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BIODIGESTER TRAINING MODULES

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Supported by: Federal Ministry for Economic Affairs and Climate Action on the basis of a decision by the German Bundestag

IKI INTERNATIONAL CLIMATE INITIATIVE

FLOW OF THE TRAINING

MODULE 1 — BIOENERGY SYSTEMS

MODULE 2 — BIODIGESTION TECHNOLOGY

MODULE 3 — EFFECTIVE ADOPTION OF BIODIGESTERS

BIOENERGY SYSTEMS

MODULE 1 of 3

ONG JVE BENIN
JEUNES VOLONTAIRES POUR L'ENVIRONNEMENT
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BIOENERGY BASICS

Q: What is the energy transition, and why is bioenergy important?

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CLEAN ENERGY IS CRITICAL FOR DEVELOPMENT

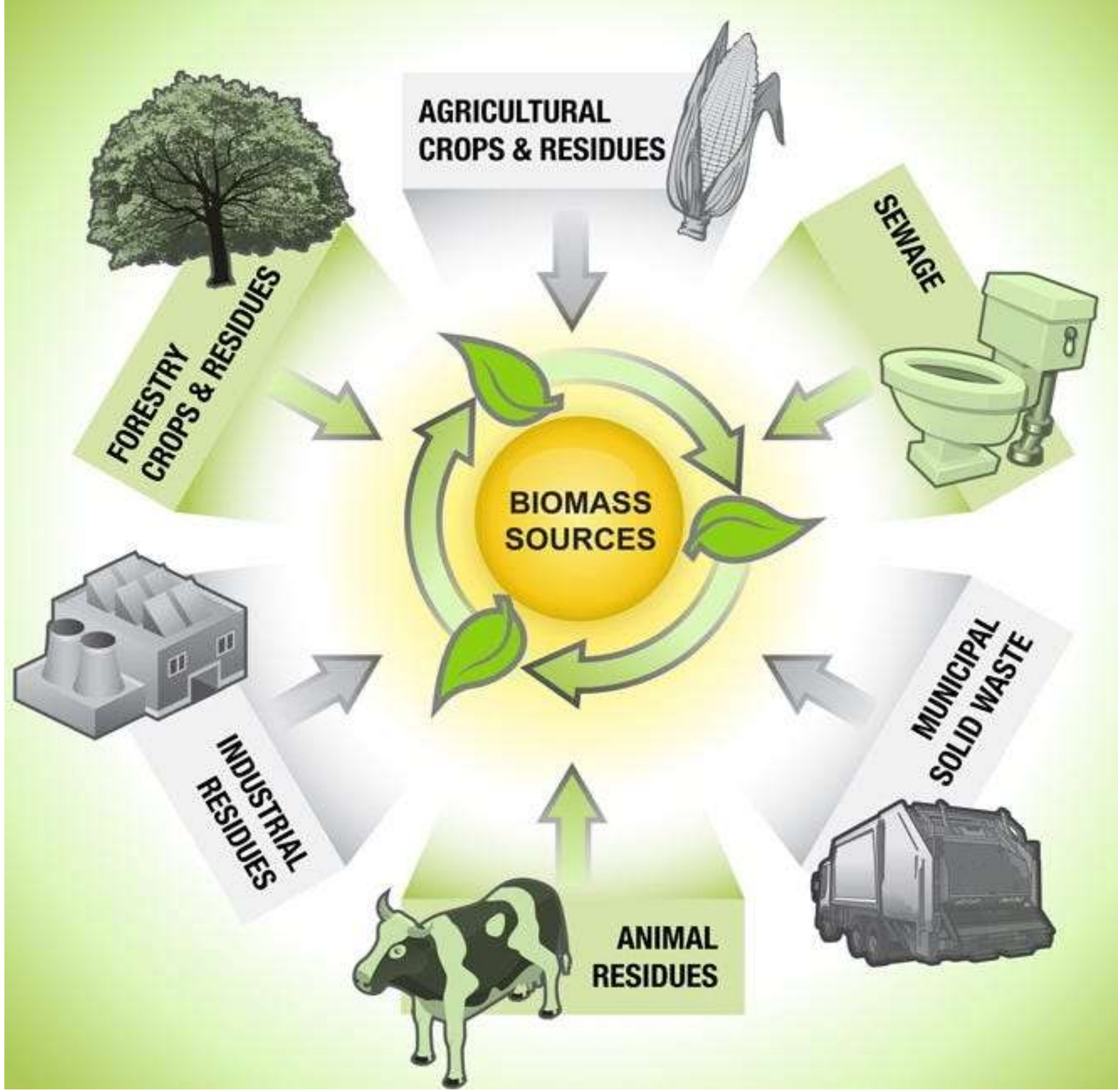
Energy is a fundamental flow for human activity, and so **energy insecurity**—a lack of access, affordability or availability—**ripples across and compounds existing crises, and makes recovery difficult.**

WHAT IS BIOENERGY?

- Bioenergy is a source of energy from the **organic** material that makes up **plants**, known as biomass, which originates from different sources such as agriculture, forests and waste
    - These include **firewood**, cattle **dung** etc.

- Biomass contains carbon absorbed by plants through photosynthesis, and through burning, releases energy (heat) that can be used to generate work and electricity.

- Traditional biomass is useful and critical, BUT it burns **inefficiently**. Processing and upgrading it can help create a more **efficient and cleaner fuel.**



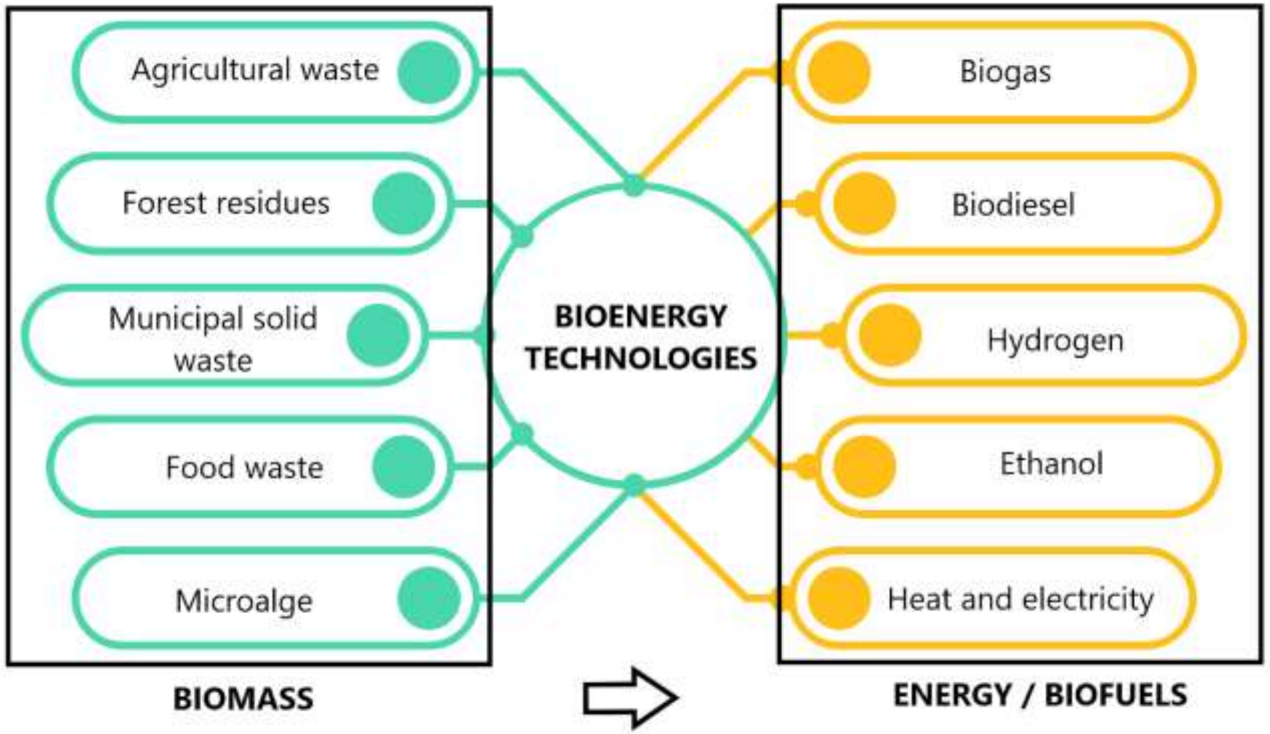
Salman Zafar (2022). https://www.bioenergyconsult.com/biomass-energy-introduction/

COMPOSITION OF BIOENERGY SYSTEMS

- Due to the significant amount of **carbon chains** in its composition, biomass can also be transformed into **liquid** and gas through various chemical and biological processes.

- These end products are known as **biofuels**.

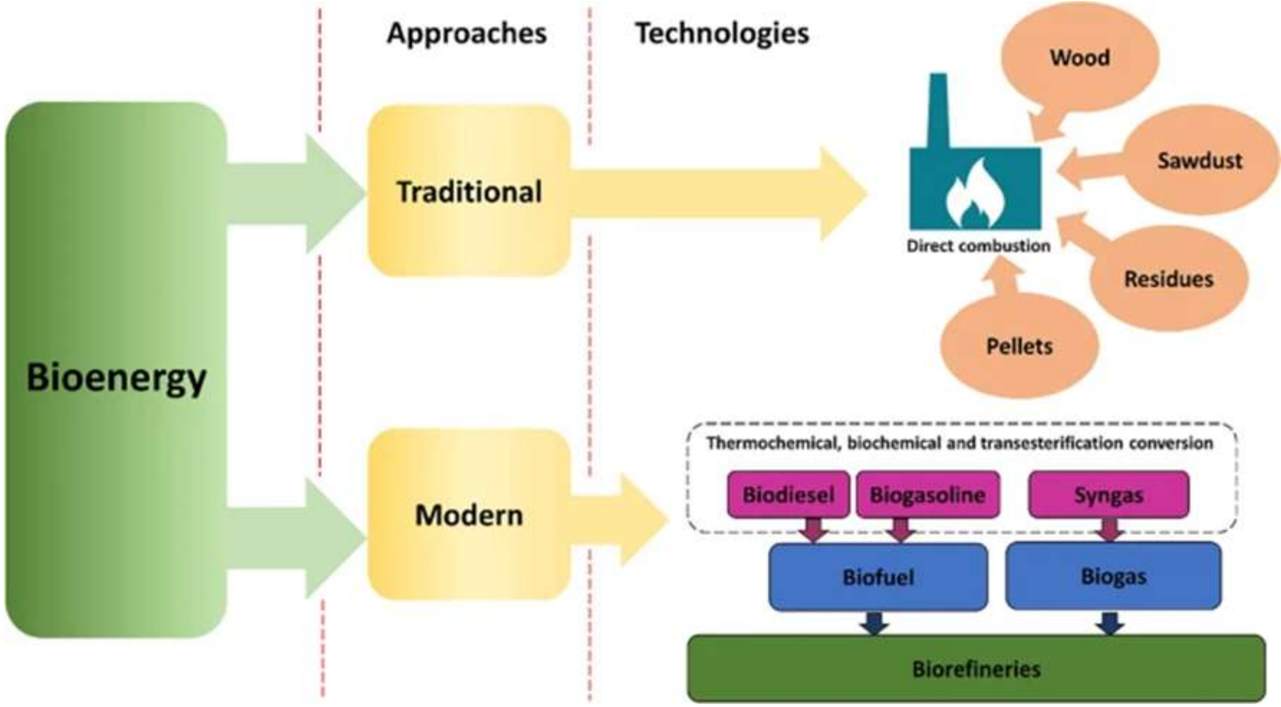
- The term bioenergy is used to cover biomass and biofuels together.

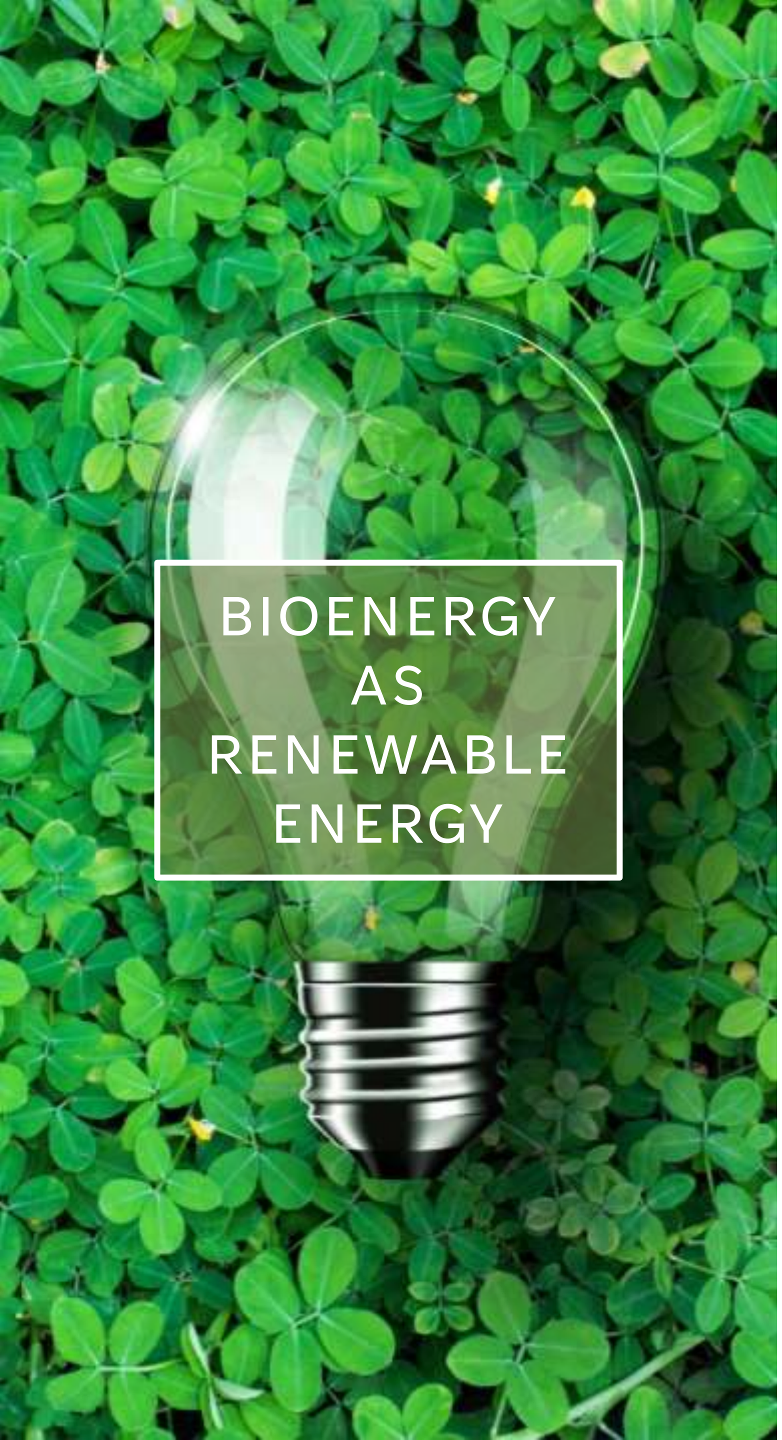


TRADITIONAL VS. MODERN BIOENERGY SYSTEMS

- Traditional bioenergy systems refer to the direct **burning** of biomass with **simple** devices. Traditional bioenergy has been used for centuries and is still prevalent.
  - But this burning is **uncontrolled**, **inefficient** and **polluting**

- Modern bioenergy refers to biomass used alongside modern heating technologies, power generation and transport fuels.
  - This encompasses the transformation of biomass to liquids or gas through special technologies and processes
  - In the transformation, the energy content is improved, and impurities are removed; it is more **efficient and cleaner**, but may require improved equipment





BIOENERGY AS RENEWABLE ENERGY

REDUCTION IN CO_2 EMISSIONS

Bioenergy sources i.e. plants/trees store CO_2; across its lifetime bioenergy emits less than fossil fuels

REPLACING FOSSIL FUELS

Certain biofuels can replace fossil fuels in power, heating and transport

RENEWABLES FOR DIRECT USE

One of the few portable forms of renewable energy as liquids or gas

REDUCTION IN CO_2 EMISSIONS

- Plants and trees i.e. bioenergy sources also function as a carbon sink by removing cumulative CO_2 from the atmosphere.

- Compared to natural forms of carbon sinks, Bioenergy Carbon Capture and Storage (BECCS) can store CO_2 for a longer time and in a stabler way if sequestered in geological formations.

REPLACING FOSSIL FUELS

- Bioenergy can meet the needs of transport and industry as fuel and feedstock.

- The potentials of bioenergy can be further harnessed through advancements in biofuel technologies to be deployed in heavy freight, shipping and aviation

- *Future trajectory: Heating of space and water for industrial and residential purposes, as well as cooking*

RENEWABLES IN DIRECT USES

- Bioenergy is expected to take over the roles currently played by fossil fuels, especially in the electricity sector, which requires dispatchable sources to balance the grid

- Mixing biofuels with fossil fuels can make full use of the existing infrastructure, while effectively reducing the emissions intensity of the same facility

- Depending on the use, improving bioenergy systems such as cook stoves, boilers or combustors, enhances their generation potential and energy efficiency

BIOENERGY TECHNOLOGIES

Q: How can modern bioenergy be harnessed?

