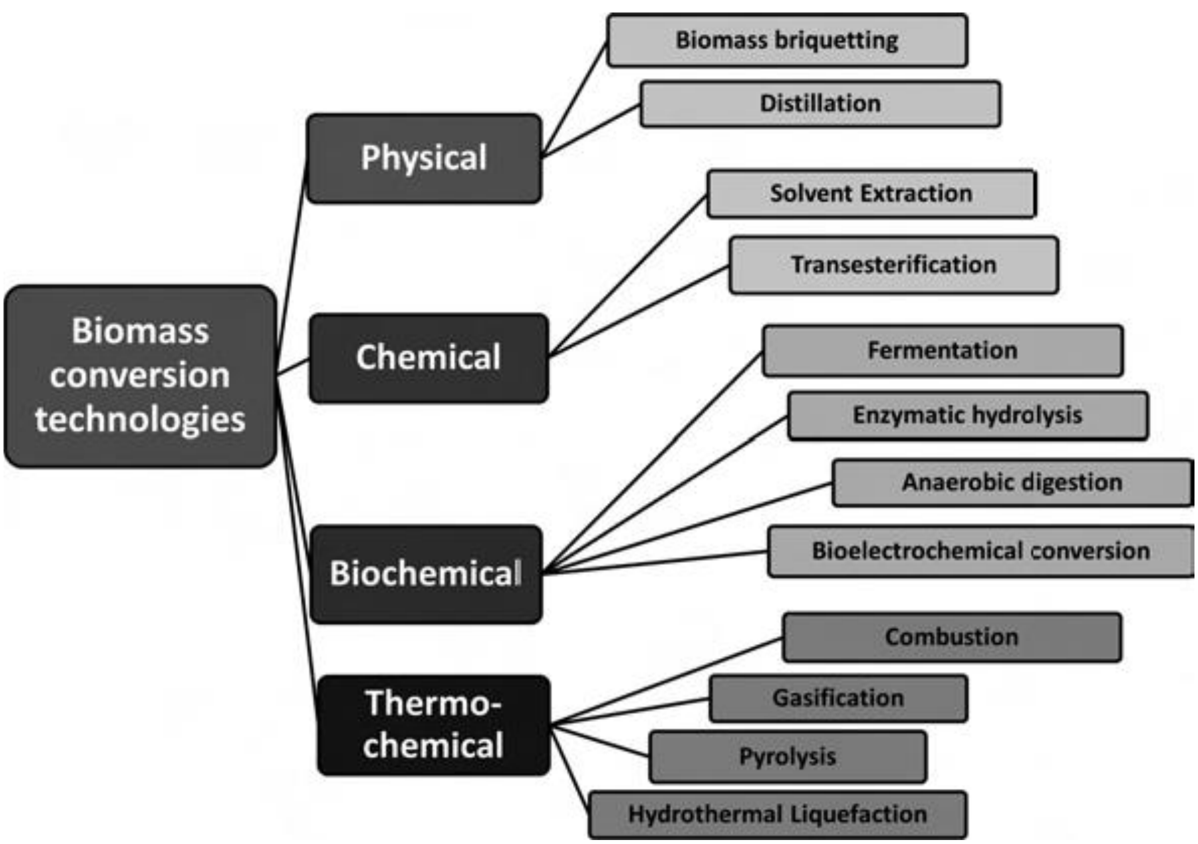
Biomass conversion technologies

Depending upon the simplicity or complexity of the available feedstock and the desired end products, different biomass conversion technologies have been developed over the past few decades. Technologies such as yeast fermentation, transesterification, and distillation for the production of first-generation biofuels have already been successfully implemented on a commercial scale. However, new technologies that are emerging with the different generation of feedstocks are still at experimental or demonstration stages. To make biofuel prices competitive with the traditional fossil fuels, the production technology must be as cost effective as possible. Moreover, it must not have any negative impact on the environment. The current existing bioconversion technologies can be broadly classified into three main categories (i.e., physical, biochemical, and thermochemical methods) as shown below:



