
Biomass

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Content

Introduction

- Transforming organic matter into renewable energy
- From trash to electricity, heat & biofuels
- Key role in the global energy transition

Context

- Biomass = organic material (plants, residues, waste)
- 60% of renewable energy in Europe comes from biomass
- Used for electricity, heating, and transport fuels

What is biomass ? : Definition & history

Definition

According of encyclopedia, **Biomass** is the **total mass of biological material,** both living and recently dead, in a defined area. In an ecological context, biomass often **refers to the amount of biological material** in different parts of an ecological pyramid or in different ecological communities. In terms of **energy supply,** biomass refers to **plant material that is grown as a source of energy.**

Source:https://www.encyclopedia.com/earth-and-environment/ecology-and-environmentalism/environmental-studies/biomass

History of Biomass energy

Traditional Biomass (Prehistory – 19th Century)

Prehistory (Hundreds of Thousands of Years Ago): The discovery of fire by early humans marks the beginning of biomass use, relying on wood and later charcoal for heating, cooking, and light.

Ancient Civilizations: Wood, crop waste, and dried animal dung were the primary fuels for societies globally, a reliance that continued for millennia.

17th–18th Century: Early scientific understanding of organic matter decomposition begins.

- **1600s:** Jan Baptist van Helmont discovered that flammable gases could be produced from decaying organic matter.
- **1776:** Count Alessandro Volta discovered methane emissions from naturally occurring organic sites.

The History of Biomass: The Big Picture | Impactful Ninja

History of Biomass energy

Modern Biomass and Bioenergy (19th Century – Present)

The 19th century saw the development of technologies to convert biomass into cleaner, more versatile fuels like ethanol and biogas, setting the stage for modern bioenergy.

19th Century:

- Ethanol gained early traction as a fuel source.
- Rudolf Diesel invented the diesel engine in the 1890s, which he intended to run on a variety of fuels, including vegetable oil.

20th Century:

- Early 1900s: Henry Ford's Model-T car was designed to run on ethanol, though cheap gasoline quickly replaced it.
- World Wars (1914–1945): Petroleum shortages during the wars led to temporary surges in interest and use of biomass fuels (ethanol, wood gas).
- 1970s Oil Crises: The energy crises triggered a renewed, sustained interest in developing renewable alternatives like modern biomass and biofuels, leading to significant R&D.

21st Century:

- Focus shifts to advanced biofuels (second and third generation) from non-food sources (like cellulosic biomass and algae) and highly efficient power generation (combined heat and power systems).
- Biomass becomes an integral part of global strategies for decarbonization and sustainable waste management.

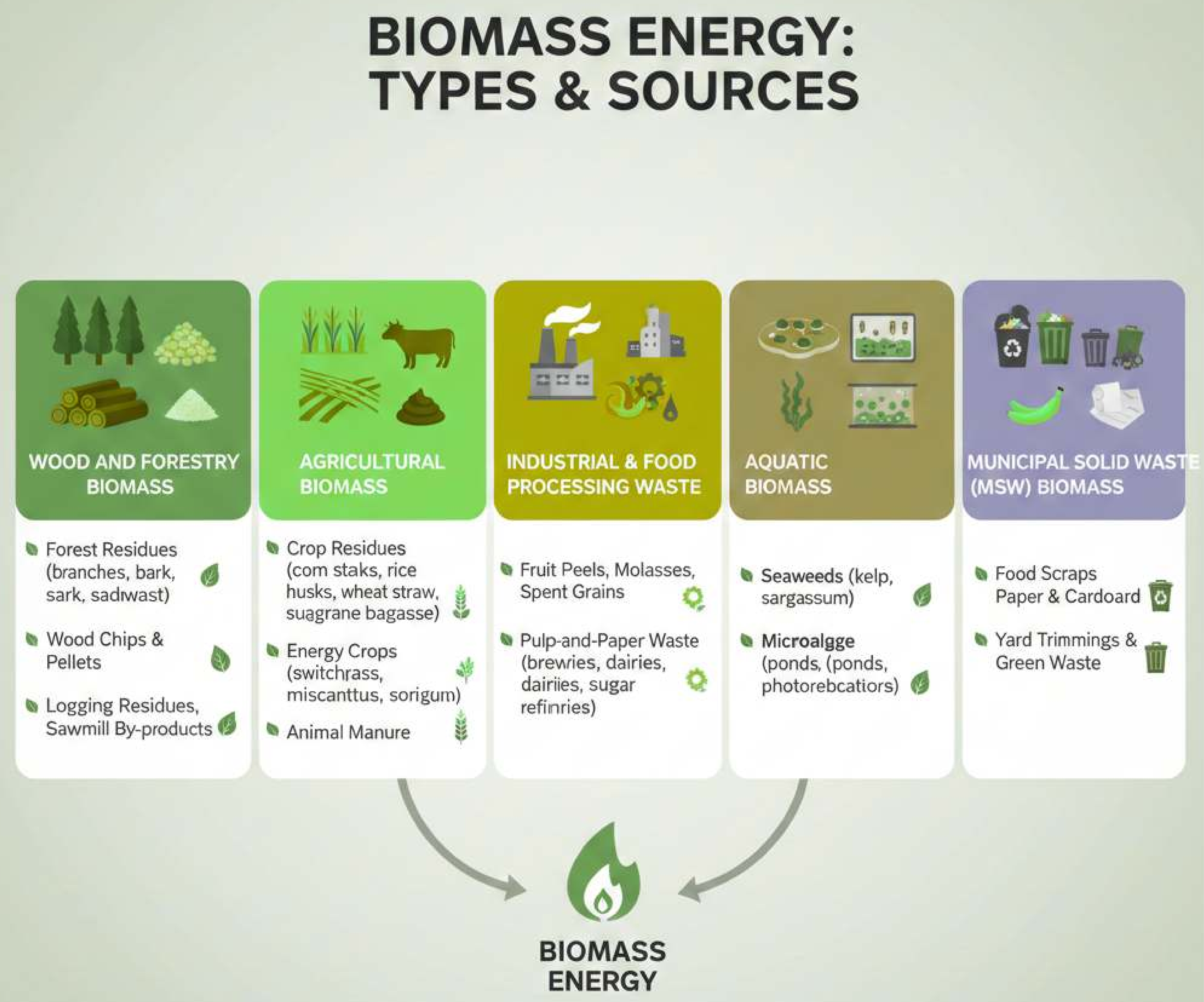

HISTORY OF BIOMASS
Biomass has been around since man discovered fire, but was not thought as a fossil fuel replacement until the 1970s
Biomass was used as a lamp fuel during the 1800s
The U.S used biomass in the form of wood for
91%
of its energy consumption
The first Model-T Fords used ethanol for fuel up until 1908
Piktochart


A NEW ENERGY ERA
21ST CENTURY
SUSTAINABLE, GREEN BIOENERGY
CHARCOAL ERA
PRE 19TH CENTURY
COAL ERA
19TH CENTURY
PETROLEUM ERA
20TH CENTURY

Conclusion: History of biomass

- Biomass has evolved from basic discoveries (methane from manure, fermentation) to major engine innovations powered by biofuels.
- Periods of crisis (the 1970s energy crisis) repeatedly revived global interest in biomass as an alternative to petroleum.
- Scientific advances in microbiology and engineering led to modern biogas plants and biodiesel technologies.
- Since the 1980s, biomass has become a structured industry, supported by policies and large-scale production.
- Today, biomass remains a critical global energy source, used by billions of people and playing a major role in renewable energy systems.

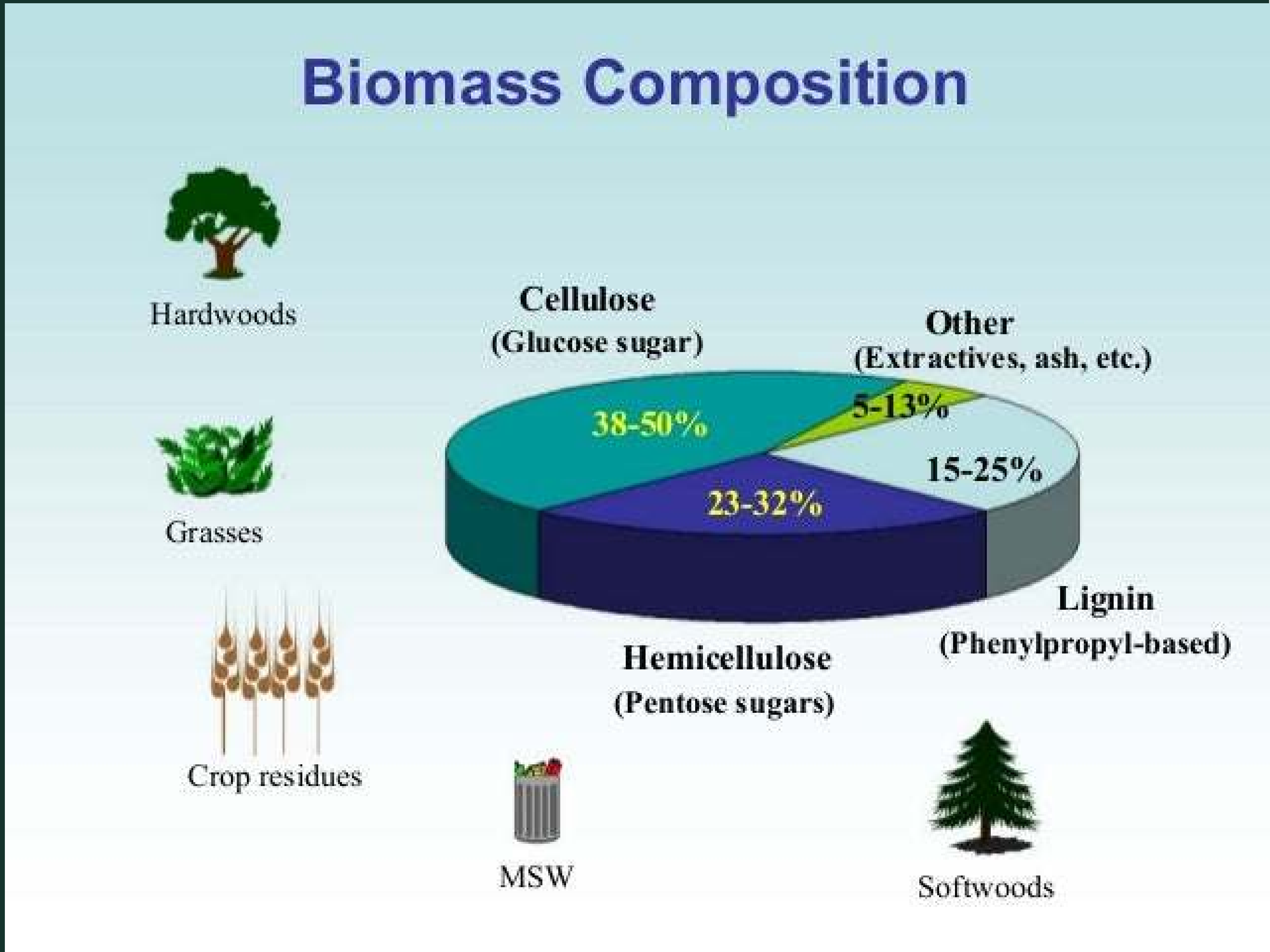
Type and sources of biomass



General Characterization of Biomass

I. Biochemical Composition

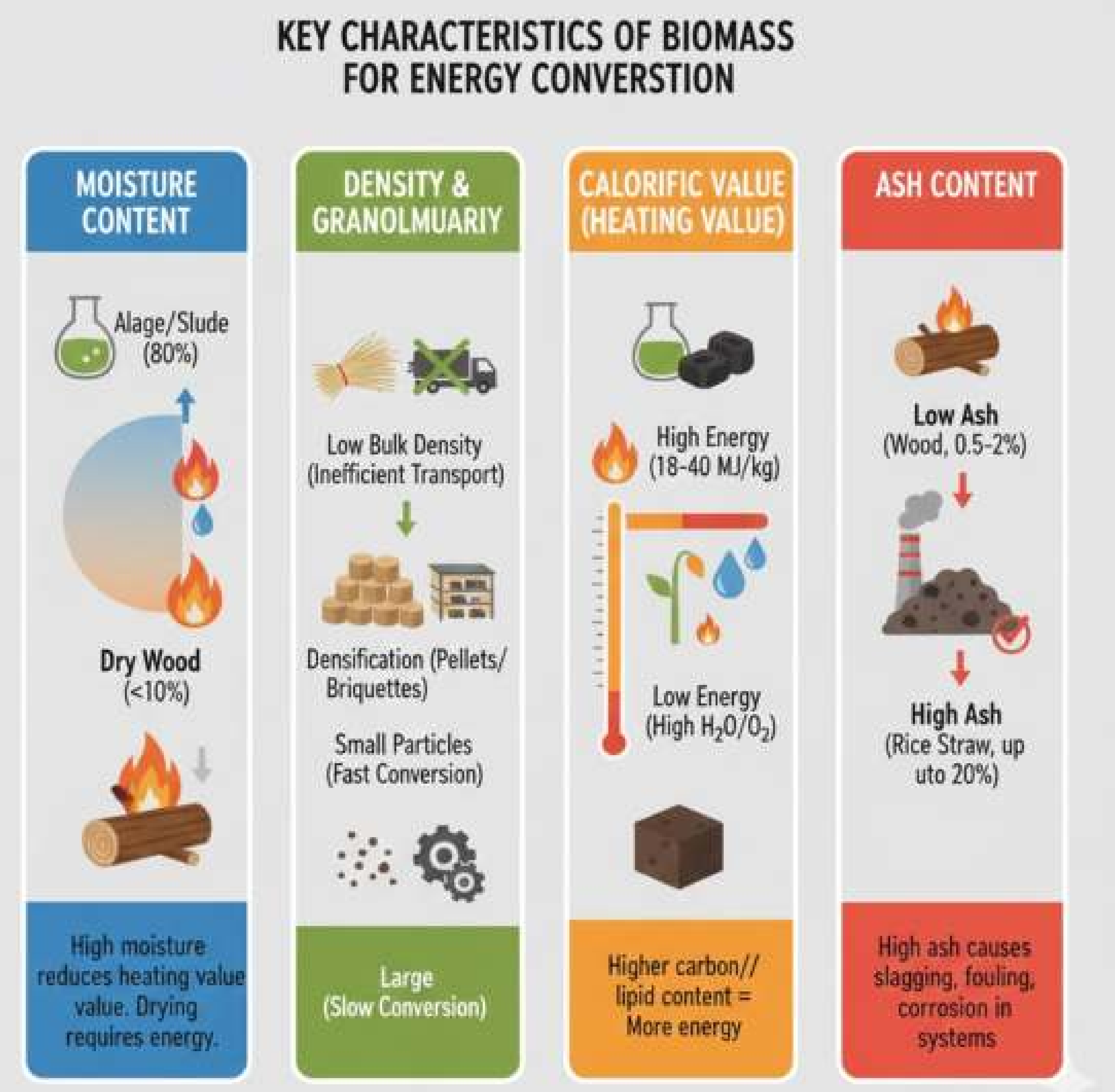
- **Carbohydrates** form the main fraction of most biomasses.
- Structural sugars: c**ellulose and hemicellulose** dominate in **lignocellulosic** materials.
- **Storage sugars**: starch and simple sugars (glucose, sucrose) appear in crops like cereals or sugarcane.
- **Lignin** is the aromatic polymer that gives rigidity to plant biomass. It is abundant in wood and agricultural residues, but almost absent in starchy crops and microalgae.
- **Proteins** vary widely depending on the biomass: very low in wood, but extremely high in some microalgae. Their nitrogen content matters for evaluating potential NOx emissions during thermal conversion.
- **Lipids** (oils and fats) are key in biomasses used for biodiesel production, especially oilseeds and microalgae.