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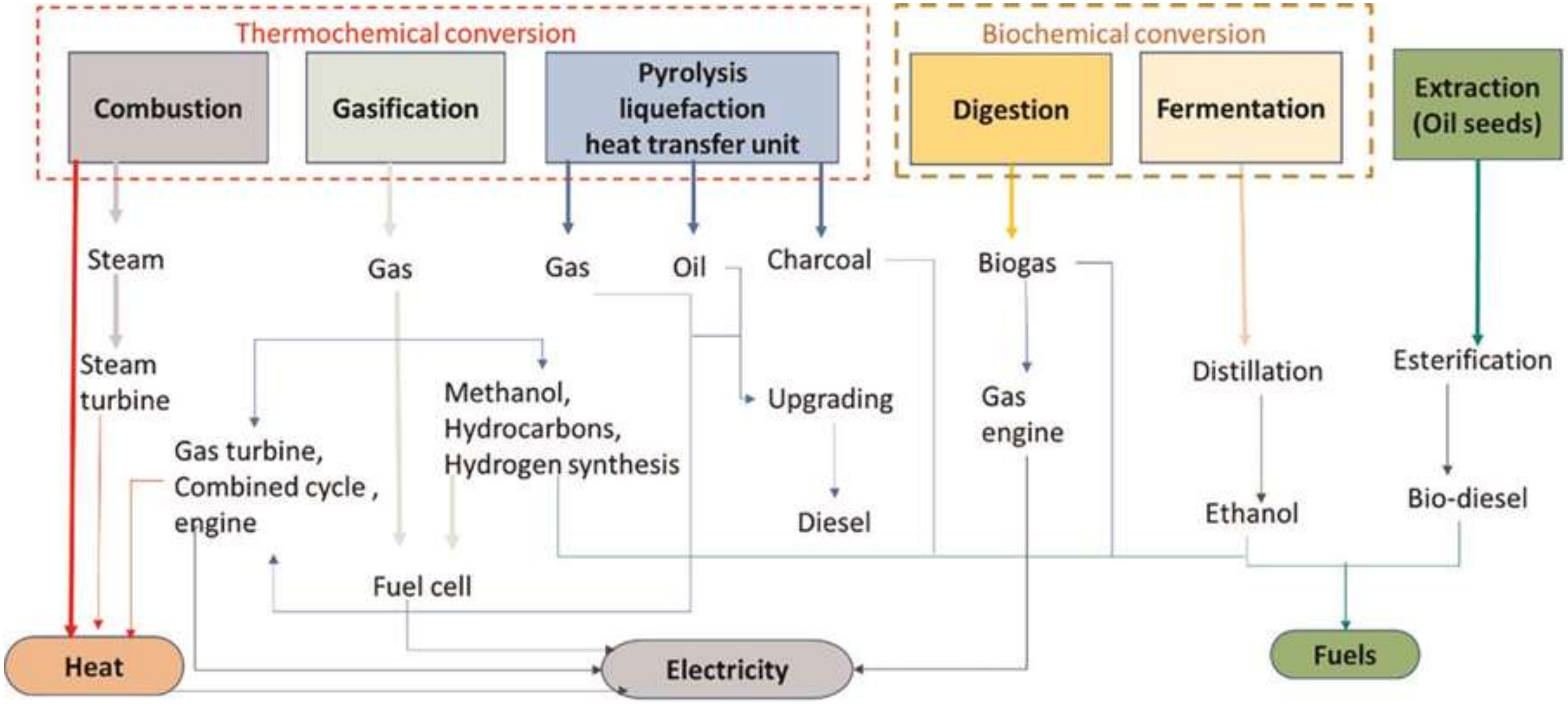
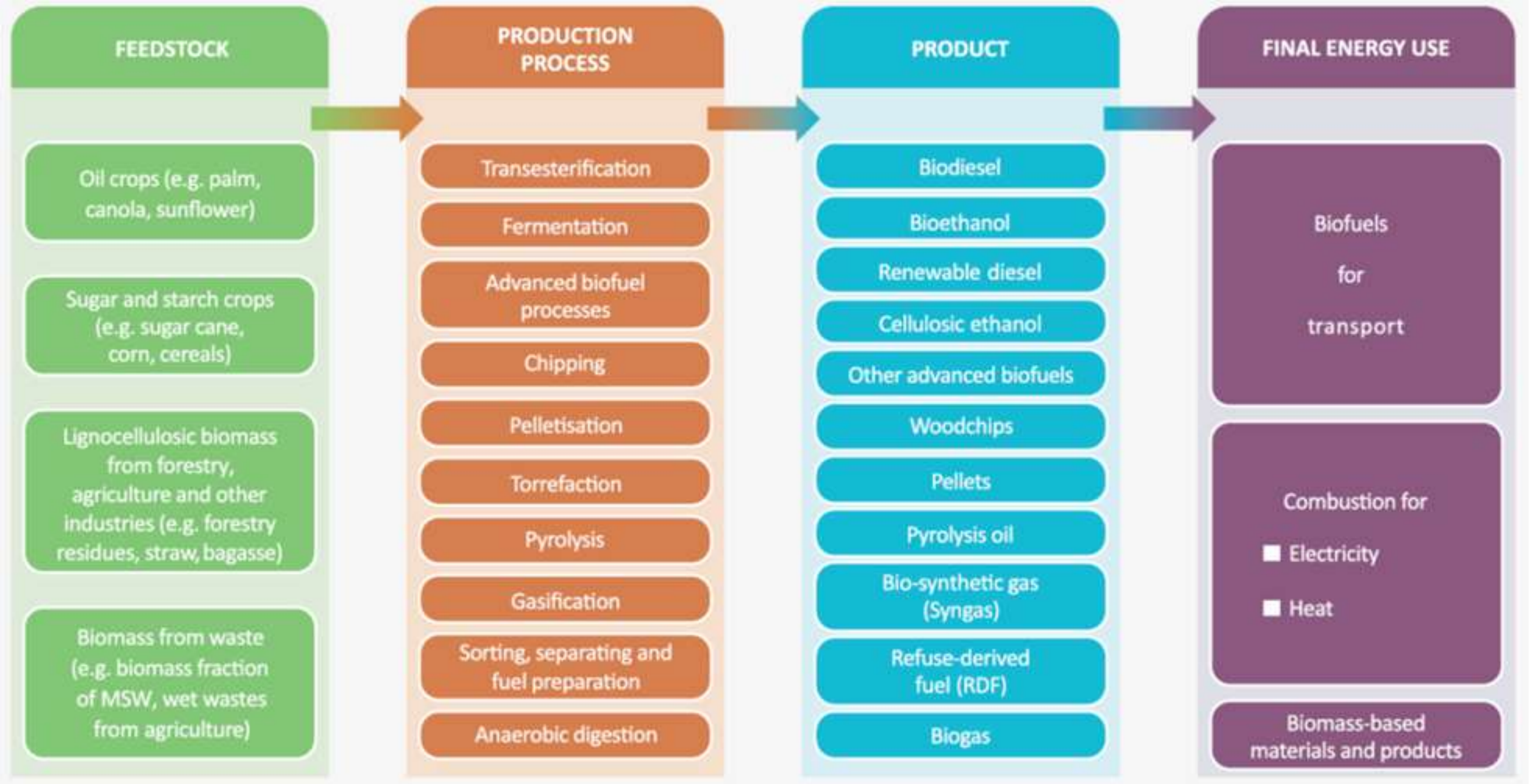
PATHWAYS FOR BIOMASS CONVERSION TO FINISHED PRODUCTS



Source: https://www.intechopen.com/chapters/80728

PATHWAYS FOR BIOMASS CONVERSION TO FINISHED PRODUCTS



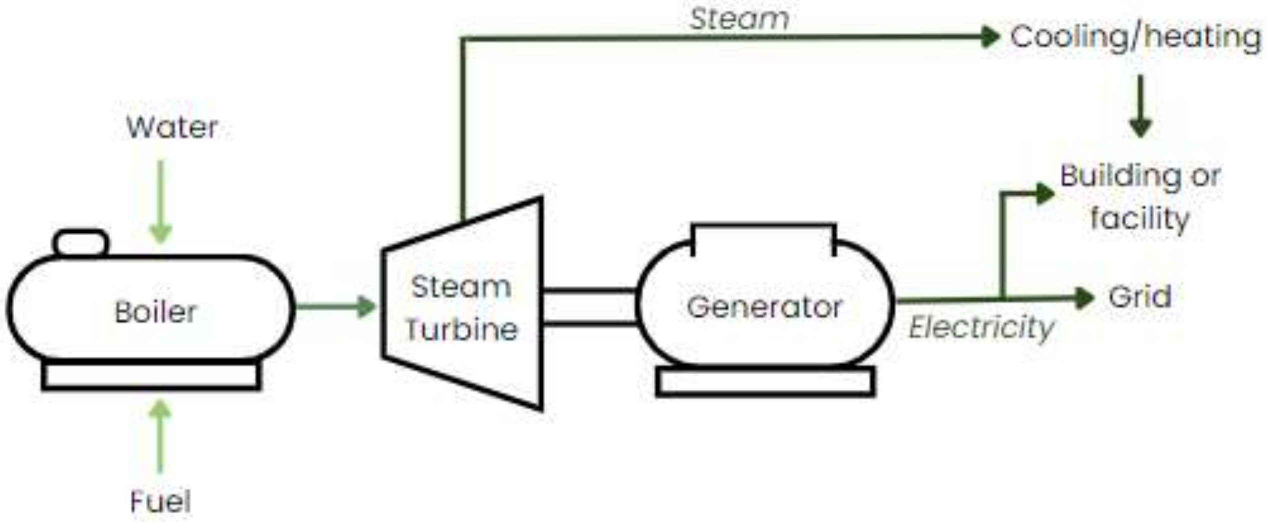
Source: https://www.ieabioenergy.com/bioenergy-a-sustainable-solution/

THERMOCHEMICAL CONVERSION PROCESS

- Thermochemical conversion is a process that involves the **use of heat and chemical reactions** to convert biomass or other organic materials into useful energy forms, such as heat, electricity, or biofuels.
- Thermochemical processes depend on the **degradation** of biomass and the following chemical reactions occurring at moderate to high temperatures.
- Biomass undergoes structural breakdown which degrades to condensable vapors, and eventually disintegrating to gaseous molecules with rise in temperature typical of dry thermochemical processes.
- This technology is considered to be cost-effective, and it is mainly constituted of three common thermochemical processes for converting biomass into biofuels and chemicals.
- These processes are pyrolysis, liquefaction, and gasification

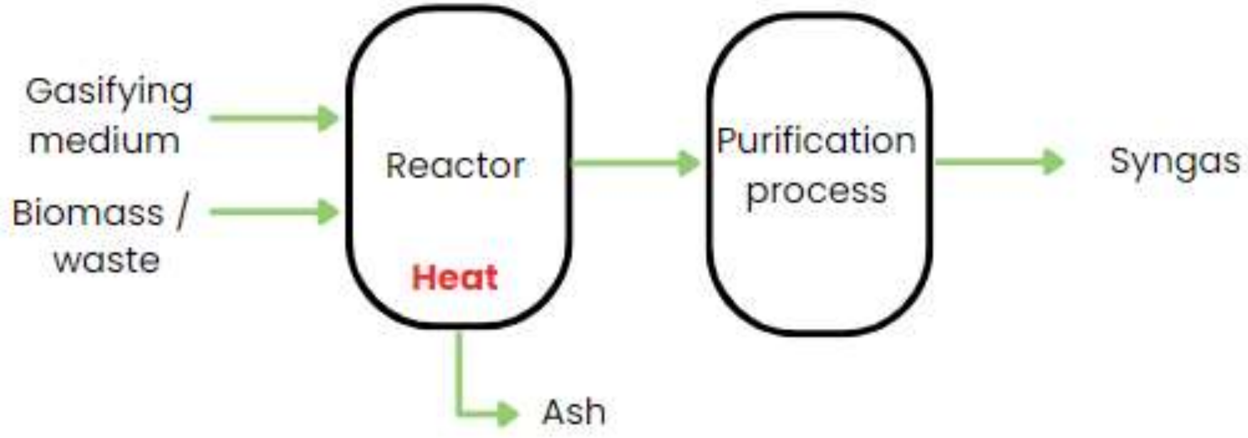
CONTROLLED COMBUSTION

- Combustion is the most **common** and straightforward thermochemical conversion process.
- It involves the direct **burning** of biomass in the presence of oxygen to produce heat.
- The heat generated can be used for **space heating, industrial processes**, or converted into electricity through steam turbines.
- Combustion releases CO_2 into the atmosphere, but since the carbon dioxide is taken up by plants during photosynthesis, it is considered a carbon-neutral process.
- This process can be part of a cogeneration system, which allows for a distributed generation of electrical or mechanical power from the treatment of different types of biomass.



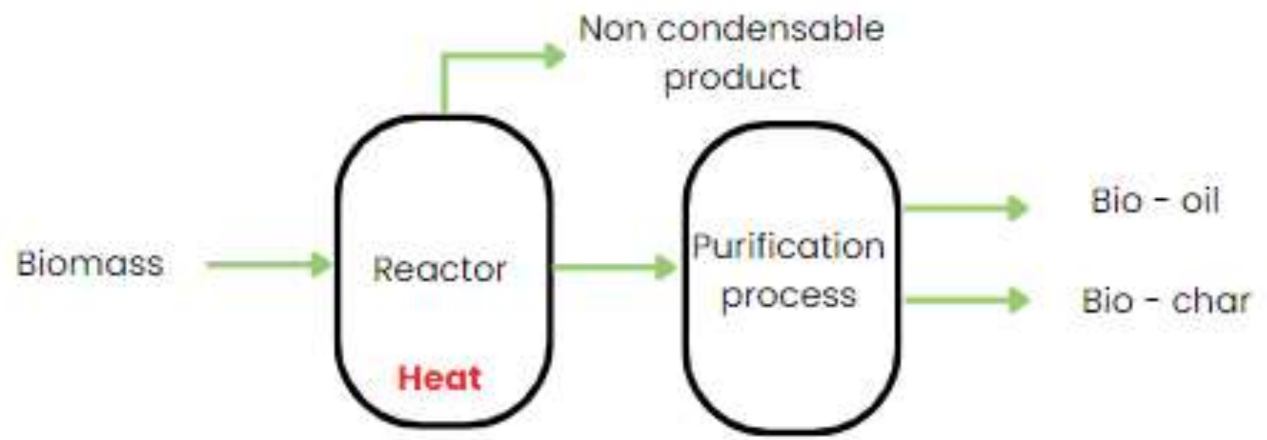
GASIFICATION

- Gasification is a thermochemical process that converts biomass or other carbonaceous materials into a combustible gas called **producer gas or synthesis gas (syngas)**, that can be used for different purposes.
- Typical feedstock for gasification is cellulosic biomass such as wood chips, pellets or wood powder, or agricultural byproducts like straw or husks.
- The gasification of the feedstock takes place at **700° – 1600°C** in the presence of a gasification medium, and the feedstock is exposed to a limited amount of oxygen or steam, which allows for partial oxidation of the biomass. The process rearranges the molecular structure of the feedstock and packs the energy into chemical bands in the syngas



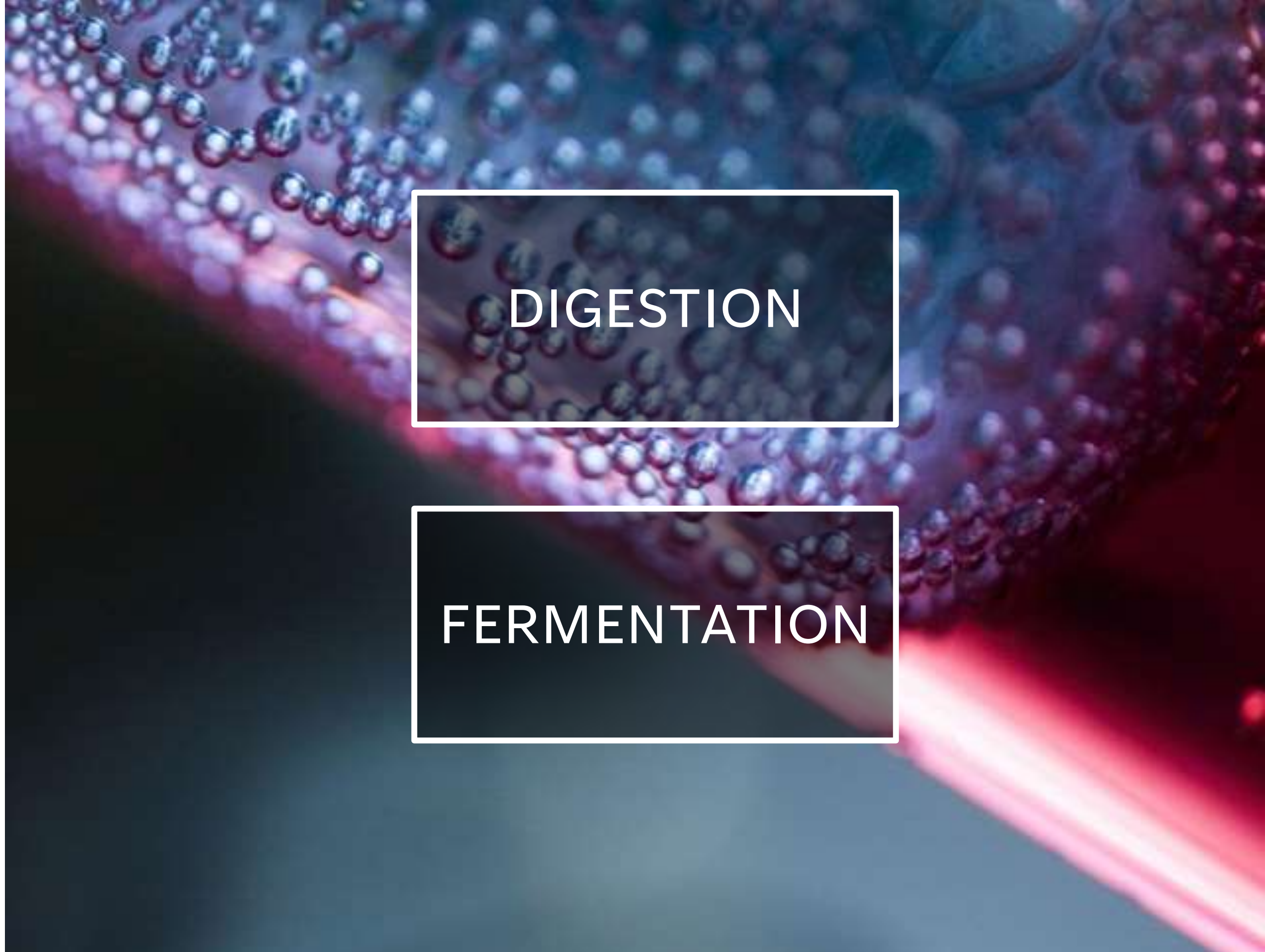
PYROLYSIS

- Pyrolysis is a process that decomposes biomass in the absence of oxygen at elevated temperatures.
- The feedstock is heated in a controlled environment, leading to the breakdown of complex organic molecules into simpler compounds like bio-oil, syngas, and biochar.
- Despite the relatively higher calorific values of products derived from pyrolysis, compared to those derived from gasification, the volume of gasses produced are usually much lower due to the lack of oxygen carrier, and the proportions of these products depend on the pyrolysis conditions.



