SAARC ENERGY CENTRE
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Online Capacity Building of SAARC Professionals on Commercial Scale Biogas Plants
August 23-27, 2021

Feedstock Types, Their Availability, Cost And Procurement W.R.T to SAARC Member States

Aug. 24, 2021, 3:35 – 4:30 pm

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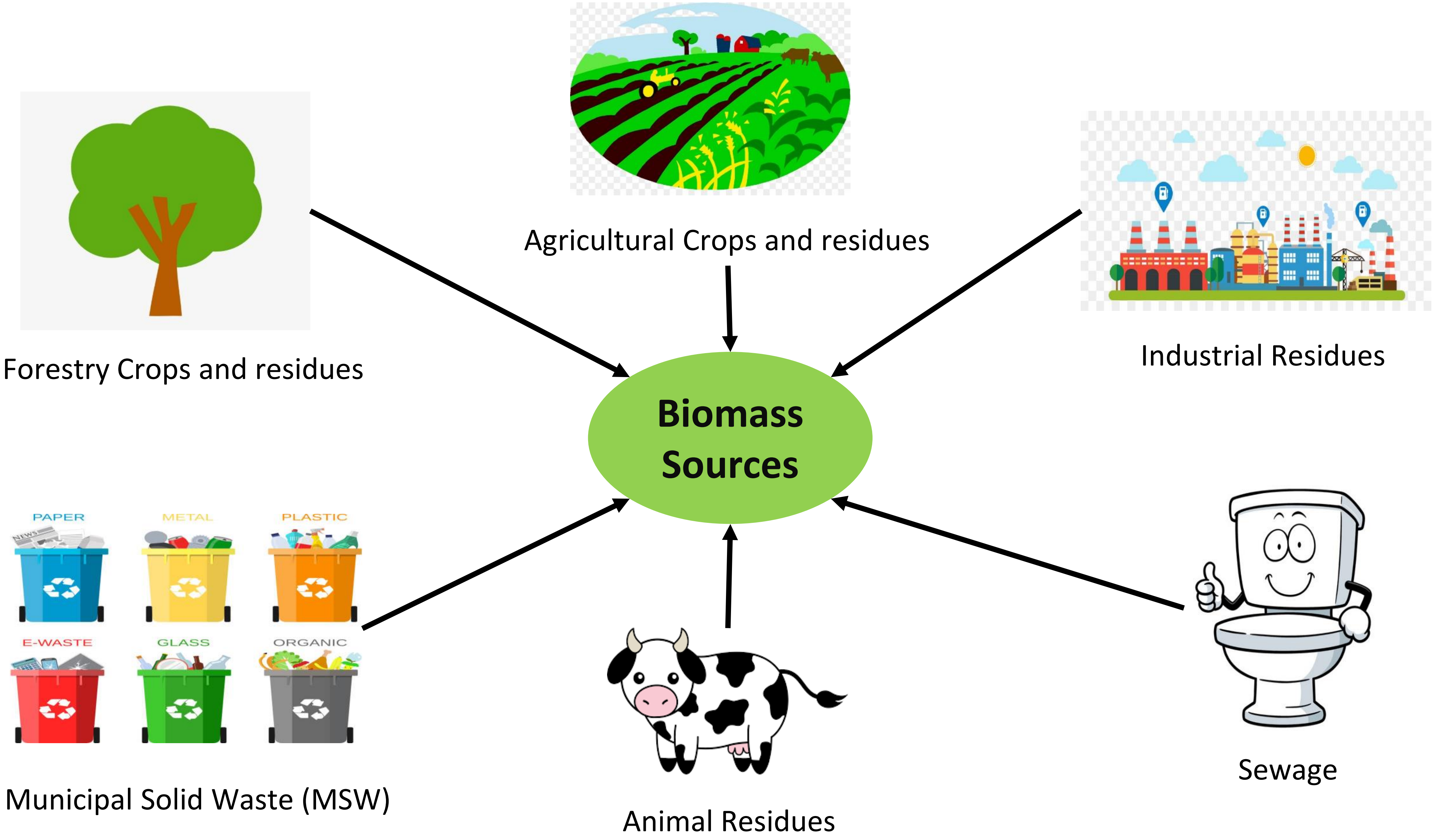
Learning objective:

- To understand the advantages and challenges associated with different feedstocks for biogas production

Biomass

- Biomass is renewable **organic material** that comes from plants and animals (or living organisms).
- A sustainable source of energy used to create electricity or other forms of power.
- At present, biomass accounts for **10 %** of the global energy supply and **13 %** of energy consumption.
- In 2016, the global primary energy supply was **13.8 billion** tons of oil equivalent

Source: https://doi.org/10.1016/j.nbt.2020.10.004


Agricultural Crops and residues
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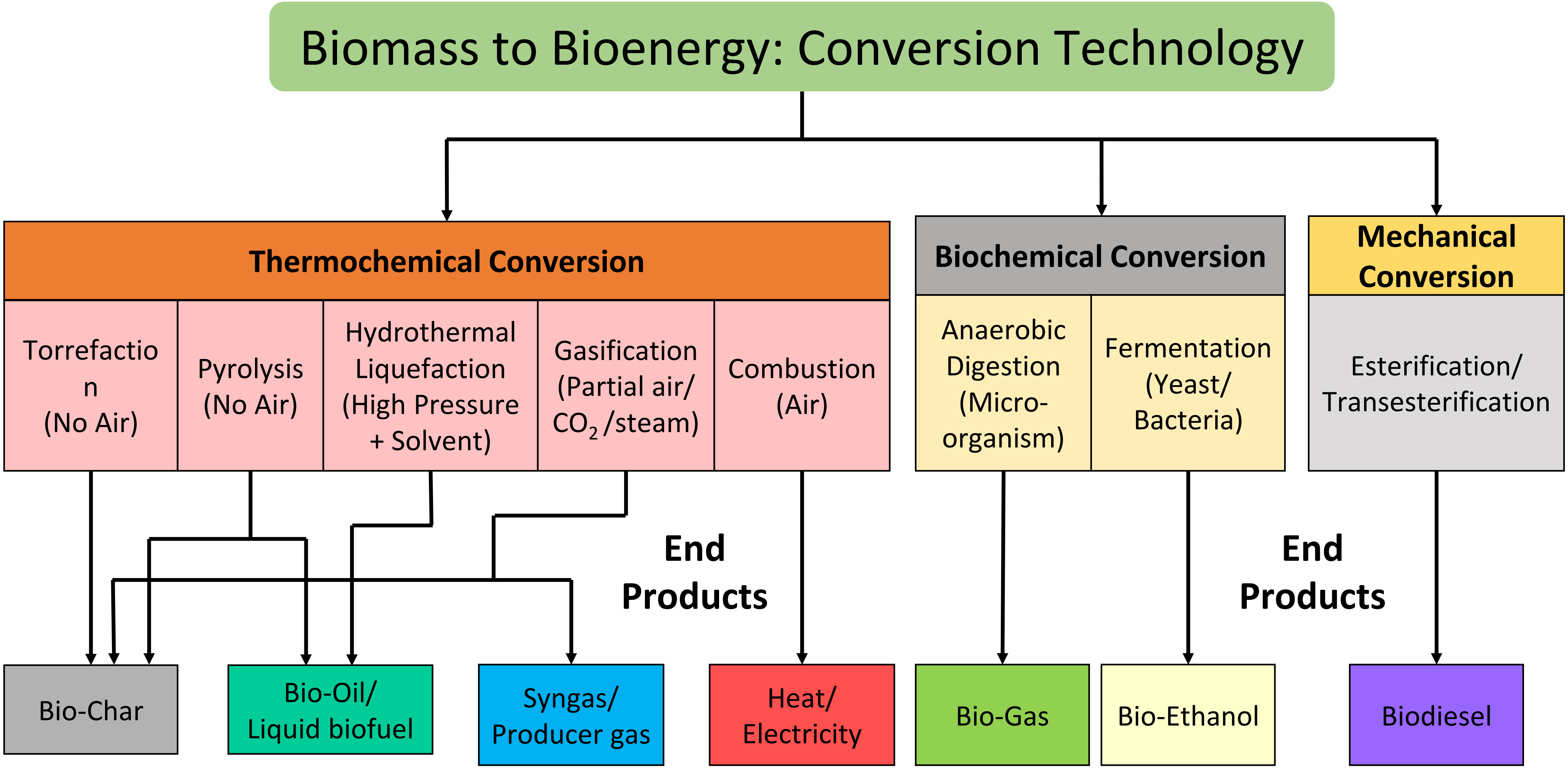
Biomass to Bioenergy: Conversion Technology
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Biochemical Conversion
Mechanical Conversion
Torrefaction (No Air)
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Gasification (Partial air/ CO_2 /steam)
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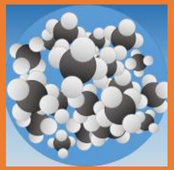
Fermentation (Yeast/ Bacteria)
Esterification/ Transesterification
End Products
End Products
Bio-Char
Bio-Oil/ Liquid biofuel
Syngas/ Producer gas
Heat/ Electricity
Bio-Gas
Bio-Ethanol
Biodiesel