General Characterization of Biomass

2. Physicochemical Properties

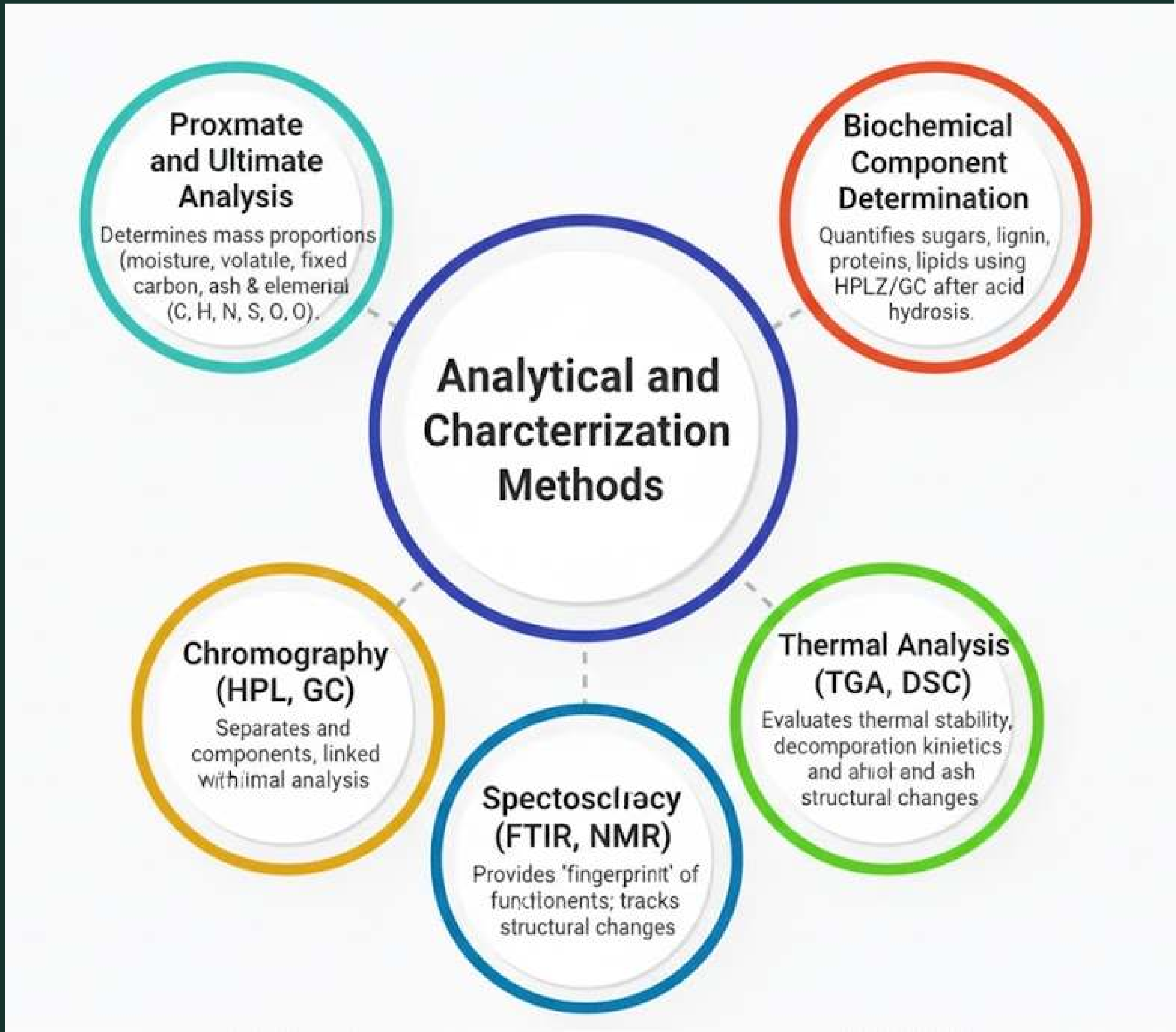
- **Moisture Content:** Biomass can contain from less than 10% moisture (dry wood) to over 80% (algae, sludge). High moisture reduces the heating value and often requires energy-intensive drying before conversion.
- **Density & Granulometry:** Raw biomass often has low bulk density (example straw), making transport and storage inefficient. Densification (pellets, briquettes) improves logistics and feeding into reactors. Particle size affects surface area and influences heat and mass transfer during processing.
- **Calorific Value (Heating Value):** Biomass rich in carbon or lipids has a higher energy content (≈18–40 MJ/kg). Materials with high moisture or oxygen content have lower heating values.
- **Ash Content:** Represents the inorganic residue after combustion. Low in wood (0.5–2%) but very high in residues like rice straw (up to 20%). High ash levels can lead to slagging, fouling, corrosion, and other operational issues in thermal systems.



General Characterization of Biomass

3. Analytical and Characterization Methods

- **Proximate and Ultimate Analysis:**
  - Proximate Analysis: Determines the mass proportions of moisture, volatile matter, fixed carbon, and ash. It is crucial for predicting the combustion and pyrolysis behavior of the material.
  - Ultimate Analysis (CHNS-O): Quantifies the elemental content of Carbon, Hydrogen, Nitrogen, Sulfur, and Oxygen. This is essential for mass and energy balances and for evaluating potential pollutants (N, S) .
- **Biochemical Component Determination:** Standardized acid hydrolysis protocols, followed by quantification using HPLC or GC, are used to determine the exact contents of monomeric sugars (structural and reserve), insoluble and soluble lignin, proteins, and lipids .
- **Thermal Analysis (**TGA, DSC): These techniques are employed across all biomass types to evaluate thermal stability, decomposition kinetics, and ash fusion temperatures, which are critical for reactor design .
- **Spectroscopy** (FTIR, NMR): They provide a "fingerprint" of functional groups and chemical bonds. FTIR is particularly useful for tracking structural changes in lignin and carbohydrates after chemical or physical pretreatments .



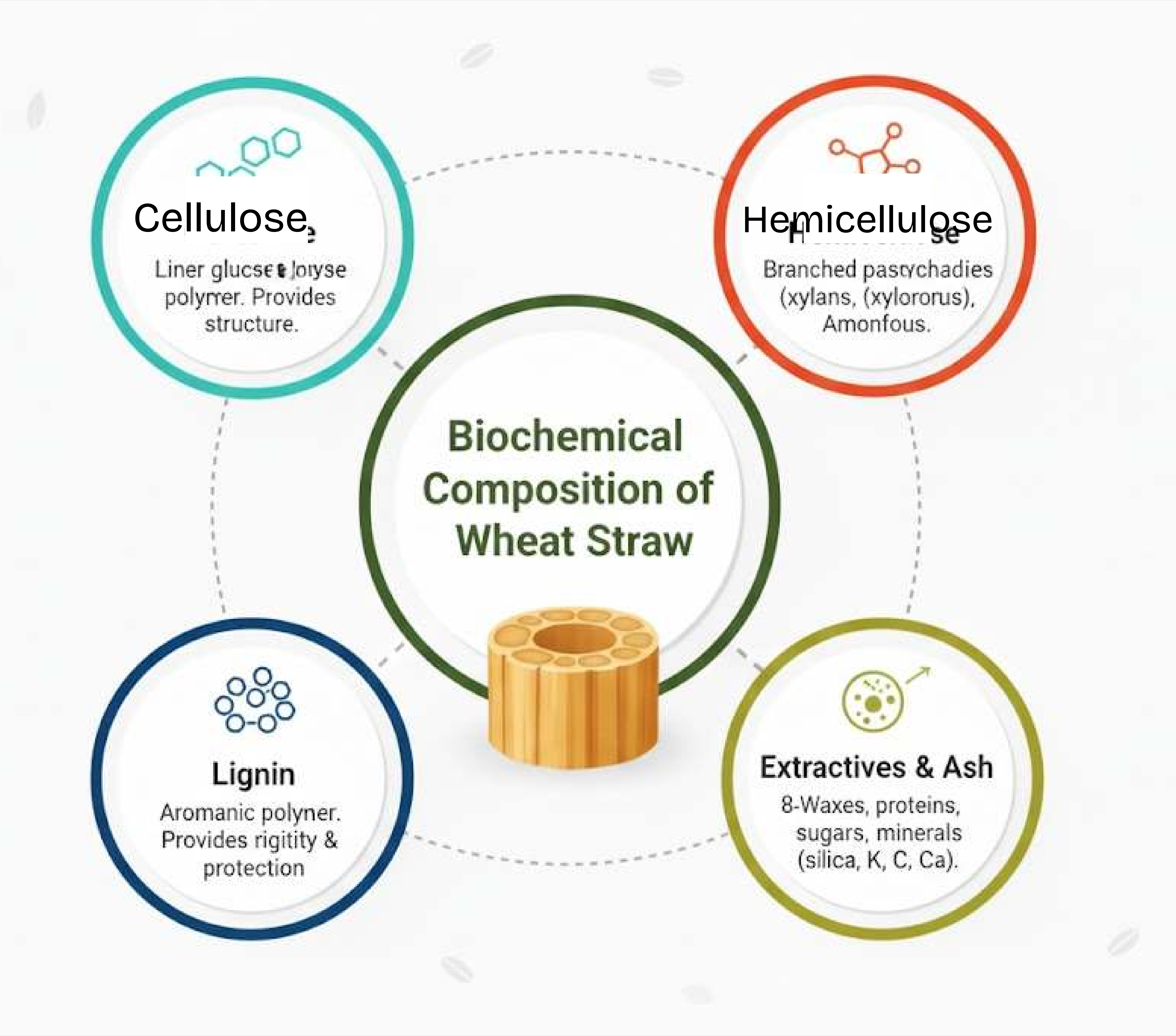
4. Specific Biomass for Experimental Studies - Wheat Straw

Composition: Its moderate lignin content and high carbohydrate ratio (cellulose and hemicellulose) make it a prime candidate for the production of fermentable sugars (bioethanol) .

Cellulose: 35% – 40%

Hemicellulose: 20% – 25%

Lignin: 15% – 20%



BIOMASS CONVERSION PROCESS

The biomass conversion process takes place in several successive stages. These stages vary depending on the processes chosen, but they generally include:

1

PRETREATMENT

A crucial step for improving process efficiency. It may involve mechanical or chemical processes to reduce the size of biomass particles.

2

CONVERSION

Depending on the process, this can be thermal, chemical, or biological. For example, gasification transforms biomass into syngas.

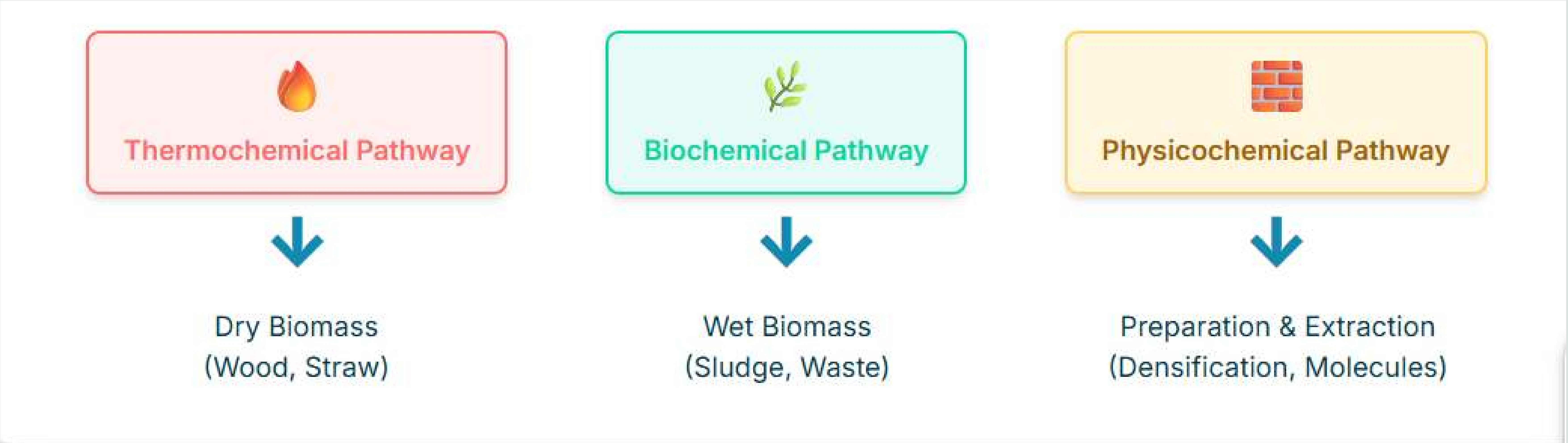
3

REFINING

This involves purifying or converting intermediate products into final products, such as biodiesel or ethanol.