BIOCHEMICAL CONVERSION PROCESS

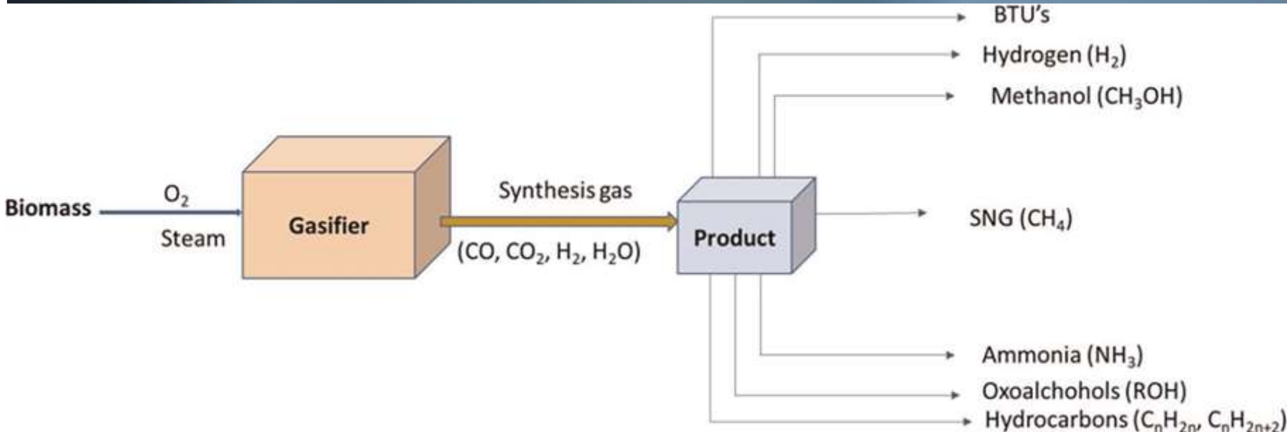
- Biochemical conversion is a process that involves the **use of biological agents, such as microorganisms, bacteria or enzymes**, to convert biomass into value-added products or energy.
- It harnesses the natural biochemical reactions and metabolic pathways of living organisms to transform feedstocks into desired end products.
- Biochemical conversion is widely employed in various industries, including biofuel production, biorefineries, pharmaceuticals, and biotechnology.
- Biochemical conversion is one of the few methods for extracting energy from biomass that is environmentally friendly.



DIGESTION

FERMENTATION

Overview of the sequence for derivation of syngas from biomass



BIOCHEMICAL CONVERSION PROCESS

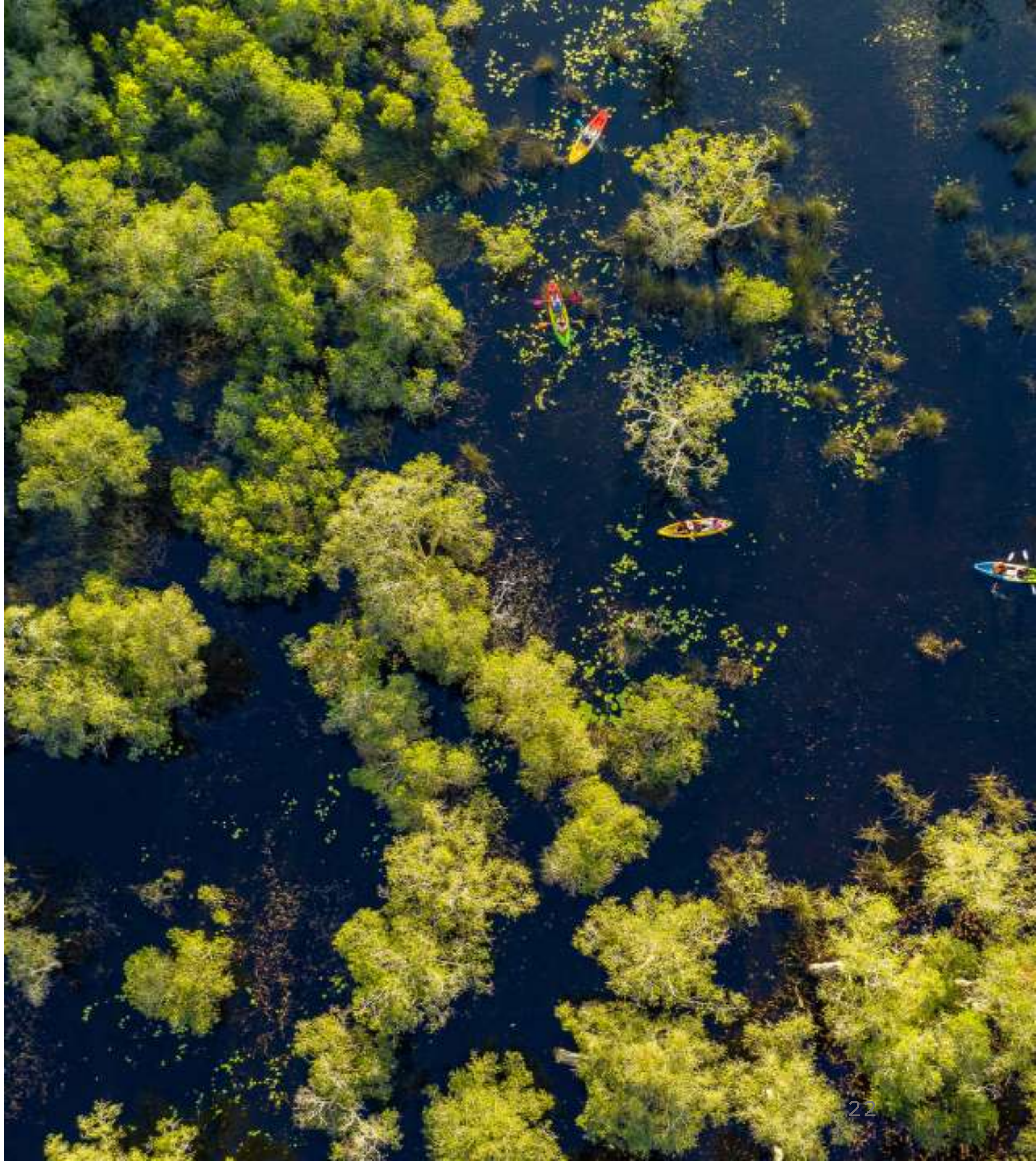
- There are two distinct processes used in bioenergy systems for the production of renewable energy from organic waste materials.

- **Aerobic digestion:** In aerobic digestion, organic waste is decomposed by microorganisms in the presence of **oxygen**.

- **Anaerobic digestion**: Anaerobic digestion involves the decomposition of organic waste in the ***absence of oxygen.***

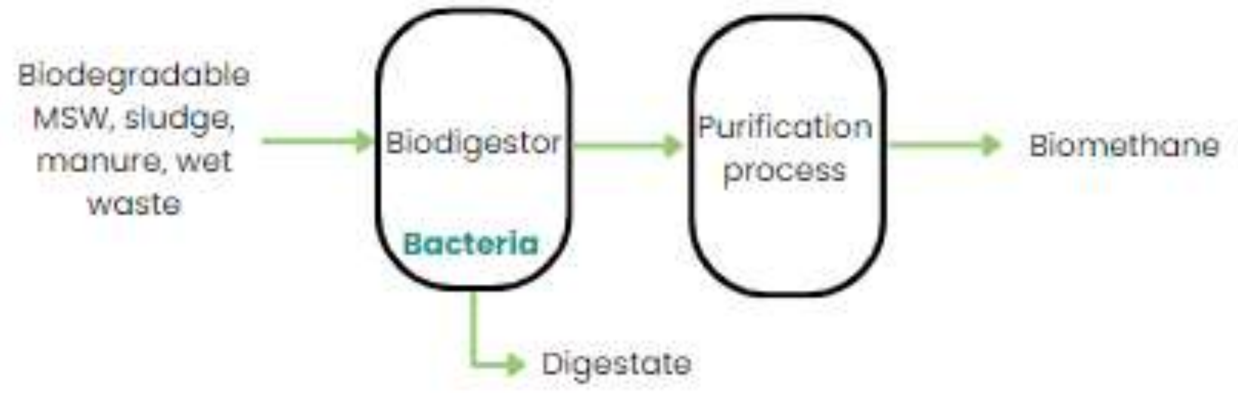
AEROBIC DIGESTION

- In aerobic digestion, organic waste is decomposed by microorganisms in the **presence of oxygen**. The process typically occurs in a controlled environment, such as an aerobic digester or composting system.
- Microorganisms metabolize organic matter, converting it into CO_2, water, and heat. The heat can be used for various purposes.
- The final product of aerobic digestion is usually a nutrient-rich material called **compost**, which can be used in agriculture to improve soil fertility and structure.
- Aerobic digestion is well-suited for organic waste materials with high moisture content, such as **food waste and wastewater sludge**. It is a **faster** process compared to anaerobic digestion.



ANAEROBIC DIGESTION

- Anaerobic digestion involves the decomposition of organic waste in the **absence of oxygen**. The process occurs naturally in environments such as landfills, swamps, and the digestive systems of animals. However, it can also be facilitated in controlled anaerobic digesters.
- During anaerobic digestion, a microorganisms break down organic matter, producing biogas as a byproduct.
- Methane is the primary component and can be used as a **fuel** for heating, electricity generation, or in vehicles. Leftover digestate, can be used as a **fertilizer**.
- Anaerobic digestion is particularly effective for high-strength organic waste, including agricultural residues, manure, and energy crops.
- Anaerobic digestion also helps in waste management by **reducing the volume of organic waste** and minimizing methane emissions, as methane is a potent greenhouse gas.



3 STEPS OF BIOCHEMICAL CONVERSION

- Biochemical conversion typically involves three main steps:
  - **Pretreatment**: Methods vary depending on the types of feedstock being used, but at this stage, the general aim is to break down complex molecules, remove impurities, and enhance accessibility to the desired compounds.

  - **Enzymatic hydrolysis** or **fermentation**: Microorganisms are used to break down complex organic molecules into simpler compounds. The resulting compounds can be used for various purposes, including biofuel production or the synthesis of other biochemicals.

  - **Downstream processing**: After the enzymatic hydrolysis or fermentation, the resulting products need to be purified or refined. This step involves separation, purification, and concentration of the desired compounds from the fermentation broth or enzymatic hydrolysate.


CASE STUDIES
Selected Cases of Biogas initiatives worldwide

CAMBODIA'S NATIONAL BIOGIESTER PROGRAM

- Initiated by the national Ministry of Agriculture, Forestry and Fisheries in cooperation with the Netherlands Development Organization.

- The program's main objectives are to reduce the use of firewood and coal for cooking and lighting, to reduce deforestation and air pollution and its related health impacts.

- Between 2006 and 2021, nearly 29,000 biodigesters were constructed.

- The program uses animal waste to generate biogas for the cooking and lighting needs of farmers in 15 provinces (representing nearly 145,000 people) as the main beneficiaries.

- The program included partial subsidies for the building stage, as well as some of the equipment (one cooking pot, bricks, and one gas lamp). Access to loans from microfinance partners for construction of biodigester systems was facilitated.

Biogas for clean cooking via the Cambodian National Biodigester Program
http://nbp.org.kh/

ON-FARM GENERATOR POWERED BY MANURE METHANE

DANNY KLUTHE FARMS, NEBRASKA, USA

- Developed through a partnership between Nebraska Public Power District, grants from the United States Department of Agriculture (USDA) and the Nebraska Environmental Trust, Danny Kluthe Farm's Olean Energy is cataloged as the first on-farm generator powered by manure methane

- It is a complete mix digester system that generates methane as it stirs and heats waste, it is fed by manure from the farm operation to an in-ground concrete tank with an insulated flexible cover.

- After the biogas comes off the biodigester passes through different filters to take the moisture and impurities out, and used to feed the engine which is running a generator 24 hours a day, seven days a week.

- The biogas is also fed into a compressed natural gas tank to run a 80% methane and 20% diesel pickup and the farmer tractor.

- Farm has a 80 kW capacity and generates 35.000 ft^3 per day of biogas.

Source: https://www.nationalhogfarmer.com/environmental-stewardship-winners-2013/manure-digester-means-nebraska-farm-powered-pigs

SENEGAL'S NATIONAL BIOGAS PROGRAM

- The Senegalese National Biogas Programme is managed by representatives of the country's Ministry of Environment, Ministry of Energy and the National Committee on Climate Change.

- The program has seen two phases of development, with the first phase installing 8,000 domestic biodigesters, with the second phase aiming for at least 27,500 biodigesters by 2030. With support from the international community, it is expected that the target could be raised to 52,000 units.

- The program contributes towards diversification of the energy mix and climate change mitigation, while generating local employment via the development of nearly 25 small-scale biogas enterprises and over 500 skilled jobs.

- The main beneficiaries of this program are the rural households in Senegal providing them a clean and renewable alternative to traditional firewood and charcoal for cooking.

BENIN'S CONTEXT

Q: What is happening in Benin regarding bioenergy?

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POLICIES, ENABLING FRAMEWORKS AND INSTITUTIONS

- **Alliance pour le Biodigesteur en Afrique de l'Ouest et du Centre (AB-AOC)**: This alliance aims to contribute to the decreasing land degradation and accelerated forest loss in several African countries, improving food and energy security through the promotion of biodigestion technologies.
- This initiative involves eight countries of West and Central Africa and it is headquartered in Burkina Faso. Through the promotion, development and implementation of biodigesters, this alliance seeks to improve the living conditions and resilience of rural and peri-urban populations, implementing biodigesters at domestic, semi-industrial or industrial scale, depending on the needs identified in member countries.

POLICIES, ENABLING FRAMEWORKS AND INSTITUTIONS (CONT.)

- **Politique Nationale de développement des énergies renouvelables:** This policy seeks to define a systemic approach of the Renewable Energy management framework, to guarantee the sustainable exploitation of the available natural resources.
- The National Renewable Energy Development Policy recognizes the production of biogas from wet biomass through anaerobic digestion as one of the potential ways of conversion of biomass into energy, setting up several activities to help identify high-performance biogas production systems

POLICIES, ENABLING FRAMEWORKS AND INSTITUTIONS (CONT.)

- **Agence Béninoise d'Electrification Rurale et de Maîtrise de l'Énergie (ABERME):** Works alongside the Benin Ministry of Energy to implement state policy in the field of rural electrification and energy management. It contributes to different national and regional strategies for energy transition of the country.

POLICIES, ENABLING FRAMEWORKS AND INSTITUTIONS (CONT.)

- **Plan d’Action National de la Bioénergie:** This Bioenergy Policy is part of ECOWAS and seeks to create an enabling environment by addressing institutional, legal, financial, social, environmental and capacity gaps, in order to promote a modern, sustainable and dynamic bioenergy sector in this region. This policy is aiming for a target of 40% adoption of alternative fuels, including technologies for biomass transformation, for cooking by 2030.

END OF MODULE 1

BIODIGESTION TECHNOLOGY

MODULE 2 of 3

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BASICS OF BIODIGESTERS

Q: What is biodigestion, and how does it work?

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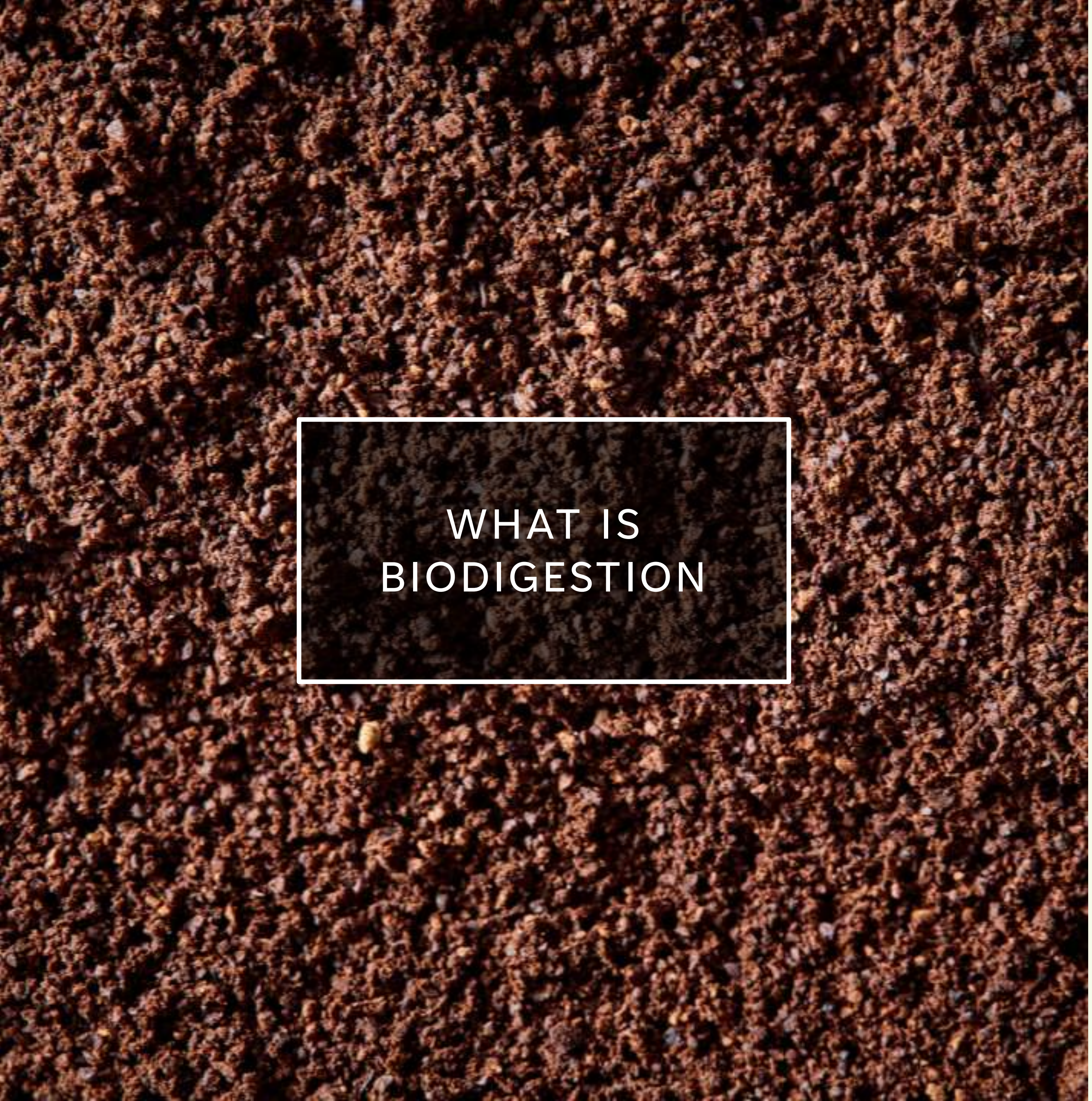


