Aalto University
School of Engineering

Biological treatment processes of water and waste
Lecture 6

WAT - E2180

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Lecture outline

Storage processes

Storage polymers

Applications

Anaerobic processes

Anaerobic digestion

Fermentation

Biological phosphorus removal

Removal mechanism

Existing process configurations

Storage processes

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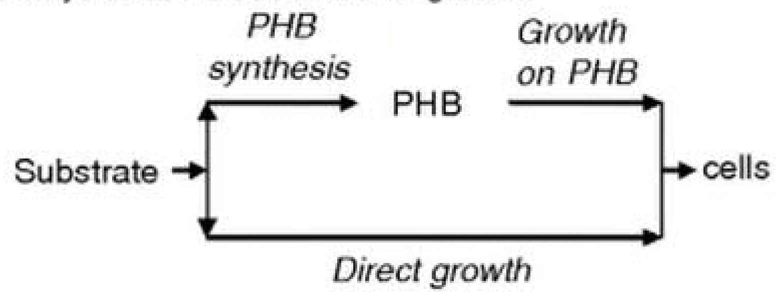
Role of storage processes in growth

- **Substrate can be converted and stored within bacterial cells as energy storage**
- **Bacterial growth can be based on direct growth on the substrate or on growth on these storage polymers**
- **Growth on storage has a bit lower yield (energetically less efficient) – 4 - 10% less sludge production**
- **Common storage polymers Polyhydroxyalkaonate PHA and polyhydroxybutyrate PHB**
- **Storage polymers are a benefit in bacterial competition**

Two ways to use a substrate for growth.



PHA & PHB

PHA

- Up to 90% cell dry weight
- Similar characteristics to plastics
- Biodegradable
- Example: Mars, Attero Venlo (PHA from biowaste)

PHA&PHB production

Important things to consider

- **Production yield**
- **Volumetric productivity**
- **PHA&PHB concentration**
- **PHA&PHB composition**

PHB: example Mirel (USA)

Caproates: animal feed,

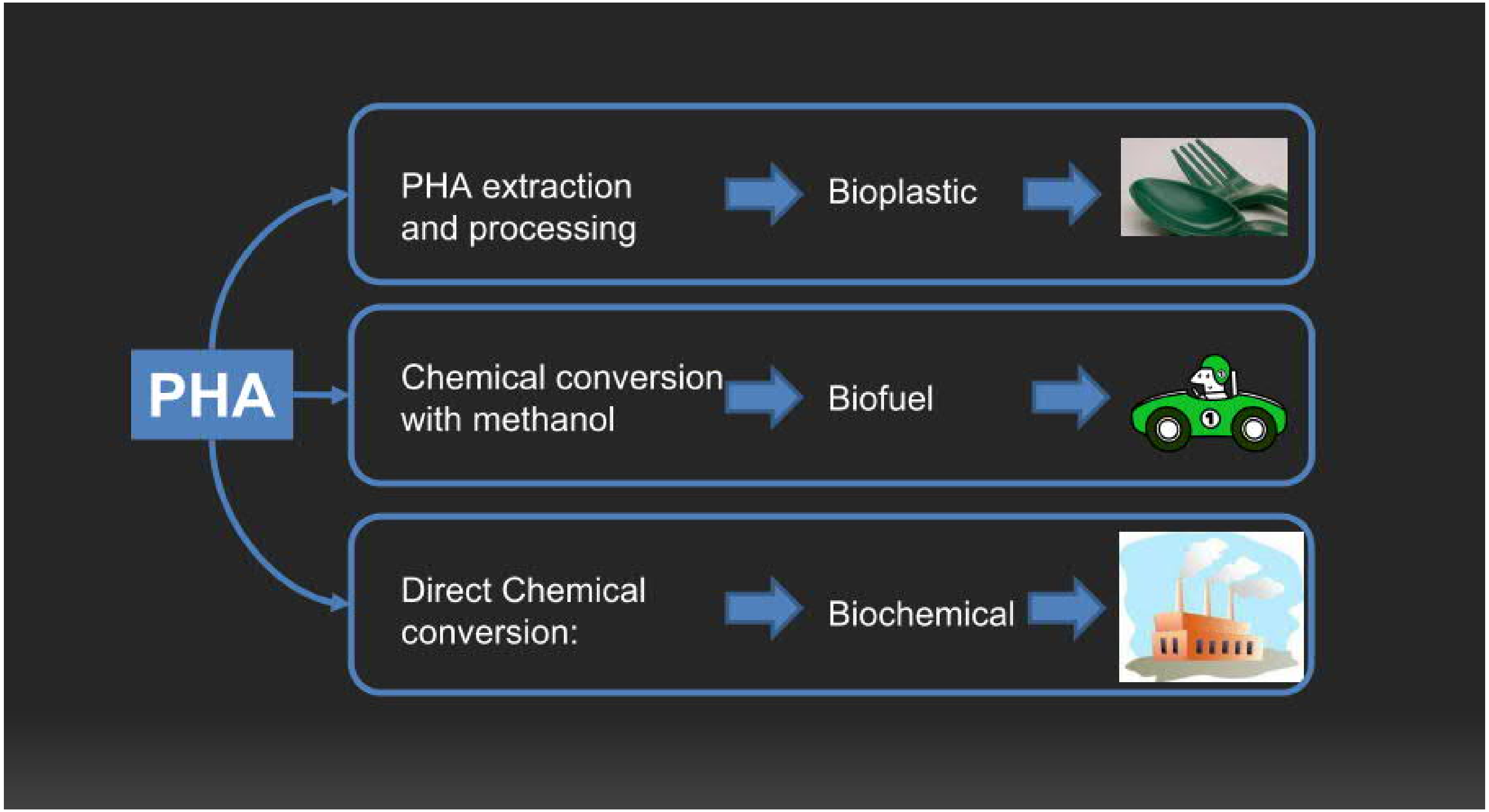

PHA
PHA extraction and processing
Bioplastic
Chemical conversion with methanol
Biofuel
Direct Chemical conversion:
Biochemical

Table 15.1 Some Companies Involved in PHA Production.