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- **Physical Methods**

1. Biomass Briquetting

Biomass briquettes are alternatives to coal briquettes that are made using densification of agricultural or forestry residues and other waste biomass. They are also known as bio-coals. They can be produced in compact well-defined shapes such as cubic, prismatic, or cylindrical as per the requirement of the consumer. The densification is performed to enable the use of less volume of the biomass for the same amount of energy output. Besides improving the energy density per unit volume, briquetting helps in handling otherwise bulky or uneven biomass, reducing its water content, increasing the calorific fraction, lowering the ash content, and providing high homogeneity to the feedstock. **The major goals for producing biomass briquettes are** to *provide high value to an existing product* and *lower the transportation costs*. The process of densification is two steps—compaction to reduce the raw material volume and sealing to ensure the stability of the final product.

عملية التكثيف (Densification) : 1. الضغط/الدمج (Compaction) يتم ضغط المادة الخام لتقليل حجمها وجعلها أكثر كثافة. 2. التحزيم أو الإغلاق (Sealing) تثبيت الشكل النهائي ومنع تفكك القطع لضمان بقاء المنتج صلب ومستقر

The biomass briquettes can be used in several domestic and industrial applications such as cooking fuel as a substitute to coal, firing in industrial furnaces, steam and heat generation in boilers, and for residential heating.

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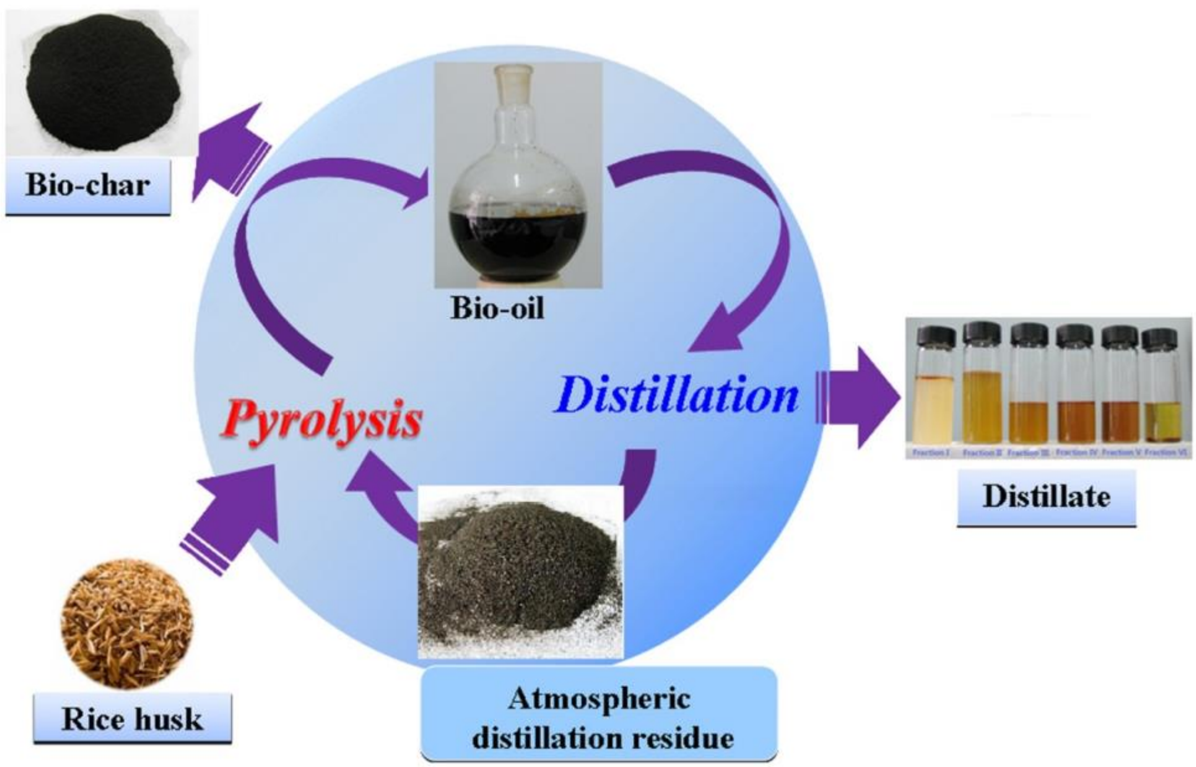
2. Steam Distillation