WHAT IS BIODIGESTION

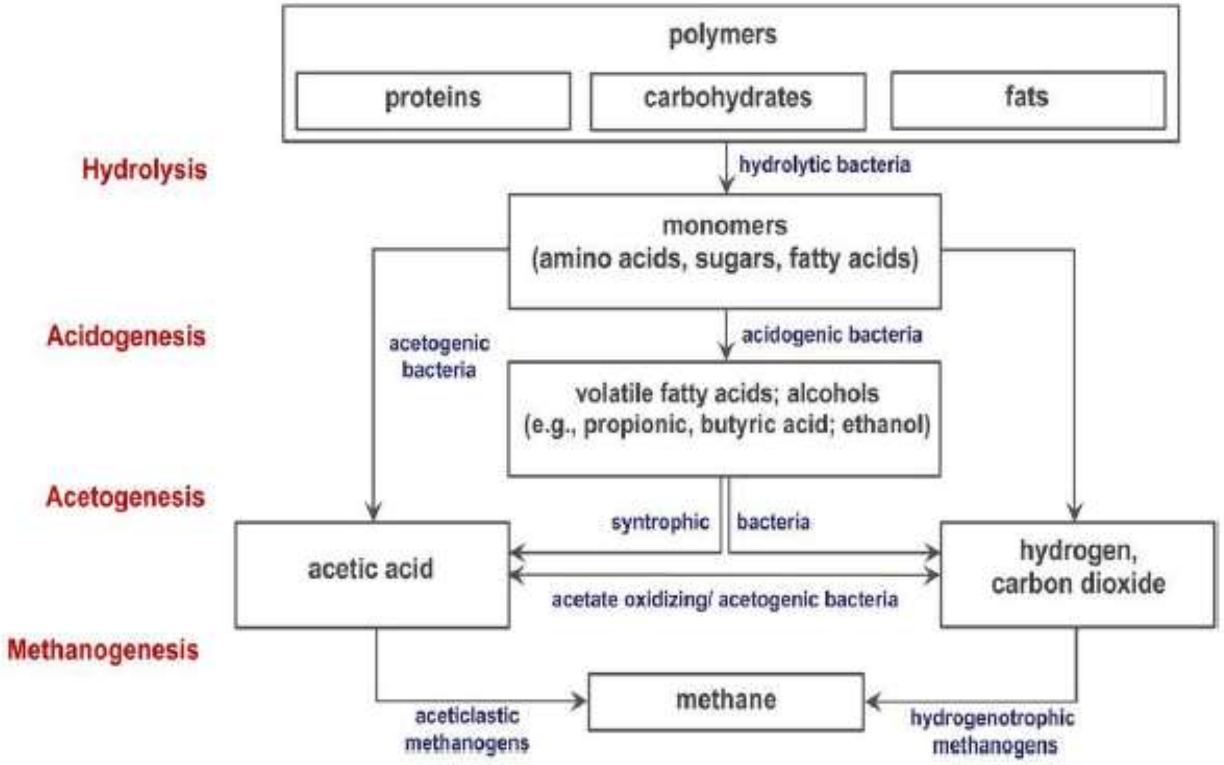
BIOLOGICAL PROCESS

Transformation of organic waste into valuable products such as biogas and slurry in an anaerobic environment (this differentiates it from other transformations).

STAGES OF BIODIGESTION

- Biodigestion involves breaking down and transforming large particles (polymers) into methane

- This process takes place across several stages, where various bacteria are involved



Source: Anaerobic digester / Biogas System Operator guidebook. EPA 2020.

STAGES OF BIODIGESTION

STAGE 1: HYDROLYSIS AND FERMENTATION

- Animal and agricultural waste consists of complex compounds

- **Complex** organic molecules are broken down into **simple** end-products (including sugars, amino acids, glycerol, and complex carbohydrates)

- The conversion is enabled by the involvement of two types of bacteria, namely **hydrolytic and fermentative bacteria**, as well, enzymes that catalyze the biological reactions.

- These reactions need to take place in the absence of **oxygen**.

STAGES OF BIODIGESTION

STAGE 2: ACIDOGENESIS AND ACETOGENESIS

- The simple products are further converted into acetic and propionic acids, ethanol, carbon dioxide and hydrogen.

- The bacteria involved in this stage are acidogenic bacteria.

STAGES OF BIODIGESTION

STAGE 3: METHANOGENESIS

- Methanogenic bacteria transform the products of the previous stage into biogas, reducing all the compounds to **methane** and **carbon dioxide**

OPERATING PARAMETERS

TEMPERATURE

ORGANIC MATTER AND LOADING RATE

RETENTION TIME

CARBON-NITROGEN RATIO

PH LEVEL

MOISTURE AND COMPOSITION

AIR

TEMPERATURE

- As living organisms are involved (bacteria), they thrive in certain temperatures

- In small- scale systems temperature is ensured with the heat of the ground while in large scale systems heaters are required in the biodigester.

- For **mesophilic** bacteria, this is usually 25–40° Celsius. **Thermophilic** bacteria are active at temperatures over 45–50° Celsius, requiring external heating.

- Thermophilic bacteria have **higher yields** of biogas with a higher methane content; however, they can be more expensive to operate given the energy input required.

ORGANIC MATTER AND LOADING RATE

- The **organic matter** deposited in the biodigester varies from waste such as slurry and municipal waste, to biomass such as crop residues or household waste.

- The **rate** at which feedstock is added to the biodigester must be as consistent as possible to not disturb microbial populations.

- In case there needs to be an increase, it should be done gradually to allow them time to adjust.

- Biodigesters can be fed daily or every few days, depending on the design and volume.

RETENTION TIME

- Retention time refers to the average length of **time** the feedstock remains in the biodigester.

- This time is important for maintaining a **healthy microbial population** in the system.

- This is variable depending on the **temperature** and **other factors** such as the quality/composition of the feedstock etc.

- On average, this is around **20 days**, but can be higher or lower depending on the weather conditions, biodigester design etc.

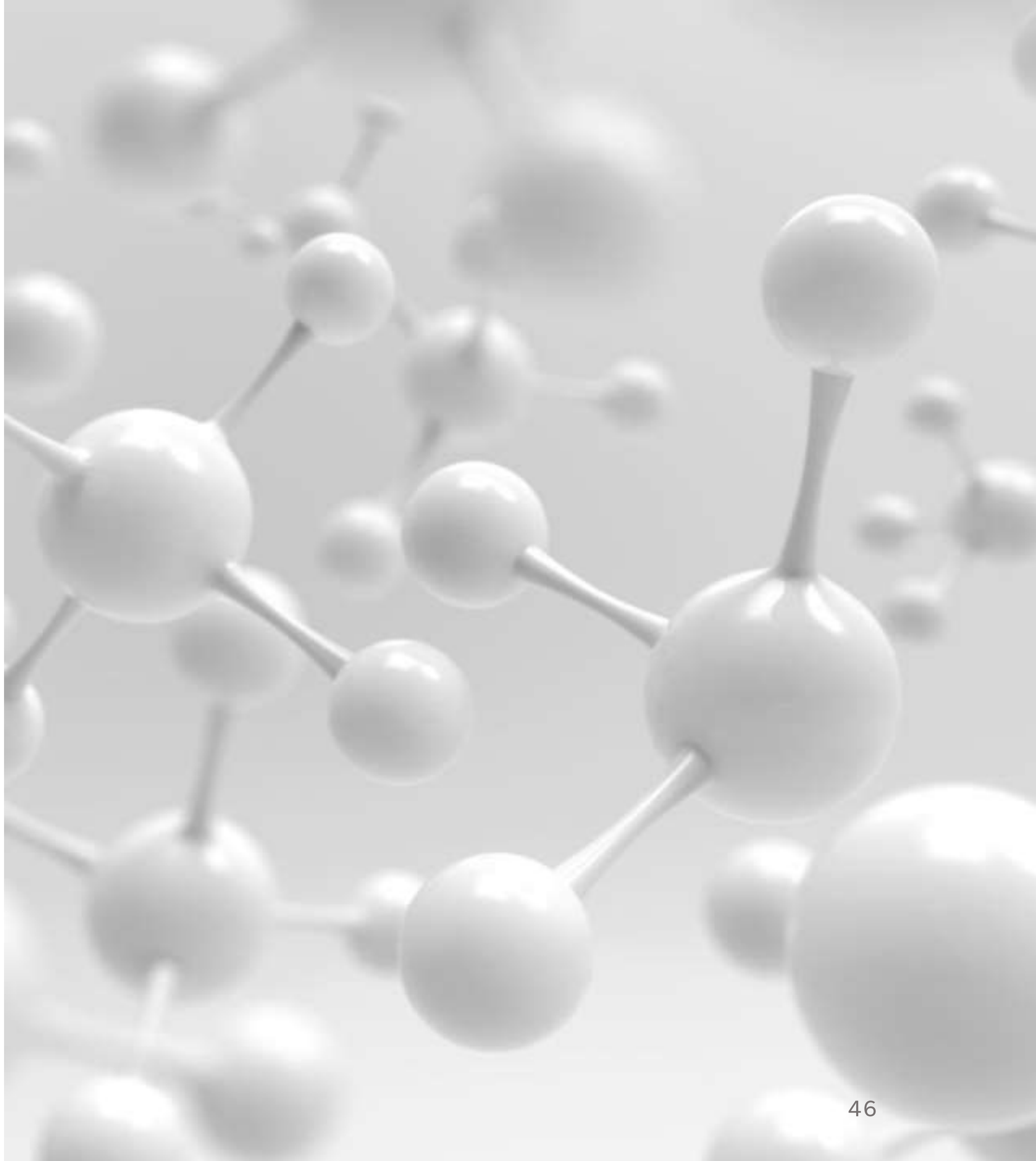
CARBON-NITROGEN RATIO

- A sub-optimal ratio of carbon to nitrogen can create problems for the bacteria.

- If the amount of **carbon** is higher, the volume of gas produced is affected.

- If the amount of **nitrogen** is higher, this can create an imbalance in the pH—which is harmful for the bacteria.

- This can be addressed by using a mix of feedstock, including animal manure and organic solid waste.



PH LEVEL

- The best operating window for pH is 6–8.5 pH (close to neutral)

- Acidity is a common problem, so if pH levels are affected, some lime can be added to bring them back to neutral

- However any such changes should be done gradually and in moderation

MOISTURE AND COMPOSITION

- The substrate should **not be too dry** as this can negatively affect the decomposition process.
- If there is too much water, the biogas production volumes will be lower.
- When using cow dung, the ratio is around **1:1 or 2 for cow dung and water.**
- Dry or old cow dung should be avoided.

(LACK OF) AIR

- As the bacteria active in biodigesters are **anaerobic**, they may not be active if air gets in.

- It is important to check for **leakages** to ensure efficient operation

COMPONENTS OF A BIOGAS SYSTEM

Q: What are the components of a biogas system?

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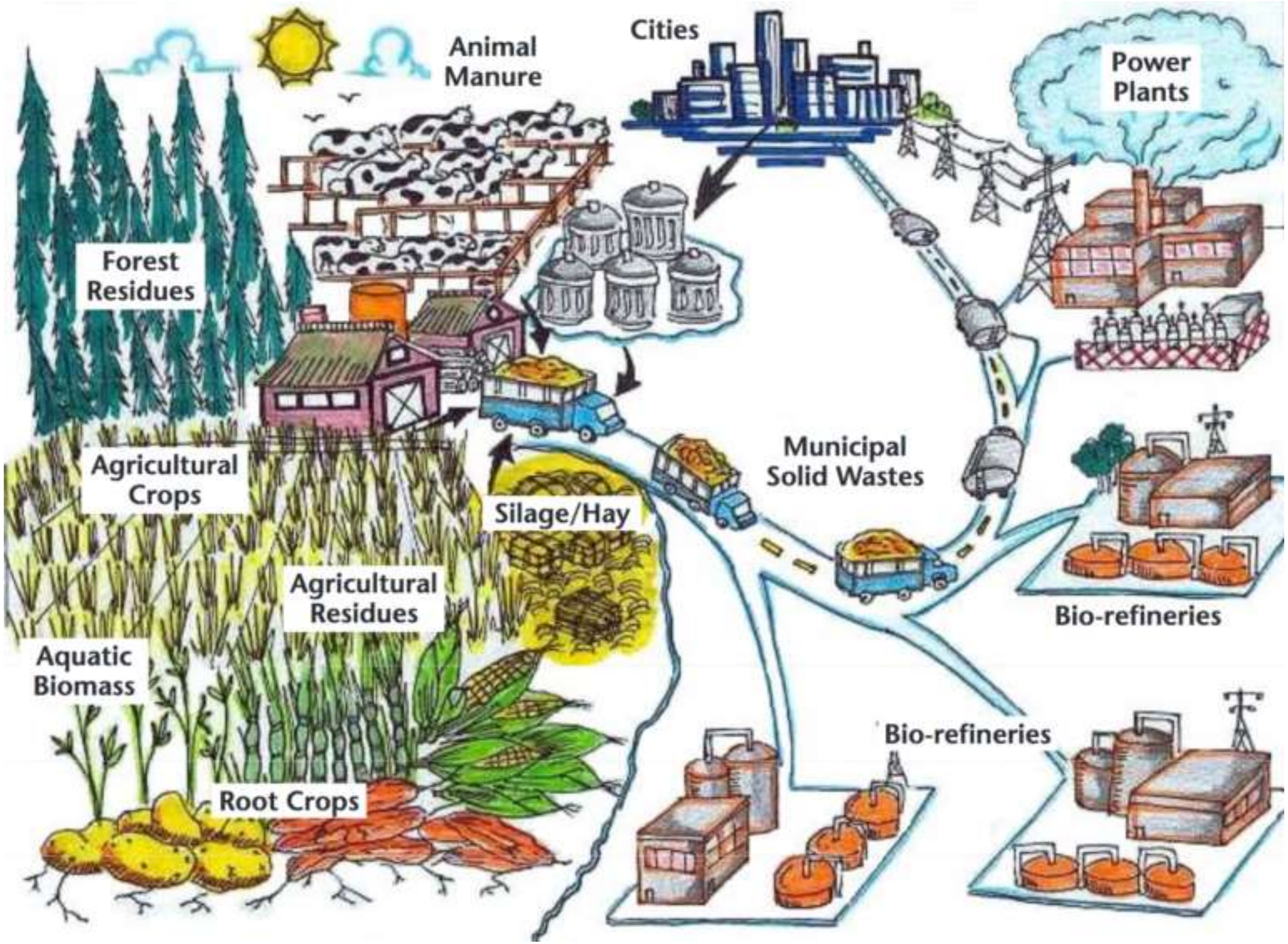
ILLUSTRATION OF A BIOENERGY SYSTEM



Source: Zongliu (2017). Manure to Energy: Understanding Processes, Principles and Jargon. Texas Animal Manure Management Issues.

TYPES OF FEEDSTOCK

PHYSICAL PRE-TREATMENT

CHEMICAL PRE-TREATMENT

BIOLOGICAL PRE-TREATMENT

TYPES OF FEEDSTOCK

- Appropriate feedstocks to use in biodigesters are wet waste or wet biomass, with moisture content higher than 60%. Below is an overview of organic residues from different origins.

Type of input	Origin
Animal residues	Animal manure from dairy cattle, swine, poultry and beef Cattle.
Plant residues	Crop residues, weeds, crop stubble, straw, fodder in poor condition.
Human residues	Wastewater sludge, organic fraction of municipal solid wastes, organic wastes from households.
Agro-industrial residues	Rice bran, pomace, rice, cossettes, molasses, seed residues, seed residues.

TYPES OF FEEDSTOCK (CONT.)

- Residues involved in the biodigestion process can be categorized into four classes considering their physical appearance, dilution level, concentration grade, and quantitative features. The table below details this categorization.

Class	Physical appearance	Substrate	Quantitative features
Class 1	Solid	Domestic trash Solid manure Crop residues	> 20% (TS) 40% - 70% (OF)
Class 2	Highly contaminated sludge, high viscosity	Animal manure	100 -150 g/l (COD) 5% - 10% (TS) 4% - 8% (VS)
Class 3	Fluids with high suspended solids (SS)	Feces Breeding animals and leaven diluted with wash water Slaughterhouse wastewater	3 - 17 g/l (COD) 1 - 2 g/l (SS)
Class 4	Highly contaminated fluid with suspended solids	Wastewater from agro-industries Waste water	4 - 500 g/l (COD)

TYPES OF FEEDSTOCK (CONT.)

- Total solids (TS), moisture, volatile and non-volatile matter, solid concentration, are some other properties of the feedstocks that influence biogas quality and production. The table below provides the optimal properties ranges that can help to improve biogas yield.

Biowaste	TS	VS	C:N ratio
Cattle dung	17.5 %	75	23.73
Vegetable waste	16 %	90	19.47
Fruit vegetable waste	62.2 ± 16 g/L	50.8 ± 11.2 g/L	17.4
Sewage sludge	154.9 ± 18.1 g/L	101.9 ± 10.8 g/L	6.3
Food waste	166.3 ± 26.7 g/L	149.0 ± 24.3 g/L	17.4
Neem leaves	90 %	74 %	27.17

PHYSICAL PRE-TREATMENT

- **Mechanical pre-treatment** includes processes that involve physical force

- **Milling** is the most common way—including hammer mills and knife mills, which are generally used for dry biomass

- If done for large-scale plants, it can be quite expensive due to the electricity required to power the mills

- The aim is to increase the specific surface area by breaking down the biomass into smaller sizes. It can help increase biogas yield and reduce scum.

PHYSICAL PRE-TREATMENT (CONT.)