Biogas

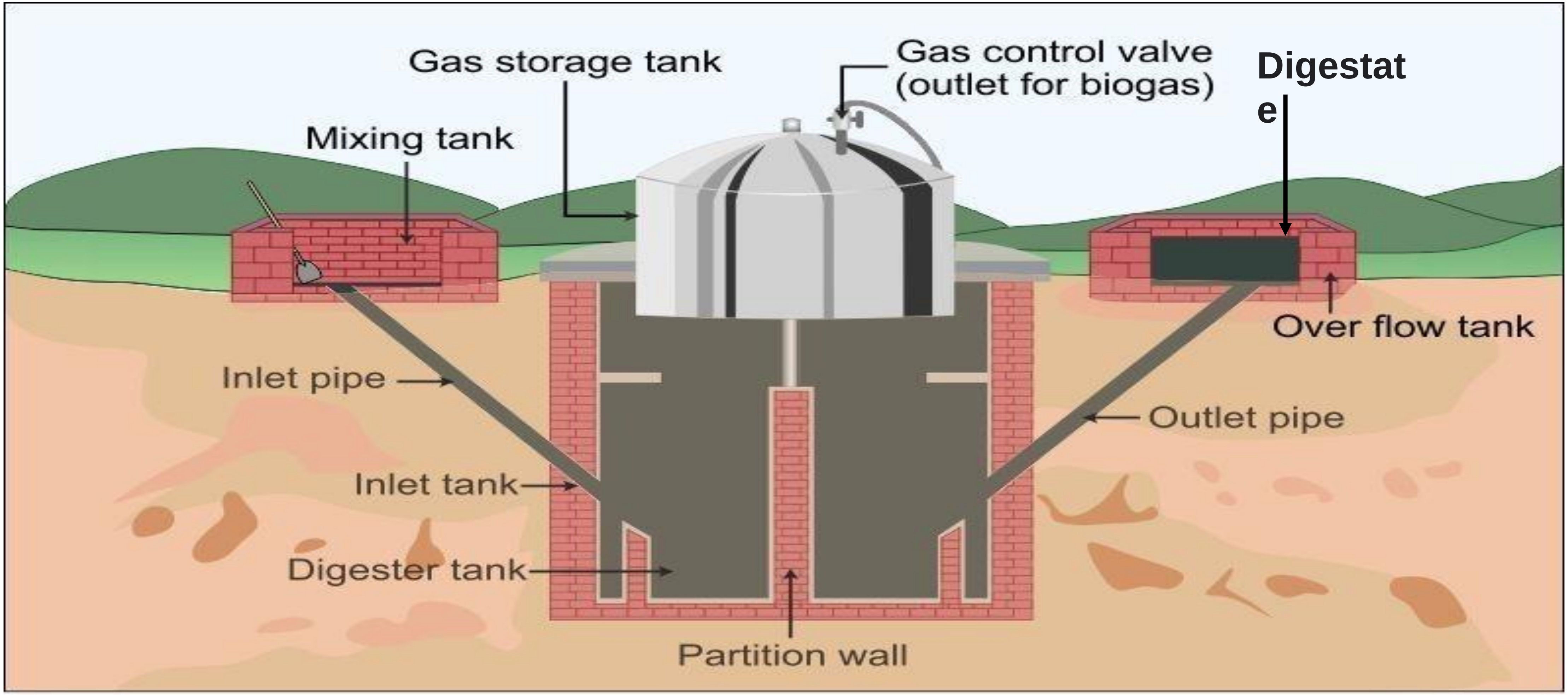


Biogas is the mixture of gases produced by organic matter in the absence of oxygen (anaerobically), primarily consisting of **methane** and **carbon dioxide**.

Biogas can be produced from raw materials such as agricultural waste, manure, municipal waste, plant material, sewage, green waste or food waste.

Biogas is produced by **anaerobic digestion** with methanogen or anaerobic organisms, which digest material inside a closed system, or fermentation of biodegradable materials. This closed system is called an anaerobic digester, biodigester or a bioreactor.

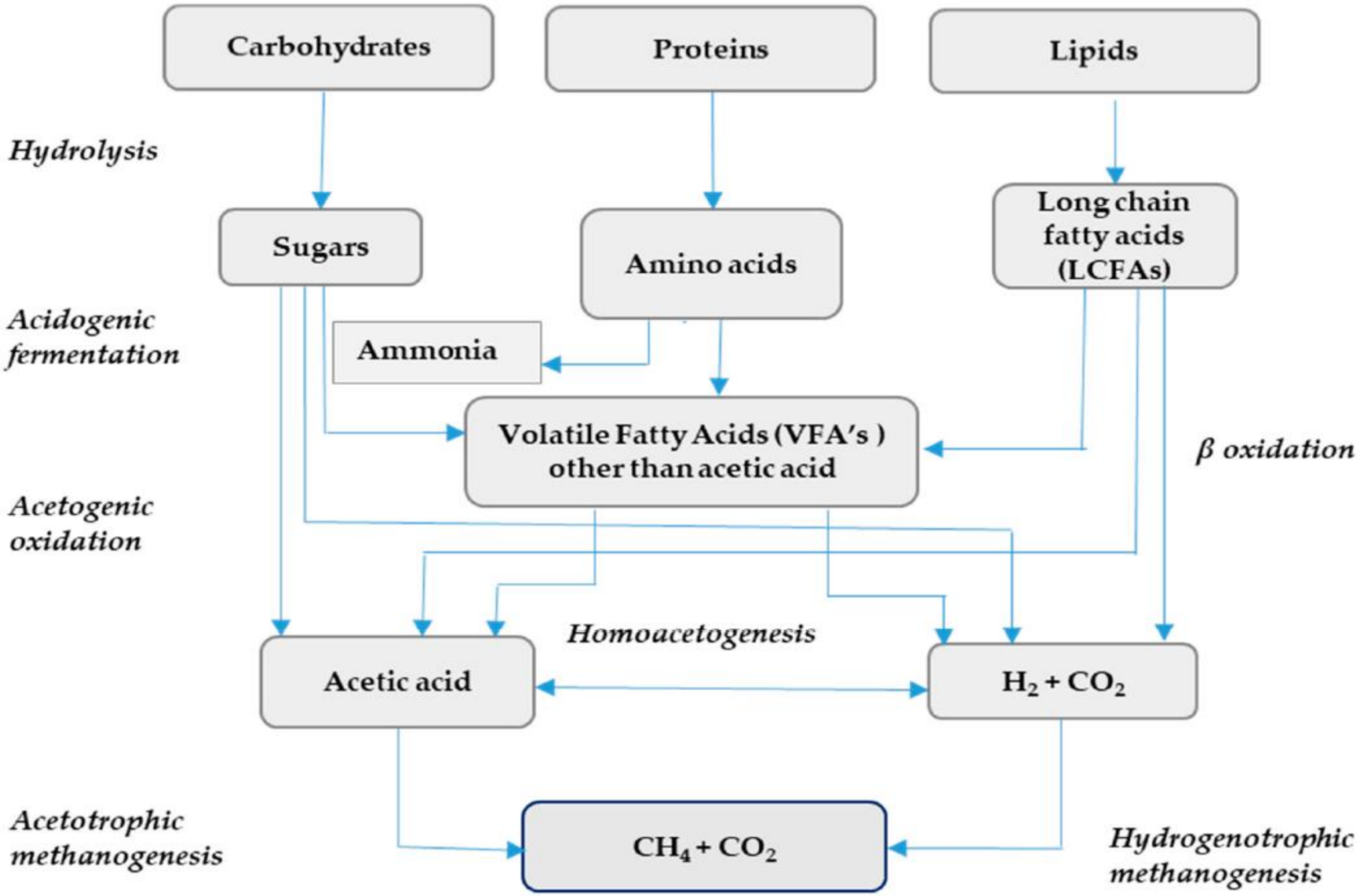
Biogas Plant (Anaerobic Digestion)



