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Converting Biomass into Biofuel using Production Techniques: A Review

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ABSTRACT

Biomass is a widely popular form of renewables as an alternative to fossil fuels, the dwindling oil resources, and escalating environmental issues related to climate change. Biofuel has gained significant importance as a source of bioenergy due to its two characteristics: sustainability and renewal. Biomass is abundantly available in nature and can be converted into various types of biofuels. This review provides a summary of biomass and its sources, as well as types of biofuels, their generations, and technologies for producing biomass (Thermochemical, Biochemical, Biological, Physical, Ultrasonic, Microwave, Nanotechnology), discussing competitive benefits, disadvantages of these technologies and the conversion of biomass and their potential environmental impacts, in addition to clarifying biofuel products, which included production of bioethanol, biomethanol they can be used fuel for internal combustion vehicles, transportation and industry for their role in reducing greenhouse gas emissions and producing biodiesel, which is considered a good alternative to petroleum diesel. Biogas is not used as fuel unless modified, and future research can be directed toward marketing sustainable biofuel.

1. Introduction

Humanity is experiencing some environmental dilemmas that challenge human creativity in finding sustainable solutions to protect the environment in which it lives. The most prominent of these challenges is the need to preserve fresh water and agricultural lands to produce food, in addition to combating the phenomenon of global warming (Greenhouse gases) and producing energy from renewable sources other than fossil sources [1], [2].

The demand for methods of converting biomass into biofuels is expected to increase in the future and on a commercial basis as fossil hydrocarbons become scarce and expensive. Therefore, in recent years, interest has increased in reducing biofuel production costs and greenhouse gas emissions [3].

The term biofuel is defined as "biomass converted to liquid or gaseous fuels such as ethanol, methanol, methane, and hydrogen" [4], which are used to provide renewable energy services in the form of heating, cooling, electricity, and transportation. Biofuel is more complex than fossil fuels, as its chemical composition consists of acids, alcohols, and esters, while fossil fuels consist of hydrocarbons. Biofuel is produced from agricultural, domestic, and industrial waste, provided that the waste is of biological origin [5]. Therefore, biofuel may be one of the promising alternatives to petroleum fuels, as there are two types of global biofuel used in transportation, namely bioethanol and biodiesel. Raw materials are also emerging from the growth of some plants, such as the Jatropha plant, which can currently be converted into biodiesel in commercial quantities [6]. Fig. 1. and Fig. 2. show the possibility of using biofuel instead of fossil fuels used in cooking, which is a potential application of wide-ranging global importance. It is also an alternative to petroleum-based fuel, as alcohol fuel can replace gasoline in spark ignition engines. At the same time, green diesel and biodiesel are suitable for compression ignition engines [7].

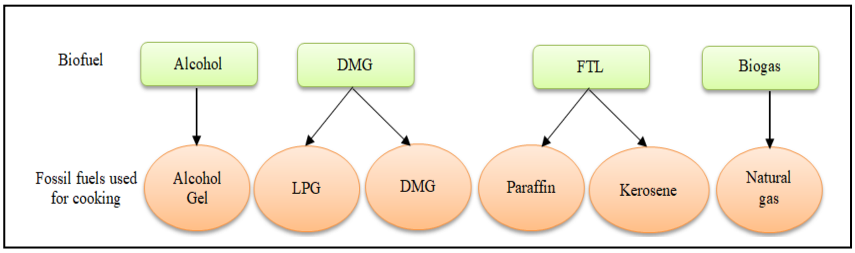

Fig. 1. Replacing fossil fuels with clean biofuels

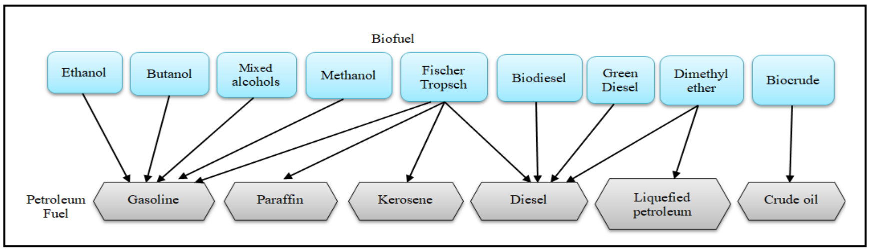

Fig. 2. Replacing petroleum-derived fuels with biofuels

Biomass is of great importance as a source of renewables, with the enormous possibility of producing biofuels for various purposes such as transportation, heat, and electricity [8], [9]. Biomass can be converted into different bioenergy forms before burning or burning and used in power plants [10].