Company	Products
Berlin Packaging Corp. (U.S.)	Zeneca/ICI Biopol
Bioscience Ltd. (Finland)	Medical applications of PHAs
Bioventures Alberta, Inc. (Canada)	PHA produced by recombinant *Escherichia coli*
Metabolix, Inc. (U.S.)	PHB, P(HB : HV) (Mirel)
Metabolix/ADM	Transgenic plant PHAs
Monsanto (U.S.)	Transgenic plant PHAs
Polyferm, Inc. (Canada)	PHAs from hemicellulose; use of *Burkholderia cepacia* on xylose
Monsanto-Metabolix (U.S.)	Biopol from *Cupriavidus necator*
Nodax Procter and Gamble (U.S.)	PHBHx, PHBO, PHBOd (Nodax)
Tianan Biologic Material Co (China)	PHB and P(HB : HV) (Enmat)
Tianjin GreenBio Materials Co., Ltd. (GreenBio) (China)	Sogreen
Biocycle Copersucar (Brasil)	PHB and P(HB : HV) (Biocycle)
Biomer (Germany)	PHB and P(HB : HV) (Biomer L)
BIO-ON (Italy)	Minerv-PHA (from sugar beets)
NatureWorks LLC (U.S.)	Ingeo biopolymer
Micromidas	Constructed microbial population able to adapt to a variety of materials, including waste

How Mirel is Made

Biodegradable*

Mirel is biodegradable in natural soil and water environments, home and industrial composting facilities, where available.

Biobased

Starting with corn.

Corn Sugar

One of many products made from each kernel of corn, used as feedstock for Mirel.

Fermentation

A patented process, transforms the sugar into Mirel biopolymers.

Applications

Mirel can be processed on conventional equipment and used in everyday products.

Formulation

Mirel is compounded into resin pellets.

Biological phosphorus removal

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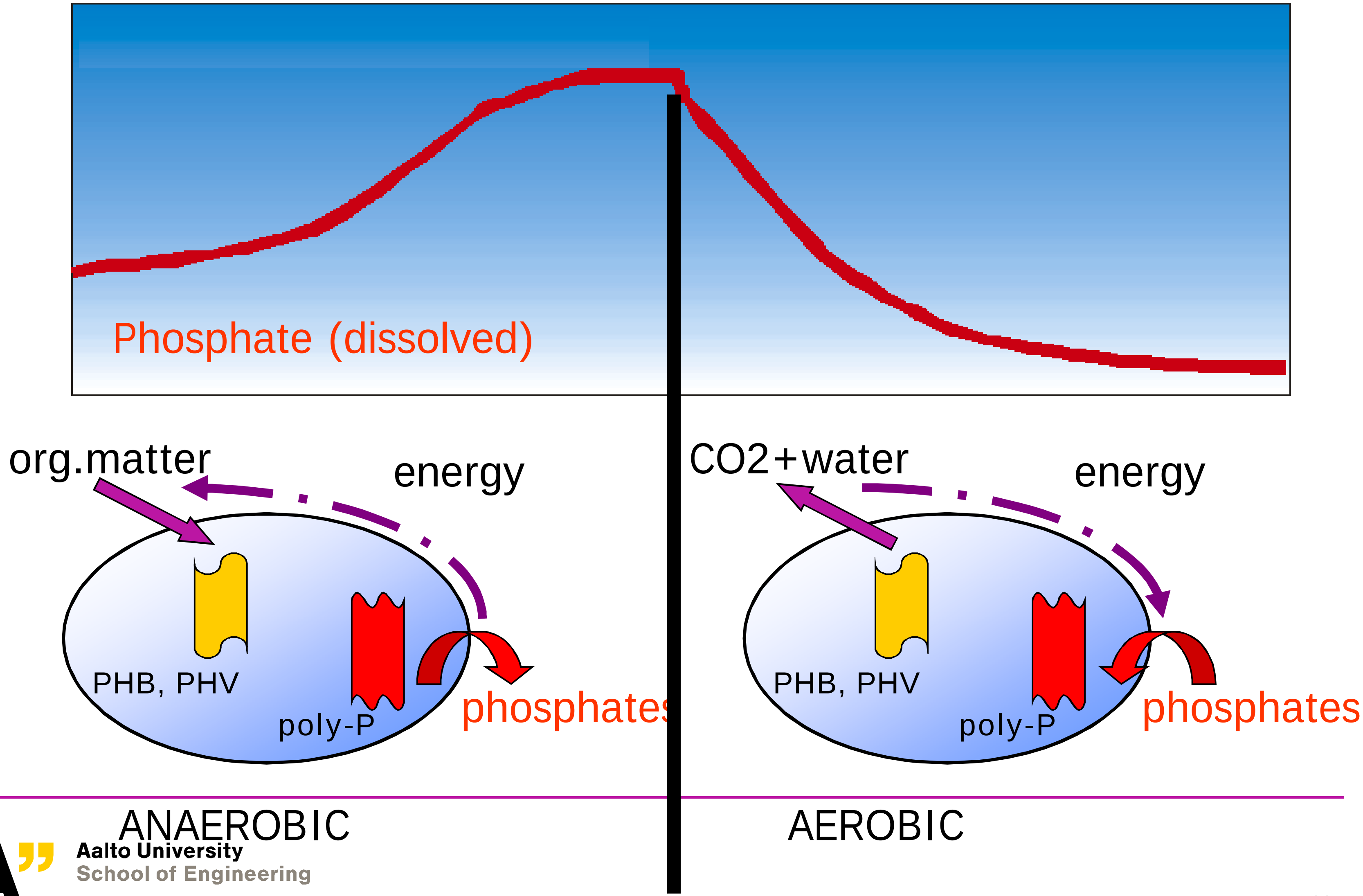
Biological phosphorus removal