Biogas plant

Source: Adapted from (https://hi-static.z-dn.net/files/dcc/2f6c6c4452ab8c9af905fb330e98a702.jpg)

Pathways of anaerobic digestion for biomethane production



Source: https://doi.org/10.3390/en12061106

Various types of biomass resources amenable to biogas production

According to the taxonomic rank (Latin regnum)

- **Vegetal** (plantae)
- **Animal** (animalia)

According to the sector generating

- **Agricultural**: animal manures and slurries, vegetable by-products and residues, energy crops.
- **Industrial**: organic wastes, by-products and residues from agroindustry's, food industries, fodder and brewery industries, organic-loaded wastewaters and sludges from industrial processes, organic by-products from biofuel production and biorefineries, etc.
- **Municipal**: source-separated household waste, sewage sludge, municipal solid waste and food residues
- **Aquatic Biomass**: microorganisms (planktonic), macroalgae and fish.

Feedstocks in SAARC member states

SAARC member	Feedstock type	Biogas production
India	Agro waste and residues	45.8 Mm^3 daily and 278.71 Mt/annum biogas generation potential
	Livestock waste	12 million dung fed house-hold biogas units (with 3448Mm^3 biogas generation potential) - working since 2010, 17,850 Mm^3 biogas, can be produced only by the dung
	Solid waste	9.23 Mm^3/day biogas production at a rate of 95 m^3/t
	Wastewater sludge	15,392 million L/day
	Industrial waste	34,627,395 m^3 waste per annum produced, biogas production potential - distillery, 87,366,094 m^3 per day dairy units, 219,409 m^3 per day poultry farms, 438,227 m^3 per day black liquor, 412,278 m^3 per day slaughter-house, 494,225 m^3 per day

Feedstocks in SAARC member states (continued)

SAARC member	Feedstock type	Biogas production
Pakistan	Livestock	Chief producer of biogas in Pakistan, 2012–2013 Pakistan harbors 172.2 million livestock that produced 652 million kg dung per day
	Metropolitan waste	Karachi bioenergy potential is 72 million m^3 and Lahore is 64 million m^3, 242 Mm^3 biogas from solid waste to reduce the energy shortfall
Nepal	Livestock waste	Biogas technology been recognized as "Gobar Gas" since 1955
Bangladesh	Crop/forest residues, livestock waste, solid waste	500 Mm^3 per annum of biogas generated by using animal dung as feedstock
Bhutan	Fuel wood, crop residues, animal manure, municipal solid waste	Crop residue generation is 390,000 tons per annum or 5,750,000 GJ per annum, which constitutes 21.1%, while MSW and animal dung share only 2% of total biomass energy potential in Bhutan

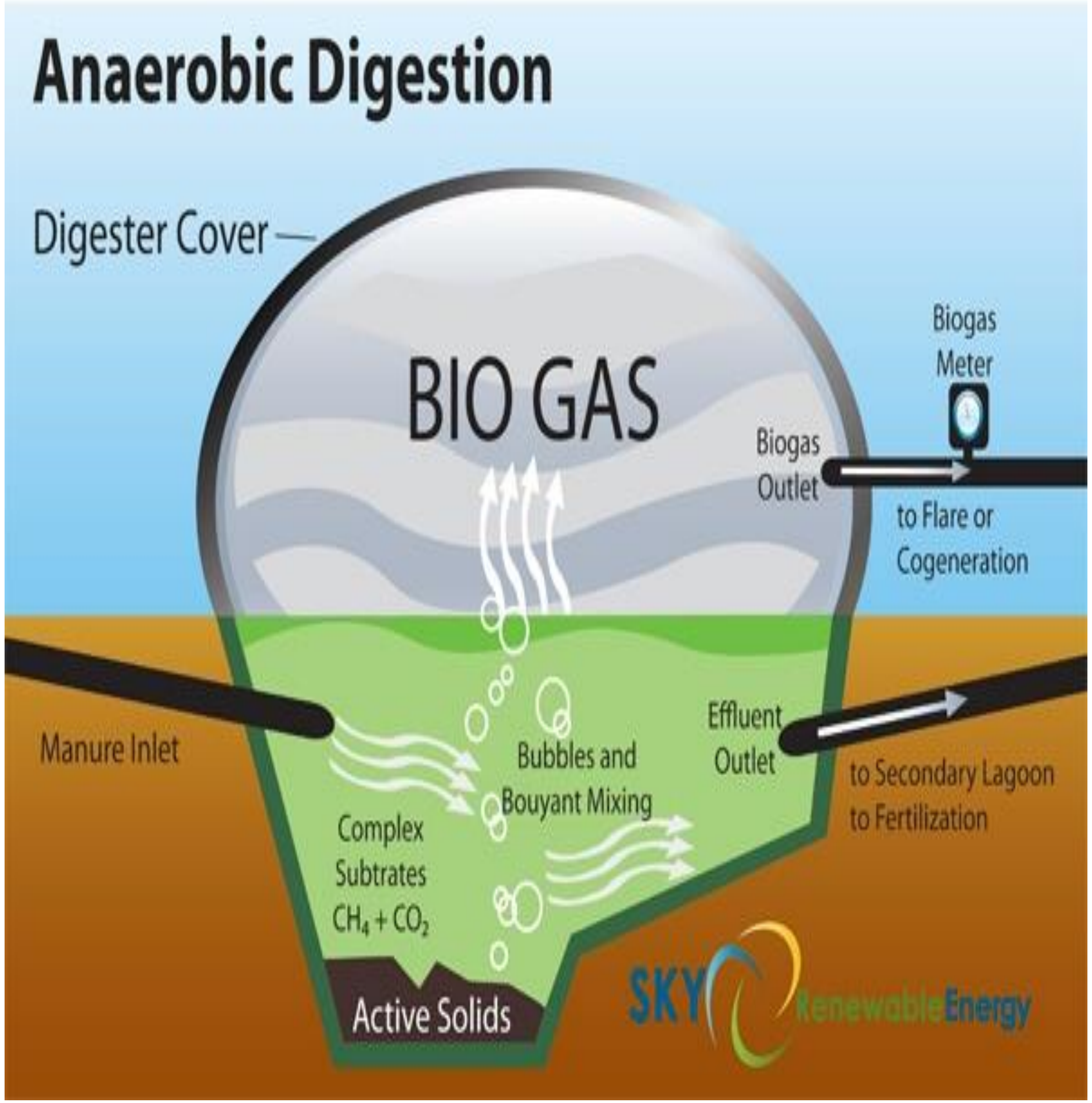
Animal manure and slurries

- According to the Food and Agriculture Organization of the United Nations (FAO), the animal agriculture sector, is responsible for **18%** of all Green House Gas (**GHG**) emissions, measured in carbon-dioxide equivalent.
- Most of these GHG emissions originate from the **13 billion tons** of animal manure and slurries estimated to be produced annually around the world.
- In fact, the US farm animal sector annually accounts for:
  - **9%** of human-induced emissions of carbon dioxide (**CO_2**).
  - **37%** of emissions of methane (**CH_4**), which has more than **20 times** the global warming potential (**GWP**) of CO_2 and
  - **65%** of emissions of nitrous oxide (**N_2O**), which has nearly **300 times** the **GWP of CO_2**.

