen as e^- acceptor (high ATP yield)
- Anaerobic organisms must find alternatives e^- acceptors
  - NO^{3-}, Fe^{3+}, Mn^{3+}, SO_4^{3+}, CO_2

Anaerobic metabolic processes

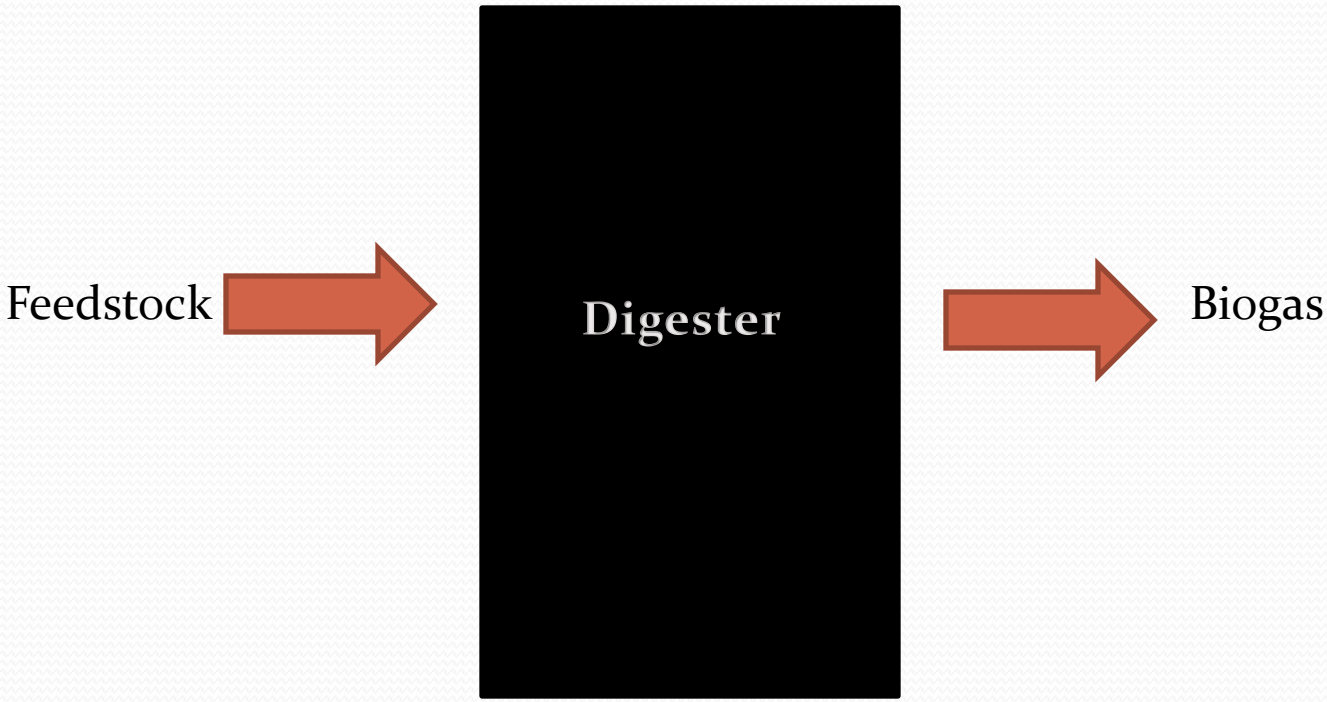
- Anaerobic fermentation
  - Organic material is e^- donor
  - Internal cell products are e^- acceptors
  - Generates lower yield of ATP
  - Can produce ethanol, butanol, acetone, acetic acid, etc.
  - Performed by bacteria and fungi (i.e. yeast)