In this review, we have reviewed, analyzed, and discussed the conversion of biomass waste to biofuel by covering recent information, presenting an overview of biofuel pathways, discussing the technologies used in the conversion, and the most crucial biofuel products.

2. Biomass

It is a type of organic material that was alive or that lived recently and includes animals and their waste, plants, and their remains. The simplest way to obtain energy from heating is by burning solid biomass such as wood. One advantage of biomass fuel is that it is often a by-product, residue, or waste product of other processes. All are considered renewable sources of biomass and depend on the carbon cycle, as shown in Fig. 3. [11], [12]. Environmentalists have found that the energy produced from using biomass as fuel has less environmental damage than fossil fuels. However, both release carbon in the form of CO_2 or CH_4 when burned. However, the carbon contained in biofuels disappears quickly. It does not cause an imbalance in environmental gases, while the carbon contained in fossil fuels leads to climate changes in the environment [13].

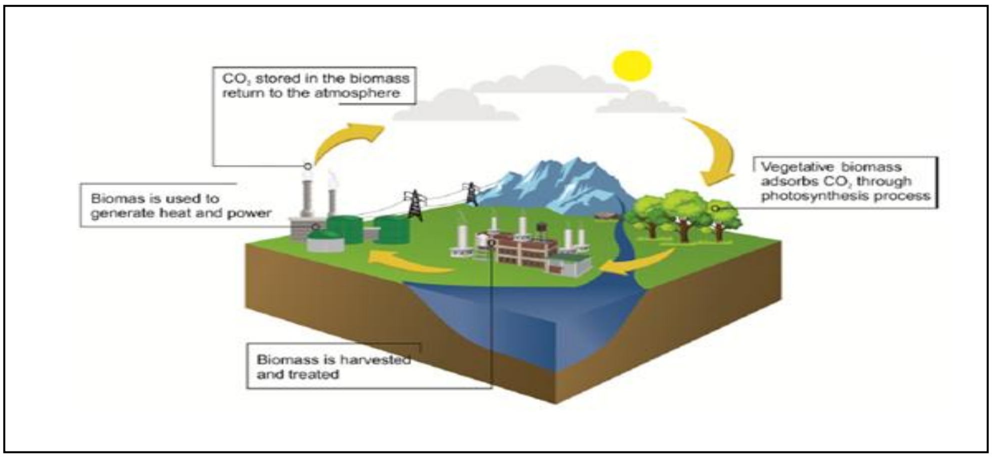

Fig. 3. Represents the worldwide carbon cycle for biofuel production from biomass