Distillation is a method of separating the components of a mixture based on boiling points by means of evaporating and then condensing the vapor into liquid. In steam distillation, steam is supplied as a means of heat to evaporate heat sensitive compounds at lower temperatures. The end product is a two-phase system with a fraction of water and the organic distillate. The desired component from the two phase system can be separated using partitioning, decantation, or any other suitable method. This process is extensively used in industries to extract oils from plants (e.g., eucalyptus oil and orange oil are produced commercially using the steam distillation method). Distillation also is used for obtaining distilled beverages from fermented products or for producing bio-oil after pyrolysis as explained in the following sections.



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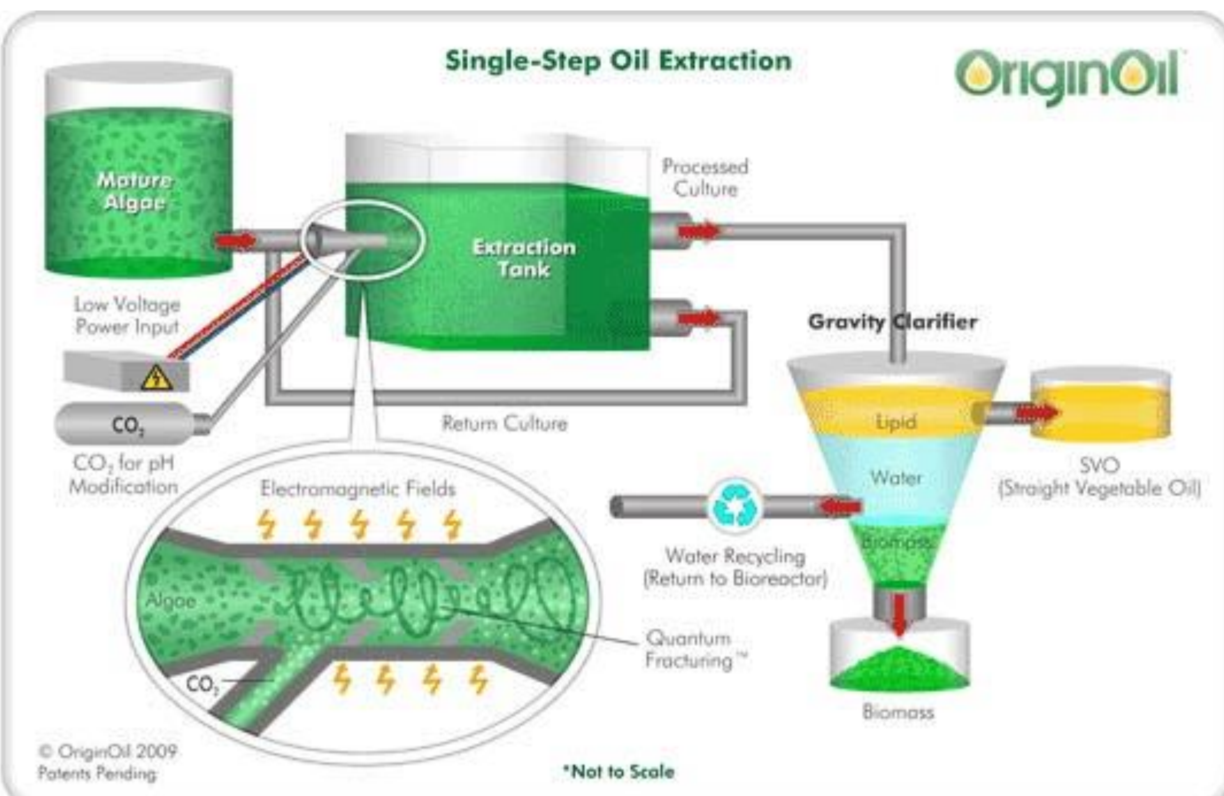
- **Chemical method**