Source: https://www.humanesociety.org/sites/default/files/archive/assets/pdfs/farm/hsus-fact-sheet-greenhouse-gas-emissions-from-animal-agriculture.pdf

Anaerobic digestion: a unique treatment solution for animal manure

- **Benefits**: renewable energy, avoidance of water pollution, and air emissions.
- **Anaerobic digestion** upgrades animal manure and slurries from environmentally polluting wastes to **valuable resources** used for the simultaneous production of **biogas** (as renewable fuel) and **digestate** (as valuable biofertilizer).
- Manures and slurries from a variety of animals can be used as feedstocks for biogas production (pigs, cattle, poultry, horses, mink and many others).



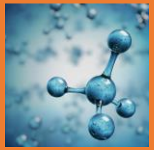
Source: https://greenerideal.com/news/energy/0124-anaerobic-digestion-turns-dung-into-renewable-energy/

Characteristics of Animal Manure biogas feedstocks

Type of feedstock	Organic content	C:N ratio	Dry matter (DM) (%)	Volatile solids (% of DM)	Volatile solids (%)	Methane Yield (m^3 CH_4/ kg VS)	Methane production (m^3 CH_4/m^3)
Animal wastes and by-products Pig slurry	Carbohydrates, Proteins, and Lipids	7	5	80.0	4.0	0.3	12.0
Pig manure, solid		-	20	80.0	16.0	0.3	48.0
Cattle slurry		13	8	80.0	6.4	0.2	12.8
Cattle manure, solid		-	20	80.0	16.0	0.2	32.0
Poultry droppings		7	5	80.0	4.0	0.3	12.6
Poultry manure, solid		-	20	80.0	16.0	0.3	48.0
Stomach/intestine content, cattle		4	12	80.0	9.6	0.4	38.4
Stomach/intestinal content, pig		4	12	80.0	9.6	0.46	44.2

Source: https://www.sciencedirect.com/book/9780857094988/the-biogas-handbook

Limitations: Anaerobic Digestion of Animal Manure



Low methane yield per unit volume of digested feedstock (10-20 m^3 CH_4/m^3) due to low dry matter content of cattle slurries.

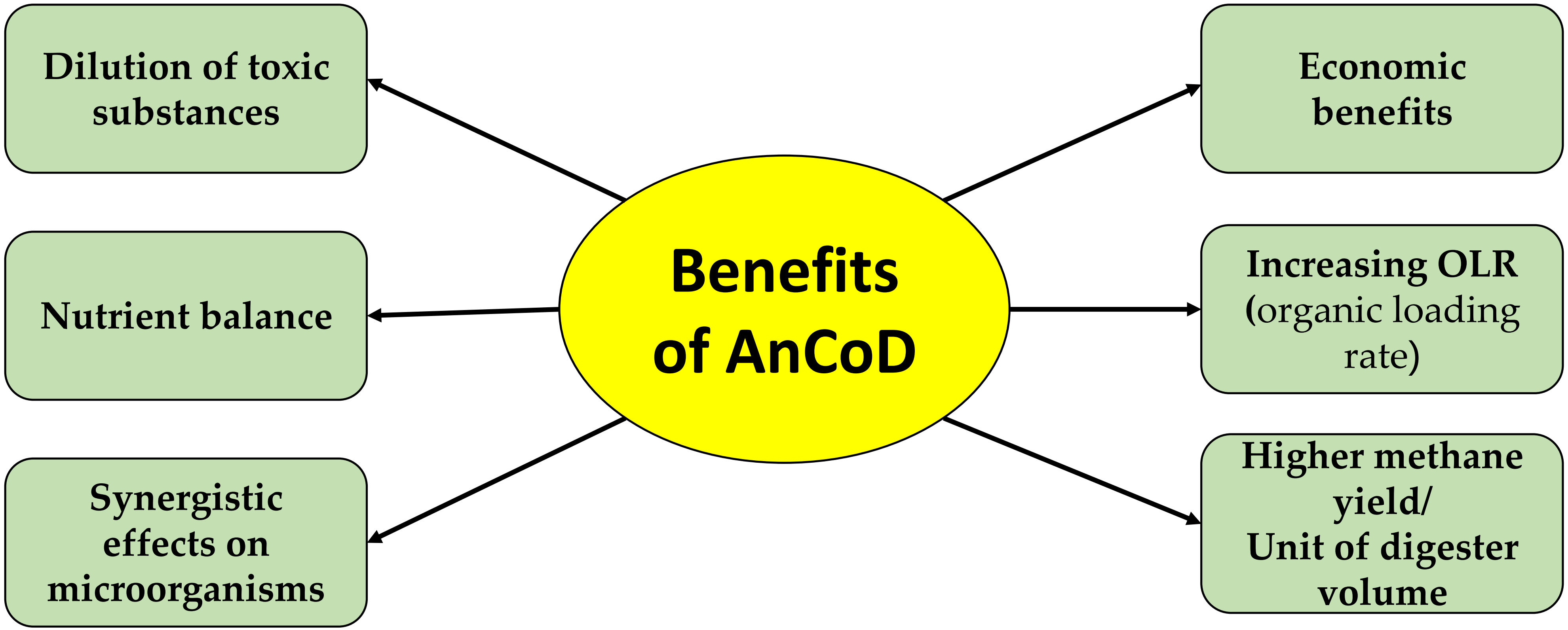
Biomass transport costs are high.

Slurries and manures both have high content of lignocelluloses, which do not participate in the digestion process for biogas production.

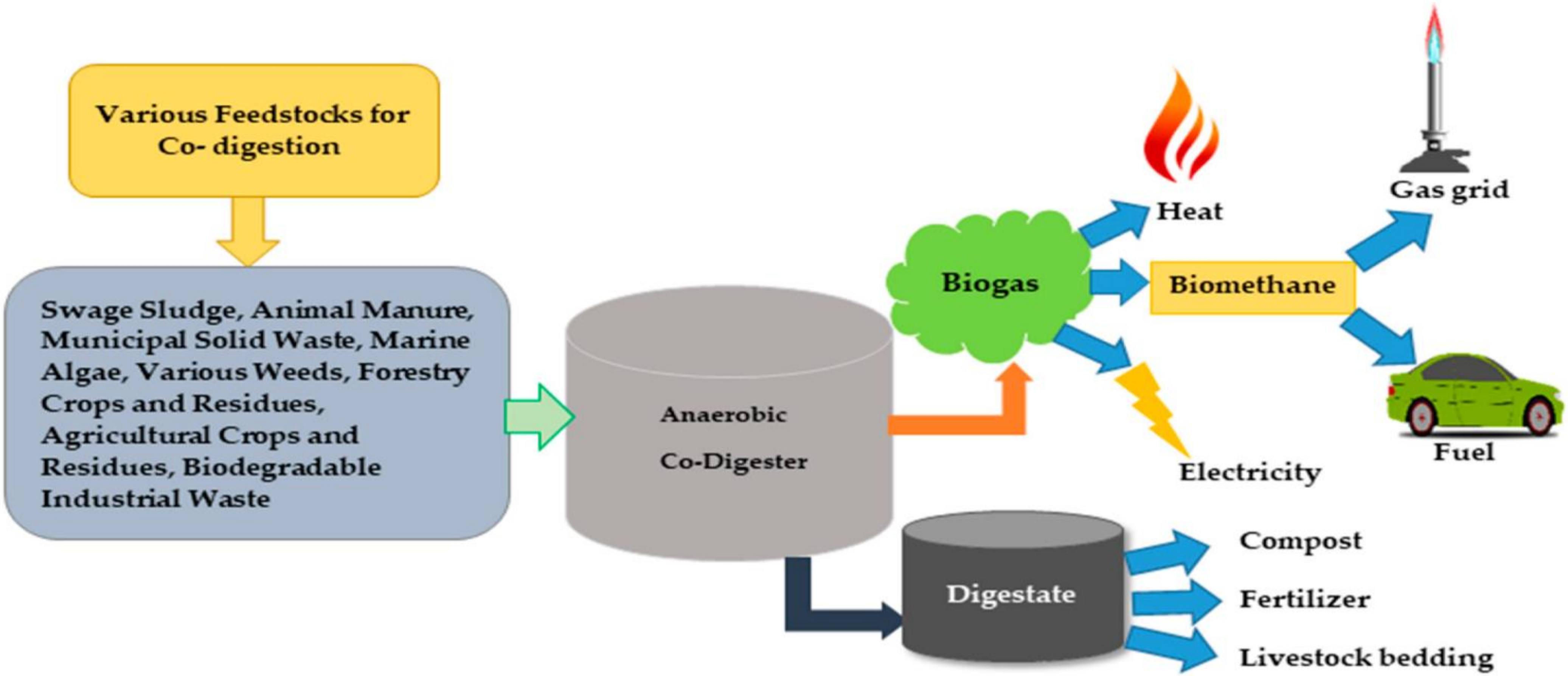
Low methane output of manure does not allow economic sustainability in mono-digestion.