- **Thermal pre-treatment involves adding heat to the feedstock**
- **It** heats up the substrate under pressure to a maximum of 220°C and holds it for a specific time, before cooling it down to make it ready to feed the biodigester.
- Thermal pre-treatment increases biogas yield only up to a certain temperature, and biogas production decreases below this temperature.
- This is also viable for large-scale operations.

CHEMICAL PRE-TREATMENT

- **Chemical pre-treatment** involves altering the substrate chemically to make it easier to digest

- Alkali treatment can be carried out with different concentrations of lime, sodium hydroxide (NaOH) and potassium hydroxide (KOH).

BIOLOGICAL PRE-TREATMENT

- **Microbiological pre-treatment** involves treating the substrate with biological agents, such as bacteria, which already begin breaking it down

- Also known as multi-stage fermentation, it is a technology in which the first steps of anaerobic digestion (hydrolysis and acidogenesis) are separated from acetogenesis and methanogenesis.

- The concept of carrying out digestion in separate vessels is similar to the multiple chambers of ruminant digestive systems e.g. cows.

- This pre-acidification step keeps pH and temperature from 4 to 6 and 30 to 50°C respectively, increasing the degradation rate by creating an optimal environment for hydrolytic enzymes to act

BIOLOGICAL PRE-TREATMENT (CONT.)

- During anaerobic digestion, complex microbial processes take place involving mainly bacteria, but also protozoa and anaerobic fungi.
- There are four different trophic groups recognized in anaerobic processes:

1. ***Acidogenic bacteria***: This group breaks down large molecules into smaller ones, making them soluble. Bacteria transform this into a wide range of fermentation end products. The majority of the products are volatile fatty acids (VFAs).

2. ***Acetogenic bacteria:*** They convert the VFAs to methanogenic substrates, hydrogen (H2), carbon dioxide (CO2), acetic acids and monocarbon compounds.

BIOLOGICAL PRE-TREATMENT

- *3. **Homoacetogenic bacteria***: They work to maintain low hydrogen partial pressure and increase the significance of acetate as a methane precursor. Two species of those bacteria have been identified, one converts ethanol (CH3CH2OH) to acetate (CH3COOH) and hydrogen (H2); the other converts carbon dioxide (CO2) and hydrogen to methane (CH4)

- *4. **Methanogenic bacteria***: The main function of this group of bacteria is to convert hydrogen, acetic acid and acetate into methane, the major component of biogas

BIODIGESTER TYPES AND TECHNOLOGIES

CONTINUOUS STIRRED TANK REACTOR (CSTR) BIODIGESTERS

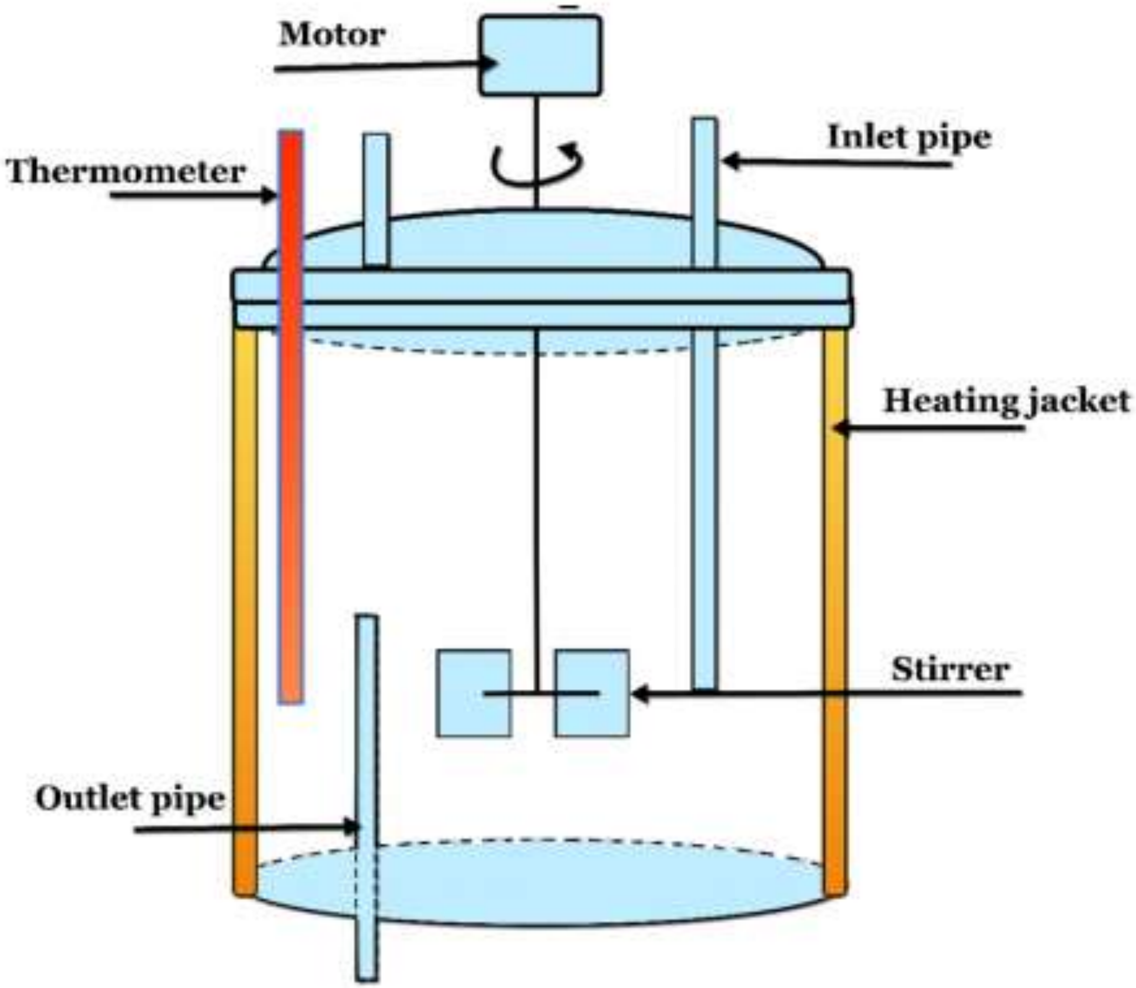
PLUG FLOW REACTOR (PFR) BIODIGESTERS

ANAEROBIC SEQUENCING BATCH REACTOR (ASBR)

SCRUBBERS

CONTINUOUS STIRRED TANK REACTOR (CSTR) BIODIGESTERS

- Continuous stirred tank reactor (CSTR) biodigesters are designed with a **single tank** where the feedstock and microorganisms are **continuously mixed** to maintain optimal conditions for biogas production. The stirring can be continuous or semi-continuous.
- Mesophilic, thermophilic, co-digestion and two-stage biodigesters are the most common types of CSTR biodigesters. They differ based on the type of microorganisms used, the operating temperature, and the feedstock.
- Thermophilic CSTR biodigesters operate at a temperature range of 50-60°C and are suitable for processing feedstock such as poultry manure, slaughterhouse waste, energy crops like switchgrass and maize, and food waste.
- Mesophilic CSTR biodigesters operate within a temperature range of 25-40°C and are commonly used for processing feedstock such as manure, food waste, sewage sludge, and agricultural residues.
- Co-digestion CSTR biodigesters can process a mixture of different feedstocks and can improve biogas yields and balance the nutrient content and acidity of the feedstock, keeping the stability of the process

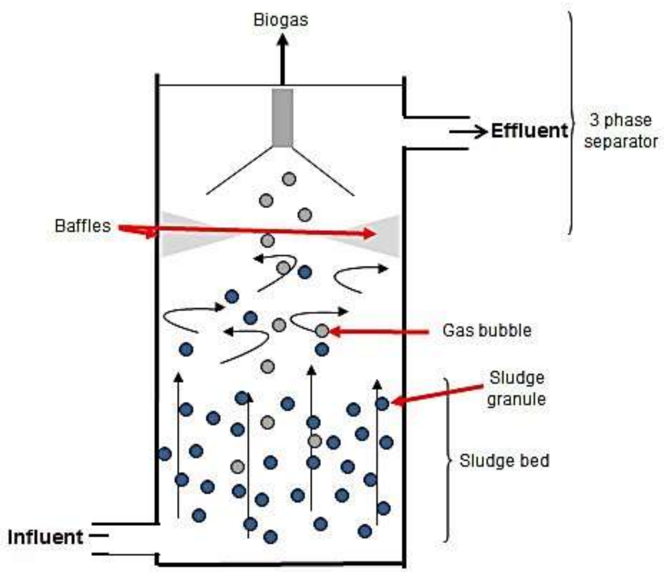


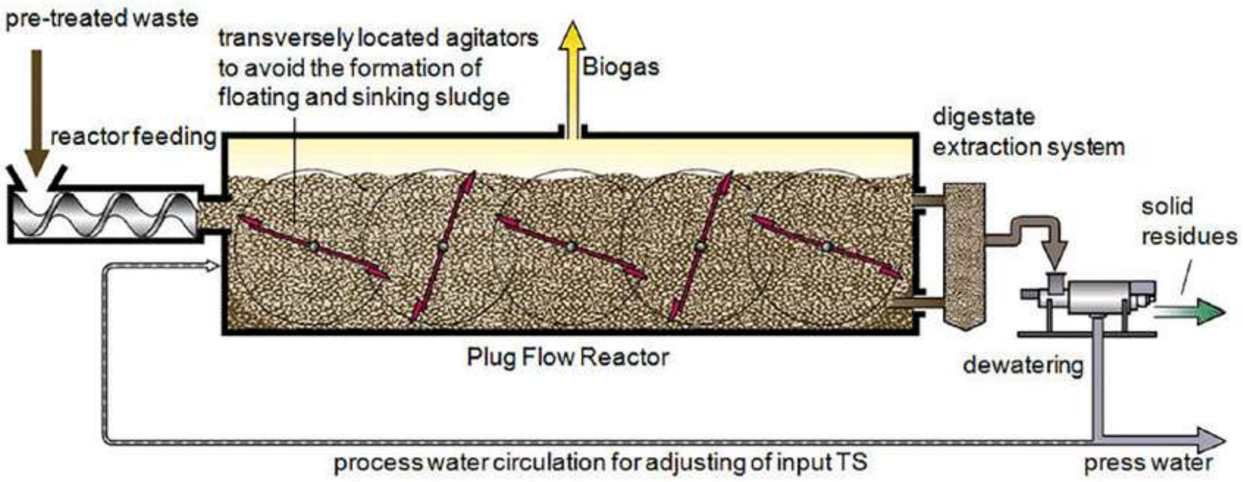
PLUG FLOW REACTOR (PFR) BIODIGESTERS

- Plug flow digesters consist of a **long tunnel-like or rectangular concrete chamber** with air-tight cover, where manure flows in at one end of the reactor and flows out at the other.

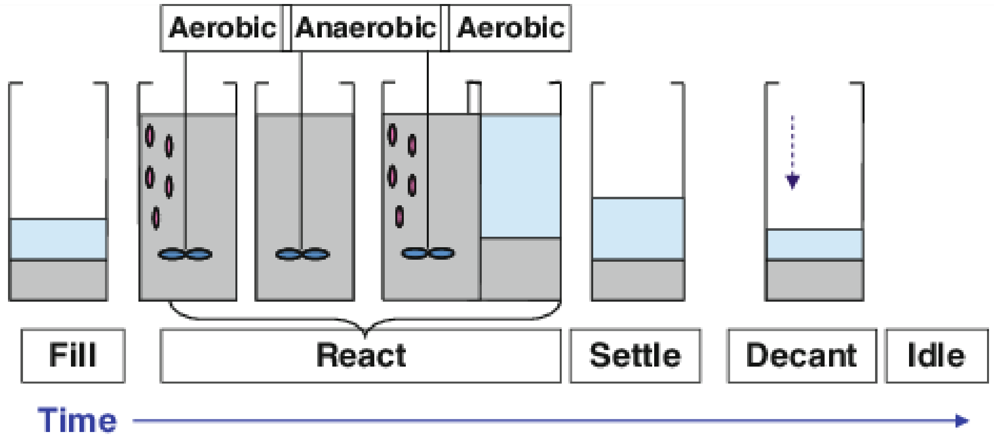
- Manure first enters a mixing pit where solids are adjusted by adding water, then as manure is fed to the reactor, the "plug" of the new manure pushes the older manure down the tank until the digestion ends. There is no need for mixing then. A "plug" takes between 15 and 30 days to pass completely through the digester. This type of digester is most suitable for manure with solids content of 10 -14%.

- This can be a vertical or horizontal design.





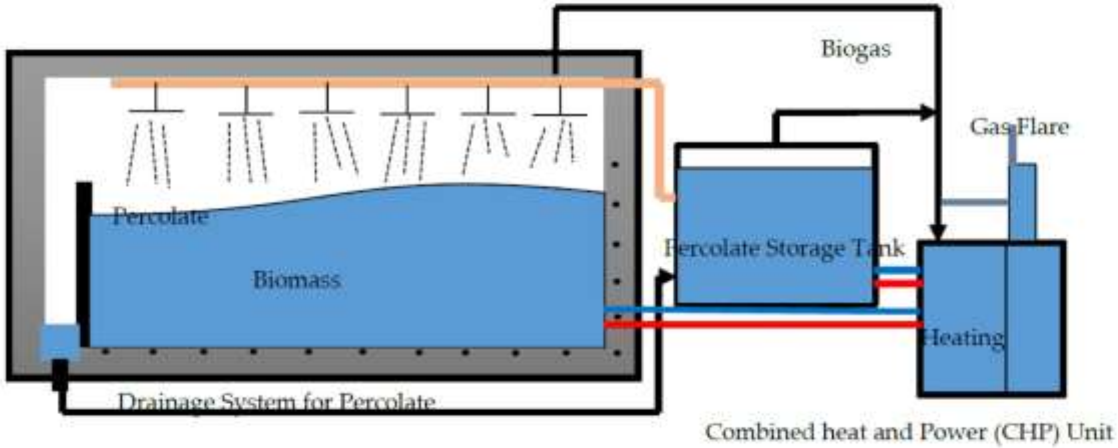
ANAEROBIC SEQUENCING BATCH REACTOR (ASBR)



- During batch processes, feedstock is fed into the digester and inoculum (=the initial bacteria sample) is added. The system is then closed and allowed to complete the digestion process. This takes place in separate batches.

- Batch scale digesters are simple in terms of technology and they involve minimal investment and maintenance costs.

Sequential batch reactor



SCRUBBERS TO REMOVE IMPURITIES

- Biogas is composed of methane, carbon dioxide and other impurities. Methane is the main fuel; the presence of the rest hampers its efficient burning

- Scrubbers can be used to remove these trace gases and improve combustion and reduce pollution

- They can involve physical or chemical absorption, adsorption on a solid surface etc.

- These are costly and energy-intensive processes, so are suitable for large-scale biodigesters

- The removal of impurities can lead to high concentrations of methane, resulting in a fuel that is equivalent to natural gas and can be used in its place

BIODIGESTER OUTPUTS

Q: What does a biodigester produce?

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BIOGAS

The main output that can be used as a fuel

SLURRY

Leftover product that is a potent fertilizer

BIOGAS

- Biogas is the **main product** obtained by the anaerobic digestion process, and it consists of a gaseous mixture formed mainly by **methane and carbon dioxide**

- The composition of biogas is typically as shown in the table:

Composition	Percentage (%)
Methane CH_4	54 - 70
Carbon dioxide CO_2	27 - 45
Nitrogen	0.5 - 3
Hydrogen	1 - 10
Carbon monoxide CO	0.1
Oxygen O_2	0.1
Hydrogen sulphide H_2S	0.15
Ammonia NH_3	0 - 0.5
Water vapor H_2O	1 - 5

SLURRY/DIGESTATE

- Once the feedstock cannot produce more biogas, it becomes bioslurry or digestate

- This is biologically stable—harmful bacteria are gone, and it emits less odor

- It is equivalent to raw manure in terms of nutrient quality, but it is less intense for plants, attracts fewer pests, and kills weed seeds

APPLICATIONS

Q: Where can I use biogas?

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FUEL

This fuel can be used in cooking or to power gas lamps for lighting

COOKING AND LIGHTING

- The biogas, once connected to a house by pipes, can be used as a **clean cooking fuel**
- It burns more **efficiently** than traditional biomass, and so creates less pollution. Less fuel is required for the same amount of cooking. Less time is spent gathering traditional fuelwood.
- If piped into the house, it can also be connected to gas lamps for **lighting**, replacing traditional lamps and kerosene
- However, the appropriate **stove** and **lamps** must be purchased

INDIRECT USES

UPGRADING/PURIFICATION

The methane quantity can be increased

VEHICLE FUEL

This biomethane can be used in natural gas vehicles

ELECTRICITY GENERATION

Biogas can be burned in an engine to generate electricity; biomethane could potentially be used in turbines (very large-scale operation)

UPGRADATION AND PURIFICATION

- **Purification** involves removing any impurities from the biogas, such as sulfur compounds, which can be harmful and corrosive to materials

- **Upgradation** involves removing carbon dioxide from the biogas (usually around 25–45% of its composition), to increase the methane content to over 90%
    - This process can be physical, chemical, cryogenic etc.