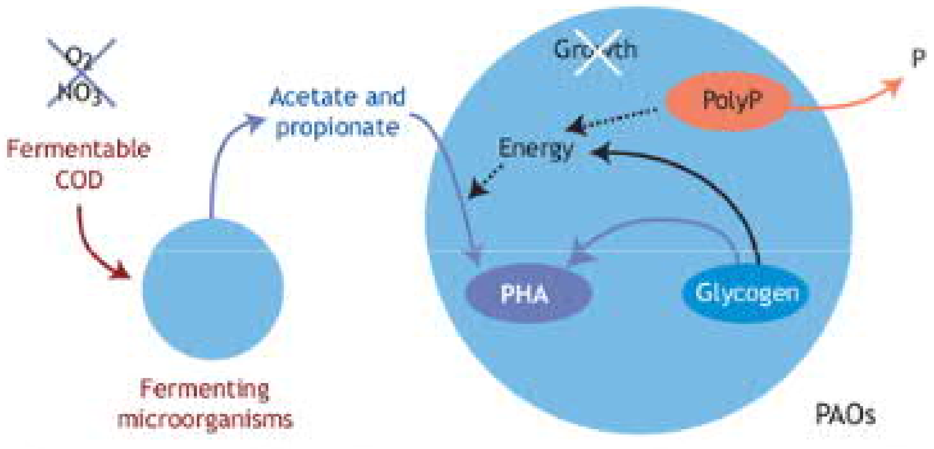
- Phenomenon was discovered by accident in India 1959
- Observed in full-scale plant in South Africa in the 70s also by accident
- Based on microbes capable of storing polyphosphates
- Require alternating anaerobic (not even nitrates) and aerobic conditions and carbon source in the anaerobic phase.
- PAOs phosphorus accumulating organisms
- Competition with GAOs (Glycogen accumulating organisms) especially in warm temperatures

BioP

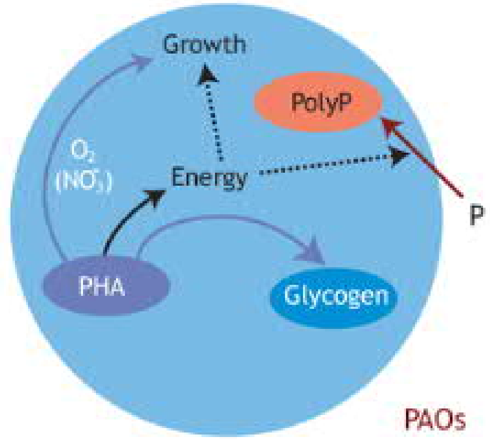

Phosphate (dissolved)
org.matter
energy
PHB, PHV
poly-P
phosphates
CO2+water
energy
PHB, PHV
poly-P
phosphates
ANAEROBIC
AEROBIC