Main conversion processes

Biomass, a renewable organic resource, can be transformed through three distinct channels, each adapted to a type of resource and a target end product.

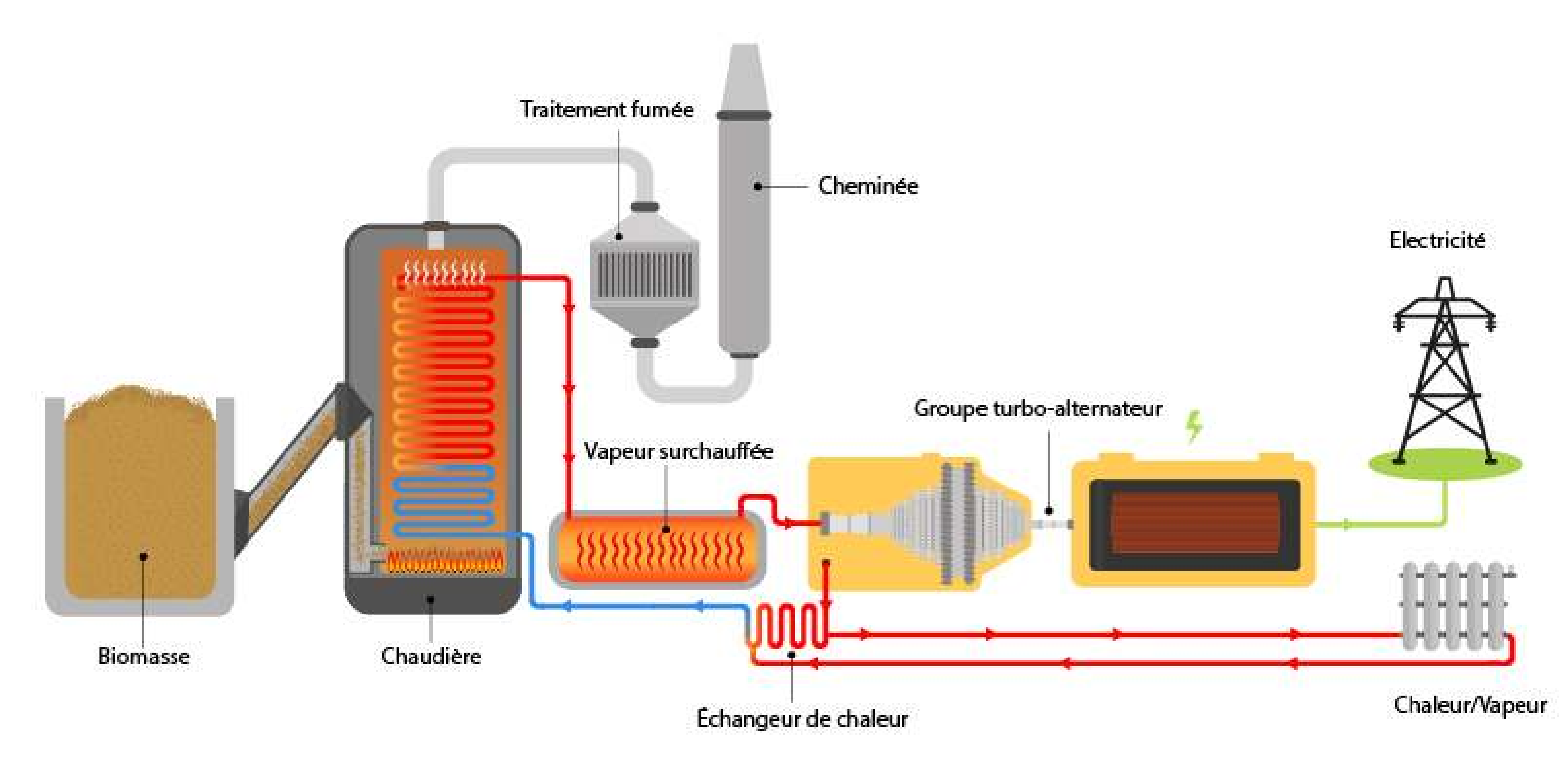


Thermochemical Processes

The thermochemical pathway uses heat to decompose biomass in the absence or controlled presence of oxygen. It is particularly suited for dry biomass.

Combustion

This is the simplest and oldest process. Biomass is burned directly to produce heat, which can be used for heating or to generate electricity via a steam turbine.



Thermochemical Processes

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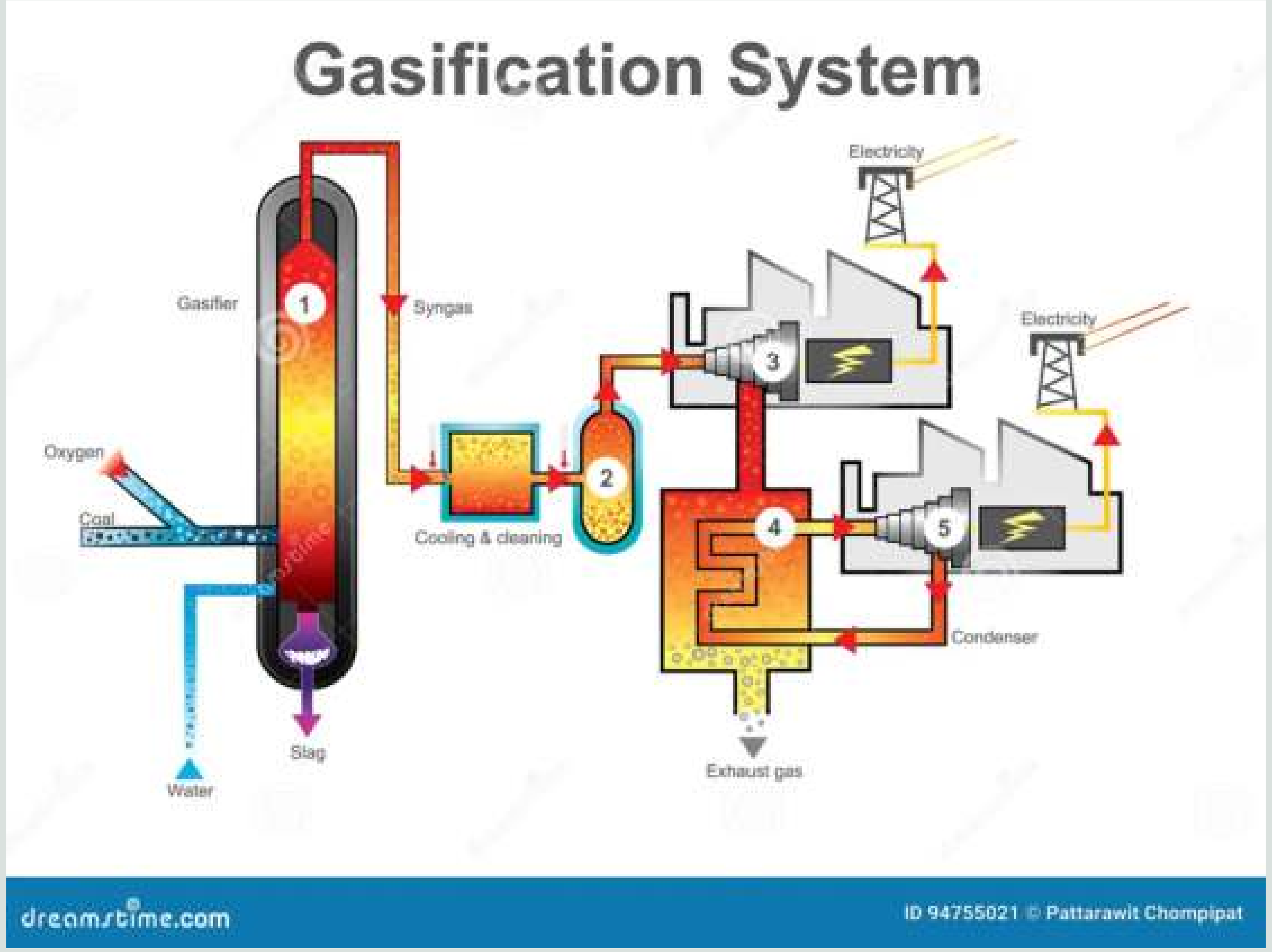
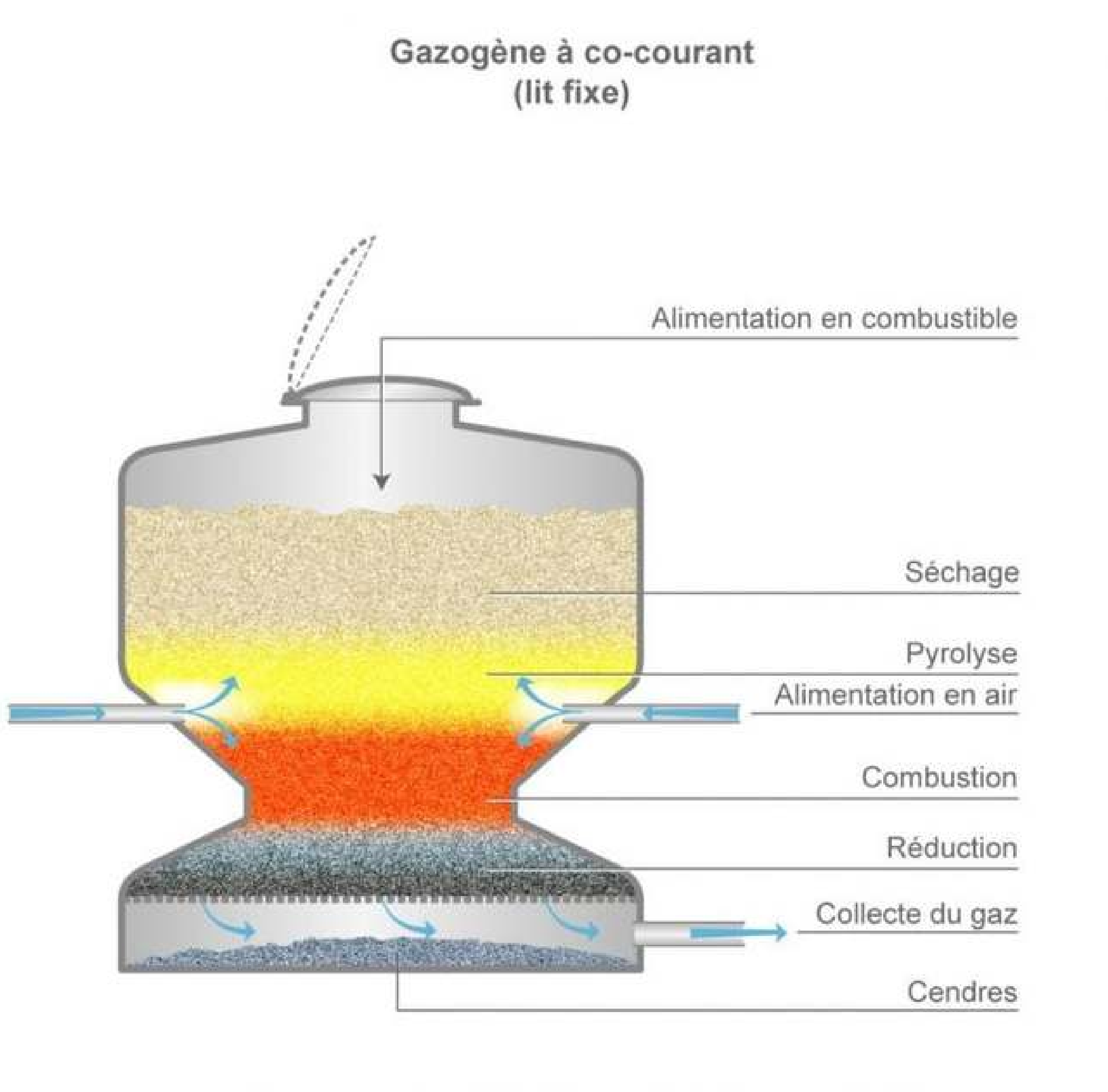
Gasification