3. Results and Discussion

The biomass feedstock from agricultural land and forests is estimated at 1.18 billion tons by the US Department of Agriculture, with current US oil consumption expected to be replaced by biofuels by 2040 [14]. The properties of biomass rely mainly on properties of raw materials such as physical properties (volatile matter, particle size, moisture content, ash, chemical structure, and energy content), which significantly affect the produced efficiencies and thus properties of the final product [15], [16]. Plants, animals, and microorganisms are all examples of biological resources; the most important biological resources are shown in Fig. 4. Straw is the by-product of confined food crops (agricultural residues) such as corn, rice, wheat, cotton, sugar crops, and beans. In tropical countries, sugarcane bagasse is the primary source of biofuel production [17]. The wood waste resulting from the wood processing industry, such as sawdust, sawdust, coffee husks, animal waste (livestock farms and poultry waste), and industrial waste resulting from paper and textile industries [18], [19]. Paper is classified as (industrial waste) and is a naturally wet raw material. There is an urgent need to treat or pre-treat this waste before disposing it into the sewage as sewage sludge contains (It is classified as industrial waste) proteins, fibers, fats, inorganic materials, ash, and non-fibrous carbohydrates, which are considered an essential source of biomass [20] municipal solid waste consists of newspapers, magazines, grass clippings, product packaging, and combustion ash. Although this waste is widely present in most countries, it remains a largely untapped energy source because it requires a high cost, making it difficult to use it as an intermediate material for most biofuel production technologies. It is a heterogeneous raw material with diverse chemical composition and properties and an environmental pollutant [21], [22]. As for the crops that are grown specifically for the production of biofuel, they include corn, which is the predominant raw material in the production of biofuel based on ethanol through fermentation conversion, and soybeans, which are considered an effective alternative to fuel, sugarcane is used to produce bioethanol, rapeseed, wheat, sugar beet, willow, palm oil, and jatropha. Hemp has also been shown to be effective as a biofuel [23]. In addition to using vegetable oils (sunflower, rapeseed, etc.), which are obtained by extraction with simple mechanical pressure, algae can be used, including organic algae, green algae, and microalgae, which generate sustainable energy [24].

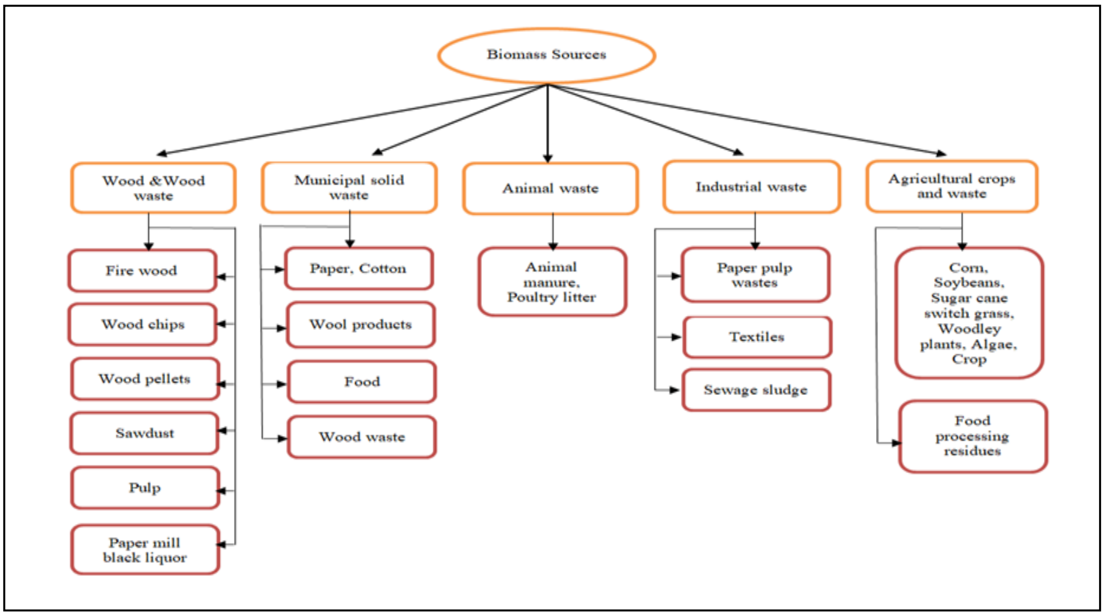

Fig. 4. Biomass sources

4. Availability of Biomass for Biofuel Production

Biomass is a renewable, easily obtained resource [25], and Fig. 5. and Fig. 6. and Fig. 7. show the global production of biomass.