BioP

ANAEROBIC CONDITIONS

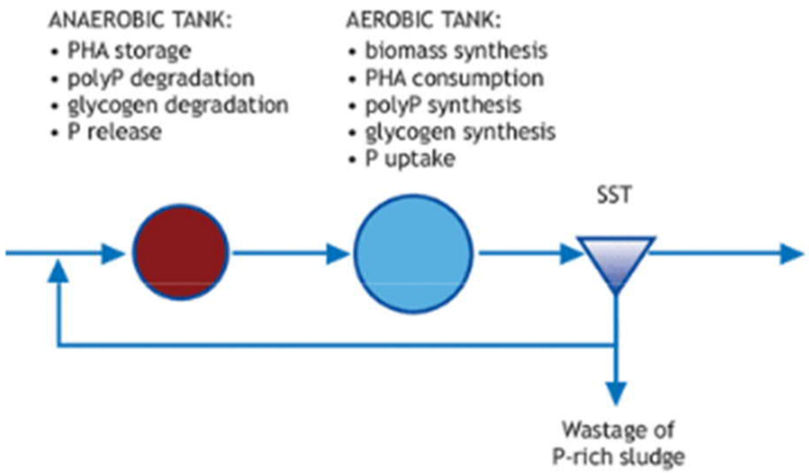


AEROBIC CONDITIONS



Principles of bioP

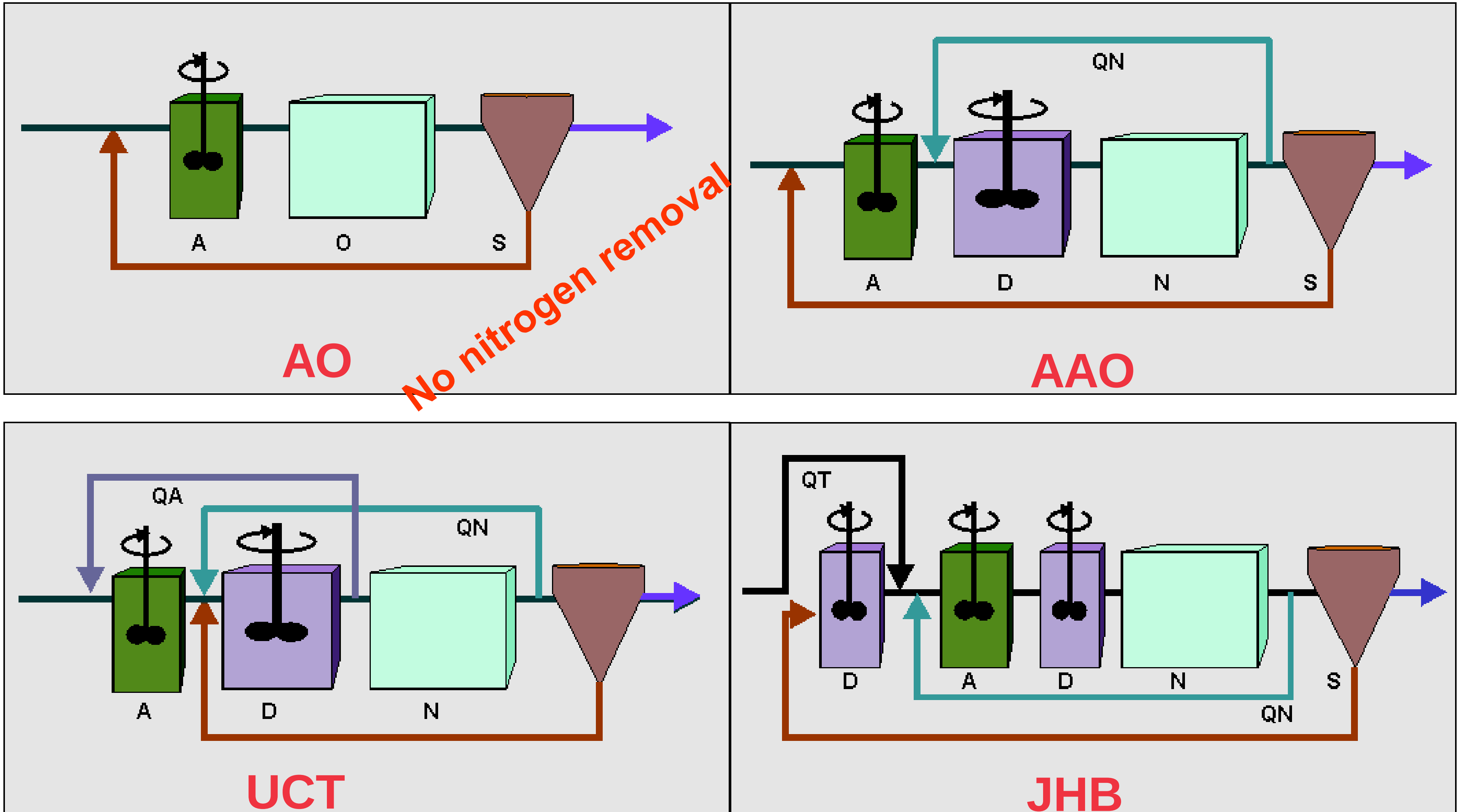
- Phosphorus accumulating organisms (PAOs) store organic matter as polyhydroxyalcanoates (PHA) in anaerobic conditions using energy from poly-P inside the cell
- In aerobic conditions PAOs store more poly-P than needed for the normal metabolism using stored PHA
- Phosphorus is removed with the sludge (3-8 % of P)



