



IIT ROORKEE



NPTEL ONLINE
CERTIFICATION COURSE

WASTE TO ENERGY CONVERSION

ENERGY PRODUCTION FROM ORGANIC WASTES THROUGH ANAEROBIC DIGESTION-1

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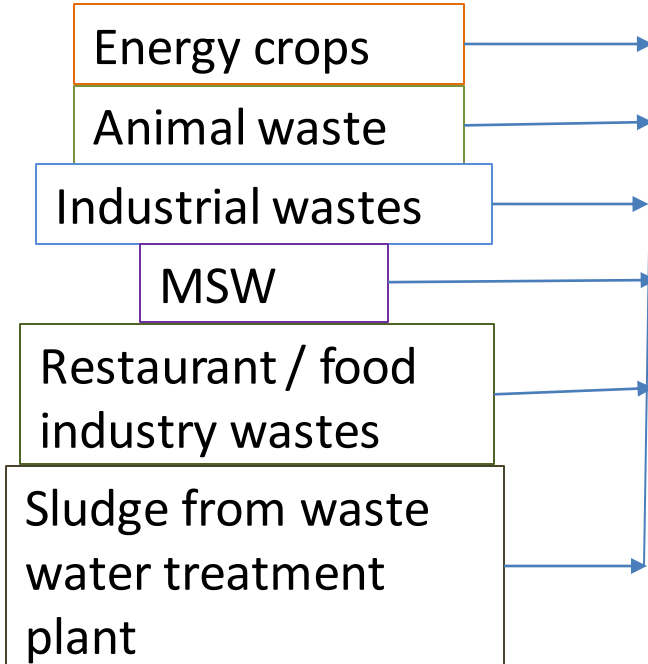
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- Mechanism of anaerobic digestion
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- Kinetics of methane formation
- Anaerobic digester and their types
- Operation of anaerobic digester
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- Impurities in biogas and their impacts
- Sludge volume in a digester



Anaerobic digestion, feedstocks and primary products

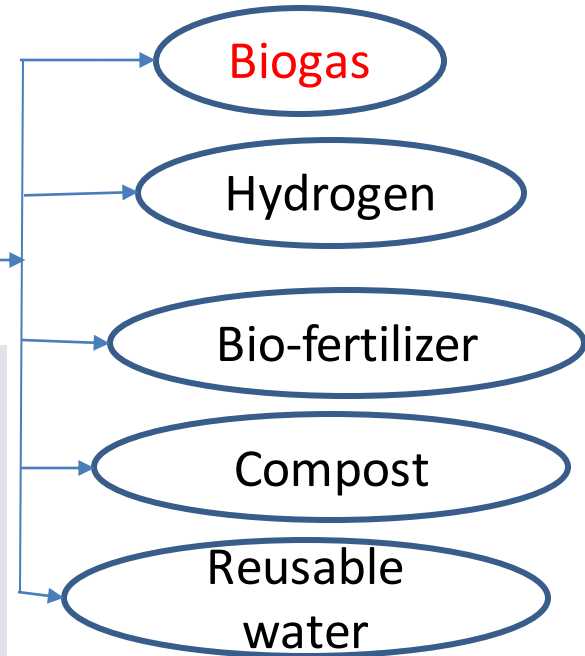
Important feedstocks



Anaerobic digestion

A series of biological processes in which microorganisms break down biodegradable material in the absence of oxygen.

Primary products



WHAT IS BIOGAS ?

Biogas is a combustible mixture of gases. It consists mainly of methane(CH_4) and carbon dioxide (CO_2) and is formed from the anaerobic bacterial decomposition of organic compounds, i.e. in absence of oxygen.