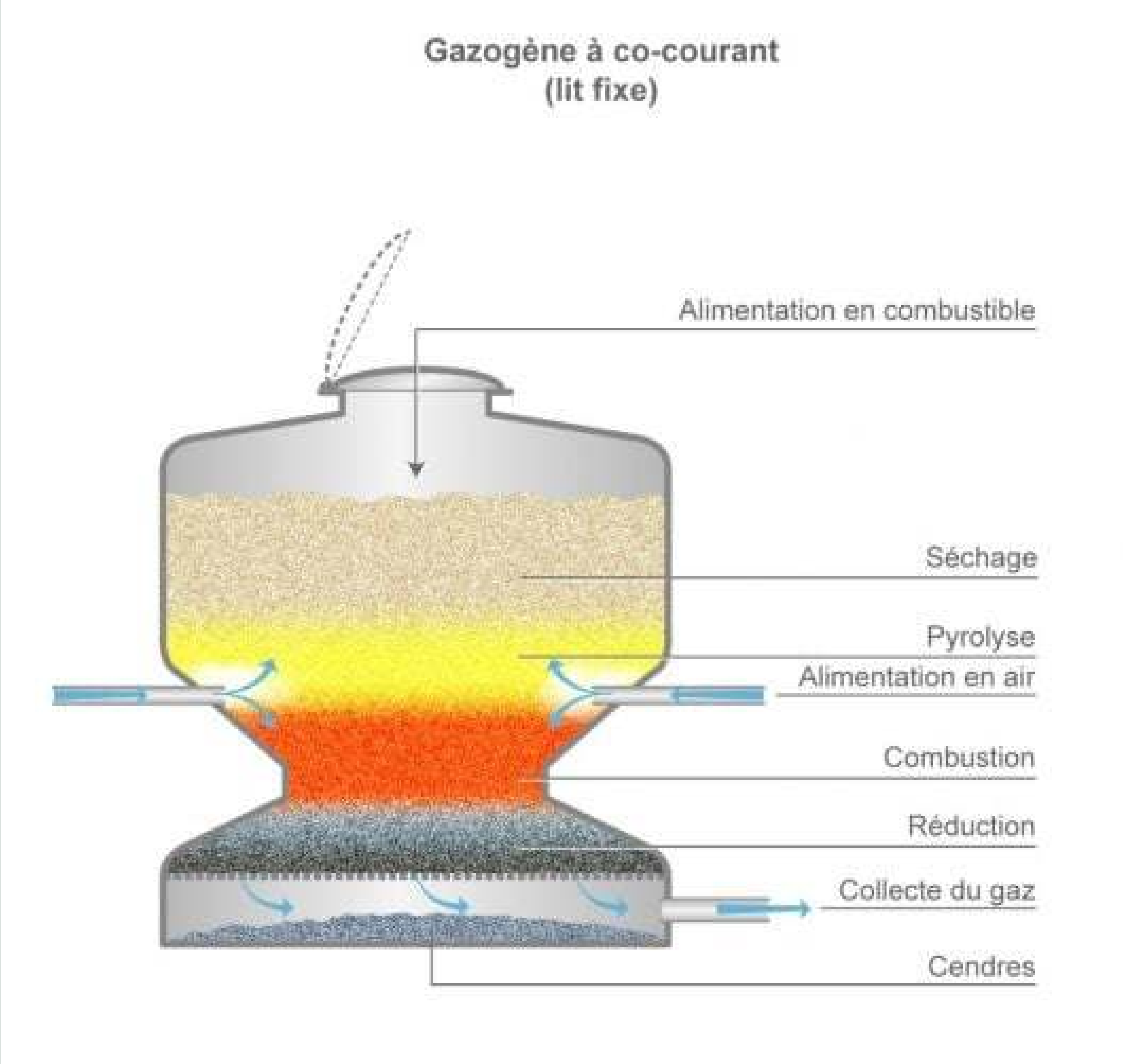
It is an incomplete combustion, at high temperature and with a limited supply of oxygen. It transforms solid biomass into a combustible gas called syngas (mixture of CO, H_2, CH_4).

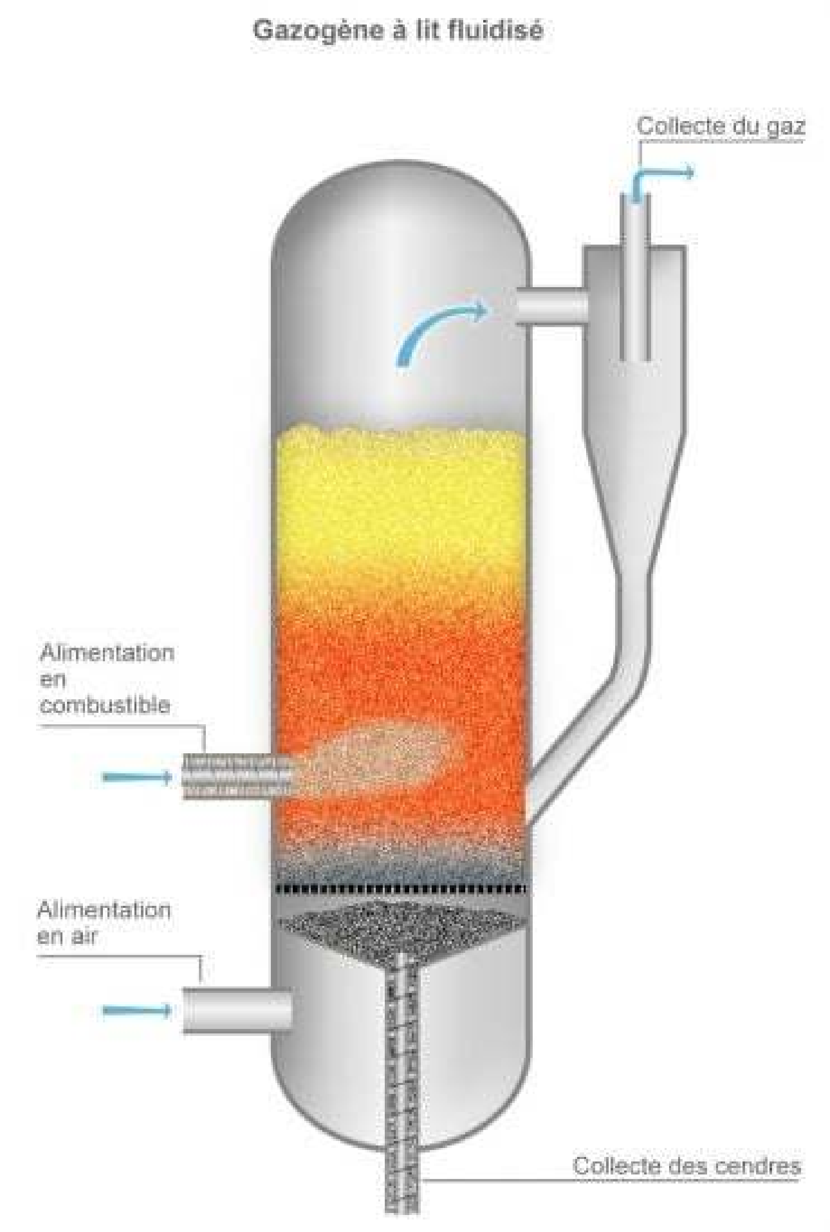


The different gasification processes

The choice of a type of process is guided by the size of the installation, the carbonaceous solid fuel used, the use of the gas produced and the maturity of the technologies.





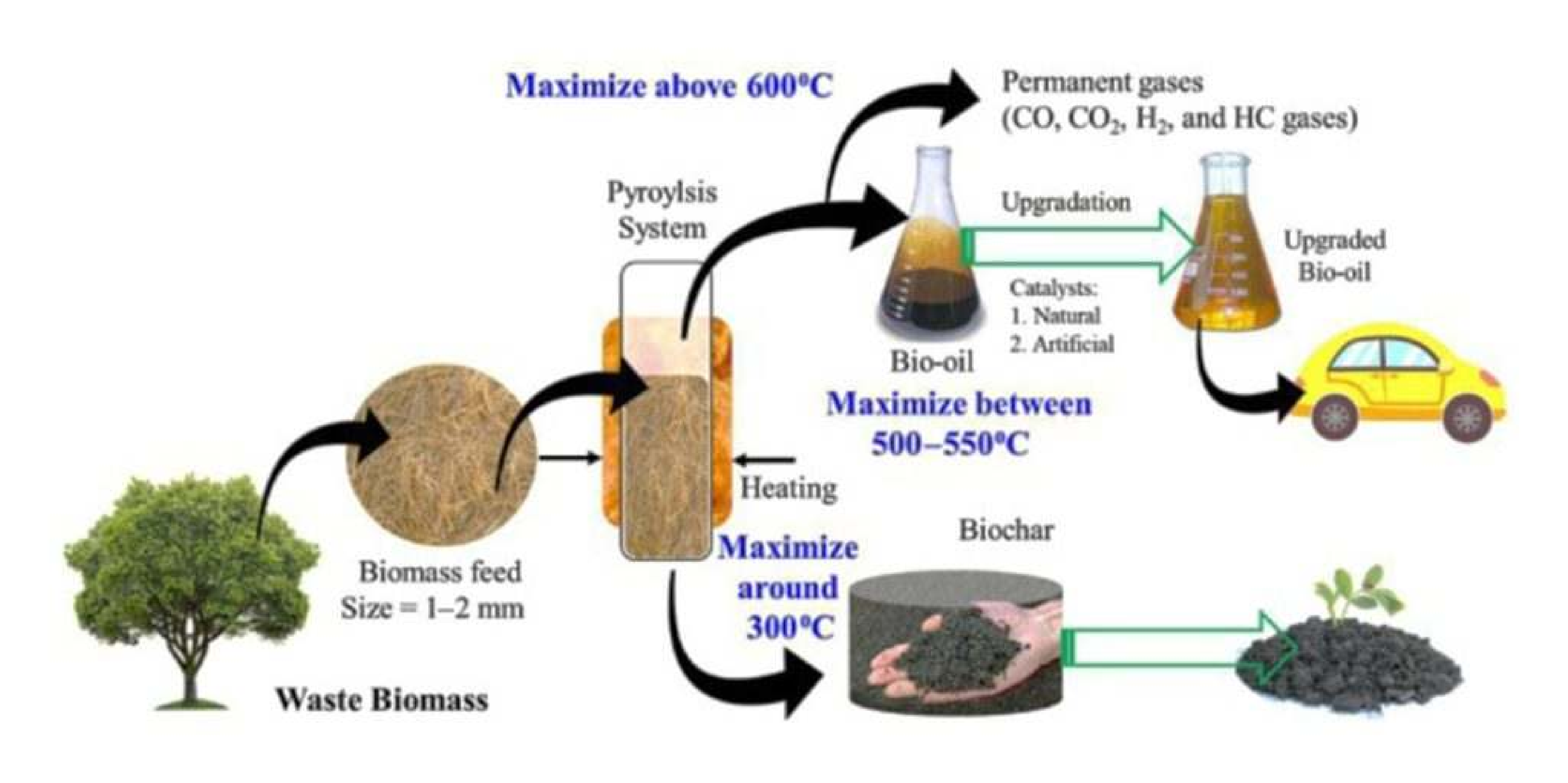


Thermochemical Processes

The thermochemical pathway uses heat to decompose biomass in the absence or controlled presence of oxygen. It is particularly suited for dry biomass.

Pyrolysis

Here, biomass is heated in the complete absence of oxygen. It does not burn, but decomposes. With products like Bio-oil (a liquid that can be refined), Biochar, Combustible gas.



Thermochemical Processes

The thermochemical pathway uses heat to decompose biomass in the absence or controlled presence of oxygen. It is particularly suited for dry biomass.

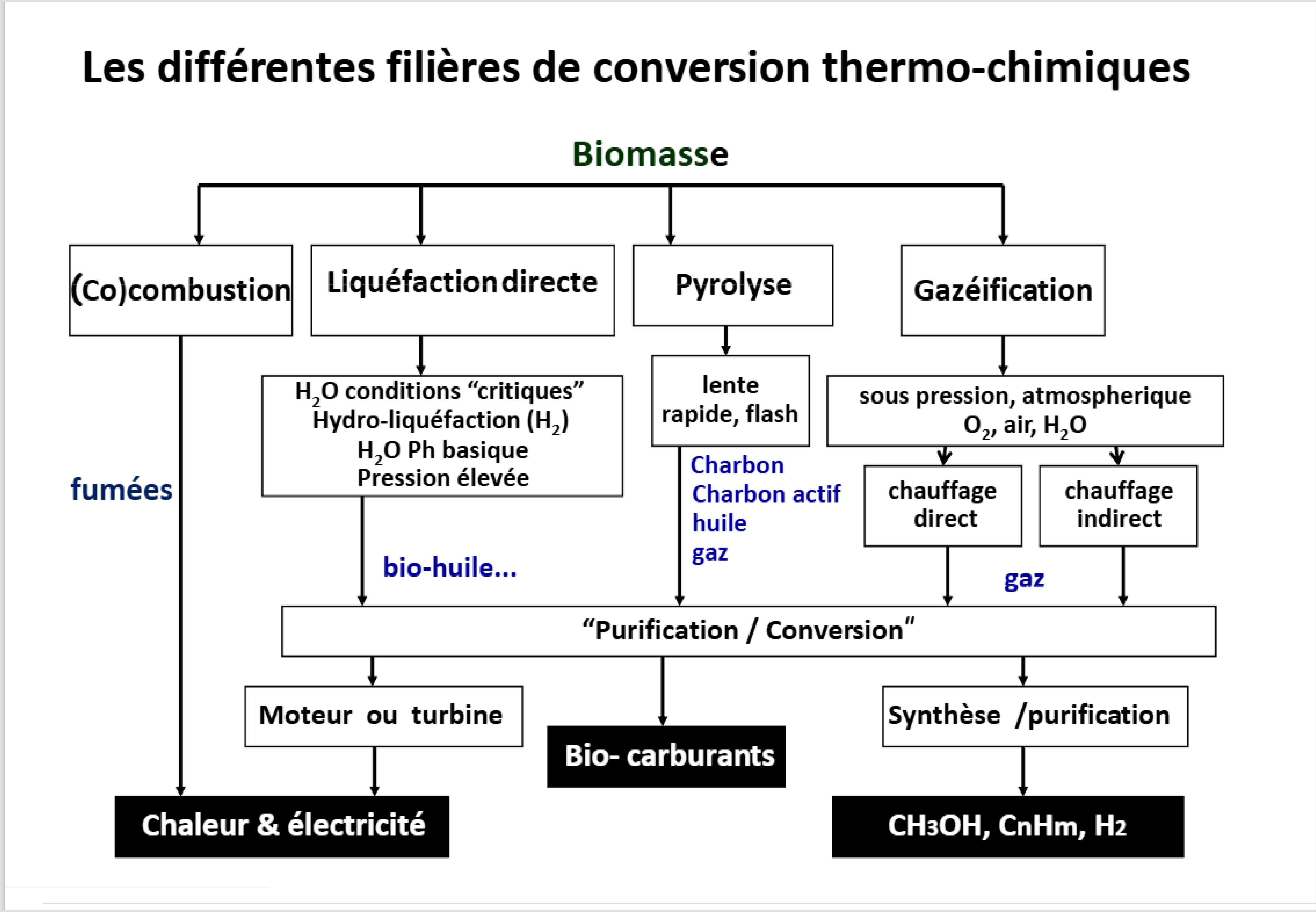
Direct liquefaction

Direct liquefaction involves heating biomass in a liquid medium, often under pressure, to break down its structures (cellulose, hemicellulose, lignin) and produce an energy-dense oil.