- However, all these processes are **costly** and **energy-intensive**, so may not be applicable to all biodigester setups

VEHICLE FUEL

- Upgraded biogas or biomethane can be used in **natural gas vehicles** directly, without modifications

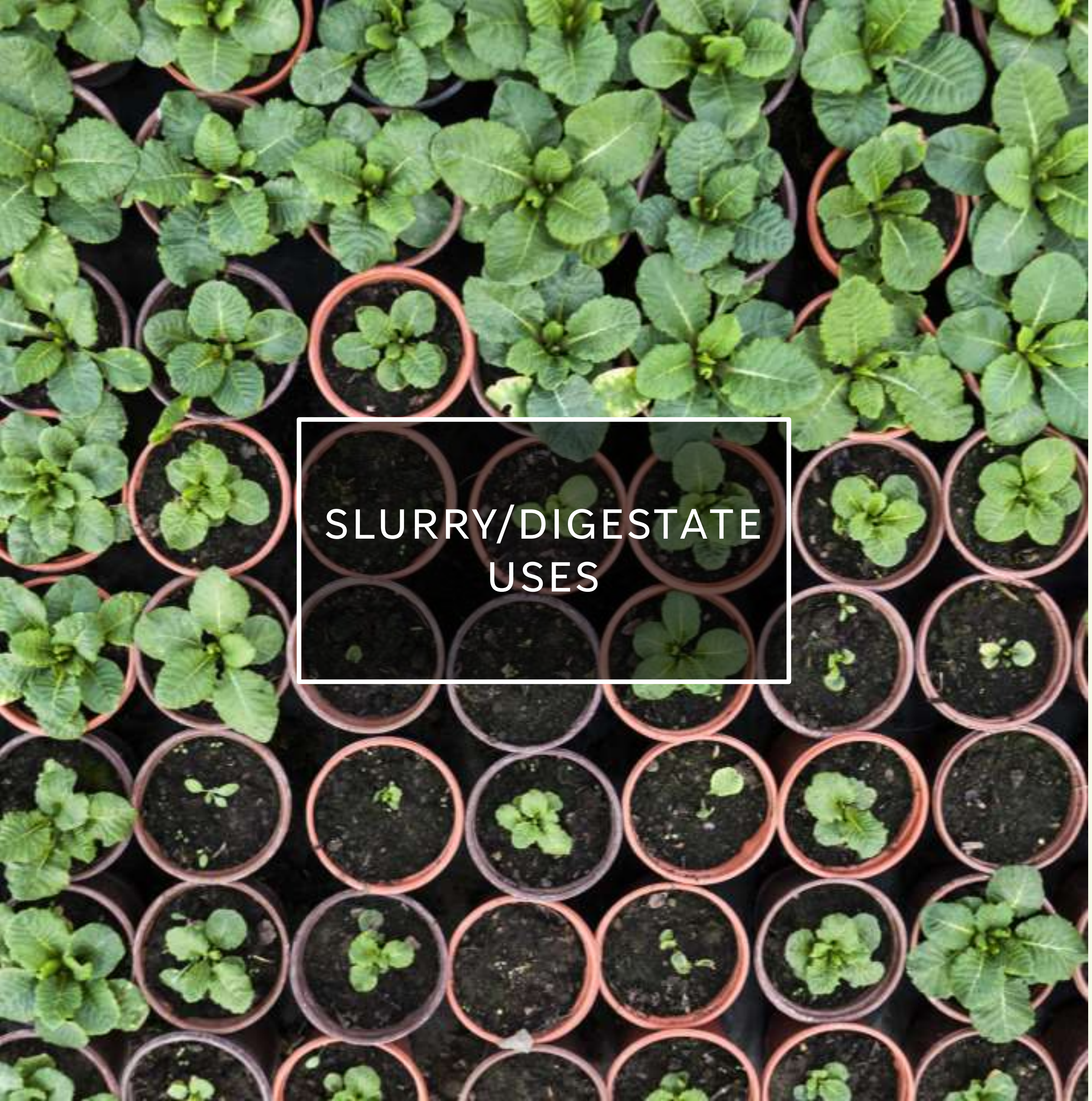
- Gasoline vehicles can also be **converted** to operate on biomethane, by installing a second fuel supply system. However, this can be costly.

ELECTRICITY GENERATION

- Biogas can be used in **engines** to generate electricity for small-scale operations

- If upgraded to biomethane, it could potentially be used to power even larger operations

- The needs of the farm can be met with this electricity, or it can be sold to the grid for additional revenue—but this can be a complicated process



SLURRY/DIGESTATE USES

FERTILIZER

This can be used as an improved fertilizer compared to raw manure

FERTILIZER FOR CROPS

- Slurry can be used as **fertilizer**, and has a number of benefits over raw manure
- It is less harsh for crops to absorb, but retains the **same nutritional value** as raw manure
- It is less odorous
- Due to the digestion process, it has fewer harmful bacteria and weed seeds

BIOGAS PLANTS

Q: What to different biodigester/biogas plants look like?

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SMALL-SCALE PLANTS

FIXED DOME

The roof of the digester is fixed, and usually made of bricks

FLOATING DRUM

The roof of the digester 'floats' on top of the pit where the gas is produced

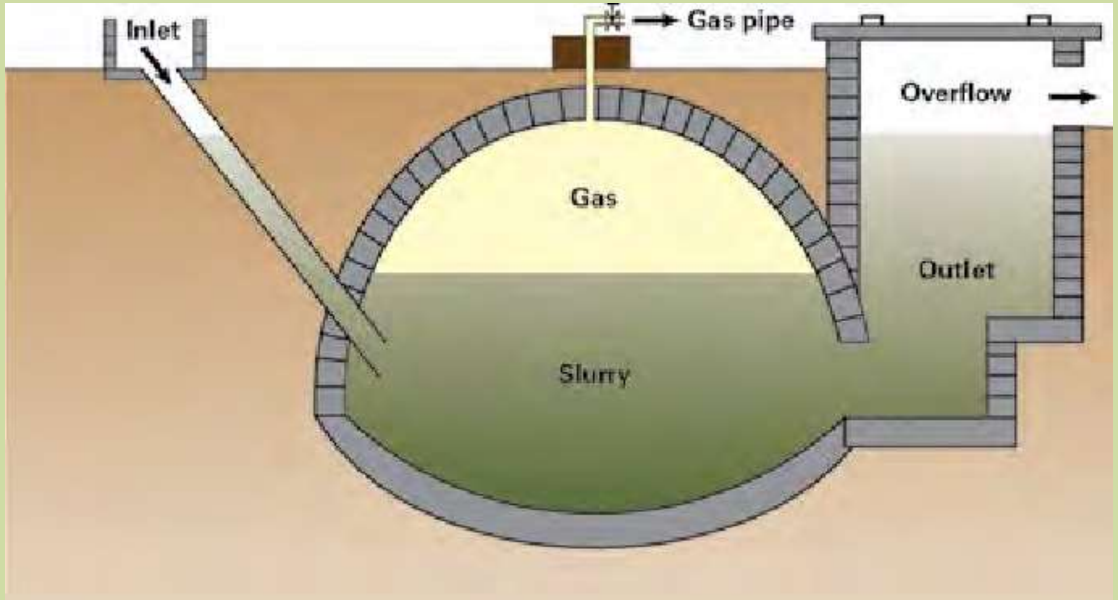
HORIZONTAL

This can be in the shape of a drum, and is low-cost and low maintenance

FIXED-DOME PLANT

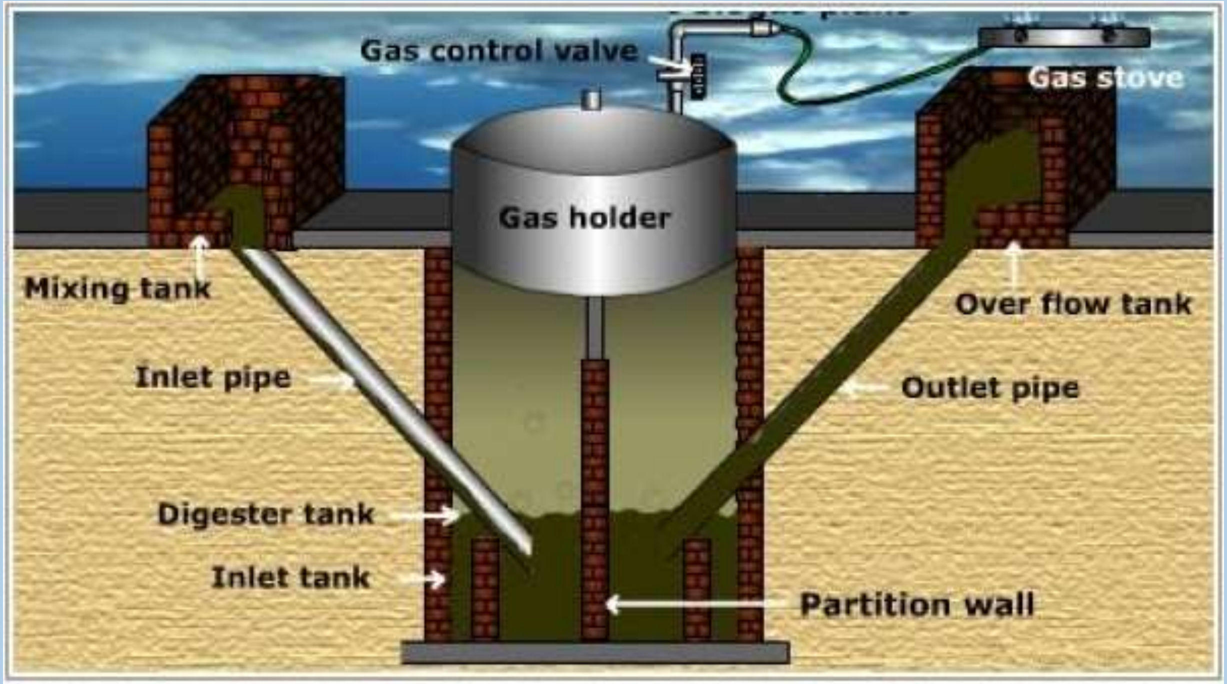
- The space where the gas is collected is solid and fixed

- Its size and dimensions can be adjusted based on the amount of feedstock and gas volumes expected



FLOATING DOME PLANT

- Generally built underground, like a pit
- The sludge is acted on at the bottom of the pit, with the gas floating upwards
- The 'roof' is a floating gas cover, which allows for optimal pressure depending on the amount of gas produced
- The gas cover can be painted black to absorb more heat, and it should have a sloping roof to avoid the collection of rainwater



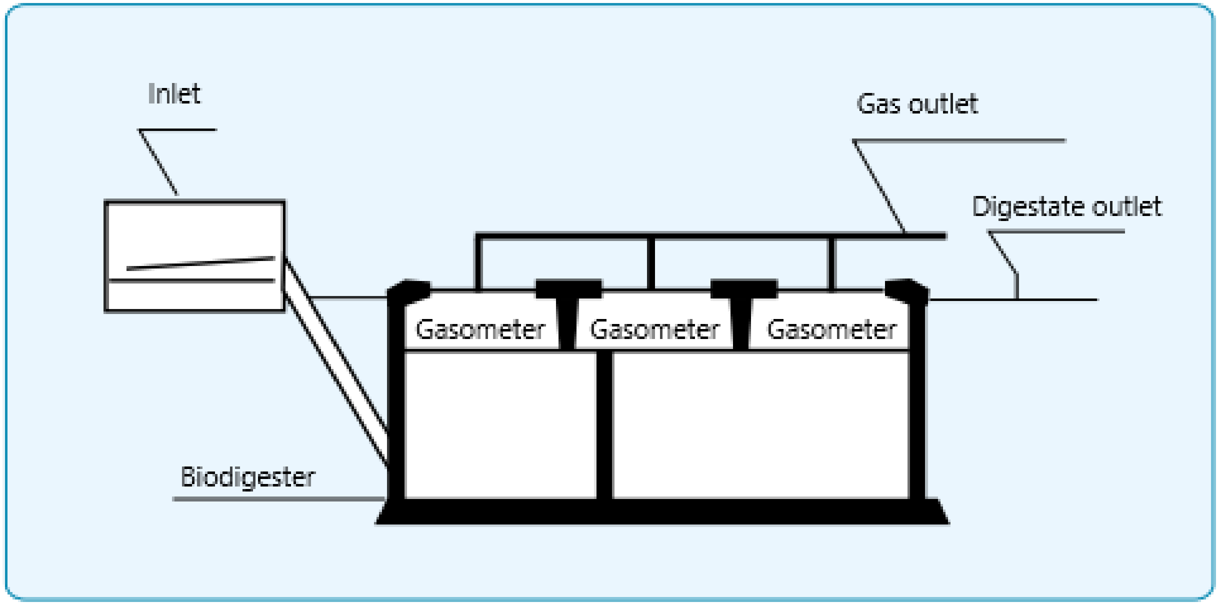
Floating dome biogas plant

HORIZONTAL DIGESTERS

- **Low maintenance and low-cost**; they are generally built underground and can have a circular, square or V-shaped cross-section

- Feedstock enters at one end and digestate exits from the other; the dome can be solid or flexible, as long as it can contain the gas and provide protection.

- Periodically the biodigester can be **emptied** (once a year on average) to clean and maintain the container. When this is done, about 1/5th of the substrate should be saved for the next batch.



FARM-SCALE

Medium- to large-scale plants can be integrated into farm operations for various purposes

MEDIUM- TO LARGE-SCALE PLANTS

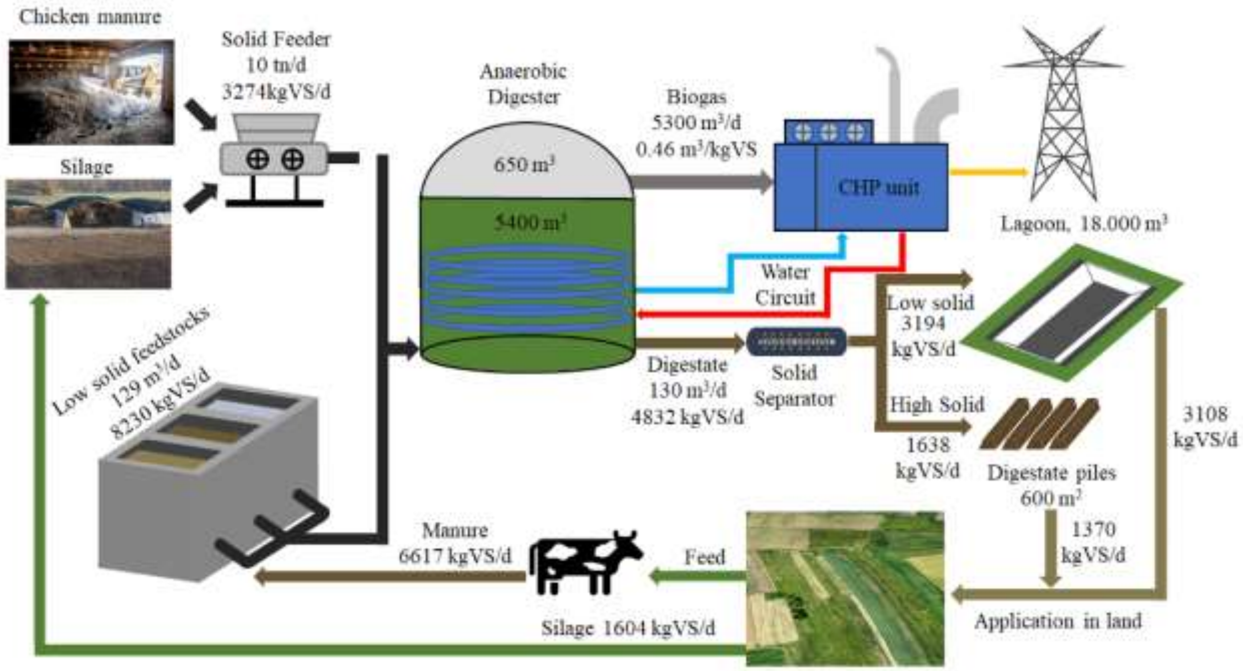
- Larger, farm-scale plants can accept feedstock including **manure, and agricultural residues** (this is called co-digestion). However, much **larger quantities** are required compared to household biodigesters.

- They can run at 30-35°C, but some operate at over 50°C, which can kill weed seeds and harmful bacteria

- The time required for the digestion process (HRT) varies depending on the design of the plant. On average, it is around 20 days.

- **Stirring** is necessary—propeller stirring is an option, as is low-speed mechanical stirring

- While many outputs are the same (biogas, digestate etc.), with an associated engine, **electricity** can also be generated by burning the gas. This can be consumed on the farm, or sold to the electricity grid.



BIODIGESTER SETUP

Q: What should I keep in mind when setting up a biodigester plant?

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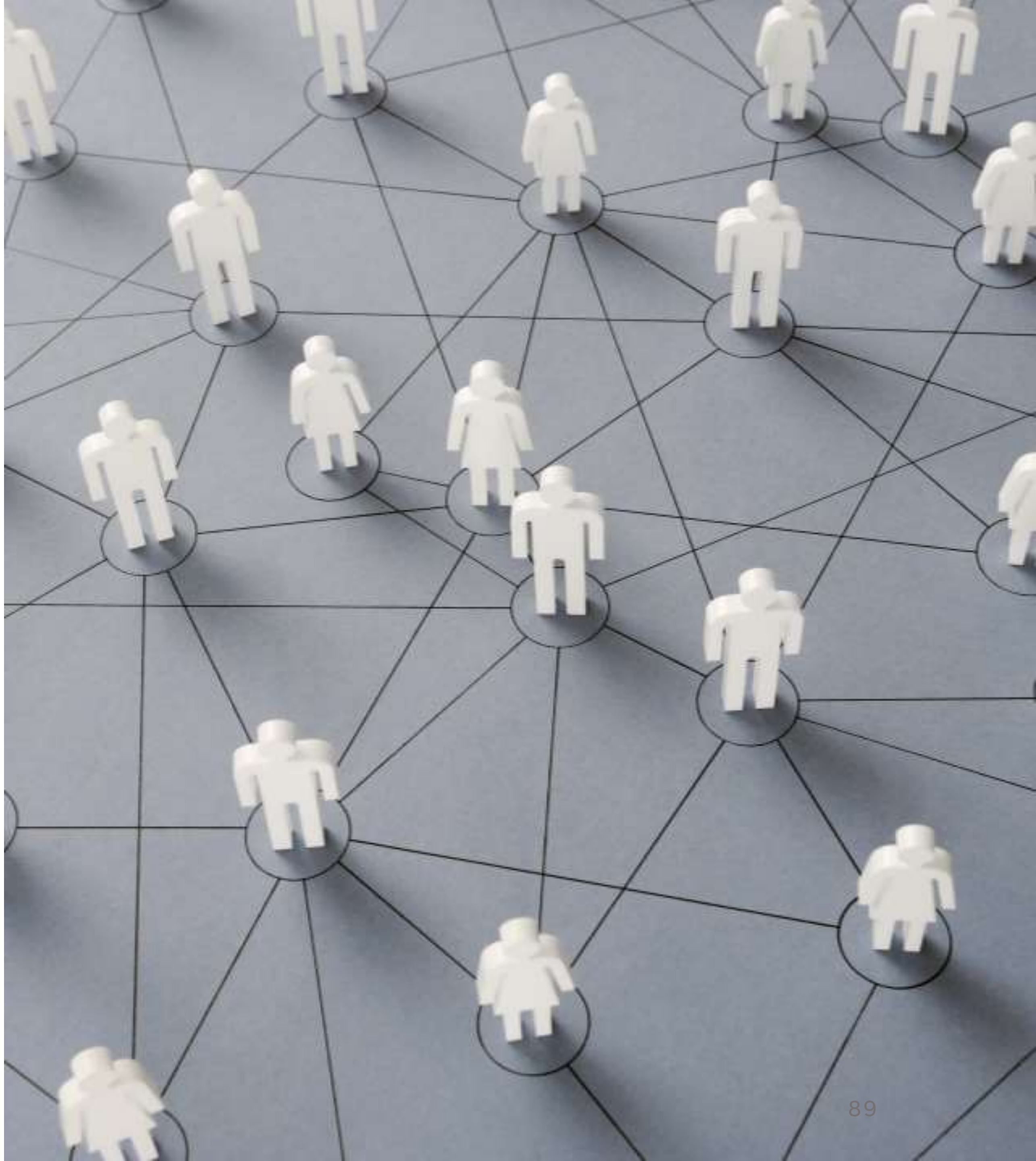
LOCATION

- The right location for the biodigester is important
- This can include proximity to the feedstock source to reduce transportation costs and losses
- It can be close to the site of final consumption e.g. the kitchen
- The type of soil/ground should be stable and appropriate for the biodigester
- It should be in a sunny area to ensure adequate temperatures

SOCIAL CONSIDERATIONS

- Especially for large-scale plants, there could be local resistance
- There may be valid concerns about the odor when processing the feedstock
- Location is therefore important again—large plants should not be very close to residential areas
- Community concerns should be heard and addressed as far as possible



ENVIRONMENTAL CONSIDERATIONS

- Especially for large-scale plants, care should be taken that any effluents do not pollute groundwater, water bodies and other vulnerable sites

ECONOMIC FEASIBILITY

- If a biodigester's financial flows do not make sense, it is difficult to implement and sustain the project

- The availability of feedstock is essential, as is the type and size of plant, in order to generate sufficient biogas/revenues

- Detailed analyses should be carried out to determine which option is the most suitable for a particular location/context

END OF MODULE 2

EFFECTIVE ADOPTION OF BIODIGESTERS

Module 3 of 3

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BENEFITS OF BIODIGESTER SYSTEMS

Q: Why should I consider installing a biodigester?