Major components of biogas

Gas	%
Methane	50-75%
Carbon dioxide	25-50%
Nitrogen	0-10%
Hydrogen	0-1%
Hydrogen sulphide	0-3%
Oxygen	0-1%



Specific biogas production potential & methane content for several wastes

Wastes	Average Dry Matter(DM) content (wt%)	Biogas Potential l/ kg Substrate	Methane Content %
Wheat straws	86.5	367	78.5
Barley straws	84	380	77
Lucene	22.5	445	77.7
Grass	16	557	84
Corn silage	34	108	52
Corn stalks	86	309	-
Dried leaves	12.5	260	58

Specific biogas production potential & methane content for several wastes

Wastes	Average Dry Matter(DM) content (wt %)	Biogas Potential l/ kg Substrate	Methane Content %
Beet leaves	13.5	501	84.8
Poultry wastes	27.5	520	68
Cattle manure	14	260-280	50-60
Horse dung	27.5	200-300	66
Sheep dung	25	320	65
Pig manure	13.5	480	60

Steps of AD

Pretreatment
for (LCB)

Complex organic compounds(carbohydrates , fats, proteins)

Hydrolytic bacteria/ enzymes

Hydrolysis

Simple organic compounds(sugar, amino acids, peptides)

Fermentative bacteria

Acidogenesis

Short chain fatty acids

Acetogenesis

H₂ producing acetogenic bacteria

Acetic acid /Acetate

H₂, CO₂

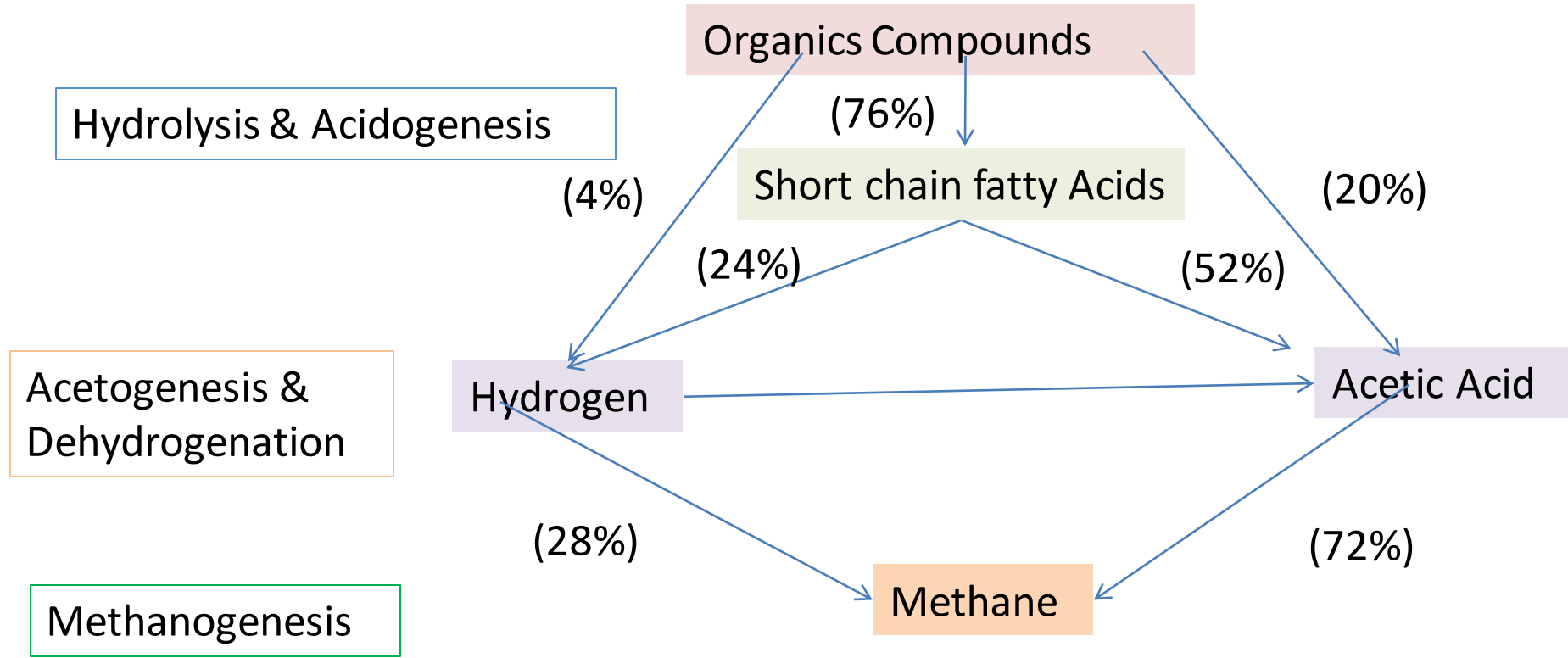
Methanogenesis

CH₄, CO₂

Methane producing
bacteria



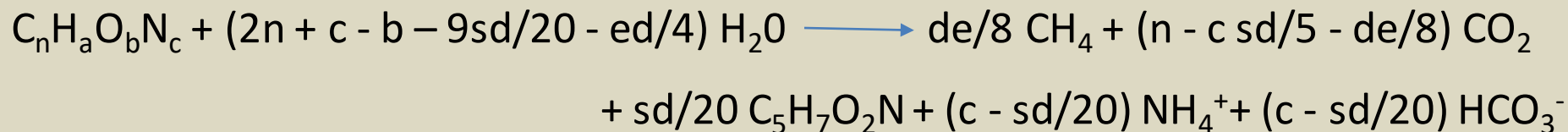
Quantitative description of biomass degradation



Elementary description of AD

Source- <http://www.fao.org/>

•In case the chemical composition of the organic matter is known, the stoichiometric equation according to McCarty (Pavlostathis et al., 1991):



where: $d = 4n + a - 2b - 3c$,

s = fraction of waste converted into cells,

e = fraction of waste converted into methane for energy ($s + e = 1$),

$\text{C}_n\text{H}_a\text{O}_b\text{N}_c$ = empirical formula of waste being digested

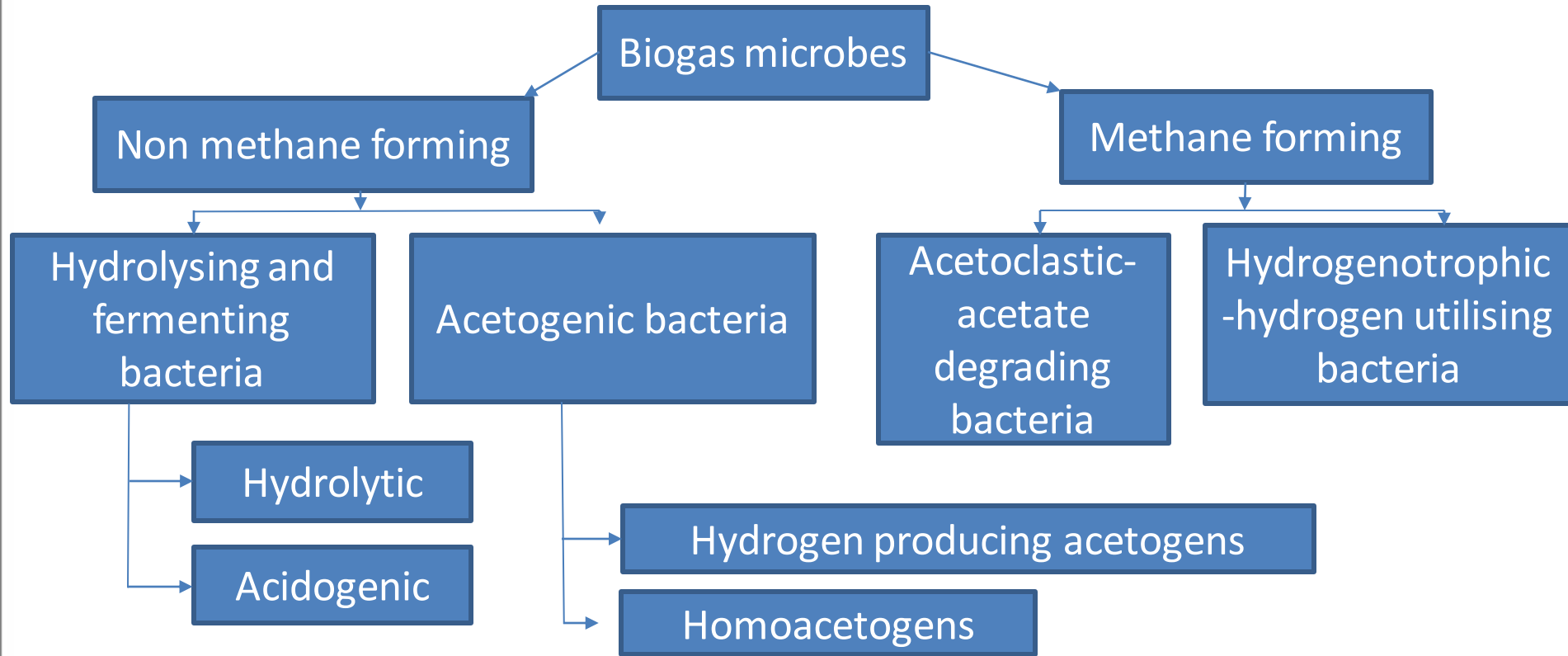
$\text{C}_5\text{H}_7\text{O}_2\text{N}$ = empirical formula of bacterial dry mass (VSS)