1. Solvent Extraction

Solvent extraction is a method of separation based on the solubility of a component in two immiscible liquids. It mainly is a two-phase system (i.e., an aqueous phase [polar like water] and an organic phase [non-polar like organic solvent]). The solvent rich in the solute (i.e., the desired component) is called the extract whereas the solvent depleted with solute is called the raffinate. Hexane is the most commonly used solvent for industrial purposes. Usually, for obtaining the desired product, the solvent extraction is accompanied by evaporation and distillation processes. It is used for the processing of perfumes, vegetable oils, and biodiesel. Furthermore, it can be used for the extraction of value-added compounds from biomass such as trepenoids, sterols, and waxes. The extracted biomass can later be used for biofuel production.



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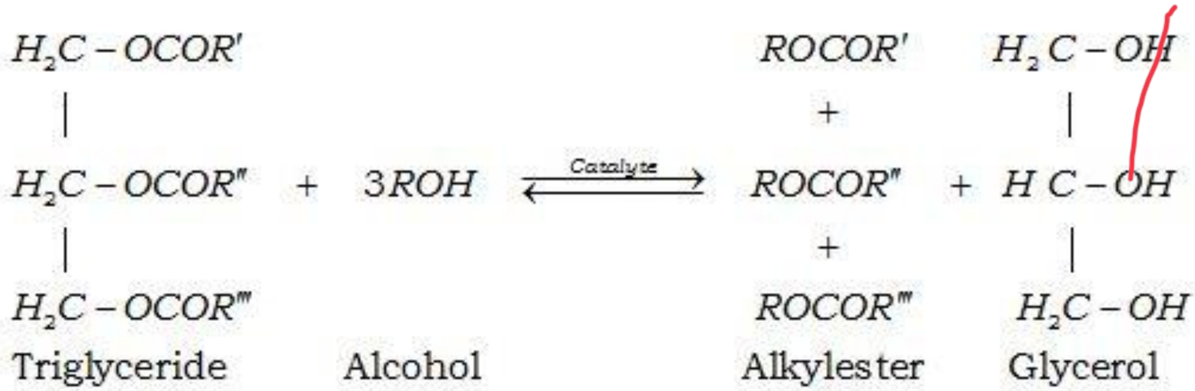
2. Transesterification

Animal or plant fats oils are usually composed of triglycerides which are the esters formed by the free fatty acids and glycerol. These triglycerides cannot be used as a fuel due to their high viscous properties that cause incomplete combustion, carbon deposition, and so on. The viscosity of oils can be reduced using different methods such as blending with petroleum diesel, micro-emulsion, thermal cracking, and transesterification reaction. Among these, transesterification is the most common method of producing biodiesel from oil seed crops. It involves a reaction of primary alcohols with triglycerides of fatty acids (oil from energy crops) in the presence of a homogeneous or a heterogeneous catalyst to form fatty acid ethyl or methyl esters (biodiesel) and glycerol. It is estimated that transesterification can covert 98% of triglycerides into biodiesel. The advantage of using ethyl or methyl esters is that they can be directly used as a substitute for diesel. Also, since the transesterification process is well established in existing petroleum refineries, the technology can be easily implemented for biomass-based biodiesel production.