Anaerobic metabolic processes

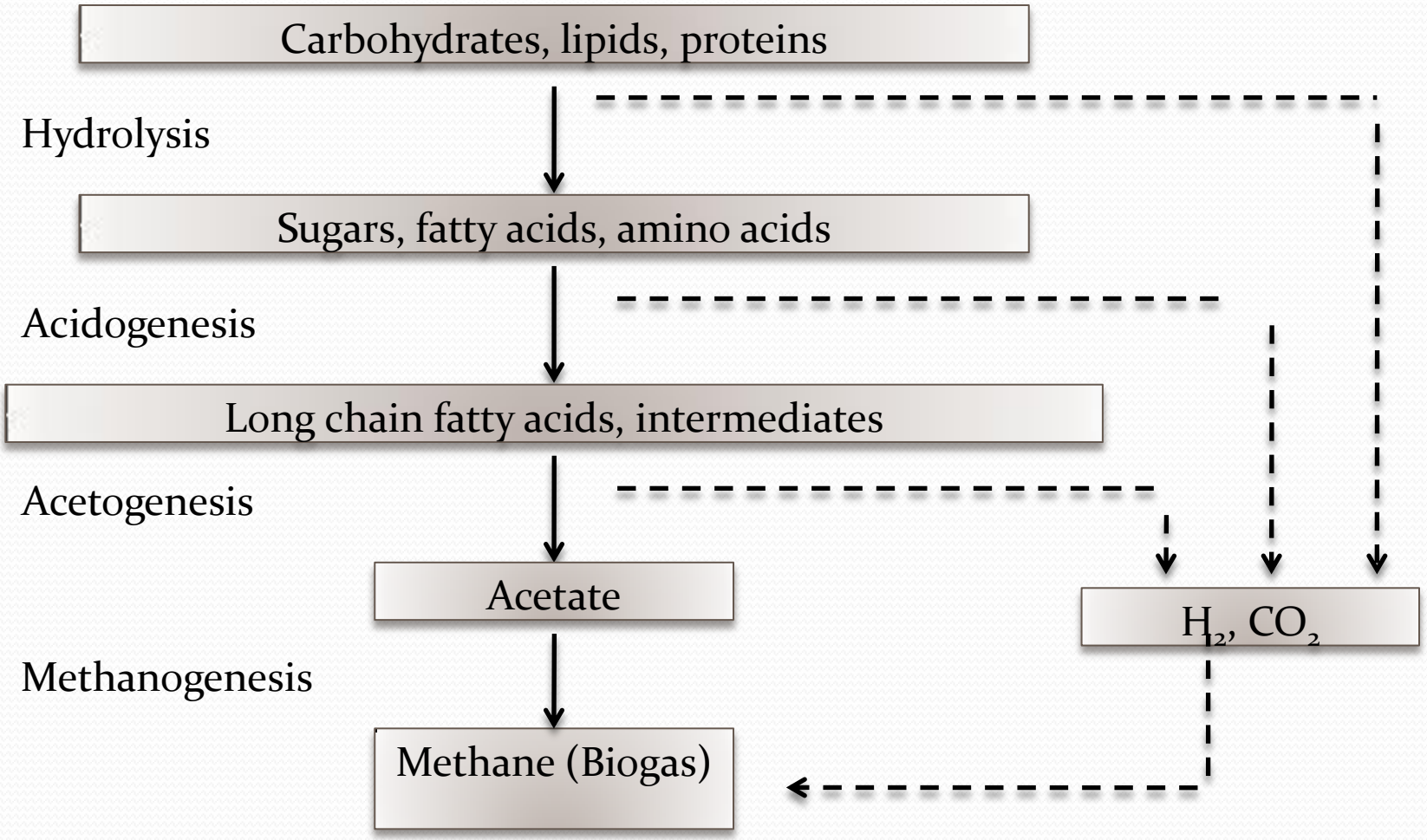
- Anaerobic respiration
  - Uses organic compounds as e^- donor (at least in AD)
  - Requires external, alternative e- acceptor (allows electron transport chain to function)
  - Generates reduced compounds (e.g. CH_4)
  - Predominantly performed by bacteria and *archaea*
- Both fermentation and respiration occur during AD