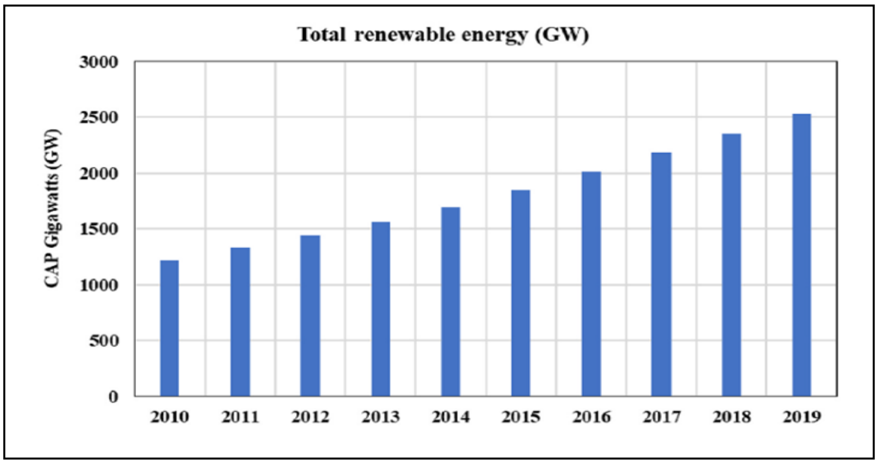

Fig. 5. Global production of renewable biomass

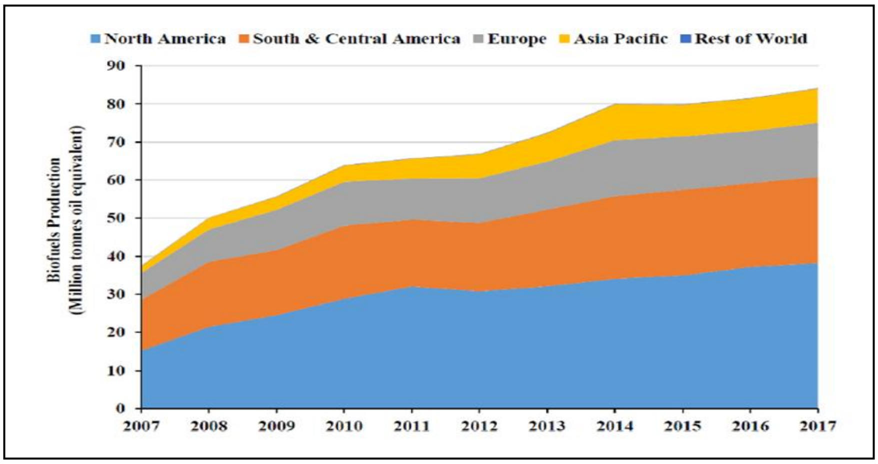

Fig. 6. Global bioenergy location

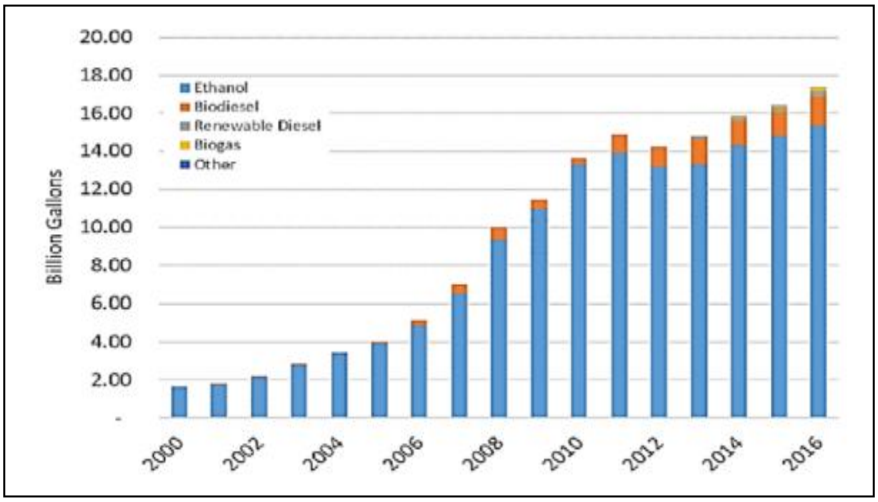

Fig. 7. World biofuel production

Biomass is converted in two ways: directly into biofuel or indirectly by converting it into another form of green energy. (50-150 exajoules) It can be saved annually from biomass generated from agricultural waste and sewage waste, and it is expected that by 2050, the size of the world's primary energy market will be between (600-1000 exajoules) annually [26]. According to OECD estimates in 2017, approximately 182 tons of crop residues from corn, wheat, rice, and sugarcane burned in China, India, and the United States, equivalent to 15.77 MT of CO_2 [27] by 2050 the amount of biowaste is expected to increase, as agricultural waste will continue to represent the most significant proportion of the total biomass supply [28].