Hydrothermal Liquefaction (HTL)

Hydro-liquefaction

Thermochemical Processes



Thermochemical Processes

Conditions opératoires des procédés thermochimiques

Procédé	Température	Atmosphère	Produits	Rendt.
Combustion	> 900° C	O_2 (air)	$CO_2 + H_2O + N_2$ + cendres à traiter	~ 65 %
Pyrolyse	< 700° C	Gaz inerte ou faible pression	charbon + goudrons + gaz (*)	~ 45 %
Gazéification par pyrolyse rapide	> 700° C	Gaz inerte ou faible pression	Gaz (CO, H_2, CH4, C_2H_4 ...) + faibles quantités charbon (**)	~ 75 %
Gazéification	> 800° C	Air ou H_2O vapeur	Gaz (H_2, CO, CO_2, CH_4, N_2) + cendres à traiter	50-60 %

* pourcentages liés aux paramètres de pyrolyse

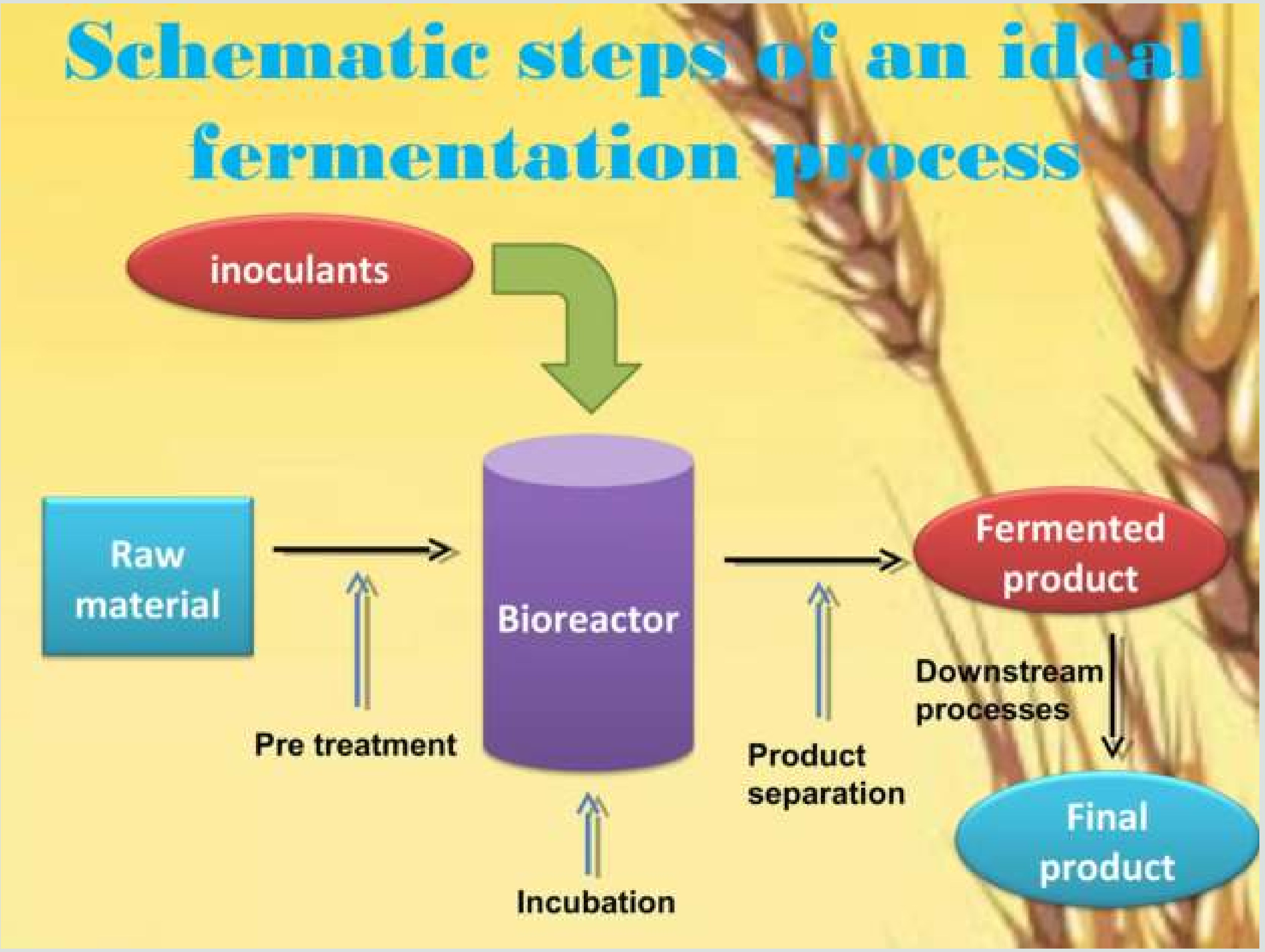
** utilisé pour les procédés autothermiques

Biochemical Processes

Biochemical conversion uses biological reactions to transform biomass. This process is particularly effective for materials rich in sugars and starches. Here are the two main methods of biochemical conversion:

Fermentation

Fermentation is a metabolic process that converts sugars into acids, gases, or alcohol, usually in the presence of yeasts or bacteria. It is a key process for producing biofuel from biomass.



Biochemical Processes

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Anaerobic Digestion

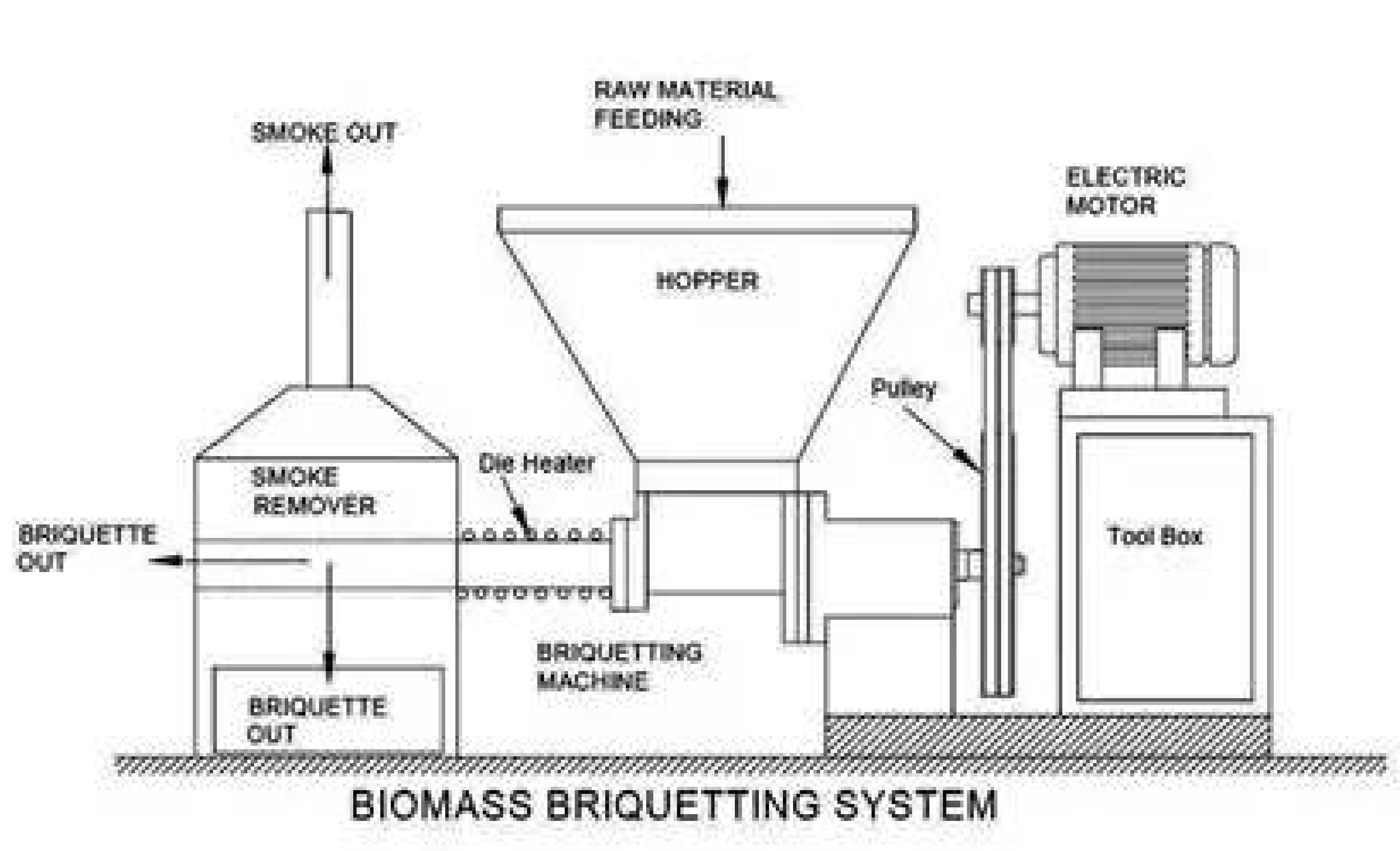
Anaerobic digestion of biomass is a biological process in which microorganisms decompose organic matter in the absence of oxygen to produce biogas, composed mainly of methane (CH4) and carbon dioxide (CO2).

1. Hydrolysis
2. Acidogenesis
3. Acetogenesis
4. Methanogenesis

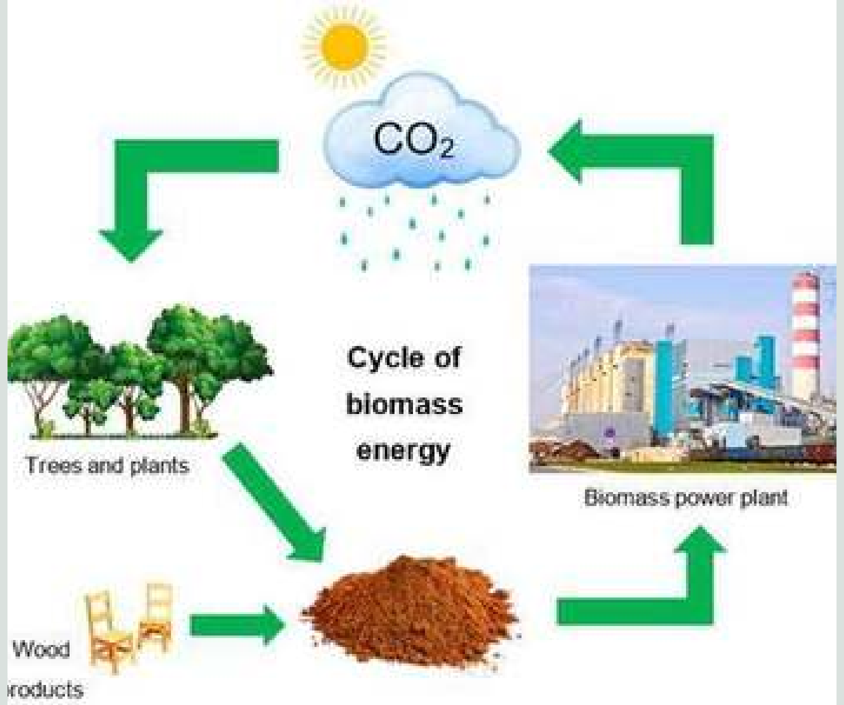
Physico - chemical processes

Briquette/Pelletization

These processes are mechanical pre-treatment techniques that increase the mass density (low to begin with) of solid biomass (sawdust, chips, straw, agricultural residues), making it easier and more economical to handle, store and transport for energy recovery (combustion, gasification).



Energy value of biomass



Biomass energy cost of production

Biomass value in production

ENERGY VALUE OF BIOMASS

Globally, large amounts of biomass are required to produce energy because the energy content of biomass , measured by their calorific value, specifically the **Lower Heating Value (LHV)**, is generally not very high.
The calorific value is a measure of the amount of energy that a fuel or material can release when it is completely burned. There are two types of calorific values:

- **The Higher Heating Value (HHV) and the Lower Heating Value (LHV).**
- **However, we will focus on the LHV because, unlike the HHV, it does not include the energy from water vapor. (1 kWh = 3.6 MJ)**