AD is much more elaborate that people think

Not just a black box…

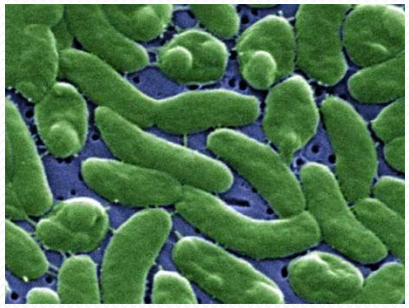


…but an elegant microbial machine



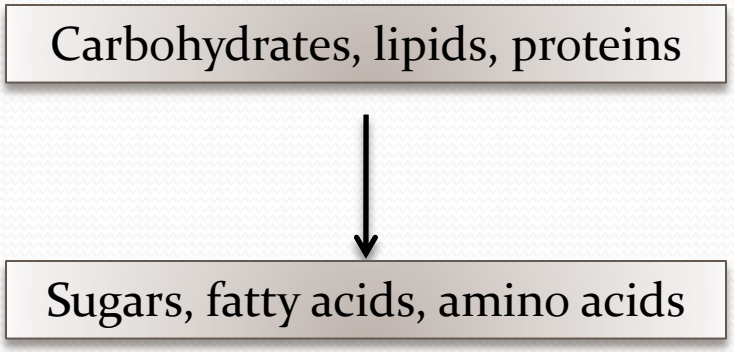
Hydrolysis

- Large organic compounds are broken down into simpler compounds
- Allows cell to take-in materials
- Performed by many organisms
  - Bacteria (including acidogens), fungi, protists



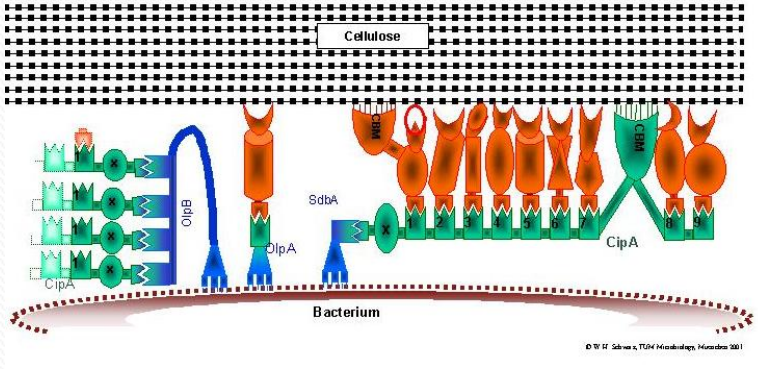
Vibrio

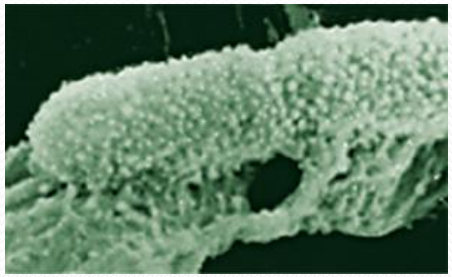
Hartmanella



Hydrolysis

- Processes uses extracellular enzymes (cellulases, amylases, lipases, proteases)
- Important for both AD and cellulosic ethanol
- Particular interest on cellulosomes
  - Extracellular structures bearing cellulases
  - Allows cell to attach and break cellulose structure

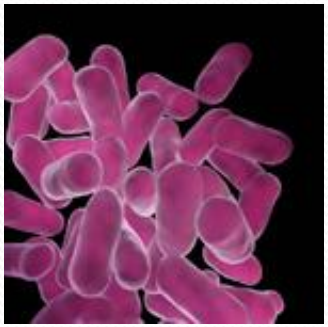




Acetovibrio cellulyticus

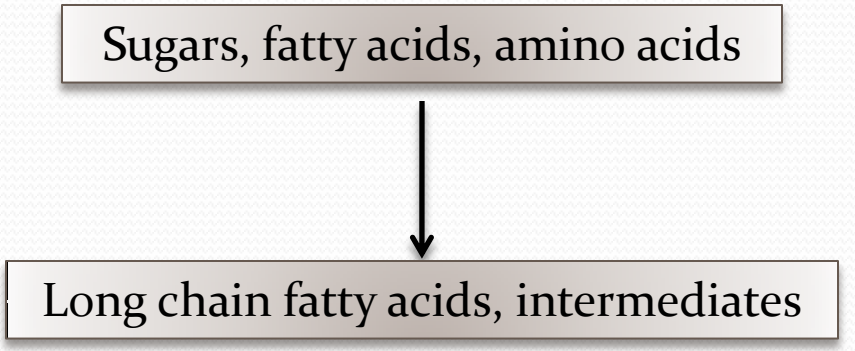
Acidogenesis

- Products of hydrolysis are fermented into fatty acid intermediaries
- Performed by acidogens
- Generally fastest step in process
- Unbalanced acidogenesis can cause acidification
- Trace oxygen consumed by facultative bacteria