Some factors affecting biogas yield

- Solid(dry matter) content in feed wastes
- C/N ratio
- Temperature
- pH of the solution
- Retention time
- Type of digester
- Microbes types

Groups of biogas microbes



Role of microbes involved in the main 3 stages of biogas production

1st stage: Fermentative bacteria

Hydrolysis and fermentation of organic substances

Cellulose
decomposing
bacteria

- Monomers
- Oligomers
- Saccharides

Protein
decomposing
bacteria

- Amino Acids

Fat
decomposing
bacteria

- Fatty acids
- Alcohols

Short chain organic acids,
aldehydes
 H_2 & CO_2

2nd stage: Hydrogen producing acetogenic bacteria

Decomposes the substances
produced in 1st stage

Acetic acid, H₂, CO₂

3rd stage: Methane producing bacteria-

Convert the substances
produced in 1st & 2nd
stage

CH₄ & CO₂

Hydrolysing and fermenting bacteria

- The first step in the fermentation of complex substrates is the hydrolysis of polysaccharides to oligosaccharides and monosaccharides, of proteins to peptides and amino acids, of triglycerides to fatty acids and glycerol, and of nucleic acids to heterocyclic nitrogen compounds, ribose, and inorganic phosphate
- Relative anaerobes of genera like Streptococcus and Enterobacterium, Bacillus, Cellulomonas, Mycobacterium are some important hydrolytic bacteria.
- Hydrolytic enzymes like cellulases, hemicellulases, amylases, lipases and proteases from these bacteria depolymerize carbohydrates, lipids, and proteins to soluble molecule.



Hydrolysing and fermenting bacteria

Complex compounds in feedstocks	Typical Hydrolysis products
Carbohydrates	Sugars, alcohols
Cellulose	Glucose, cellobiose
Proteins	Amino acids
Peptides	Fats, Fatty acids, glycerol
Lignin	Degraded very slowly

Hydrolysing and fermenting bacteria

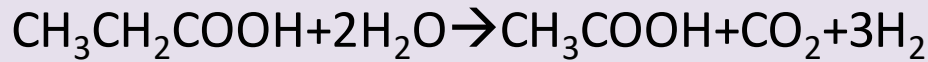
- Obligate anaerobes including *Bacteroides*, *Bifidobacterium*, *Butyrovibrio*, *Eubacterium*, and *Lactobacillus* act as acidogenic bacteria.
- Many enteric coliform bacteria, classically represented by the pathogen *Escherichia coli* in the genus *Escherichia* and pathogens in the genera *Salmonella* and *Shigella*, are also some common fermentative(acidogenic) bacteria.