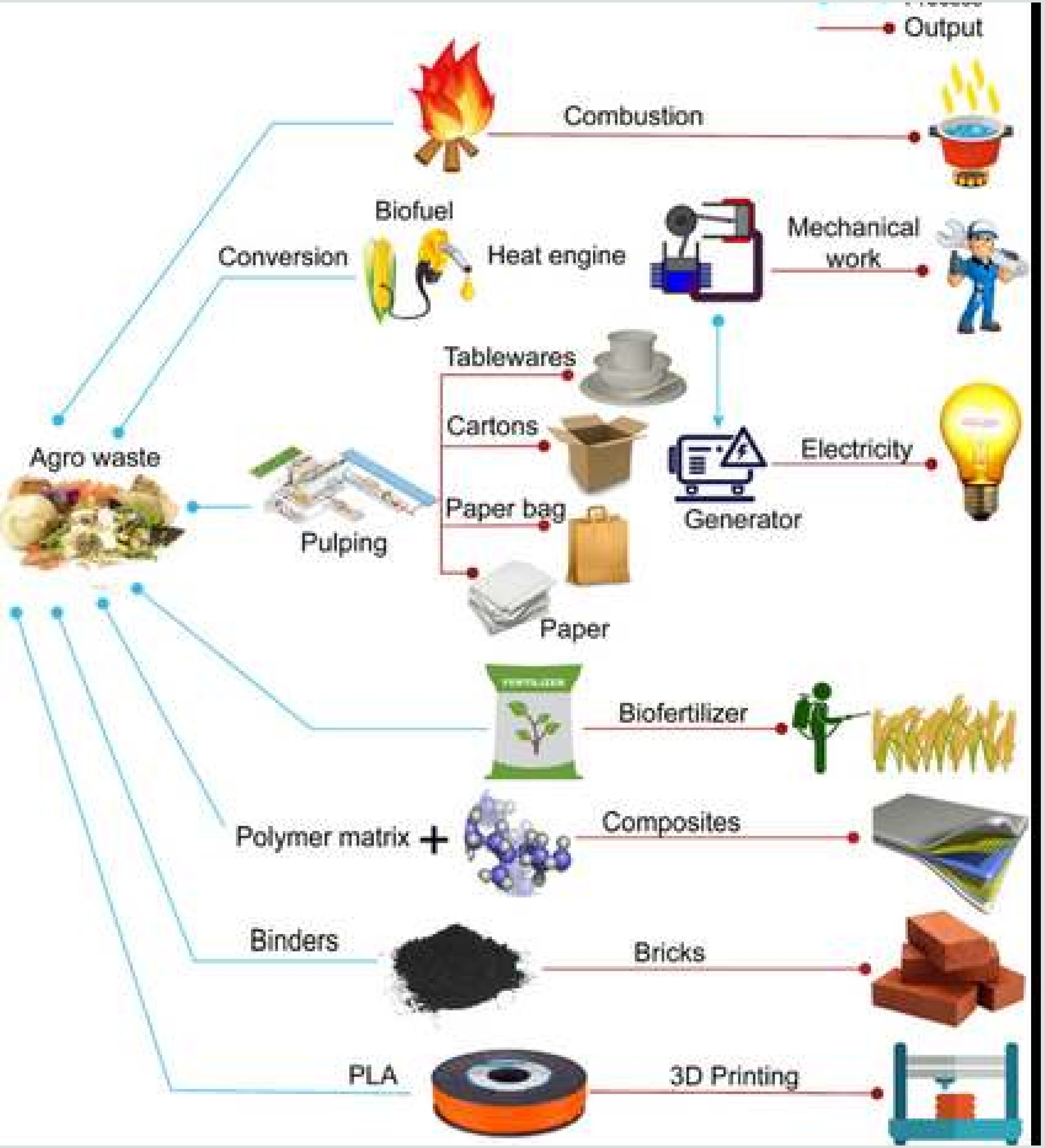
Biomass Type	LVH(Lower Heating Value)
Straw/agricultural residues	around **16MJ**
Raw wood	around **10M**J
Dry wood	around **18MJ**
Biomethane	around **36M**J

BIOMASS ENERGY COSTS OF PRODUCTION

In **biomass energy production**, there are five key factors that greatly influence costs: **feedstock availability and pricing**, **transportation expenses**, **processing technologies**, regulatory frameworks, and the scale of production.

Factors	Description	Associated cost /range
1. Feedstock Availability and Pricing	The cost of the raw material (wood, crops, residues).	Varies between €25 and €43 per ton
2. Transportation Expenses	Costs associated with moving the bulky biomass feedstock from source to the processing plant.	Accounts for 15% to 30% of the total production budget.
3. Processing Technologies	The methods used to convert biomass into energy. The choice influences efficiency, emissions.	Direct Combustion cost: \$0.08 and \$0.15 per kWh (in the U.S. context)

Valuation of Conversion Products



Bioenergy

- **Direct combustion:**

combustion of solid biomass the heat generated is used to produce steam which drives a turbine and an alternator to produce electricity.

- **Gasification**

Biomass is transformed into syngas with heating (CO, H_2, CH_4) due to a lack of oxygen that we can fire in into motor or turbine to get electricity,heat.

- **Biogas**

resulting from the anaerobic digestion of organic matter which produces methane

Biofuels

- First generation bioethanol

Sugar is extracted from plants ,Yeast ferments sugar to produce ethanol that after purification can be mixed with gasoline (E10,E85)

- First generation biodiesel

with vegetable oils reacted with methanol and catalyst we get Biodiesel (fatty acid methyl esters, FAME/FAME) that we mix with diesel (B10,B30)

- Cellulosic bioethanol (2G ethanol)

By converting cellulose into sugar with Enzymatic hydrolysis we get glucose that we ferment to get ethanol.

- BTL (Biomass-To-Liquid)

By Gasification of biomass
we get syngas
that after purification, we transform into liquid to get synthetic diesel

Biochar

from biomass pyrolysis which is a thermal decomposition process that heats organic matter in the absence of oxygen we can get solid component that help Agricultural amendment and filtration

Bioplastics

Products made from starch (corn, potato),fermented sugars (to produce PLA, PHB),
or organic residues that we can use to be Packaging,biodegradable bags,textiles,3D printed technical parts.

Specialty chemicals derived from biomass

Bio-based solvents:

-Ethanol

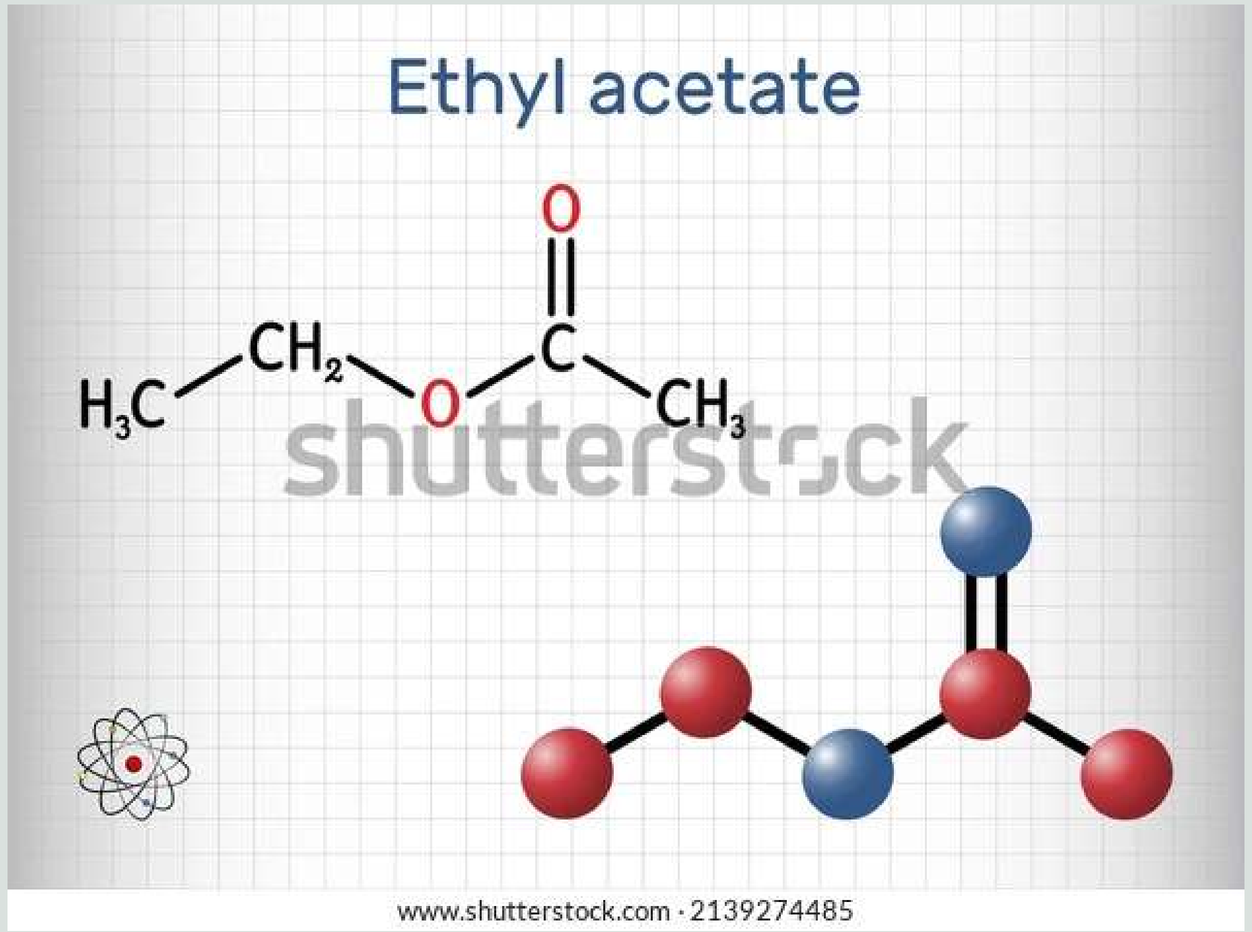
-Ethyl acetate

-Bio-based glycerol

Organic acids of biological origin:

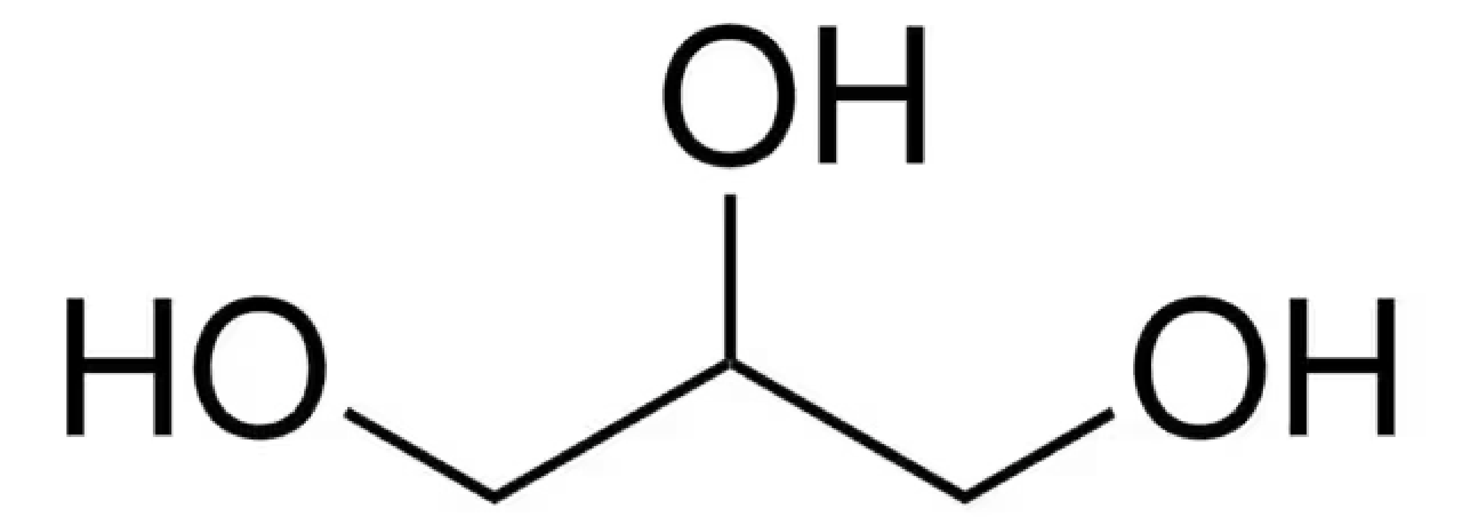
-Lactic acid

-Succinic acid



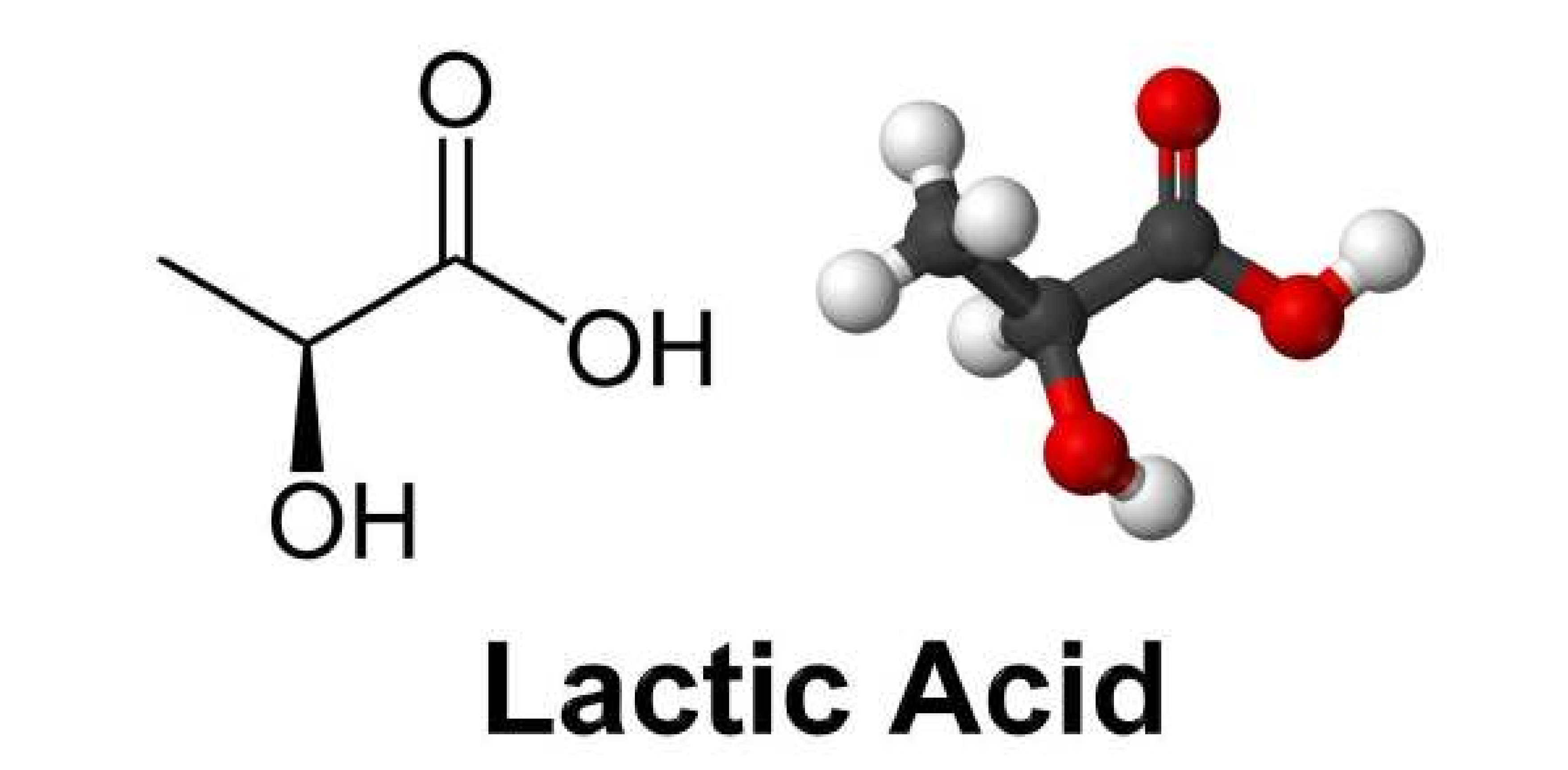
Produced by reaction between:
lactic acid (from fermentation) + ethanol.