Important aspects in bioP processes

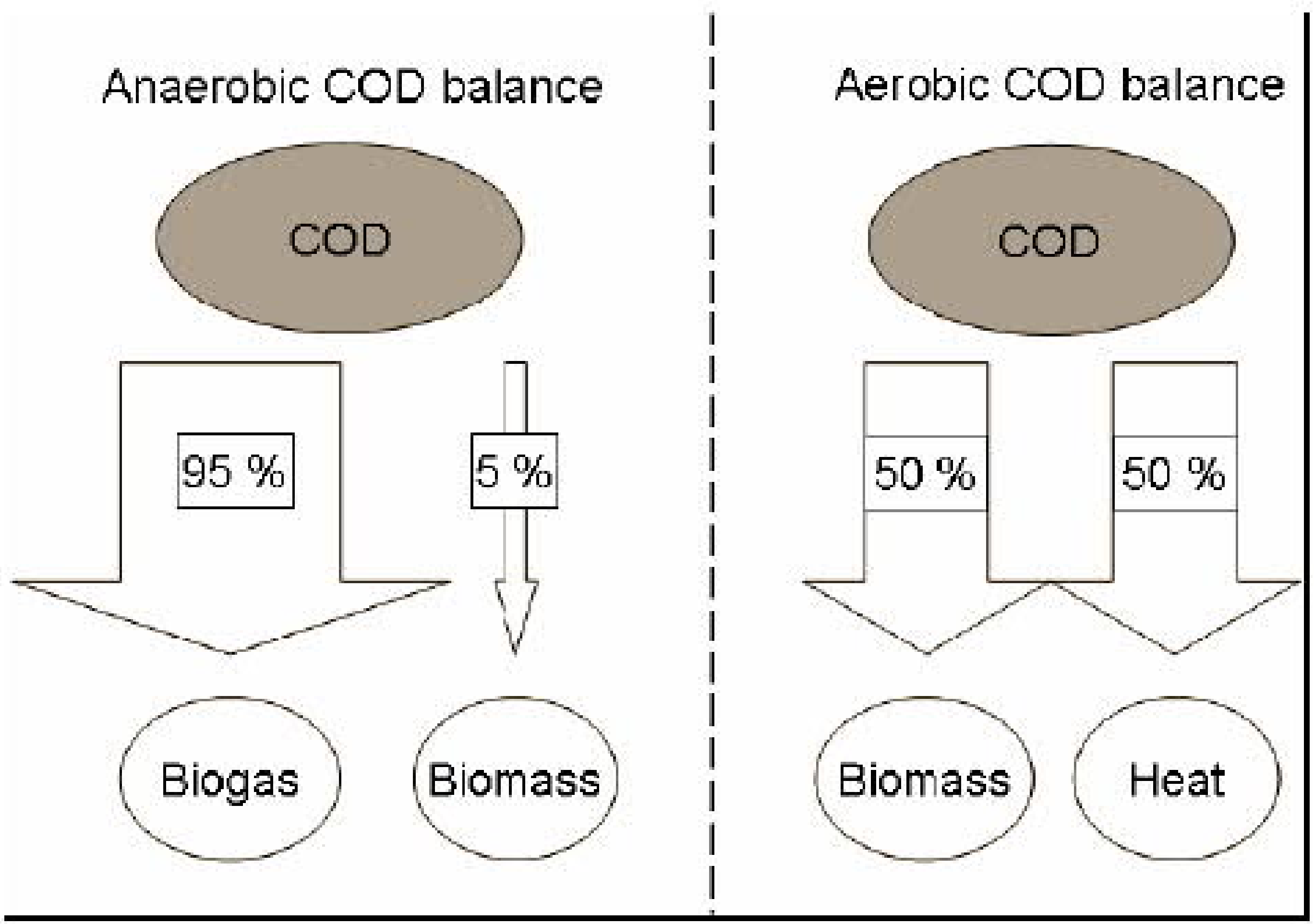
- Minimizing oxygen in the anaerobic zone
- Minimizing nitrates and nitrites in the anaerobic zone.
- Increase volatile fatty acids (VFA) concentration in the anaerobic zone. (VFA is taken up and forms PHA)
- Minimizing solids in the effluent (high P content)
- Maximizing phosphorus uptake = short SRT and good oxygen concentration pattern