Anaerobic Co-Digestion (AnCoD)

AnCoD involves a simultaneous digestion of two or more substrates. It has capability to alleviate flaws emerging in mono-digestion.



Co-digestion of multi feedstocks for waste reduction and energy recovery

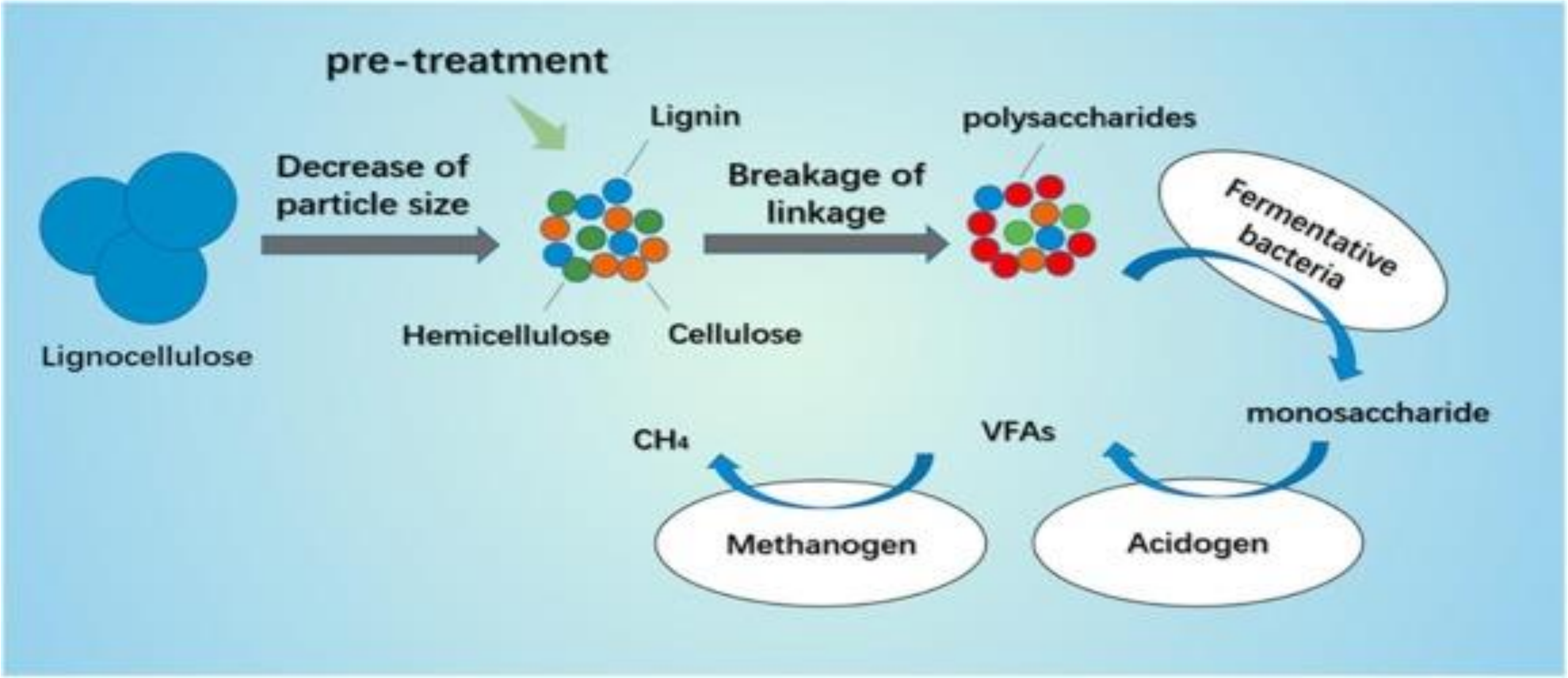


Source: https://doi.org/10.3390/en12061106

Plant (crop) residues

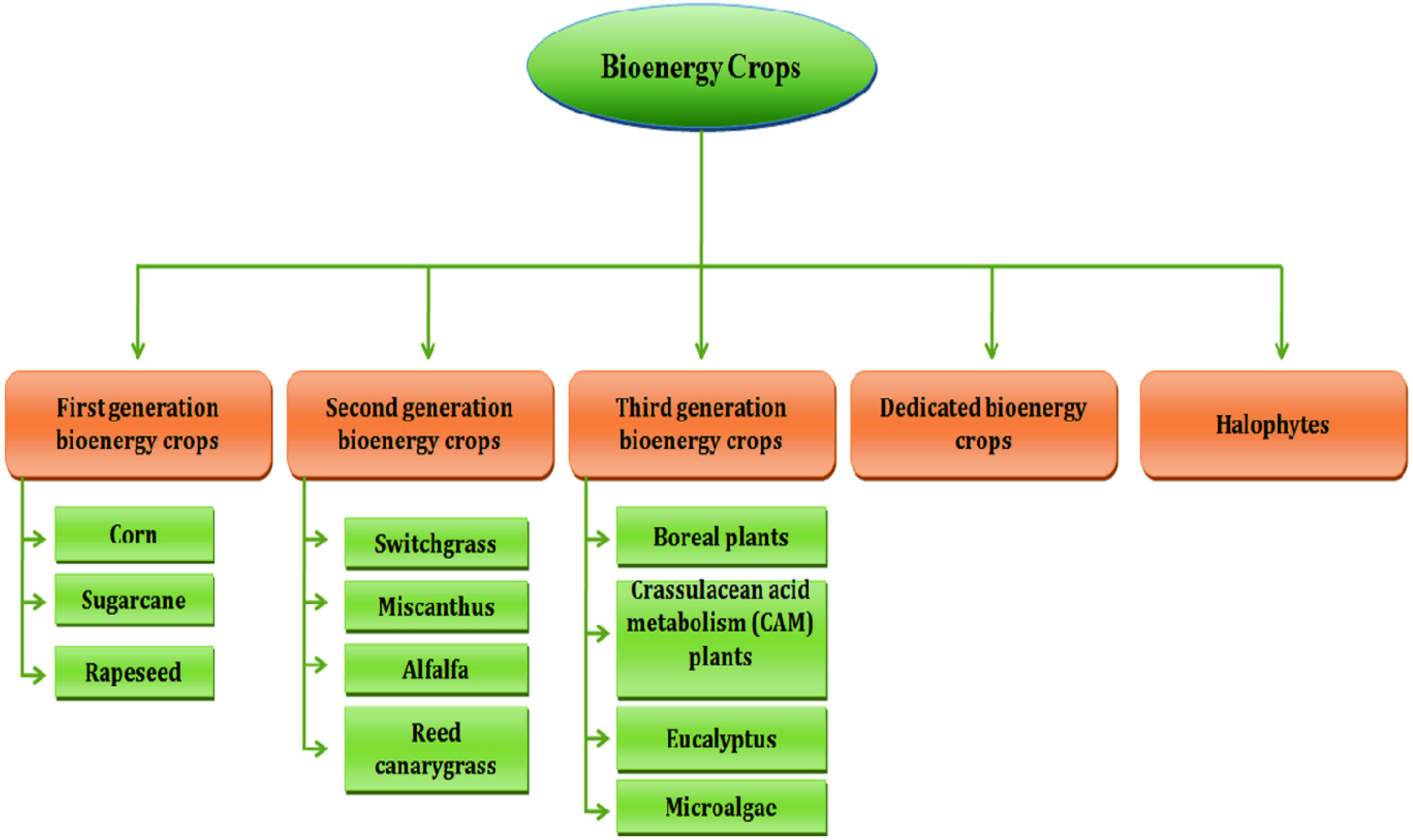
- It includes various vegetable agricultural byproducts and harvest residues, plants and plant parts, low-quality or spoiled crops, fruits and vegetables, and spoiled feed silage.
- Plant residues are usually digested as co-substrates with animal manures and other feedstock types. They need to be pre-treated before feeding into a digester.
- A particle size of 1 cm allows proper handling and mixing with other feedstock types and ensures good digestion.

