Chapter 04

4. Biotechnologies and Industry for Non-Food Purposes

4.1. Bioenergy

Bioenergy refers to the forms of energy stored in biomass (mainly through the photosynthetic conversion of solar energy). This includes energy crops, agricultural and forestry residues, and organic waste, which can be used to produce heat, cooling, electricity, or fuels. As long as it is not overexploited, it is considered "renewable."

Fossil fuels (oil, natural gas, coal, etc.) were once thought to be inexhaustible. However, various oil crises have highlighted the importance of renewable energy as a substitute for petroleum products. One such energy source is biomass, often described as "the totality of all renewable raw materials of plant or animal origin intended for non-food uses."

Biomass is a diverse fuel. Broadly speaking, it includes "all living organisms, both animal and plant, as well as their products, by-products, or waste (excretions, etc.)." Biomass constitutes the various ecosystems of the planet and contributes to their natural balance. It was initially cultivated and raised by humans for food but also provides construction materials and serves as a raw material for certain industrial processes and energy production—referred to as bioenergy.

The difference between bioenergy and fossil fuels lies in their environmental impact: bioenergy can reduce greenhouse gas emissions. This is because the carbon released during fuel combustion can be recaptured by growing plants. However, the actual emissions reduction depends on the type of bioenergy production, the transformation process, and especially the location where the raw materials for bioenergy are produced. For instance, the quality of the fuel used is important (burning wet wood increases emissions two to four times compared to dry wood).

A renewable energy source is one generated from a resource that replenishes quickly enough to be considered inexhaustible. Fossil fuels (natural gas, oil, coal, etc.) took millions of years to form. Using these fuels much faster than they are formed depletes global natural reserves irreversibly for several generations. Fossil fuels are therefore not renewable energy sources.

Biomass, when cultivated or raised by humans, is expected to renew after each use. Thus, biomass is a renewable energy source, provided that agricultural and forestry systems are sustainable and responsibly managed.

4.1.1. Sources of Biomass:

Biomass is primarily composed of carbon, hydrogen, and oxygen, along with smaller amounts of nitrogen, derived from various types of resources:

- **Agricultural products:** These can be divided into:
  - Traditional annual crop cultivation (e.g., cereals and oilseeds), mainly valued for their noble parts (grains, seeds, and tubers).
  - Crops dedicated to biorefineries, as well as agricultural and livestock residues.
- **Forestry products:** These include logs, pellets, wood chips, and residues from forestry operations or specific silvicultural practices. The utilization of forest resources must comply with sustainable exploitation practices.
- **Aquatic products:** These include algae, fishing residues, and aquaculture by-products.
- **Other organic waste:** Examples include urban waste, sludge from wastewater treatment plants, household waste, and green waste from parks and gardens.

4.1.2.Applications :

- **Wood heating:** Using logs for individual heating systems.
- **Collective wood boilers:** These utilize sawmill waste (sawdust, wood scraps) or wood chips from forestry operations.
- **Wood refining:** Through dry distillation of wood, methanol can be obtained. Various processes exist for producing bioethanol from wood cellulose.
- **Synthetic natural gas production:** An innovative and promising method involves producing synthetic natural gas from wood, which can substitute or blend with fossil natural gas.
- **The paper industry:** It uses black liquor (a by-product of pulp production) with an energy content comparable to wood to produce steam and electricity through cogeneration.

A **biofuel** or **agrofuel** is a fuel (a liquid or gaseous biofuel) produced from non-fossil organic materials derived from biomass (hence the prefix "bio" in biofuel) and serves as a complement to or substitute for fossil fuels. Currently, two main production pathways exist:

- **Oil-based and derivative pathway:** Includes vegetable oil fuels, biodiesel (or biogasoline), as well as animal fats or various fatty acids (e.g., algae).
- **Alcohol-based pathway:** Includes bioethanol, derived from sugars, starch, cellulose, or hydrolyzed lignin.

  Biogas is the gas produced by the fermentation of organic matter in the absence of oxygen. It is the result of the methanation or anaerobic digestion of fermentable waste.

The most common sources of biogas come from voluntary or involuntary organic matter stocks:

- **Crops:** Cultivated specifically for energy purposes.
- **Landfills:** The biogas content varies depending on the operational methods and their sealing. Selective collection of organic waste enables faster methanation in landfills using specific bioreactors (digesters).
- **Wastewater treatment plant sludge:** Methanation eliminates organic compounds and allows treatment plants to achieve partial or full energy self-sufficiency.
- **Livestock effluents:** Regulations mandate storage facilities for effluents (slurry, manure) with a capacity of more than six months. This storage period can be used for the methanation of effluents.
- **Agri-food industry effluents:** These can also be methanized, primarily to prevent the discharge of overly rich organic matter and, in some cases, to enable energy recovery.