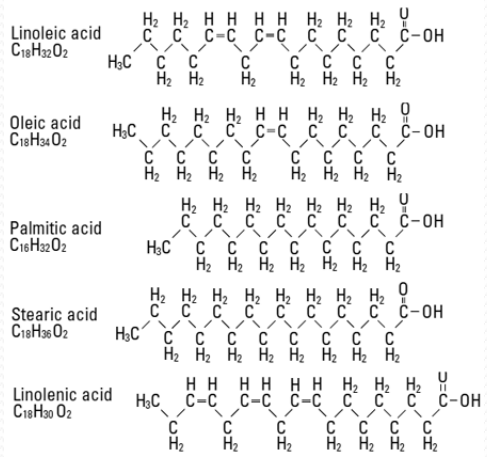
Lactobacillus

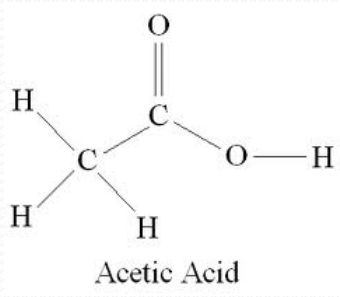
Propionibacterium



Acidogenesis

- Many different fatty acids produced
  - Long-chain fatty acids (LCFAs) (generally produced from lipids)
  - Volatile fatty acids(VFAs) (butyric, propionic, acetic acid), very important in AD

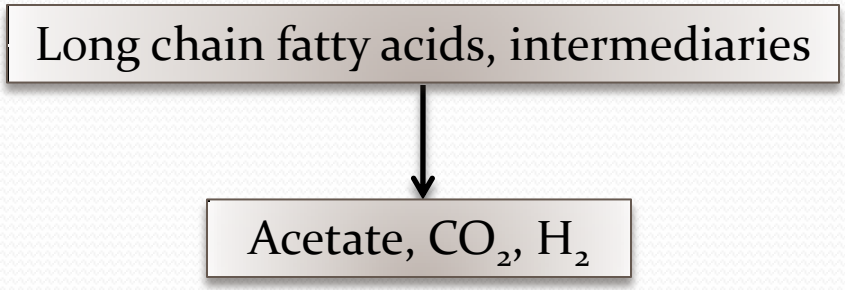




Acetogenesis

- Acetate is very important in AD
- Immediate precursor for majority of methane production
- Some acetate is produced through direct fermentation (mixed acid fermentation)
- Most is through secondary fermentation
  - Converts intermediaries (proprionate, butyrate) to acetate

Syntrophomonas



Acetogenesis

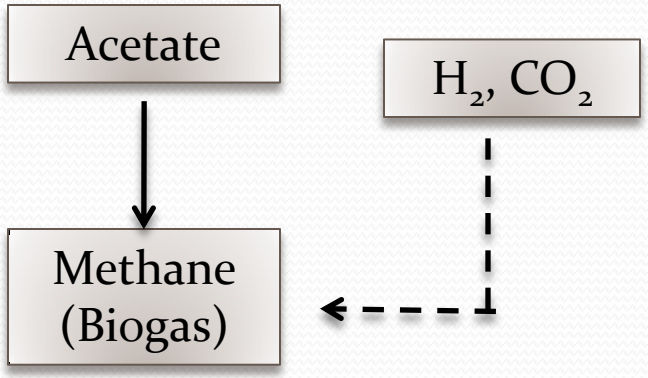
- Two groups of acetogens
  - Obligate hydrogen-producing acetogens (OHPA) – more dominant
  - Homoacetogens – less dominant, converts CO_2 and H_2 to acetate through respiration

Acetogenesis (Hydrogen syntropy)

- OHPA produce acetate, CO_2 and H_2 from fatty acids
- Acetate production inhibited at high partial pressure of H_2
- Forms mutualistic relationship with hydrogen-consuming methanogens (syntropy)
  - Methanogens consume H_2, reducing H_2 partial pressure to for acetogens
- Homoacetogens can also assist in H2 reduction