Schematic diagram of pre-treatment enhancing methane production from lignocellulosic wastes



Source: https://doi.org/10.1016/j.apenergy.2019.01.243

Energy Crops



- Energy crops are low-cost and low-maintenance crops grown solely for energy production.
- The use of energy crops as a feedstock for biogas implies some specific technologic steps prior to digestion: **harvesting, pre-processing and storage/ensiling**.
- **Herbaceous energy crops** like grass, sunflowers, maize and sugar beet are normally used fresh or as silage.
- **Maize** is the most frequently used energy crop in the majority of existing biogas plants.
- **Beet crops** are excellent biogas feedstock and also have a good uptake of nutrients until late fall, reducing in this way the risk of nutrient losses to groundwater.

Source: https://link.springer.com/chapter/10.1007/978-3-030-14463-0_12

Methane yields of some common energy crops (plants and plant parts)

Energy crop	Methane yield (m^3/Volatile solids)	Energy crop	Methane yield (m^3/Volatile solids)
Maize (whole crop)	205–450	Fodder beet	420–500
Grass	298–467	Barley	353–658
Clover grass	290–390	Triticale	337–555
Hemp	355–409	Alfalfa	340–500
Sunflower	154–400	Ryegrass	390–410
Oilseed rape	240–340	Nettle	120–420
Potatoes	275–400	Straw	242–324
Sugar beet	236–381	Leaves	417–453

Source: https://www.sciencedirect.com/book/9780857094988/the-biogas-handbook

Limitations of Energy Crops as Biogas feedstock

•Composition of crops and thus their suitability as AD feedstock varies with the stage of maturity

Cellulosic content increases with maturity, negatively affecting the methane yield of the crop.

The cultivation of energy crops requires a high input of fertilizers, pesticides and energy for harvesting and transport.

The cultivation of energy crops create the conflict of food Vs fuel chaos.

Industrial biogas feedstock

- Industrial activities that process agricultural raw materials produce significant quantities of by-products, residues, and waste.
- These industries include food and beverage, fodder, fish processing, milk, starch, sugar, pharmaceuticals, biochemicals and cosmetics, pulp and paper, as well as slaughterhouses.
- Wastes from these industries are diverse and have various methane potentials, dry matter contents, structures and compositions, according to their origin.
- The majority of them are homogenous, easily digested, and rich in lipids, proteins, and sugars.
- Industrial wastes are used as "methane boosters“ due to their extremely high methane potential.

Industrial Organic Wastes and Anaerobic Digestion (AD)

- Industrial organic wastes can be treated by AD as additional feedstocks in smaller decentralized biogas plants, large co-digesting plants or at industrial production locations.
- Co-digestion of animal manure with organic wastes results in increased process stability, due to less sensitivity to inhibitors like ammonia and sulfide.
- Co-digestion of industrial wastes have a positive effect on the economic sustainability of a biogas plant through higher methane yields, improved process stability and supplementary income paid by industries to the biogas plant.

Anaerobic digestion (AD) of by-products from biorefineries and the biofuels industry

- Biofuel production and current biorefineries are projected to accumulate huge volumes of organic by-products in the future, nearly all of which are ideal for AD.
- In grain-processing bio-ethanol plants, all silage fractions are typically anaerobically degradable
- In sugar cane bio-ethanol plants, the cane juice silage is also a suitable substrate for AD whereas the bagasse is mainly incinerated for energy recovery.
- In biodiesel production, the glycerol as well as the wastewaters are suitable substrates for AD, while the residual cake after oil extraction is often used as animal feed.

As the biofuels and biorefinery industries expand in prominence, there will be a greater opportunity for industrial AD processes to be integrated.

Source-separated organic waste: Municipal waste biogas feedstock

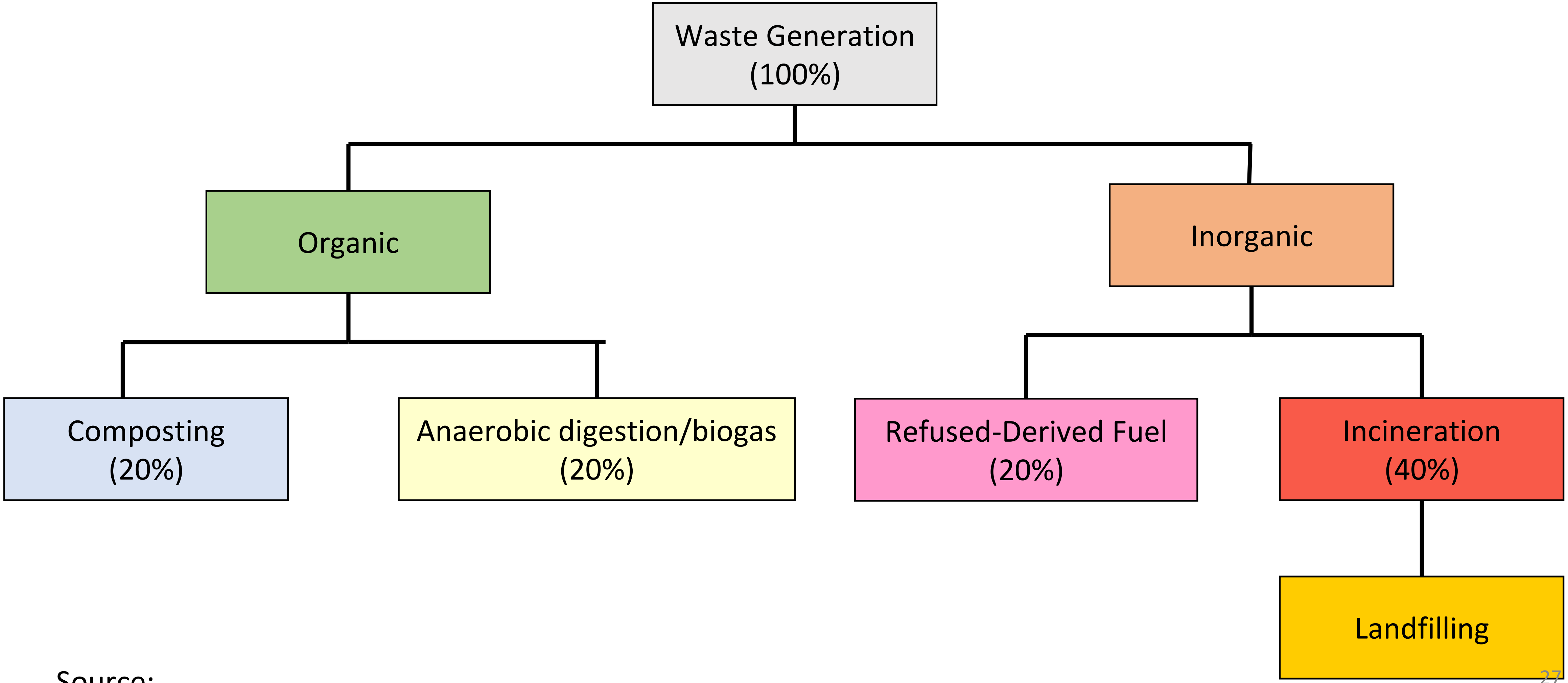
Source-separated organic waste refers to the organic fraction of household waste such as food waste, garden waste and other similar organic wastes, separately collected.

Separate collection is a solution that is capable of providing clean and high-quality materials for use as AD feedstock, reducing the stream of organic materials going to landfills and incineration.