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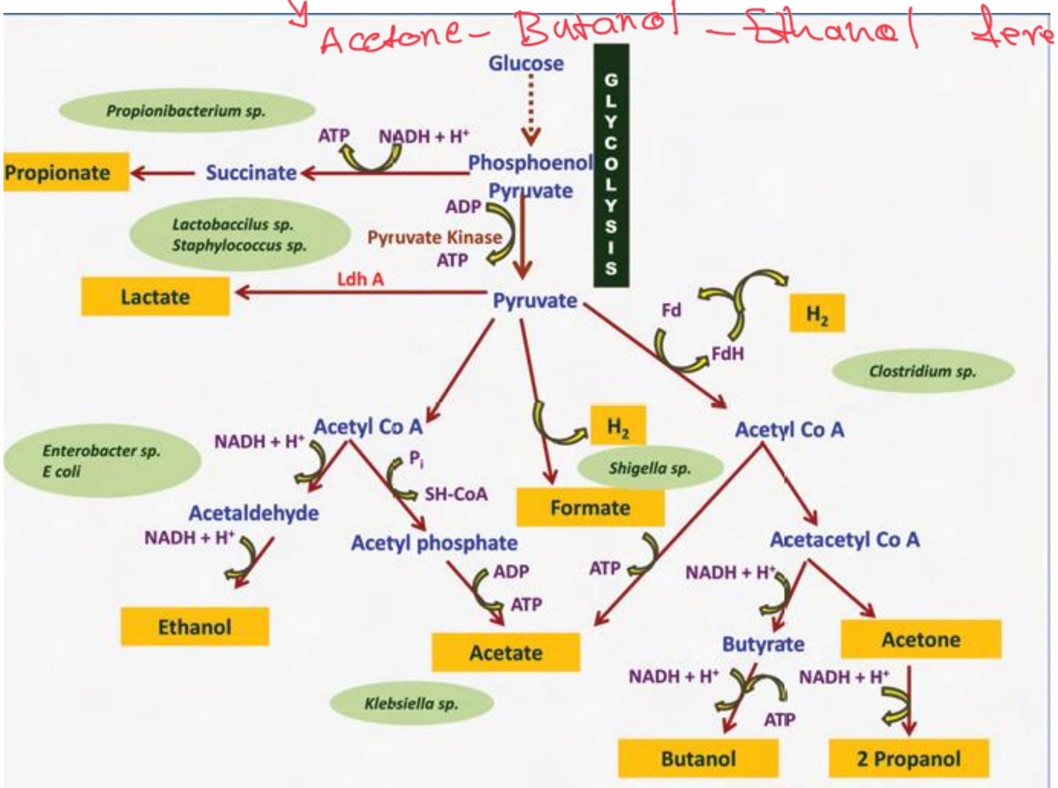
- **Biochemical Methods**

1. Fermentation

Fermentation involves the use of fermentative microorganisms to convert the biomass into liquid (ethanol, butanol) or gaseous (hydrogen) biofuels along with value-added chemicals such as lactic acid, acetic acid, and butyric acid. The complex biomass is initially pulverized or pretreated to convert it into simple monomeric units. These monomers are then finally converted to the target biofuel by the action of specific microbes. Ethanol fermentation using the yeast Saccharomyces cerevisiae is the only distinguished process that has been commercialized so far. Besides ethanol, different microbial fermentative pathways for butanol (the ABE pathway) and hydrogen (mixed acid pathway) production have also been discovered in the metabolic pathways of different bacteria and extensive research is being conducted for commercialization of these products. The figure below shows the major pathways to produce fermentation products.



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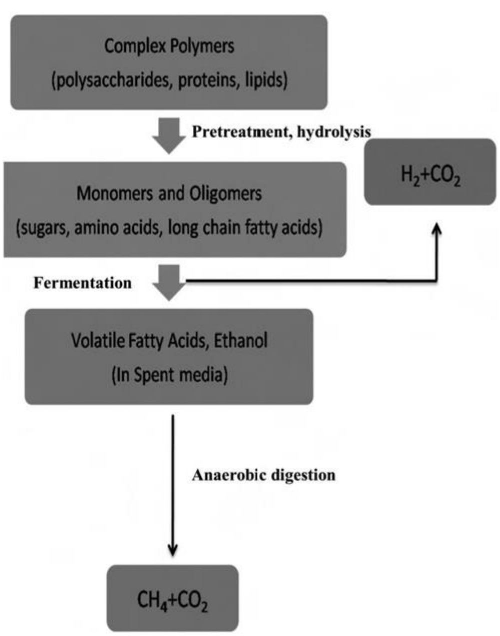
2. Anaerobic Digestion