Biological P removal processes



Anaerobic processes

Why anaerobic treatment?

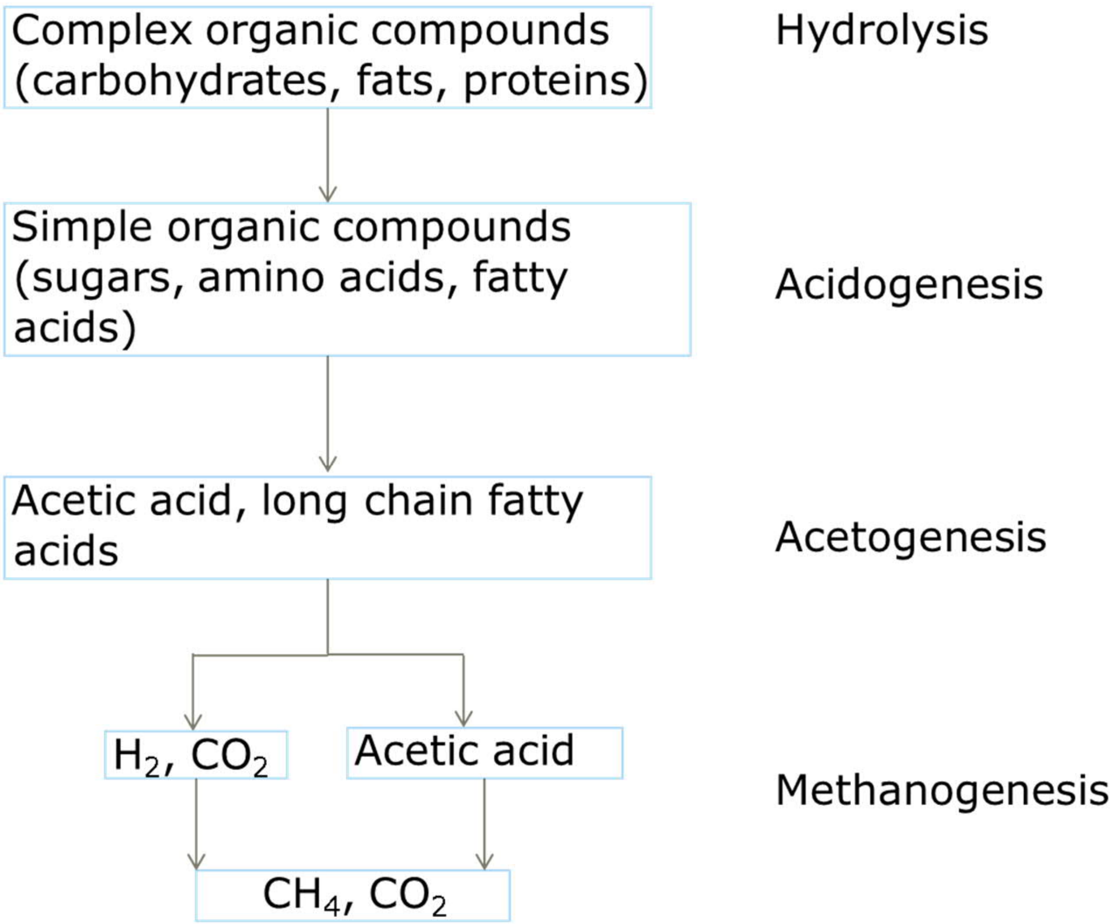


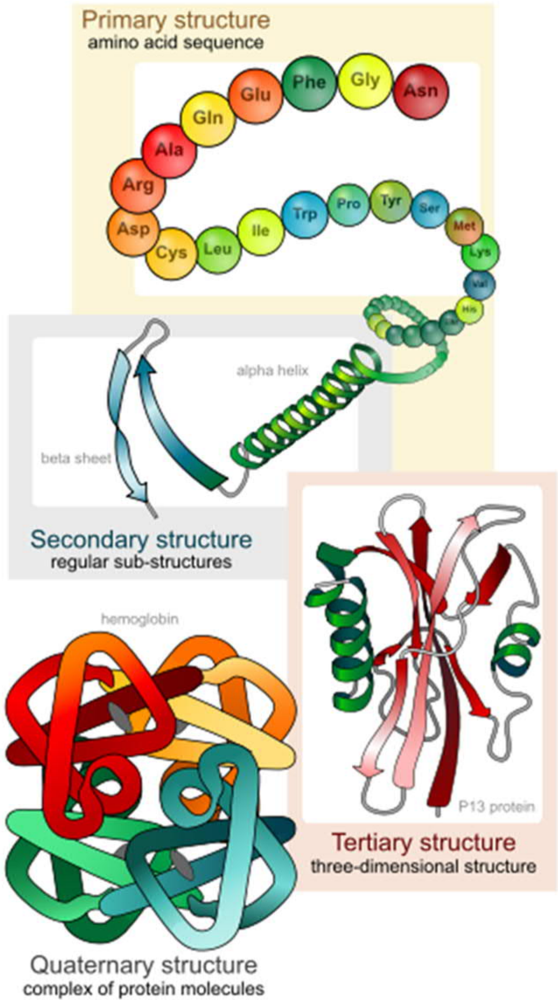
Pros and cons of anaerobic digestion

+ CO_2 as electron acceptor
+ no need for aeration
+ Low sludge yield
+ Produces methane, 90% can be used as energy (9000 kcal/m^3)
+ high loading→ less space
+ Works with certain organic compounds that can not be degraded in aerobic conditions

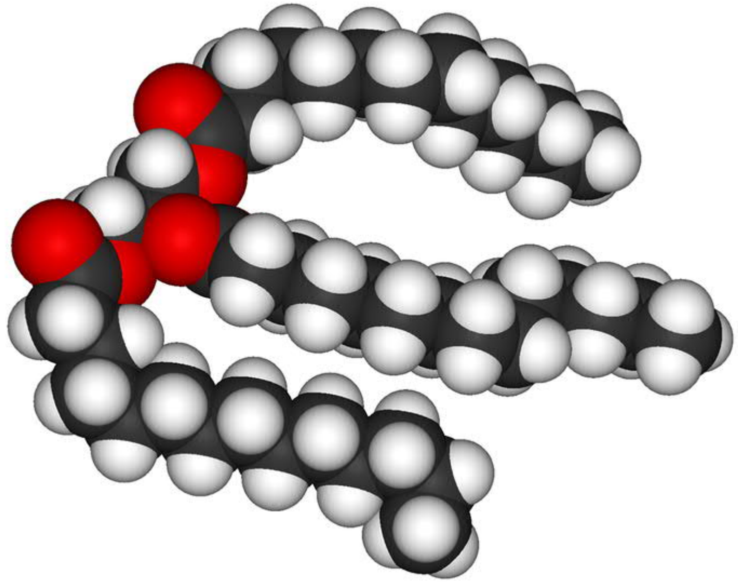
- Slow process (HRT about 30 d)
- Sensitive to toxic substances
- Long start-up
- Requires high substrate concentrations

Anaerobic digestion

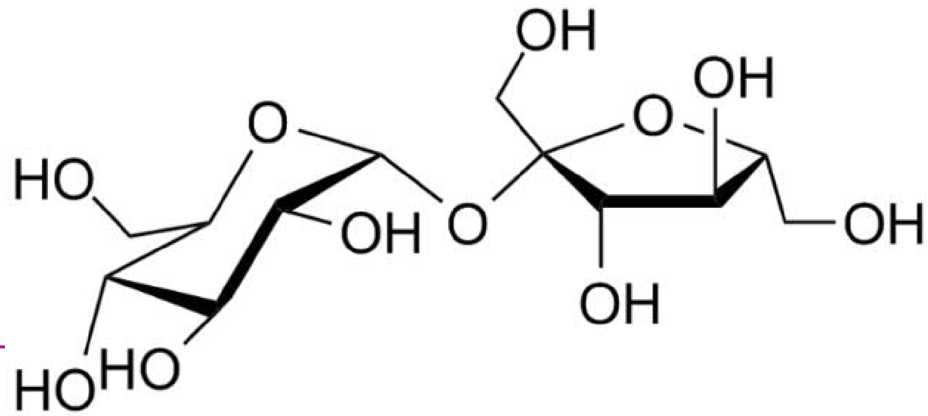




Proteins



Fats (triglyseride molecule)

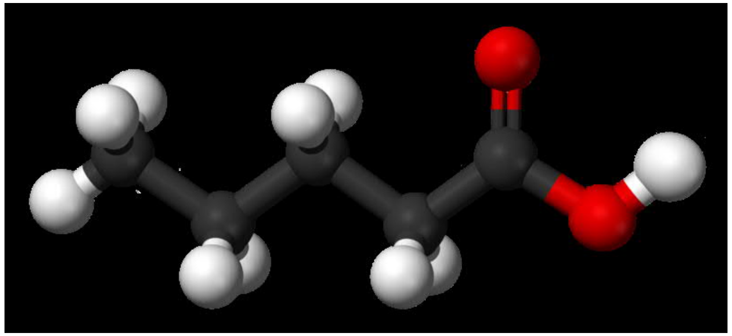


Sugar

Hydrolysis

- First step of the anaerobic digestion
- Different groups of bacteria produce extracellular enzymes to cut the larger organic molecules into smaller ones
- Larger molecules = proteins, fats, carbohydrates
- Smaller molecules = small molecule sugars, amino acids, short chain fatty acids