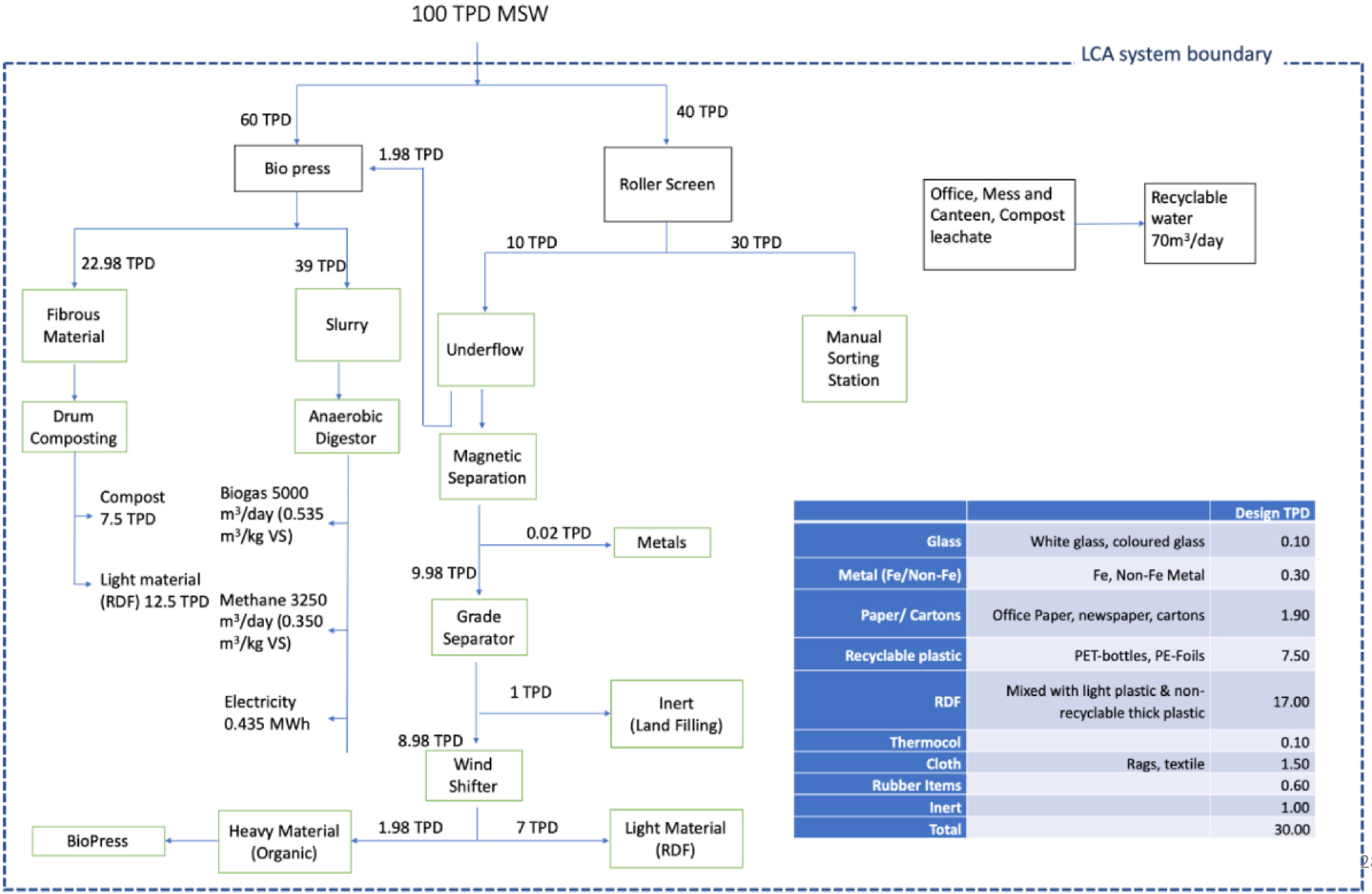
Separately collected organic household wastes are often co-digested with animal manure and slurries in manure-based AD plants.

Organic household wastes have a high biodegradability and methane yield. Their nutrient content is well balanced and favorable for the metabolism of anaerobic microorganisms.

A framework of MSW for integrated solid waste management

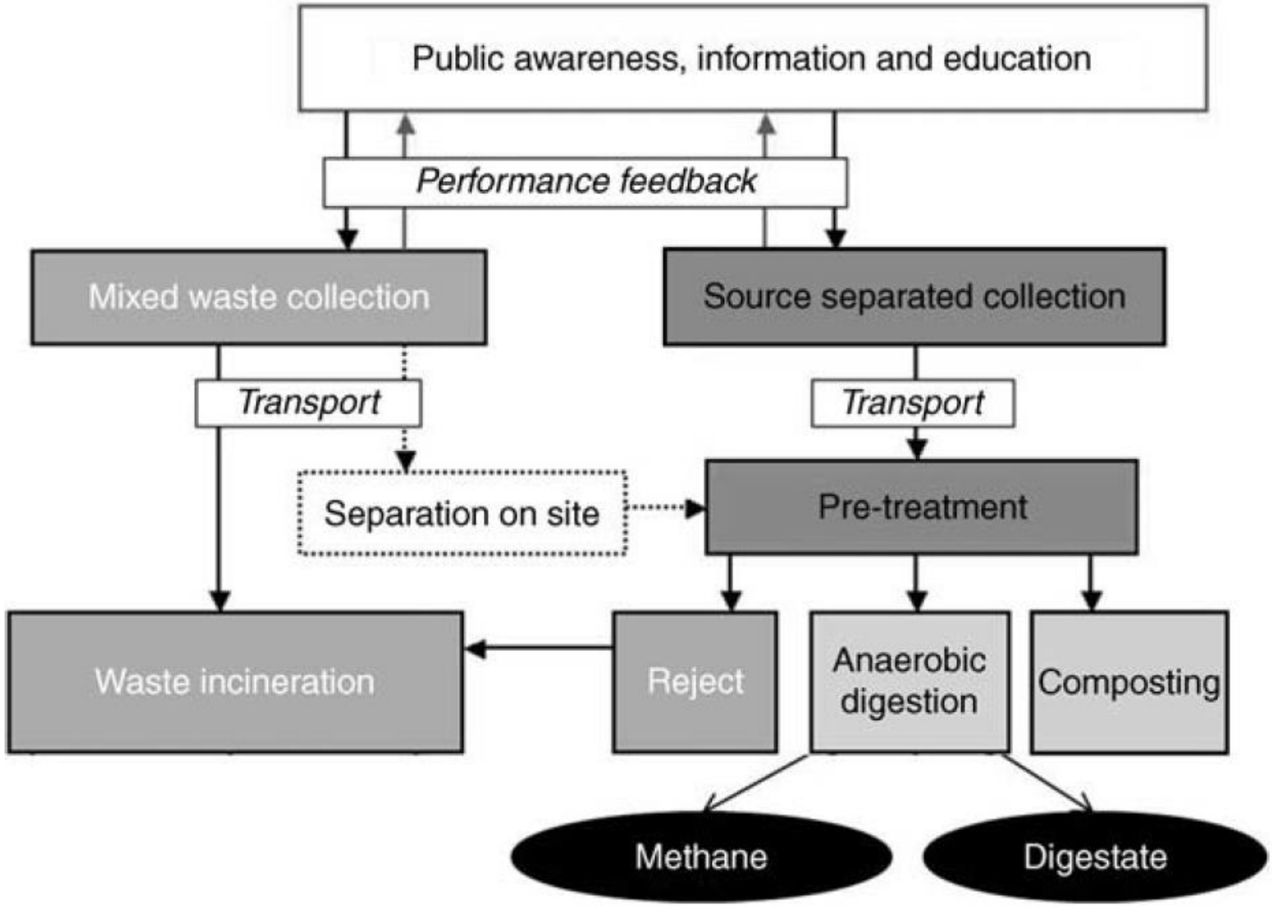


Source:
http://cpheeo.gov.in/upload/uploadfiles/files/Part2.pdf



		Design TPD
Glass	White glass, coloured glass	0.10
Metal (Fe/Non-Fe)	Fe, Non-Fe Metal	0.30
Paper/ Cartons	Office Paper, newspaper, cartons	1.90
Recyclable plastic	PET-bottles, PE-Foils	7.50
RDF	Mixed with light plastic & non-recyclable thick plastic	17.00
Thermocol		0.10
Cloth	Rags, textile	1.50
Rubber Items		0.60
Inert		1.00
Total		30.00

Separate collection of digestible organic wastes is integrated in overall waste management



Source: Wellinger, A., Murphy, J. D., & Baxter, D. (Eds.). (2013). The biogas handbook: science, production and applications. Elsevier.