Green solvent: replaces acetone or certain petrochemical solvents.
Applications: paints, inks, industrial cleaning.



Bio-based glycerol (vegetable glycerol)

By-product of biodiesel production.
Used in: cosmetics, pharmaceuticals, plasticizers.



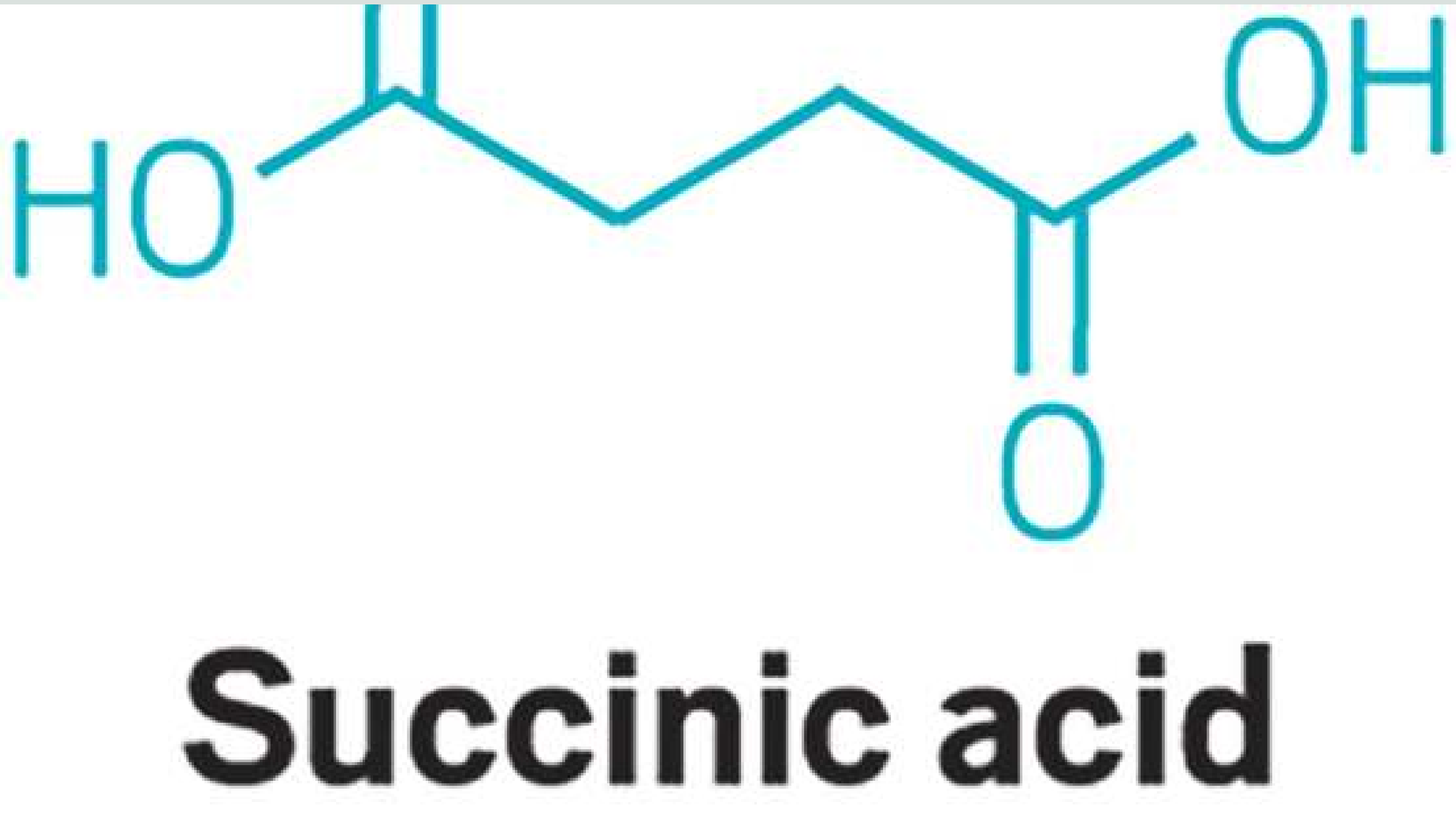
Produced by fermentation of glucose or starch.

Used to manufacture:

PLA (polylactic acid) → biodegradable bioplastic

food products (acidifiers)

pharmaceutical products



Produced by the fermentation of sugars by microorganisms.

Used for:

- plasticizers
- solvents
- food additives

GLOBAL SHARE

Based on recent global statistics (2020-2022), here is the approximate continental share for key solid biomass products:

1

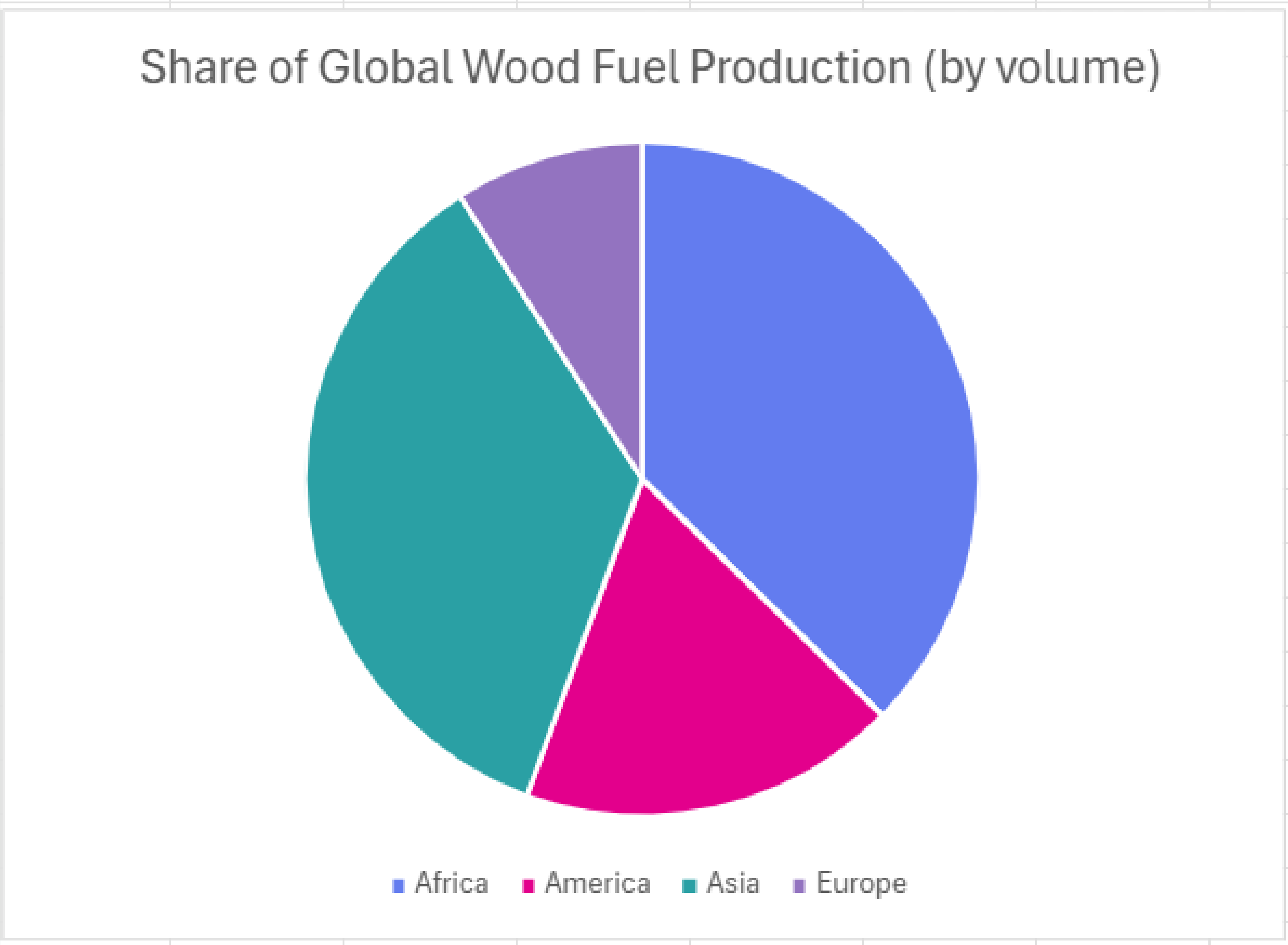
WOOD CHARCOAL PRODUCTION

Share of global wood charcoal production is approximately 66%

2

WOOD PELLETS

Europe is a leader in the production of wood pellet with a production over 55%



GLOBAL SHARE

The Americas

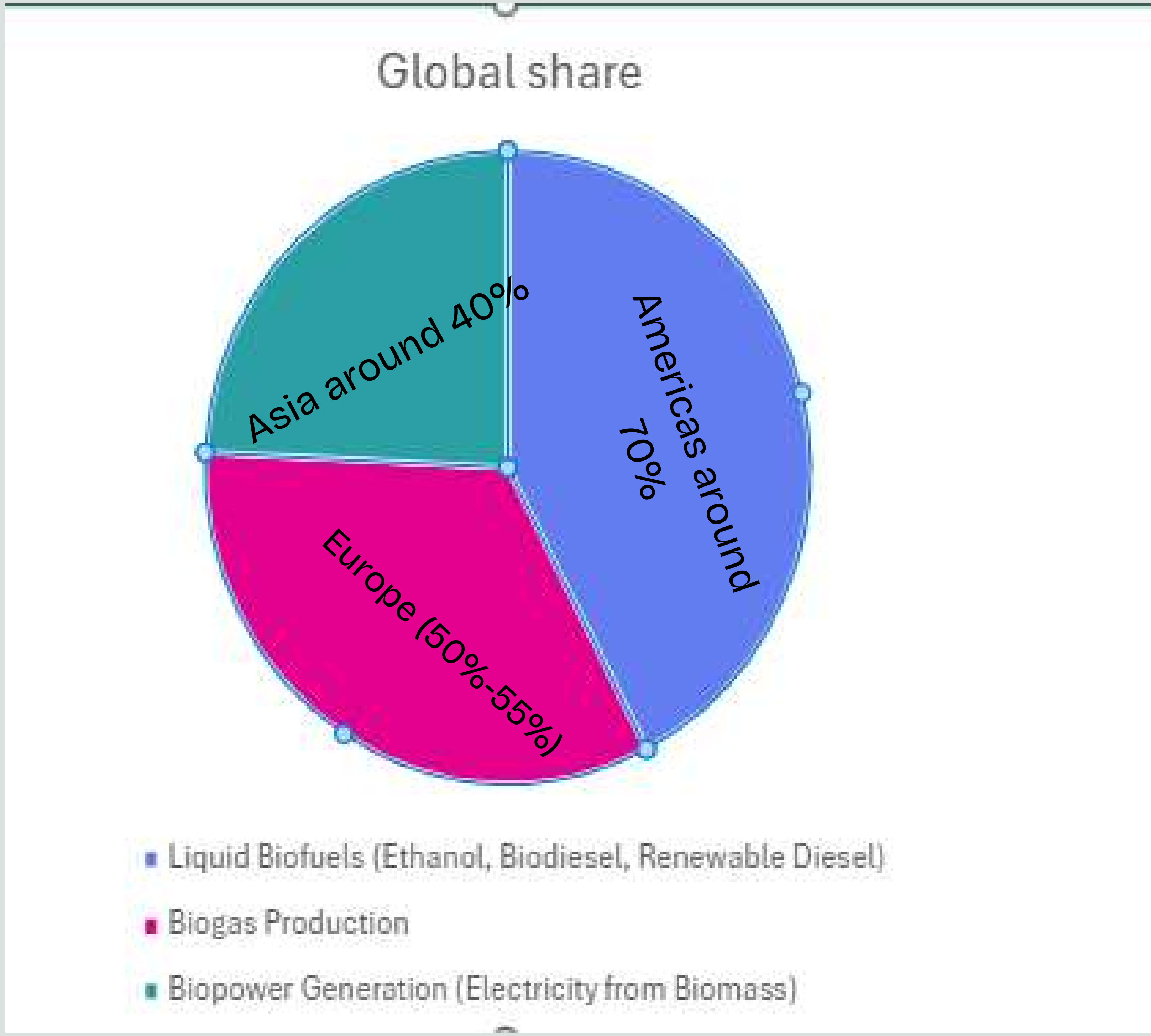
- Liquid Biofuels: 70% share, driven by mandates and large-scale production from US (corn) and Brazil (sugarcane).
- Biopower: Significant use of sugarcane bagasse (Brazil) and solid biomass (US).

Europe

- Biogas: 50%-55% share, driven by strong policy support and integration into agricultural systems.
- Biopower: 35%share, focused on high efficiency Combined Heat and Power (CHP) plants using solid biomass.
- Liquid Biofuels:15% share, driven by EU blending mandates.