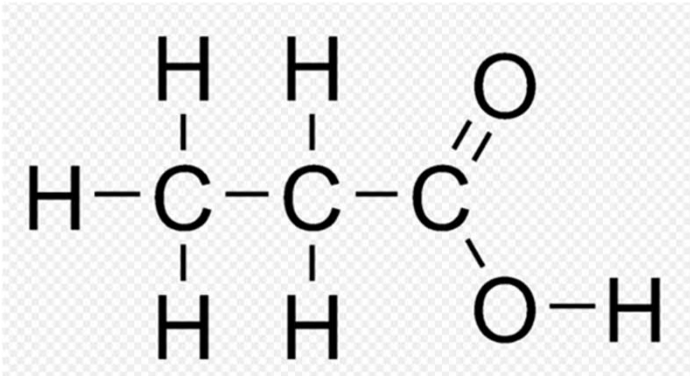
Hydrolysis products, example valeric acid



Acidogenesis

- **Second step of the anaerobic digestion**
- **Acidogenesis**
- **Bacteria degrades the organic molecules further to short-chain fatty acids and alcohols**
- **Ammonium, hydrogen and CO_2 also produced**

End product in this step, for example propanoic acid



Acetogenesis and methanogenesis

- **Third step of the anaerobic digestion**
- **Acetogenic bacteria degrades the short chain fatty acids to acetic acid (and hydrogen and CO_2)**

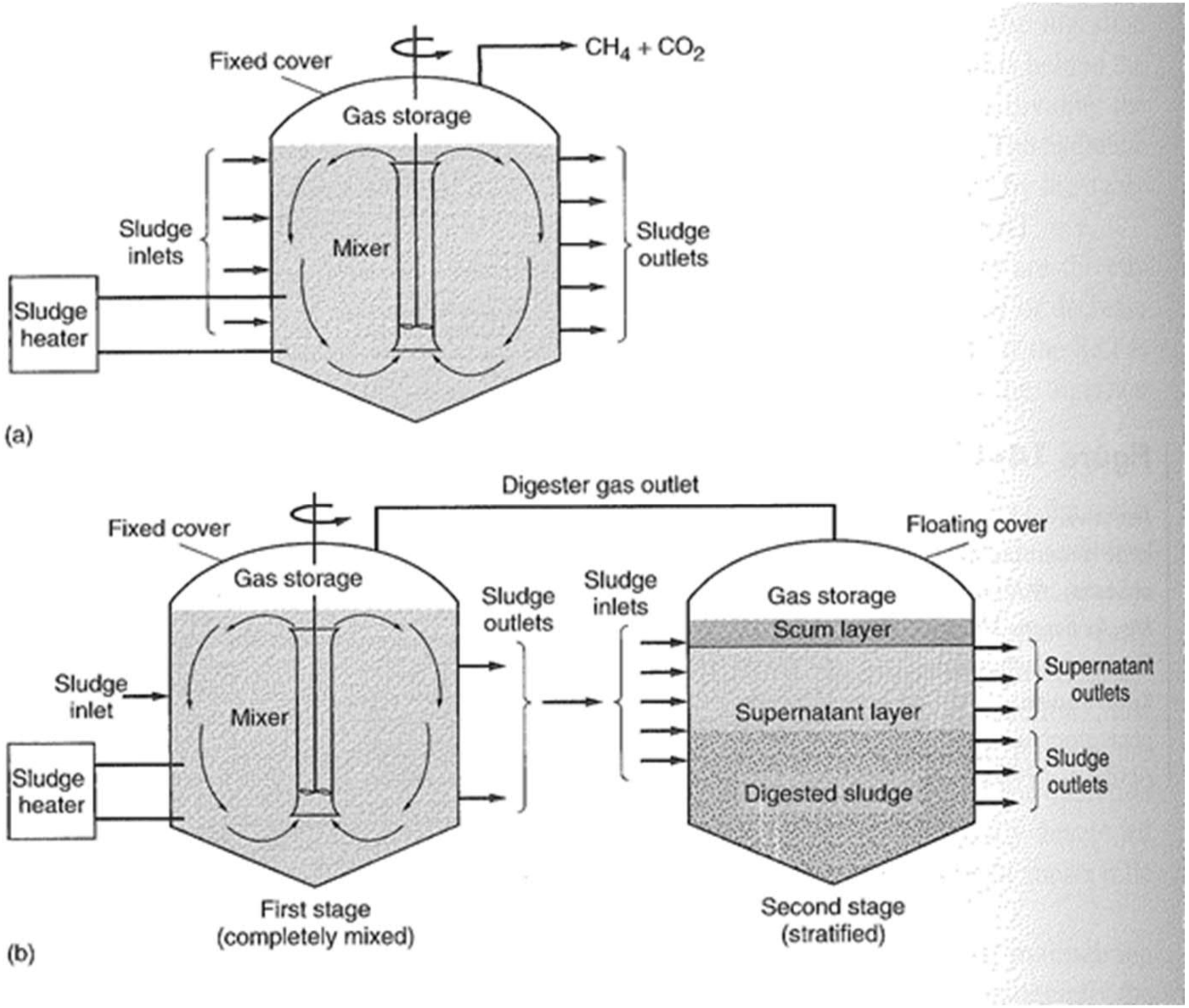
Last step of the anaerobic digestion

Methanogenic bacteria use acetic acid, CO_2 and hydrogen to produce biogas (=methane)

Pre-fermentation

- In order to produce VFA = volatile fatty acids
- VFAs are enhancing denitrification and biological phosphorus removal
- Can be done with influent waste water, raw sludge, waste activated sludge or a industrial influent

Anaerobic processes for sludge digestion (biogas plants)