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ECONOMIC BENEFITS

INCOME/COST SAVINGS

Costs can be saved due to waste being valorized: expenditures are reduced as they are replaced with biogas

JOB CREATION

Larger-scale projects can create a wide range of jobs

ENERGY ACCESS

Biogas is a renewable source of energy that is cleaner than traditional biomass; it can also be used to generate electricity

ADDITIONAL INCOME/COST SAVINGS

- **Biogas** can be used as cooking fuel, reducing time and money involved in collecting other energy sources e.g. firewood
- **Digestate** can be used as a fertilizer
- **Both** products can be sold to neighbors to generate additional income
- Improved health outcomes can reduce healthcare costs

ENERGY ACCESS

- Households can generate their own energy with waste products that are readily available to them

- **Energy security** can be improved due to steady supply of fuel; this can enable productive activities—small businesses, studies etc.

- For slightly larger-scale projects, if **electricity** is generated by burning biogas, it can be used to power households or farms through mini-grids, if feasible

JOB CREATION

- For **large-scale projects** in particular, a number of jobs can be created

- These can include locally-based engineers, technicians, skilled labor, planning, administration etc.

- For household activities, the work of operating a biodigester can be incorporated into daily activities and also foster **skill development and income generation**

ENVIRONMENTAL BENEFITS

ODOR/PEST CONTROL

Digestate is more manageable than raw manure

MANURE MANAGEMENT

Raw manure can be used to produce biogas, and then as fertilizer

FOREST MAINTENANCE

Reduced reliance on forest products

CLIMATE CHANGE MITIGATION

Climate benefits of using renewable sources and avoiding methane emissions

ODOR/PEST CONTROL AND MANURE MANAGEMENT

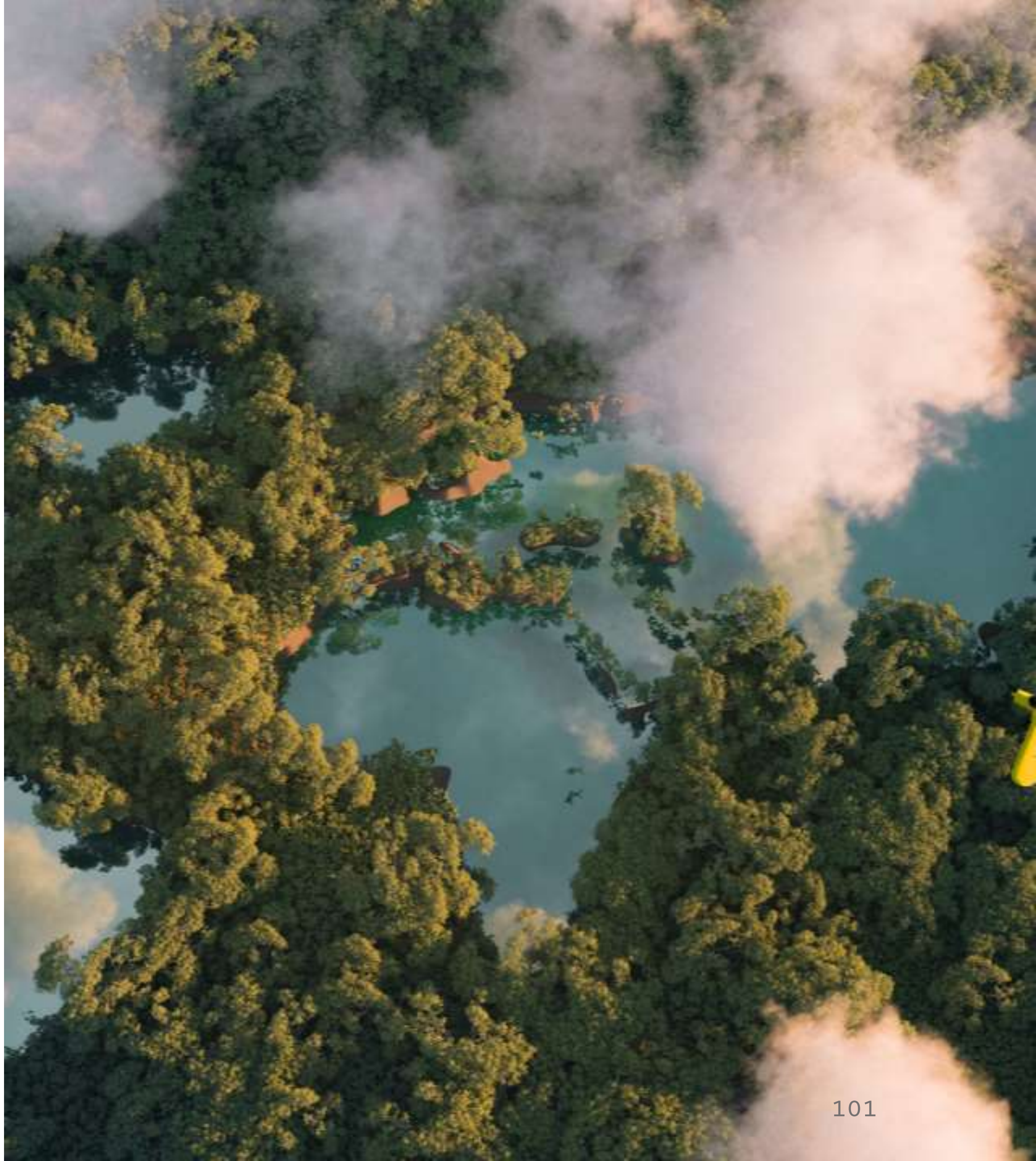
- Digestate has fewer harmful bacteria than raw manure, so it can be **stored** for longer.
- It is **less odorous** than raw manure and attracts fewer pests such as flies, rats
- As **weed seeds** are neutralized, it can reduce their spread
- It has the same **nutritional value** as manure in terms of nitrogen (N), potassium (K) and phosphorus (P)
- Digestate can be used as a **fertilizer** and is more readily absorbed by plants
- Excess manure, that is produced anyway, can in this way find various uses and lead to cost savings. By avoiding disposal, it reduces land and water pollution.

FOREST MANAGEMENT

- Over-reliance on firewood can affect forests and their sustainable use. Biogas provides an **alternative**.

- As biodigesters, feedstock sources and final uses will likely be situated **close to each other**, the time required to gather fuel is reduced.

- **Behavioral changes** will be required to use biogas—including no longer having to collect firewood, and using modern **cookware**.



CLIMATE CHANGE MITIGATION

- Methane is **worse** for the climate than carbon dioxide

- Methane is released when raw organic material such as manure is allowed to decompose naturally

- Biogas is considered **renewable**, enabling many options for **finance and support** etc.

- Local air **pollutants are reduced** when compared to traditional biomass, with associated health impacts

SOCIAL BENEFITS

HEALTH IMPROVEMENTS

By replacing traditional fuels, pollution, especially indoor, is reduced

GENDER PARITY

Indoor pollution disproportionately affects women and children; time spent collecting firewood is also reduced

HEALTH IMPROVEMENTS

- Biogas, when burned, is less **smoky** than traditional firewood or biomass

- **Reduced smoke exposure and inhalation** can lead to reduced impacts on health, especially for women and children

- The incidence of diseases such as pneumonia, cancer, and heart diseases can be **reduced**

- **Reduced odor** from digestate also leads to welfare improvements

Optimal burning—blue flame

GENDER PARITY

- The use of biogas reduces or eliminates the **time** required to gather fuel, and food cooks **faster**
- Women are most affected—they can use the **additional time** for additional tasks, including small businesses or maintaining the biodigester
- However, **new cookstoves** may be required and households will have to adapt to them

BUSINESS CASE

Q: How can I ensure my biodigester project is successfully implemented?

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BUSINESS MODEL

REVENUE SOURCES

Earnings from the sale of biodigester products and services

COSTS

Initial investment, and operation and maintenance costs

SOURCES OF FINANCE

Individual, community, private, public, philanthropic and carbon financing

OWNERSHIP STRUCTURES

Ownership and operation, and therefore risks, do not have to be borne by one individual or household

BIOGAS

Can be used to reduce costs for cooking fuel, lighting etc. or sold to neighbors if distribution is possible

FIBROUS MATERIALS

Recovered fiber can be used as bedding for cattle or sold

SERVICES

A biodigester owner can provide manure or waste management services for a fee

DIGESTATE

Same nutrients as raw manure, but more stable. It can be used or sold as fertilizer for crops, or to grow mushrooms

ELECTRICITY

In larger-scale biodigesters, the gas can be used to produce electricity which can be consumed or sold to the grid

BIOMETHANE

Large-scale biodigesters can be upgraded to produce methane, which is more valuable and has more uses (e.g. transport)

BIOGAS, DIGESTATE (AND FIBROUS MATERIALS)

- These are the main outputs of a biodigester.
- The biogas can be **piped** to a kitchen for direct use in **cooking** or **lighting**
- The piping can be **extended** to neighboring houses for use or sale
- The digestate is a strong **fertilizer** and more suitable for plants, more manageable and easier to store
- It can also be used to grow other food, such as **mushrooms**
- Fibrous materials, if sufficient quantities are recovered, are good for bedding for cattle. They can be sold as well.

ELECTRICITY, BIOMETHANE AND OTHER SERVICES

- These are more suitable for **large-scale digesters**, and have **higher capital costs** associated with them

- Biogas can be upgraded to **biomethane**, to reduce its carbon dioxide content and other impurities. It can be used in the same uses as **natural gas**.

- Biogas can also be used in a combined heat and power plant to **generate electricity** for use on a farm or sold to the grid, if feasible

- A biodigester can also be used to **manage waste**, and the owner can collect fees for processing agricultural waste if necessary

CAPITAL COSTS

The initial investment to set up the biodigester

OPERATING COSTS

The costs of running the biodigester, and any maintenance required

CAPITAL COSTS
(I.E. INITIAL INVESTMENT)

- These can be quite **high**, depending on the size of the project
- Most of the project costs are made up of this investment; operating costs are **much lower**
- Small household-scale projects are more **manageable**
- Many biodigester projects may be eligible for **assistance** from donors, or local, regional or national governments

OPERATION AND MAINTENANCE COSTS

- **Labor and training:** These can require some investment in hiring **experts** to conduct the training, as well as time to attend the training. For larger-scale biodigesters, more complex expertise would be required.
    - Collaborations with **NGOs or government skilling programs** is encouraged

- **Feedstock**: If sufficient feedstock is not available in the vicinity, it may need to be **purchased** or **transported**, which would require additional expenditure

- **Transportation**: **Transporting** feedstock or digestate, and **piping** the biogas, can add to expenses

OPERATION AND MAINTENANCE COSTS (CONT.)

- **Electricity and water**: For larger projects, electricity may be required for proper operation. However, **water** is a requirement in all projects, so adequate provisions should be made.

- **System maintenance**: This includes normal wear and tear, and expenses on spare parts, repairs etc. as well as regular maintenance activities.

- **Administration costs**: This may not be applicable to all projects, but can include costs related to insurance, data collection/monitoring etc.

OWNERSHIP STRUCTURES

INDIVIDUALS

Individuals or households can set up their own biodigester

‘LEAD FARMER’

One farmer can take up the responsibilities, with costs and returns shared among others

COMMUNITY-OWNED

A community can collectively own and operate a biodigester

THIRD-PARTY

A third-party can either own or operate a biodigester

INDIVIDUAL OWNERSHIP

- Small-scale biodigesters can be set up by **households**, usually 1-6 cubic meters in size

- There needs to **be sufficient land and feedstock** (i.e. cattle or crop waste)

- These can be **self-financed**, or there might be **programs** from governments or NGOs to support with the installation and operation

- Revenues can be earned by selling the **biogas or digestate**; or household **costs** can be reduced through savings on energy expenses

- Their use is primarily in **cooking and lighting**, which can lead to an increase in the amount of **time** available for other activities including small businesses, rest, skill development etc.

‘LEAD FARMER’ MODEL

- One farmer may **own or manage** the biodigester; similar models have been tried in dairy collectives
- They can charge **fees** for the handling of waste from other farms/households and/or the sale of the biogas and digestate
- This can work if there is initial reluctance to adopt this technology, or if the economics make sense

COMMUNITY OWNERSHIP

- **Medium-sized biodigesters** can be **collectively** owned by the community, with responsibilities being divided, as well as the returns

- Initial investment can be split across **multiple individuals**, and support programs may be available from the government or NGOs

- **Operation** and **governance** could be a challenge, so high social trust and capital can help ensure the success of such a project

THIRD-PARTY OWNERSHIP/OPERATION

- A third party, such as a private company, may consider **owning or operating** a biodigester plant

- If they are owners, the farmers could **operate** it and use the biogas in exchange for fees; they could also provide the **land** to lease

- If they are operators, the farmers could **own** the biodigester and/or the land but not have to worry about **operating** it

- These could be beneficial if there is **reluctance** to one or the other aspects of having a biodigester and to reduce risks

INDIVIDUAL OR COMMUNITY

An individual or the community collectively can put together funds for the biodigester

PRIVATE FINANCE

Finance from companies or banks

PHILANTHROPIC FINANCE

From charity organizations that can provide grant funding

PUBLIC FINANCE

Government support schemes for biodigesters, including financial assistance

CARBON FINANCE

Accessing carbon credits and financing for renewable energy projects

FINANCIAL MODEL

How will revenues be collected and shared, and over how long

INDIVIDUAL OR COMMUNITY

- The **household or community** may be able to cover the initial capital and operating costs on their own

- Challenges include how to **share** the costs and benefits

- If informal agreements are involved, this could increase the risk of **mismanagement**; guidelines should be provided on how to overcome conflict and what to watch out for, depending on the local context

PRIVATE FINANCING

- This can include private companies through various means, or banks, including micro-finance institutions

- They may provide **grants or low-interest loans**

- For larger scale projects, debt (i.e. loans) or equity (i.e. partial ownership) financing may be considered

PUBLIC FINANCE

- Local, regional and national governments may have various **programs** that can support technologies such as biodigesters

- **Grants or low-interest loans** may be provided

- Development finance institutions or international agencies may also have similar programs

- **Cooperation** with local NGOs may help in accessing this finance

PHILANTHROPIC FINANCE

- Large organizations may have philanthropic arms that can provide funds for **small scale projects**

- This may be in the form of **grants**

- **Collaboration** with NGOs can help access this finance

CARBON FINANCING

- Certain biodigester projects may be eligible for carbon financing
- However, a **clear plan and report** about its benefits must be presented
- **Partnerships** with NGOs and development finance institutions can help access this source of financing, as it is relatively new and not well developed

FINANCIAL MODELS

- The project can be implemented in several ways, with different ways of collecting or sharing revenue

- For example, **pay-as-you-go models** can be considered, where users pay a fee for the use of the biodigester

- **Mobile payments** can make transactions easier and more transparent

- Larger-scale projects may require complex **contracts** and **guarantees**, especially if electricity is generated and sold to the grid (if possible)

OPERATION AND MAINTENANCE

Q: How can I ensure the safe operation of my biodigester?

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SAFETY CONCERNS

BIOGAS HAZARDS

Biogas contains methane and is flammable which may pose certain risks

ELECTRICITY HAZARDS

Only if electricity is being generated on-site

OTHER RISKS

Other safety risks associated with the biodigester

BIOGAS HAZARDS

- **Asphyxiant risk**: Methane, hydrogen sulfide, and carbon dioxide can be dangerous at high quantities in an enclosed space.
  - *Mitigation:* Use monitors and check for leaks regularly, especially in spaces that are not well-ventilated. Make sure there is plenty of ventilation in kitchens.

- **Explosion risk:** Methane can ignite if there is a flame or other ignition source near it
  - *Mitigation*: Avoid open flames including smoking near the biodigester

ELECTRICAL HAZARDS
(IF ELECTRICITY IS GENERATED)

- **Electric shocks** due to the equipment present
  - *Mitigation*: Avoid contact with the equipment; turn to a licensed professional in case of any repair issues

- **Electrical fires** due to some malfunction
  - *Mitigation*: Switch off the electricity to the facility. Use appropriate fire extinguishers. Do NOT use water if unsure that it is an electrical fire.