Anaerobic digestion (AD) is the breakdown of organic matter in the absence of oxygen to produce biogas or biomethane. The advantage of this technology is that it can use a wide range of feedstock. The major steps involved in AD are hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Figure beside). The technology is cheaper and much simpler. It is proved to be a promising alternative to the conventional activated sludge process because it has the added advantage of energy generation along with wastewater treatment. Biogas can be a potential substitute for liquified petroleum gas (LPG) and has several advantages such as its recovery is simpler because the product (gas) automatically separates from the substrates. In addition, biogas produces enriched organic manure which can supplement or even replace chemical fertilizers. It provides a source for decentralized power generation and it can provide employment opportunities in rural areas. Furthermore, household wastes and bio-wastes can be disposed of usefully and in a healthy manner using this process. However, there are certain environmental and economic barriers that must to be addressed to make this process an efficient alternative to the existing fossil-based fuels.



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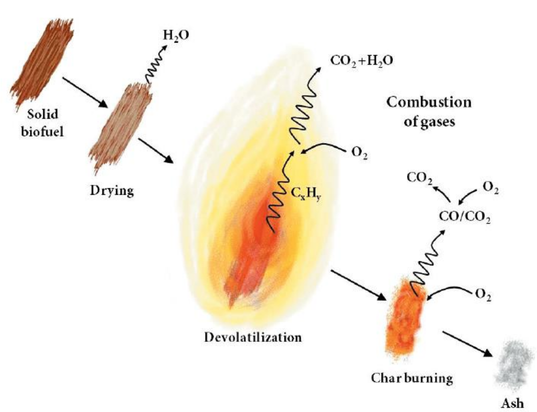
- **Thermochemical Methods**

1. Combustion

Solid biomass or low moisture containing biomass has been subjected to combustion for ages to supply heat. The complete combustion takes place in the presence of oxygen leaving CO_2 and water as the final products. The incomplete combustion produces charcoal, which can further be burned in a forced air supply to produce more heat. The combustion of biomass has lower GHG emissions compared to conventional fossil fuels, it has a high combustion efficiency, and the process is economically feasible. It is readily used in domestic stoves or boilers for heat generation. The combustion gases produced from the biomass also can be passed through a heat exchanger to produce hot air, hot water, or steam. The co-firing of biomass with the existing fossil fuels to reduce the effect of coal GHG emissions in thermal power plants is another strategy that has been implemented successfully with promising results. A further advantage of co-firing is that it requires a lower investment for adapting to existing coal-fired power plants compared to standalone biomass combustion systems. However, certain biomass tends to produce smoke, tar, or ash which can have detrimental impact on the environment. Thus, it is essential to accommodate the possible side effects of the by-products in the biomass combustion systems.



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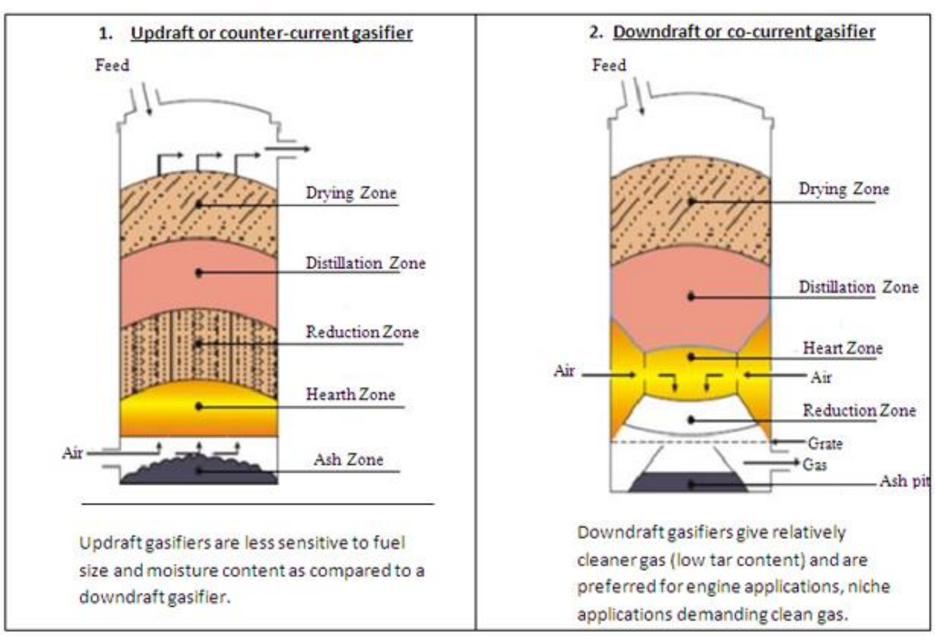
2. Gasification