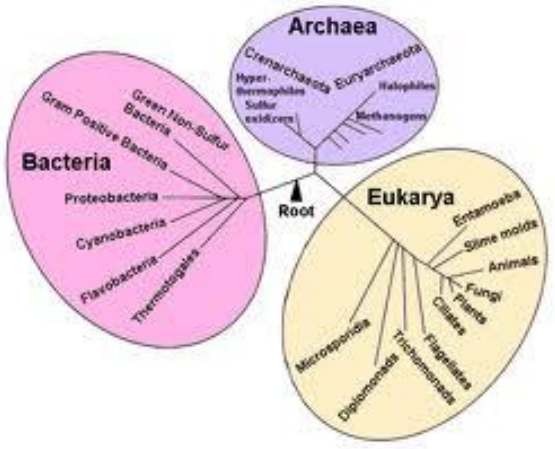
Methanogenesis

- Final metabolic phase in AD
- Methanogens produce methane gas from acetate or H_2 and CO_2
- 2/3 of methane produced is derived from acetate
- Often the rate limiting step in anaerobic digestion of acids



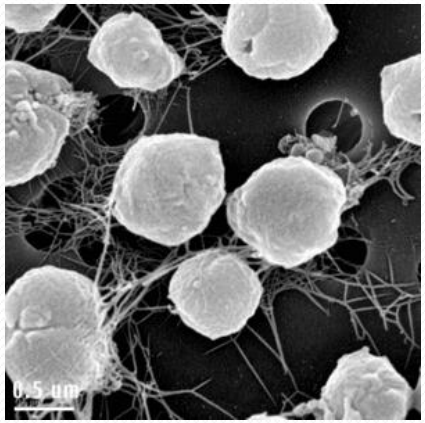
Methanogens

- All are in Archae domain
- Obligate anaerobes, but can form in biofilms and granules for aerobic protection
- Optimum performance at neutral pH (7)
- Two main groups: hydrogenotrophic and acetoclastic

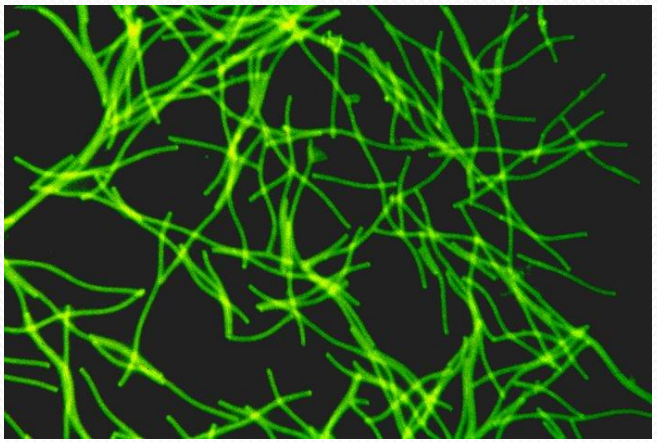


Methanogenesis

- Hydrogenotrophic methanogens
  - Produces methane from H_2 and CO_2
  - Less dominant in AD
  - Mediates syntropy with acetogens



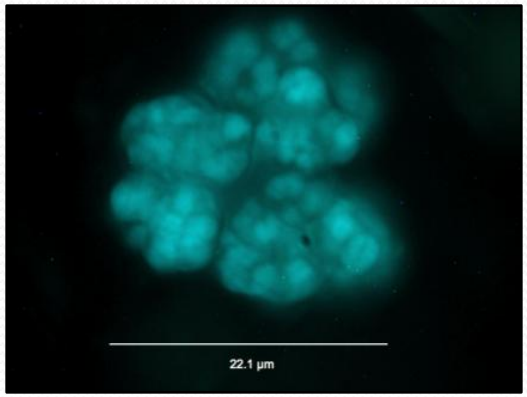
Methanococcus



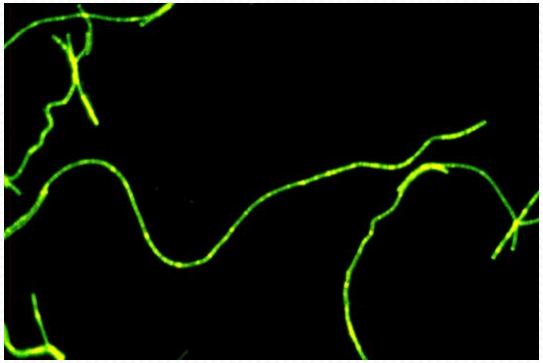
Methanospirillum

Methanogens

- Two known genera convert acetate to methane (Acetoclastic)
  - Methanosarcina – Favors high concentration
  - Methanosaeta – Favors low concentration
- Also produces CO_2 as metabolic by-product