Limitation of organic household waste as biogas feedstocks

- **Separate collection** of organic household waste as feedstock for AD is not cost effective.

- **Purity** is another limiting factor in the utilization of source-separated organic waste as a feedstock for biogas production.

- The **content of foreign materials** is heavily influenced by the human aspect, such as the population's awareness and willingness to participate in collection systems.

- Organic household wastes can **contain large levels of disruptive substances** such as metal, glass, plastic, and sand, even if purities of more than 90% are obtained.

Anaerobic digestion: sewage sludge

- Sewage sludge has a methane potential similar to animal slurries (primary sludge has a higher methane potential than waste-activated sludge).
- Various pre-treatments can be applied to increase methane yield. (e.g., mechanical disintegration, chemical hydrolyses, thermal hydrolyses and enzymatic degradation).
- Sewage sludge is often co-digested with manure or/and organic wastes from industries and households, which improves the biogas yield and the process stability.
- The limiting factor for the use of sewage sludge as biogas feedstock is the high content of pollutants and the risks related to their subsequent presence in digestate used as fertilizer.

Aquatic Biomass

- They have the potential to provide alternatives to rapidly depleting oil supplies, as well as remedies for greenhouse gas emissions reduction and carbon sequestration.
- Aquatic biomasses are feasible for wastewater remediation and generate high biomass yields.
- Two groups are of interest for the biogas sector: Macroalgae and Microalgae.
- Macroalgae are rich in natural sugars and other carbohydrates, whereas Microalgae have high photosynthetic efficiency and are rich in lipids, which are known for their high biomass yields.

Suitability of biomass as biogas feedstock

- Suitability of any biomass is dependent methane potential, particle size, dry matter content, pH, C:N ratio, the content of macro- and microelements, etc.
- Most AD processes run optimally at neutral pH (around 7), and a **C:N** ratio of the substrate mixture between **20:1 and 30:1**.
- Thermophilic AD (**55–70 °C**) has a rate-advantage over mesophilic digestion (**37 °C**) as a result of its faster reaction rates and higher-load bearing capacity and, consequently, exhibits higher productivity compared with mesophilic AD.
- An average retention time of **15–30 days** is required to treat waste under mesophilic conditions.
- The anaerobic microorganisms inside the digester need to be supplied with **some basic ingredients’** necessary for their metabolism to **increase the yield**.

Effect of Digestibility on Anaerobic Digestion

The digestibility of material depends on its content of easily digestible compounds like simple sugars.

Biogas feedstock can also contain various amounts of low digestible compounds, known as recalcitrant matter, such as lingo-celluloses.

Low molecular weight carbohydrates, volatile fatty acids and alcohols are digested in hours; proteins, hemicelluloses and lipids in days, while cellulose needs several weeks to be decomposed in anaerobic conditions.

Feedstock substrates consisting of fats and oils, known for their very high methane yields, require longer retention times and larger digester volumes.

Impurities with disturbing effects on Anaerobic digestion

- Once unwanted components enter the digester with supplied feedstock, their presence can cause perturbations of the normal operation.
- Common problems caused by unwanted components are reduction of the active volume of the digester process failure through foaming, phase separation and floating layers, or even damage to machinery such as pumps.
- The most common disturbing material is sand, often supplied with animal manure, straw and wood particles.
- It's challenging to manage the distracting effects caused by undesired components.

Effects of inhibitors on Anaerobic digestion

- Some compounds available in the feedstock may have a negative effect on the microbiology inside the digester and reduce the biogas yield are called as inhibitors.
- For example, an increased amount of volatile fatty acids (VFA) can cause process imbalance if their concentration inside the digester exceeds the pH buffer capacity of the AD process, reaching so-called shock-levels.
- High concentrations of end products such as free ammonia can also have inhibitory effects through accumulation inside the digester.

Feedstock as methane yield boosters

- Frequently used methane boosters are fatty materials such as fish oil from fish processing industries, soya bean oil and margarine from the food industry and various alcohol residues from brewing industries.

- Residues from the sugar and beverage industries and glycerin from biodiesel production are also used to enhance methane yields of the substrate mixture.

- The press cakes remaining after pressing juice or oil from grapes, olives, apples and other fruits are also a good and homogeneous biogas feedstock and can be used as methane boosters.

Feedstock influence on plant operation

- The composition and characteristics of the feedstock is vital in determining the size of the digester and the investment cost of the plant, as longer retention times require a larger digester volume.

- The feedstock also determines the quality and quantity of biogas and digestate produced, and therefore has a direct impact on the overall economy of the biogas plant.

- The feedstock supplied determines the main objective of the AD treatment:

  - for source-separated household waste, the primary aim is sustainable waste management, waste reduction and recycling of organic matter.
  - In the case of energy crops, the main aim of AD is production of renewable methane.

Feedstock description and declaration

Each type and load of feedstock supplied to a biogas plant should be accompanied by documentation containing a detailed description of the material, provided by the feedstock producer. The following basic information must be included as a minimum.

1. Origin. The name and address of the feedstock producer and supply company where these are not one and the same, which process the waste
2. originates from and the raw materials or original processed materials used in the process.
3. For household waste, the area from where waste was collected, whether or not it is source-separated and type of collection containers used (plastic bags, paper bags, bins, other).
4. Methane potential.
5. Chemical composition (pH, dry matter, organic dry matter, macro- and microelements).
6. Contamination (chemical and biological).
7. Description (color, texture, consistency, smell, etc.).
8. Potential hazards related to handling, storage or recycling as fertilizer.
9. Particle size.
10. Availability (amount and length of time material of the same quality is available).

Resource availability and supply chain issues

- The use of the existing biomass potential for biogas production is generally limited by natural and human-made causes as well as by the annual natural biomass regrowth.
- In the case of wastes such as municipal solid wastes (MSW), agricultural wastes, food wastes or industrial wastes, availability is limited by the quality and purity of the waste.
- The main challenge is to introduce sustainable waste collection and separation systems which would increase the availability of organic wastes for AD.
- Due to the generally lower energy content and diluted nature of farm wastes, there are economic limitations with respect to sustainable biomass transportation distances.
- The main limitation of energy crops specifically grown for biogas production is related to lower sustainability than biogas from residues and to land use issues related to competition with food production.

Organizing biomass logistics

The logistics of biogas feedstock and digestate are determined by the feedstock types used in the biogas plant.

The characteristics of the feedstock and the digested effluent (digestate) related to energy content, density, state of aggregation (liquid/solid), seasonality and hygienic aspects determine the logistical concept and auxiliary components of the biogas plant such as:

a) Distance between feedstock source and biogas plant
b) Distance between biogas plant and digestate use
c) Suitability of road access
d) Transport system
e) Storage facilities for feedstock and digestate
f) Hygienic safety measures
g) Digestate application on the fields

Influence of biomass logistics on location of the biogas plant

The choice of location for setting up a biogas plant is determined by the feedstock logistics, road access and the availability of feedstock. Other general aspects that should be considered include:

1) The size and ownership of the property
2) Classification of the property in official spatial plans
3) Legal aspects, including the required permits
4) Dedicated characteristics of the site
5) Access to necessary infrastructure
6) Opportunities to sell the heat
7) Vicinity to neighbors
8) Competition with other biogas plant operators and farmers

Conclusions

- ✔ A large variety of biomass types and categories suitable as feedstocks for the production of biogas using Anaerobic Digestion (AD).
- ✔ Each feedstock material has benefits and limitations, influencing suitability, local availability as well as overall biomass logistics and biogas plant location.
- ✔ Aquatic biomass may prove to have potential as a valuable energy feedstock, including for biogas.
- ✔ The limited agricultural area and the price fluctuations of energy crops will increase the need for research into modern agricultural systems with high productivity and improved sustainability.
- ✔ In the industrial sector, the utilization of AD technologies for energy recovery from by-products and wastes will increase in the future with the aim of reduced energy costs, cleaner technologies and sustainable waste management.
- ✔ In future, the development of the sector of biofuels and biorefineries will produce large amounts of by-products, for which biogas technologies are valuable options.

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