Gasification traditionally has been used to convert carbonaceous fossil fuels to gaseous compounds by supplying limited amounts (compared to combustion) of oxygen, air, or steam at high temperatures. The same process also is implemented for biomass conversion to syngas or producer gas. The composition of the produced gas is dependent upon the raw material, the process type, and operating conditions. Syngas is composed of carbon monoxide (CO) and hydrogen (H_2), whereas the producer gas is several gases such as CO, CO_2, H_2, CH_4, and N_2. Both gases can be used for the production of bioenergy and bioproducts. The most direct application involves use in dual-mode engines to produce heat, steam, and electricity. It also can be used in (combined heat and power) CHP generating systems such as combustion engines, steam turbines, or fuel cells.
The biomass-derived syngas also can be used to produce biodiesel and bioethanol. The major limitation for this process, however, is the moisture content of the biomass, which can increase the energy requirement of the process (i.e., for producing dry biomass). The biomass particle emissions also can cause impurities in the syngas produced that might require further processing steps. Thus, it is essential to select the appropriate biomass to minimize the energy losses.



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3. Pyrolysis

Pyrolysis is the thermal decomposition of biomass that occurs in the absence of oxygen. It has been used widely to produce charcoal (from wood) and coke (from coal). The process can be used to produce biochar, bio-oil, and flue gas from biomass. During pyrolysis, the long chains of carbon, hydrogen, and oxygen compounds present in the biomass break down into smaller molecules. The decomposition starts at 300°C and proceeds to 900°C and above. The efficiency of the process and the final nature of the product or products generated are influenced by various operational parameters such as the reaction temperature feedstock, biomass heating rate, and pressure. The particle size of the feed is the most influencing factor. The smaller the particle size, the higher the heat transfer rate from particle to particle. The large size biomass can cause incomplete decomposition or high ash formation, which is undesirable. Thus, it is necessary to resize the biomass particle to the appropriate range to obtain a high yield of the desired products.

Depending on the operational parameters, the pyrolysis process can be divided into three categories—slow pyrolysis, fast pyrolysis, and flash pyrolysis. Slow pyrolysis occurs at low temperatures ranging from 300°C to 700°C, with a very low heating rate. It is used generally to produce biochar. It usually occurs at very high solid retention times (SRT) ranging from few hours to days. Fast pyrolysis, on the other hand, occurs at high temperatures (>800°C) with high heating rates (>10–200°C/second (s)) in shorter SRTs (2–10 s). This process effectively yields 50%–60% bio-oil, 30%–40% biochar, and 10%–20% gaseous side products such as hydrogen, methane, carbon monoxide, and carbon dioxide. These gases can be upgraded to various chemicals and other transportation fuels by applying various techniques such as steam reforming (H_2), the Fischer-Tropsch reaction (methanol, hydrocarbon), and syngas fermentation (ethanol). Flash pyrolysis is like fast pyrolysis; however, extremely high heating rates (103–104°C/s) with extremely low retention times (<0.5 s) is applied to obtain high yields of bio-oil (70%–80%).

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