Asia

- Biopower: 40% share, making it the largest generator, driven by China and India's waste-to-energy projects.
- Biogas: 30%-35% share, with massive growth potential utilizing agricultural residues and animal waste.
- Liquid Biofuels: 10%-15% share, a fast-growing market (example of India and Indonesia)



ENVIRONMENTAL AND SOCIO-ECONOMIC ASPECTS

ENVIRONMENTAL ASPECTS

Benefits	Challenges
Carbon Neutrality: When biomass is harvested and regrown sustainably, the CO2 released during combustion is theoretically offset by the CO2 absorbed by the new plants during photosynthesis.	**Air pollution**: While cleaner than raw fossil fuels, the combustion of biomass still releases air pollutants, including particulate matter (PM), nitrogen oxides, and carbon monoxide (CO).
Waste Reduction: Utilizing organic waste (agricultural residues, forestry byproducts, municipal solid waste) for energy converts material that would otherwise be sent to landfills.	**Deforestation:** While cleaner than raw fossil fuels, the combustion of biomass still releases air pollutants, including particulate matter (PM), nitrogen oxides, and carbon monoxide (CO).

ENVIRONMENTAL AND SOCIO-ECONOMIC ASPECTS

SOCIO-ECONOMICS ASPECTS

Benefits	Challenges
Rural Economic Development and Job Creation: Biomass production and conversion create jobs across the entire value chain	**Infrastructure Cost**s: While cleaner than raw fossil fuels, the combustion of biomass still releases air pollutants, including particulate matter (PM), nitrogen oxides, and carbon monoxide (CO).
Energy Security and Independence: Utilizing domestically sourced biomass resources reduces reliance on imported fossil fuels	**Health issues:** Specially in Africa

ÉTUDE DE CAS : LE PROJET BIOTFUEL

OVERVIEW

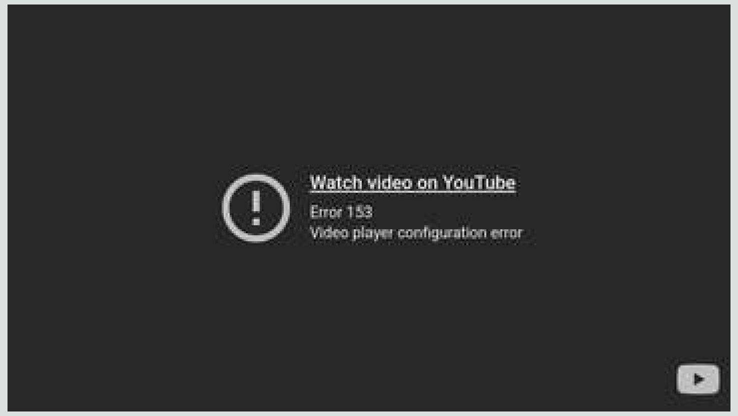
The BioTfueL project (2010s to 2020s) was a major French-led industrial demonstration aimed at perfecting the process for producing advanced biofuels from non-food biomass.

Objective

The project aimed to prove that non-food agricultural and forestry residues (like straw and wood chips) could be reliably and efficiently converted into high-quality, liquid transportation fuels

Key technology

The project integrated thermochemical processes to convert rigid lignocellulosic biomass (agricultural and forest residues) into high-quality liquid fuels.



ÉTUDE DE CAS : LE PROJET BIOTFUEL

BENEFITS OF THE BIOTFUEL

High-Quality Fuels including bio-diesel

Significant CO_2 Reduction over 80%

offer high energy density for transport

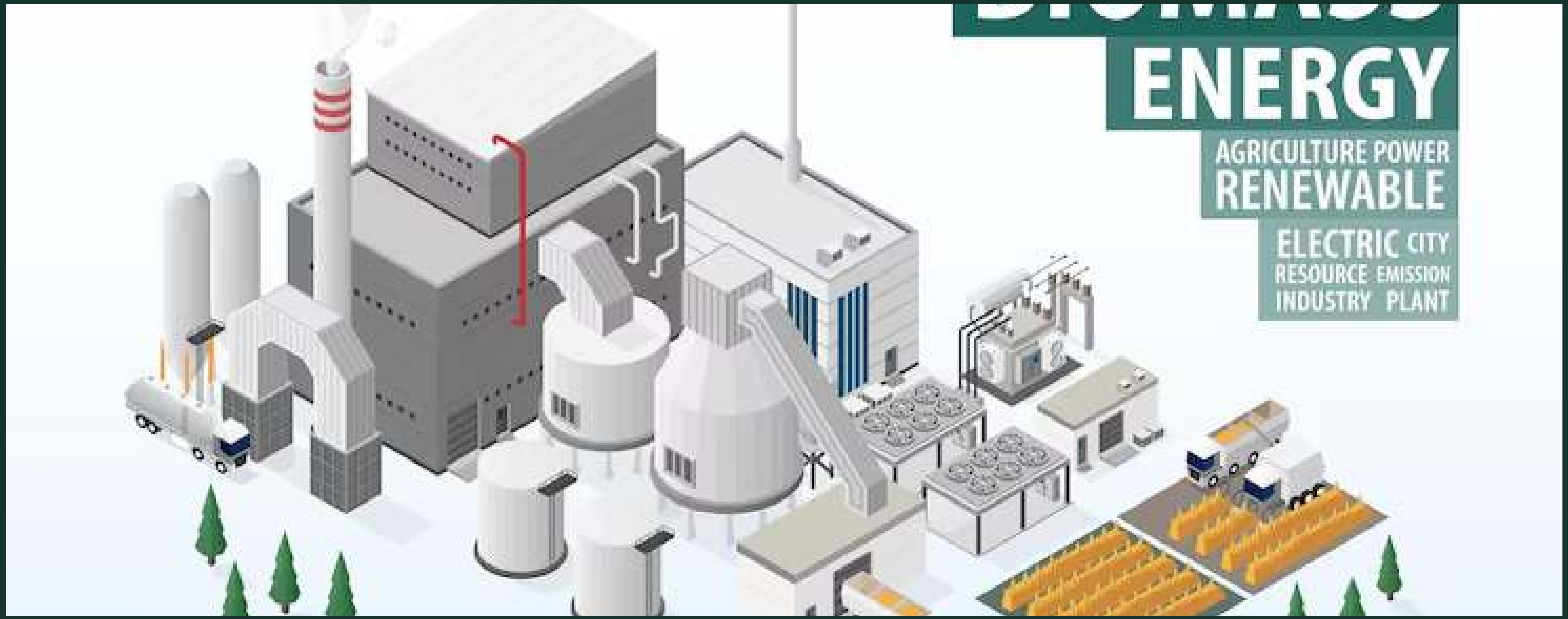
ÉTUDE DE CAS : LE PROJET BIOTFUEL

KEY CHALLENGES

Economic and Financial Weakness(high production cost)

feedstock availability: the prices and availability of residues are subject to climatic hazards

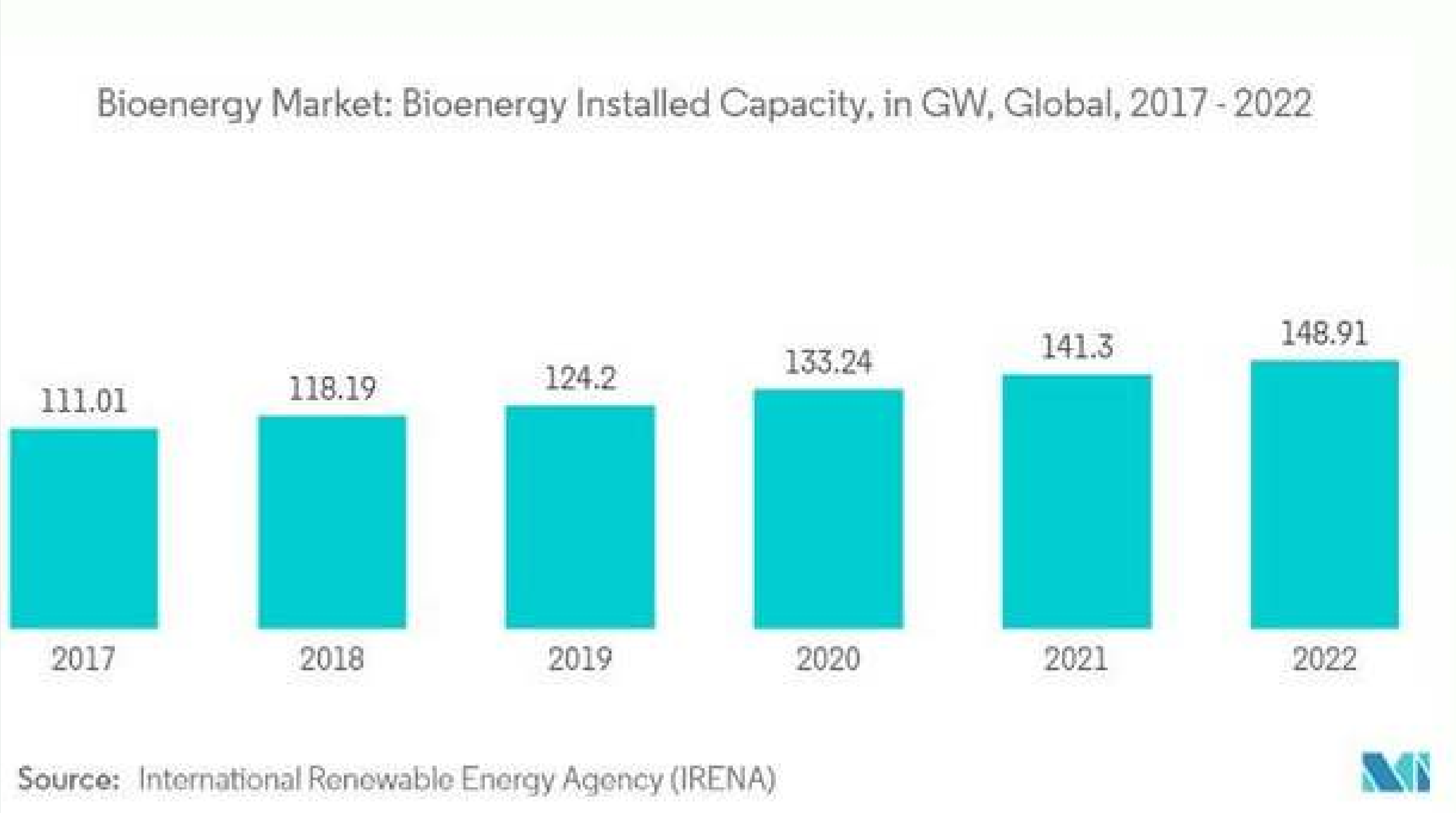
Technical and Operational Complexity: the process generates tars that contaminate the syngas and poison the expensive downstream catalysts, necessitating complex and costly gas cleaning



Biomass: Futur outlooks

Global overview

Bioenergy holds the greatest potential for expansion among renewable energy technologies, primarily because the technology is mature and biosmass serves as a relatively straightforward substitute for fossil fuels.



Modern Bioenergy Consumption Projections

- By 2023, it had grown further reaching approximately 155-160 GW globally.
- Forecasts suggest continued growth is expected to reach 39 EJ by 2030.

Global Biomass Energy Market

The biomass energy market is experiencing significant global growth, driven by the increasing needs for renewable and sustainable energy sources.

- The Asia-Pacific region stands out as a leader in this sector, with countries like China and India investing heavily in biomass projects.
- The United States is a net exporter of biomass energy sources
- Europe is expected to dominate the Market

Global Biomass Energy Market

- Africa presents immense potential for modern bioenergy, driven by the high productivity of its biomass resources.

- In Sub-Saharan Africa (excluding South Africa), biomass, including solid wood fuel and agricultural residues, accounts for over 80% of the total energy supply for heating, cooking, and processing agricultural products.

- Yet, the adoption of clean cooking technologies within this population is minimal, leaving a significant gap in sustainable energy solutions.

The issues of solid cooking fuel and traditional cookstoves

Inefficiency of traditional cookstoves

Open fires typically have an energy efficiency of only 10-15%. This means that out of 100% of the energy stored in the biomass (e.g., wood), only 10-15% is effectively used for cooking, while the rest is lost as heat to the surrounding air.

Public health problems

- Incomplete combustion in traditional stoves produces harmful by-products like carbon monoxide (CO) and particulate matter which can lead to respiratory diseases.
- An estimated four thousand Africans die prematurely every day from household

SOLUTIONS

ADVANCED BIOMASS COOKSTOVES

Energy efficiencies of 30-50%
Natural-draft gasifier: equiped with insulated combustion chamber allowing low levels of emissions

MODERN FUEL AND RENEWABLE

- Liquefied petroleum gas(LPG): Clean cooking fuel at point of use; very low emissions and high efficiency
- Biogas: The fuel used is renewable biomass/waste

MODERN BIOENERGY GROWTH OPORTUNITIES

Echnological Advancements

Second- and third-generation biofuels, such as bioethanol and biodiesel, offer promising alternatives to petroleum products, particularly in the transportation sector.

Adoption of Circular Economy Principles

The shift toward a circular economy supports the expansion of biomass energy by encouraging the reuse of waste and agricultural by-products, contributing to a greener and more sustainable energy transition.

Modern bioenergy threats and warnings

Criticism over impacts on food security and biodiversity

Bioenergy production raises concerns about food security and biodiversity due to its reliance on agricultural and forest lands.

Fluctuation in Agricultural Prices

Biomass energy's production competes with food markets, potentially displacing crops for human and animal consumption and driving up prices.

Modern bioenergy threats and warnings

Spacial footprint

Biomass is often less favorable compared to other renewable energy sources due to its large spatial footprint, low energy efficiency, and limited scalability.

Less competitive long-term solution

Additionally, while wind and solar energy continue to become more cost-effective with technological advancements, biomass remains constrained by its dependence on raw materials, which cannot be sustainably industrialized on a large scale.

CONCLUSION

Faced with rising environmental pressures and the limits of fossil fuels, biomass has become a crucial alternative energy source. It can produce solid, liquid, and gaseous bioenergy through various conversion technologies, with advanced biofuels like bioethanol and biodiesel offering strong potential. However, biomass is only sustainable if it provides real environmental benefits and does not threaten global food supply. Projects such as BioTfueL show that producing advanced biofuels from non-food residues is possible, highlighting the importance of innovation. Ultimately, the future of biomass depends on maintaining a strict balance between energy production and food security, turning waste into a key resource for decarbonization and a circular economy.

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