Hydrolysis product	Conversion during acidogenesis
Sugar	Fatty Acids (succinate, acetate, proprionate, lactate, formate), carbon dioxide, hydrogen
Alcohols	Fatty acids, CO ₂
Amino acids ammonia, sulphides, CO ₂ , H ₂	Fatty acids
Glycerol	Acetate , CO ₂

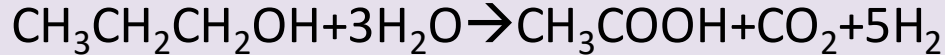
Acetogenic bacteria

■ Hydrogen producing acetogens

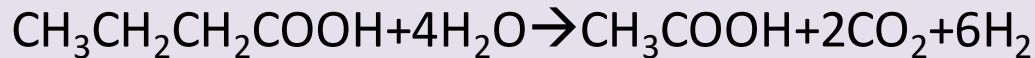
- Propionate



- Propanol



- Butyrate



■ Homoacetogens

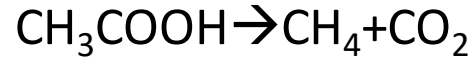


Clostridia and Acetivibrio are some example of acetogenic bacteria

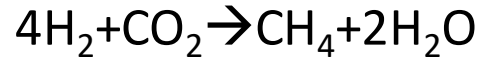


Methanogenic bacteria

■ Acetoclastic methanogens



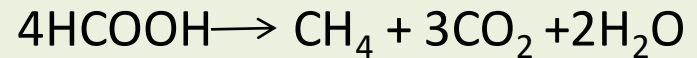
■ Hydrogenotrophic methanogens



- Formic acid and methanol can also be converted to methane by bacteria

- ~70 % of methane is produced by this route
- These are highly sensitive and having slowest growth rate

- ~30 % of methane is produced by this route
- These are less sensitive and having higher growth rate



Methanogenic bacteria

Methanogenic bacteria are unicellular, Gram-variable, strict anaerobes that do not form endospores. Their morphology, structure, and biochemical makeup are quite diverse. More than ten different genera have been described.

The methanogens have been divided into three groups based on the fingerprinting of their 16S *ribosomal* RNA (rRNA) and the substrates used for growth and methanogenesis

Group I contains the genera *Methanobacterium* and *Methanobrevibacter*;

Group II contains the genus *Methanococcus*; and

Group III contains several genera, including *Methanomicrobium*, *Methanogenium*, *Methanospirillum*, and *Methanosarcina*



Pathways for fermentation

Embden–Meyerhof–Parnas (EMP pathway) is responsible for the production of pyruvate from sugar as an intermediate product, which is further converted to acetate, fatty acids, carbon dioxide, and hydrogen

- At low partial pressures of hydrogen, acetate is favoured.
- At higher partial pressures, propionate, butyrate, ethanol, and lactate are favoured, generally in that order (McInerney and Bryant, 1981)

There is also a special mode of cleavage of intermediate pyruvic acid to formic acid by enteric bacteria that is not found in other bacterial fermentations

Pretreatment for lignocellulosic biomass and wastes

Pretreatment method	Processes	Possible changes in biomass	Notable remarks
Physical pretreatments	Milling(ball milling, hammer milling)	-Increase in accessible surface	-Most of the methods are highly energy demanding
	Irradiation(gamma-ray irradiation, microwave irradiation)	-Decrease in cellulose	-Most of them cannot remove lignin
	Other methods (Hydrothermal, pyrolysis)	-Decrease in degrees of polymerization	-Preferable not to use for industrial applications



Pretreatment method	Processes	Possible changes in biomass	Notable remarks
Chemical & physico-chemical pretreatments	Explosion(CO_2 , SO_2 explosion)	-Increase in accessible surface area	-These methods are among the most effective & include the most promising processes for industrial applications -Usually rapid treatment rate -Typically need harsh conditions -There are chemical requirements
	Alkali(sodium hydroxide, ammonia)	-Partially or nearly complete delignification	
	Acid(sulphuric acid, hydrochloric acid)	-Decrease in cellulose crystallinity -Decrease in degrees of polymerization	
	Gas(NO_2 , SO_2)	-Partial or complete hydrolysis of hemicelluloses.	
	Oxidizing agents(H_2O_2 , O_3)		

Pretreatment for lignocellulologic biomass and wastes

Pretreatment method	Processes	Possible changes in biomass	Notable remarks
Biological pretreatments	Fungi & actinomycetes	-Delignification -Reduction in degree of polymerization of cellulose -Partial hydrolysis of hemicelluloses	-Low energy requirement -No chemical requirement -Mild environmental conditions -Very low treatment rate -Did not consider for commercial applications

Thanks...