4.2. Biomaterials and Agro-Polymers

4.2.1. Biodegradable materials are materials capable of undergoing decomposition into carbon dioxide, methane, water, inorganic compounds, or biomass through the enzymatic action of microorganisms. The biodegradability of a material is thus defined as its intrinsic ability to be broken down by microbial activity, progressively simplifying its structure and ultimately converting it into CO_2, H_2O, and/or CH_4, as well as new biomass. Various sources of polymers can be used to produce such materials. Depending on the origin of the raw materials and the synthesis pathways, there are two main methods for producing biodegradable materials:

- Biodegradable polymers derived from the petrochemical industry.
- Biodegradable polymers derived from renewable resources.

The **plastics industry** is one of the most significant sectors within the chemical industry in terms of both quantity and diversity of applications. As this industry primarily relies on fossil resources, it must rapidly find alternatives to conventional raw materials. Due to their abundance and diversity, plant-based polymers offer a new source of renewable raw materials for the plastics industry.

The renewed interest in renewable raw materials within the plastics sector aligns with environmental sustainability goals and the need to manage finite fossil resources. Plant-based raw materials, primarily polymers, possess particularly attractive properties for the plastics industry, such as:

- Biodegradability.
- Biocompatibility.

- Selective permeability.
- Adjustable physico-mechanical properties.

These properties allow for targeted applications across various fields, including packaging, textiles, agriculture, pharmaceuticals, electronics, and medicine.

4.2.2.Major classes of bio-polymers derived from plants:

Polymers from plants, or bio-polymers (also called agro-polymers), often form the cell walls of plants, such as cellulose and lignin. Microorganisms can also produce polymers through the fermentation of plant-derived molecules, which are similarly classified as bio-polymers.

Polysaccharides (plants/algae) :

- Starch, Cellulose, Agar, Alginate, Carrageenan, Pectin, Gums, Konjac

Polysaccharides (via bacterial fermentation) :

- Xanthan, Dextran, Gellan, Curdlan, Pullulan, Elsinan

Proteins:

- Zein, Gluten, Polyamino acids

Polyphenols:

- Lignins, Tannins, Humic acids

Polyesters :

- Polylactic acid polymers (PLA)
- Polyhydroxyalkanoates (PHA)

Other polymers:

- Polymers synthesized from oil (e.g., nylon)
- Polyisoprenes: Rubber

4.2.3. The Biodegradability of Bio-Polymers

Bio-polymers are synthesized in plants or animals through enzymatic pathways, making them readily degradable in biological environments. The biodegradability of most bio-polymers is attributed to the presence of easily cleavable bonds, such as ester or amide bonds, which break down into simpler molecules and smaller fragments. These fragments can be assimilated by microorganisms for their biosynthesis, releasing CO_2 and H_2O.

In contrast, conventional petrochemical polymers, such as polyethylene or polypropylene, have a carbon backbone composed of strong covalent C-C bonds, requiring significantly more time and/or the presence of a catalyst (thermal, electromagnetic radiation, or chemical) for degradation.

4.2.4. Applications

Three main areas of application are identified based on the properties of bio-polymers:

- **Medicine**
- **Agriculture**
- **Packaging**

Bio-polymers are also used for more specialized and advanced applications in sectors such as the automotive industry, electronics, and construction.

4.3. Biomolecules and Cellular Activities

This field focuses on the production of products (polymers, sweeteners, amino acids, etc.), the invention of processes (biorefineries), or the generation of bioenergy on an industrial scale using biomass as a renewable raw material. These raw materials (e.g., corn, straw, sugar, beets, wood, oilseeds) are transformed into finished products (e.g., amino acids, enzymes, pharmaceuticals, ingredients, polymers, bioplastics, bioethanol), typically through the use of microorganisms. These methods represent the gradual transition of our industrial system from fossil primary raw materials to renewable biological materials.

White biotechnology is directly aligned with the goals of sustainable development by:

- Utilizing renewable carbon sources (instead of fossil carbon).
- Enabling reactions at normal temperatures (reducing energy consumption).
- Producing limited waste.
- Avoiding the use of solvents.
- Often minimizing water consumption.

These approaches lead to the concept of **"integrated biorefineries,"** where plant-based raw materials (whole plants, residues, microorganisms) are used to produce a range of intermediate or final products for diverse industrial sectors (food, biofuels, biomaterials, additives, pharmaceuticals, enzymology, etc.).