Digestion processes

Mesophilic

33 – 37 ºC

Retention time about 21 days

Thermophilic

54 – 55 ºC

Retention time about 14 days

Requires more energy

Anaerobic processes in wastewater treatment

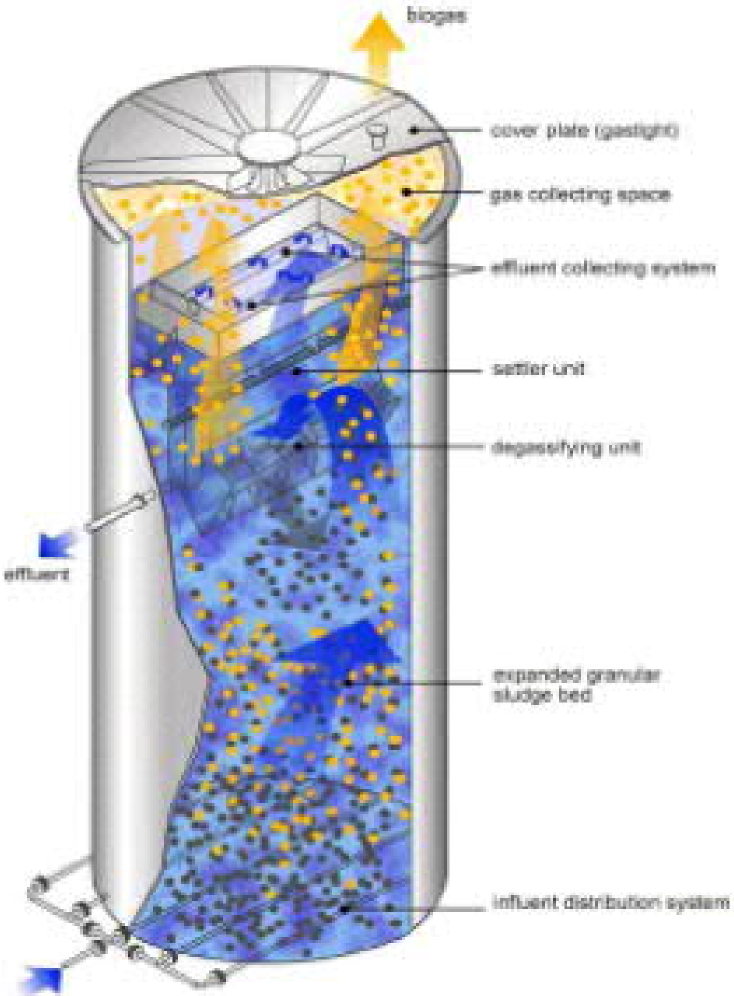


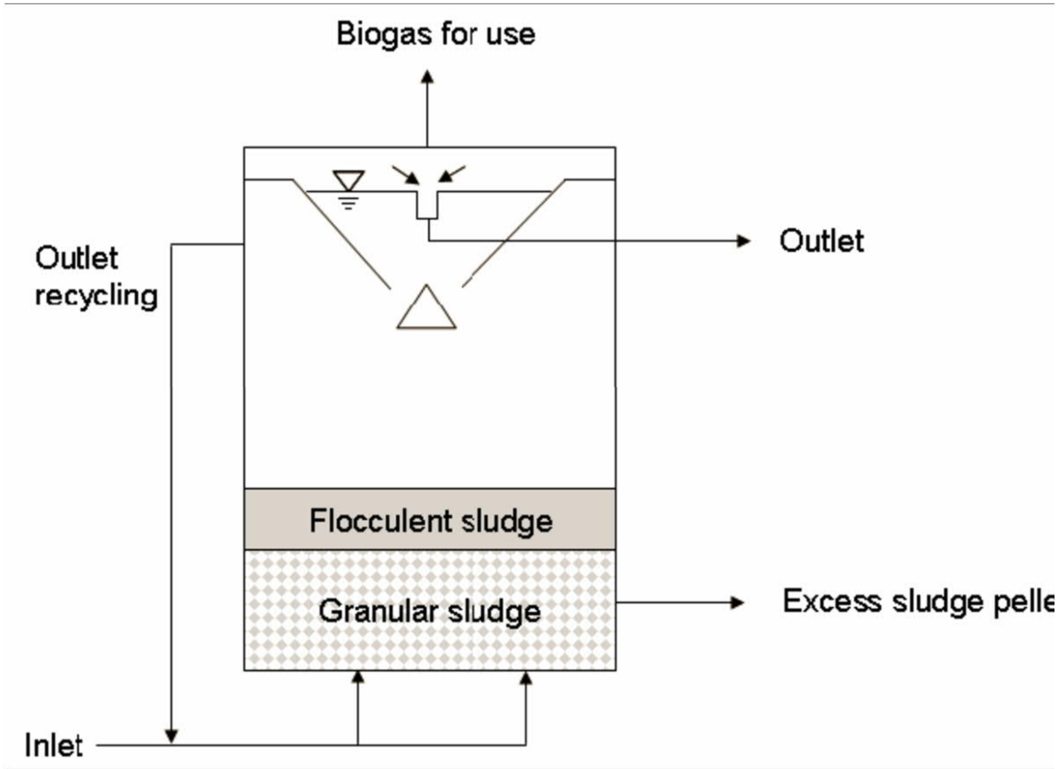
Figure 1: Typical Biobed® EGSB reactor

Typical Biobed® EGSB plant at Lapin Kulta, Haparanda (Finland)

UASB reactor (Upflow anaerobic sludge blanket)

Granular biomass is created in the reactor

Biomass is kept in suspension by the gravity of the granules and the upflow of wastewater



Reading material

Biological wastewater treatment (Course book):

Chapters

7.1 – 7.4