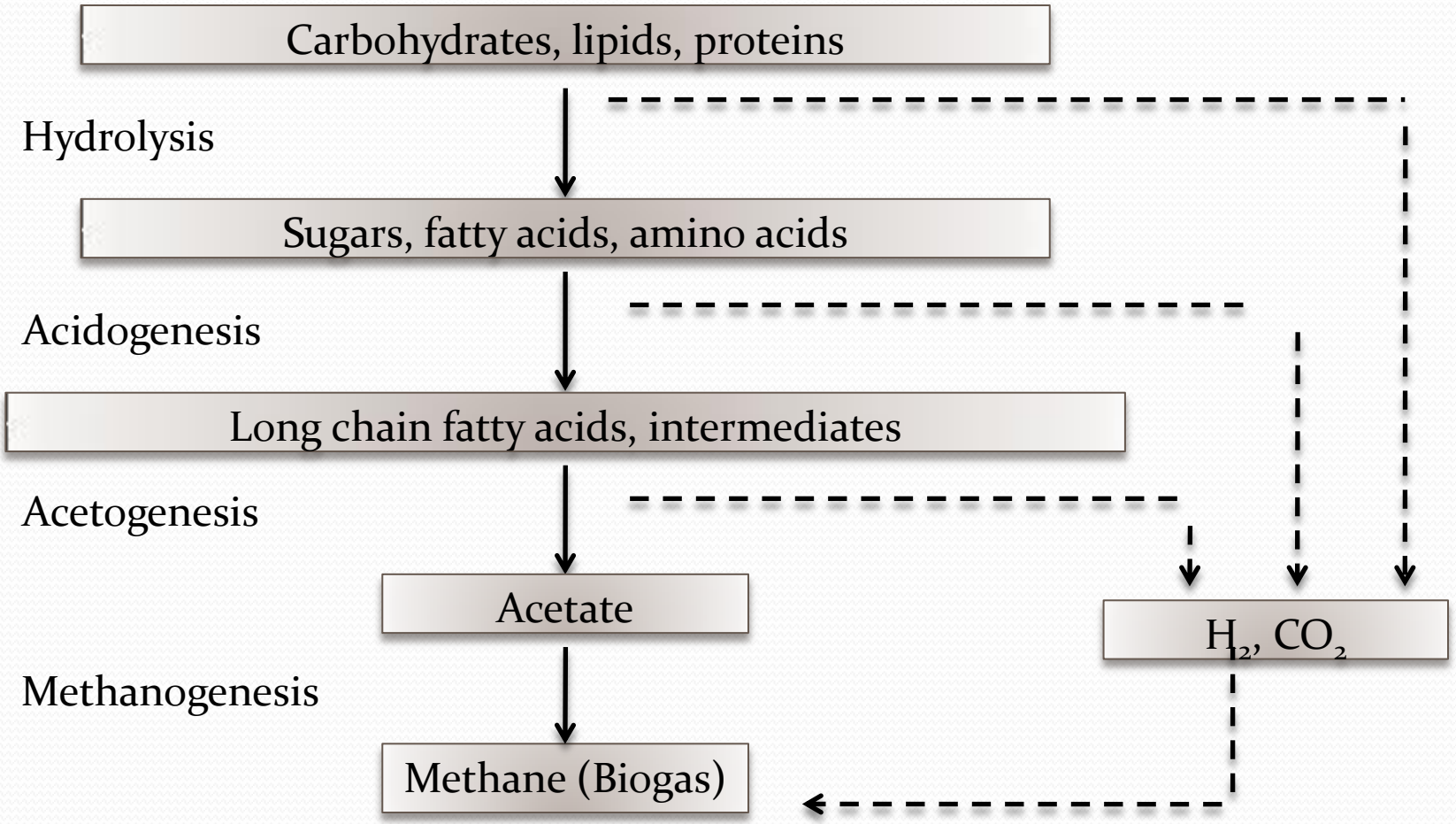


Methanosarcina sp.



Methanosaeta sp.

Questions?


Carbohydrates, lipids, proteins
Hydrolysis
Sugars, fatty acids, amino acids
Acidogenesis
Long chain fatty acids, intermediates
Acetogenesis
Acetate
H_2, CO_2
Methanogenesis
Methane (Biogas)