OTHER SAFETY HAZARDS

- **Drowning and falling** into the biodigester
  - *Mitigation*: Make sure openings that can present a falling hazard, especially for children, are sealed or there is fencing around it. If working near a large tank, make sure there is someone nearby.

- **Burns** can be a risk in larger facilities with heat exchangers, boilers, pumps etc.
  - *Mitigation*: Clearly label hot surfaces and ensure there is an easily accessible first aid kit.

GENERAL PRACTICES

These are good safety practices that are easy to follow

MAINTENANCE PRACTICES

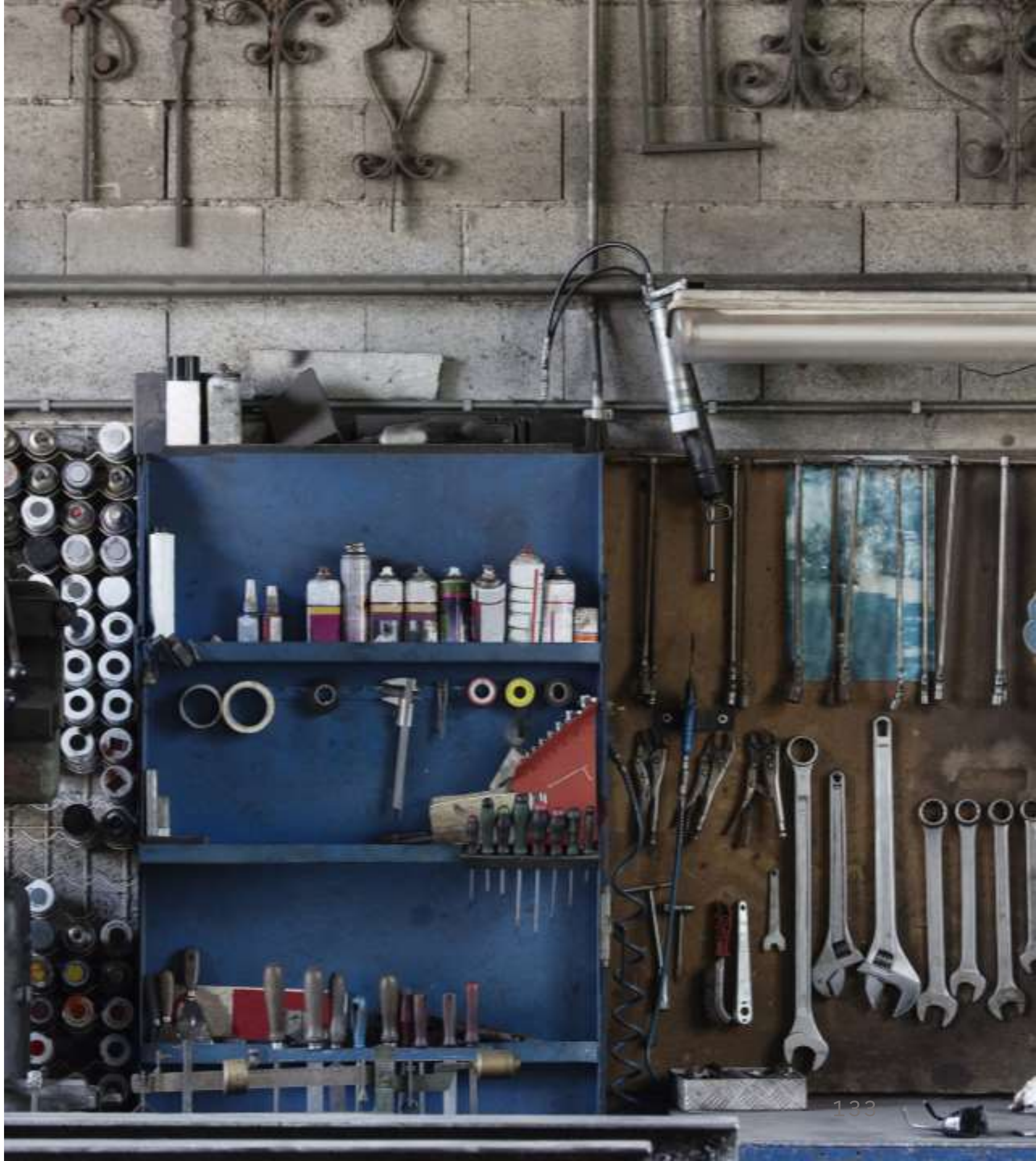
If maintenance is required, these practices can ensure the smooth functioning of the biodigester

SAFETY PRACTICES

These can help avoid the risk of injuries or accidents

GENERAL PRACTICES

- **Remember: temperature, air, and quality organic material are the 3 important parameters. If changes are needed, they should be done gradually and in moderation.**
- Ensure that there is sufficient **feedstock** and willingness to implement such a project in the community
- Take advantage of **training** opportunities and awareness campaigns; connect with local government resources and NGOs
- **Innovate**—local solutions can help overcome constraints
- Consider the availability of **water**, as it is essential for operating a biodigester
- **Situate** the biodigester (in households) close to the kitchen to reduce the amount of piping etc. required



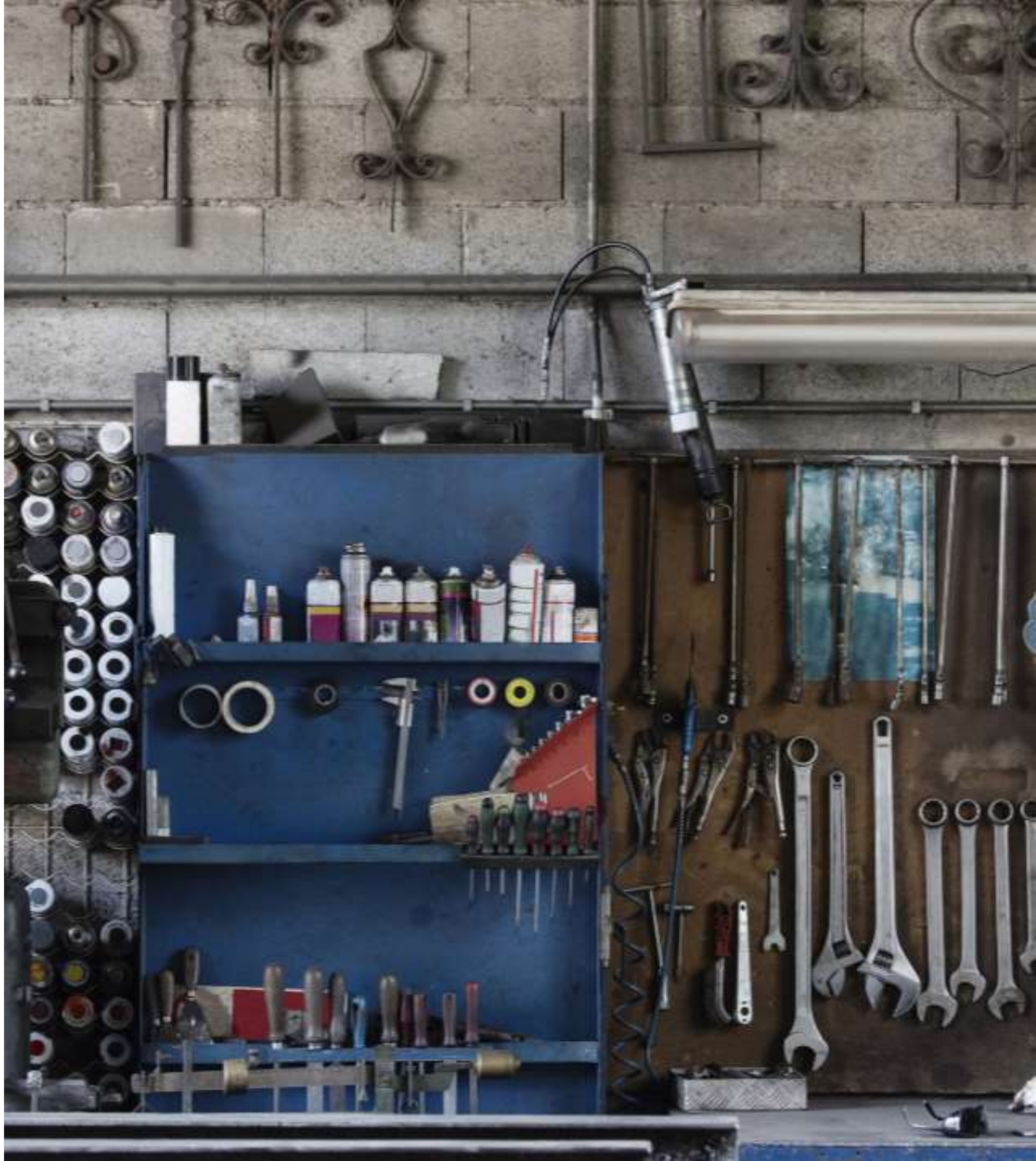
GENERAL PRACTICES

- **Clean** the mixture before use, removing large amounts of straw, stones etc. Be careful about any chemicals getting in e.g. cleaning solutions, medicines etc.

- Do NOT use **very dry or old manure, or a very wet mixture**. For cow dung, a 1:1 or 2 ratio to water should be used. Use a stick—if the solid matter doesn't stick, there is too much water.

- **Avoid metals** in the construction of pipes, chamber etc.—cement and plastic are preferred

- **Financial** aspects are important—see what ownership and revenue models are most appropriate for the community



MAINTENANCE PRACTICES

- **Leaks** are the biggest issue. Check for them regularly, using a soap and water mixture. Check the pipes, valves etc. monthly or even weekly.

- **Water** should be **drained** regularly. Its presence can affect the pressure and the quality of the gas and flame.

- **Acidity** is a common problem in the mixture. Some lime can help bring back pH levels to neutral.

- **Cleaning** is important. The overflow opening should especially be cleaned regularly to avoid blockages.

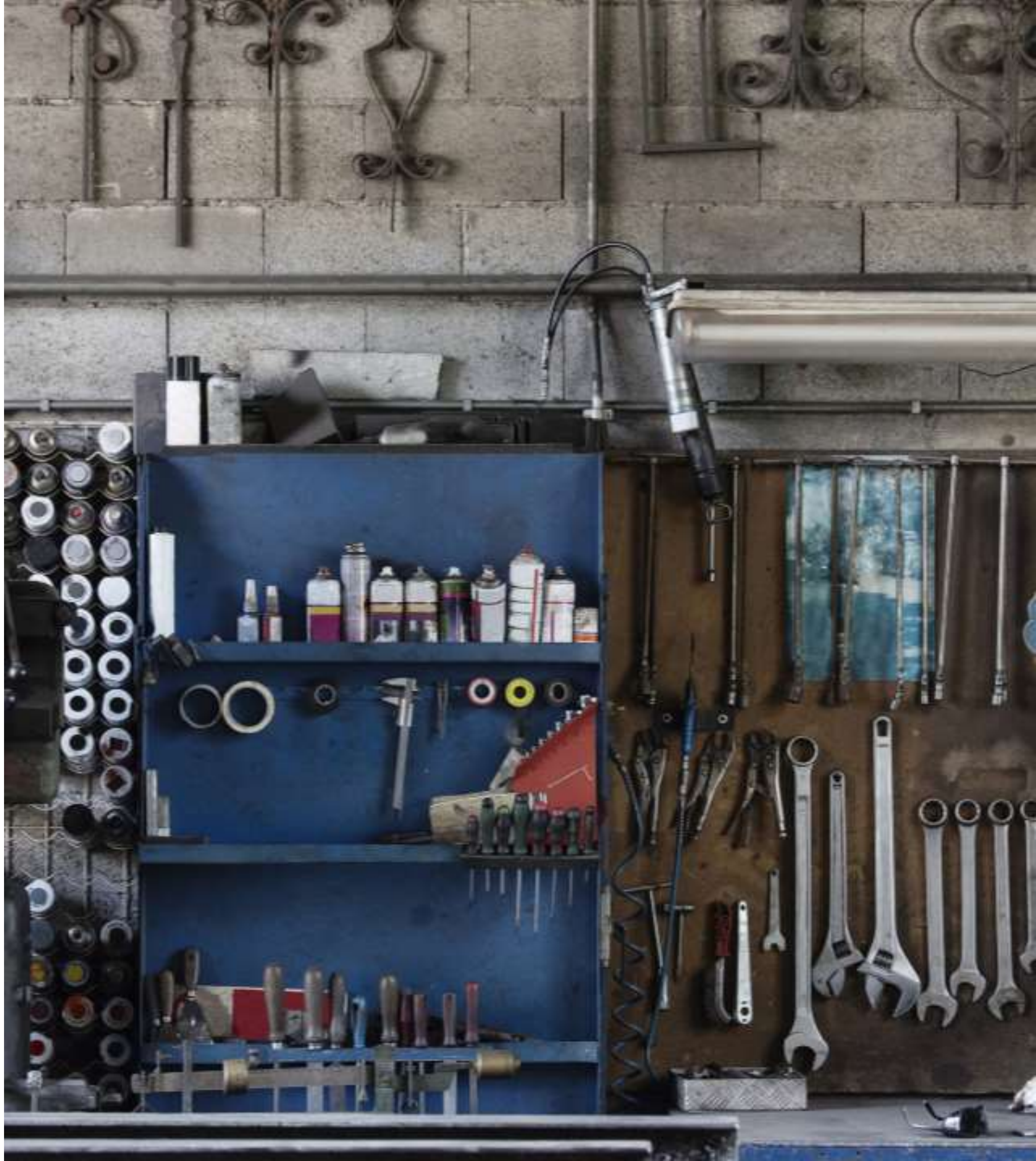
- Pay attention to the **flame**—if it is orange, or does not burn well, it is a sign that something is wrong with the mixture/composition.

MAINTENANCE PRACTICES

- **Empty** the digester every 18 months or so and clean out any sludge/residue at the bottom

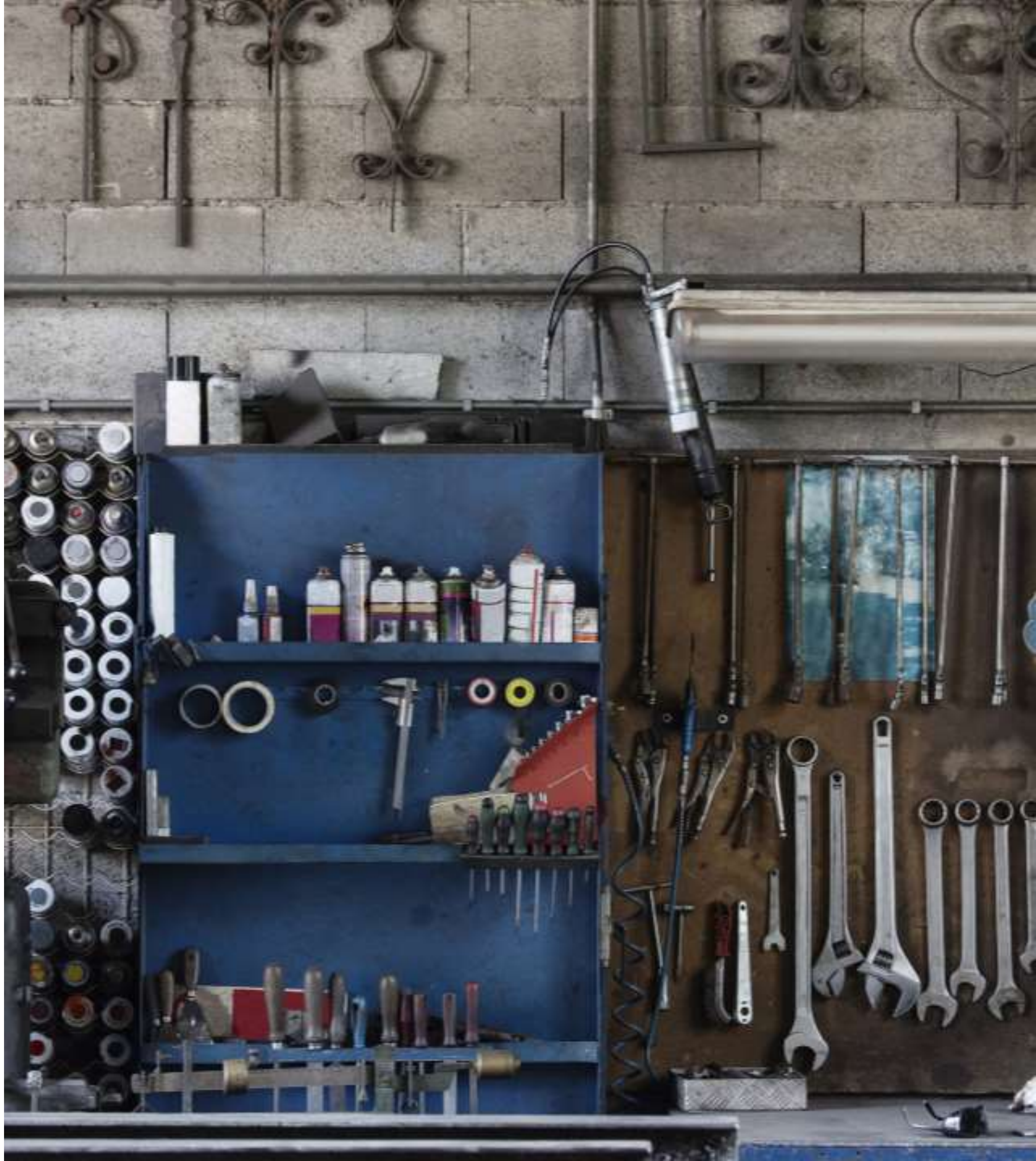
- At times, a layer of **scum** can form on top that can affect the quality of gas. This should be broken up with a rod periodically. The feedstock should be examined if there are impurities.

- Understand the **maintenance needs** at the beginning, including the need for spare parts etc.



SAFETY PRACTICES

- **Avoid** open flames or cigarettes near the biodigester
- **Avoid** any heavy equipment e.g. tractors on top of the biodigester
- **Cover** any large openings to avoid accidental falls
- Regularly **monitor** the pressure from the biodigester to avoid leakages or damage and optimal operation



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