5. Availability of Biomass for Biofuel Production

Biofuel (bio) is the energy produced from any possible use of biological matter. However, its definition from an economic perspective is somewhat different, as it is about the fuel that can replace oil, which causes significant environmental pollution. Its price is related to the degree of political stability in different regions. There are currently two biofuels that can run all common types of engines: biodiesel and bioethanol. One of them is based on oils, the other on alcohol. Their advantage is that their use is similar to the current use of oil. One of the modern solutions that is constantly gaining more supporters and investors is the extraction of oil from unicellular algae, as it has been shown that these green microscopic organisms have a high capacity to produce oil [29], [30], [31].

5.1. General classification biofuels

Biofuels can be classified into three types:

1) Conventional Biofuel:

This type is produced by implementing specific proven technological processes, such as esterification, distillation, and fermentation [32].

2) Advanced Biofuel:

The methods and pathways used to produce this variety are currently under research and development; due to the increasing need for agricultural products, a problem or fear has emerged of humans exploiting agricultural lands by planting materials that can be converted into biofuel instead of planting valuable food crops, as well as disrupting the environmental systems [33], [34] the term "advanced biofuel" includes ethanol derived from sugar, cellulose, hemicellulose, starch, and lignin [35].

3) Alternative Biofuel:

The use of sustainable fuel has become urgent and necessary, so many countries are seeking to find alternative fuel sources to fossil fuels, and it is essential to develop future services and replace traditional energy sources, including liquid fuel, heavy fuel, and coal [35].

5.2. Biofuel Generation

Biofuels are classified based on generation, and Fig. 8 shows the general generations of biofuels.

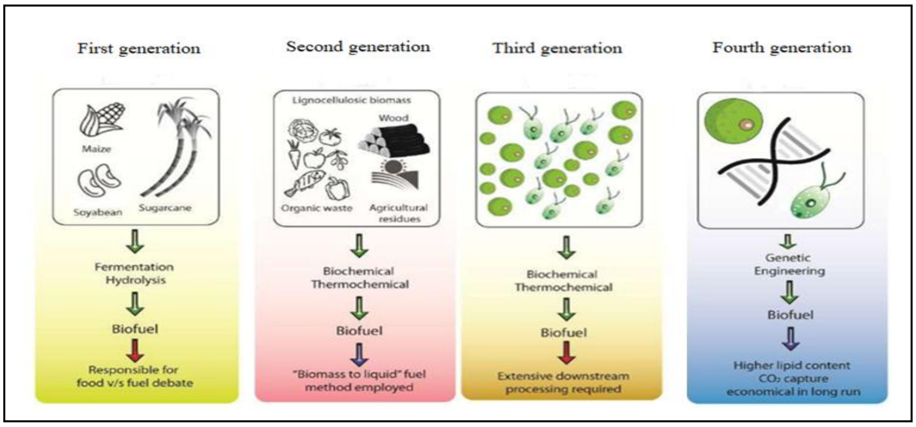

Fig. 8. Biofuel Generations

First-Generation Biofuel: The primary material for first-generation biofuels consists mainly of sugarcane, starch, vegetable, and animal oils [36]. Bioethanol is derived primarily from sugar and corn and is used by biorefineries in the United States. This generation takes several forms depending on the technologies used in production, such as solid biofuel, alcohol, green diesel, and biodiesel, which are suitable for use in electricity generation or as gasoline, as shown in Fig. 9. [37], [38].

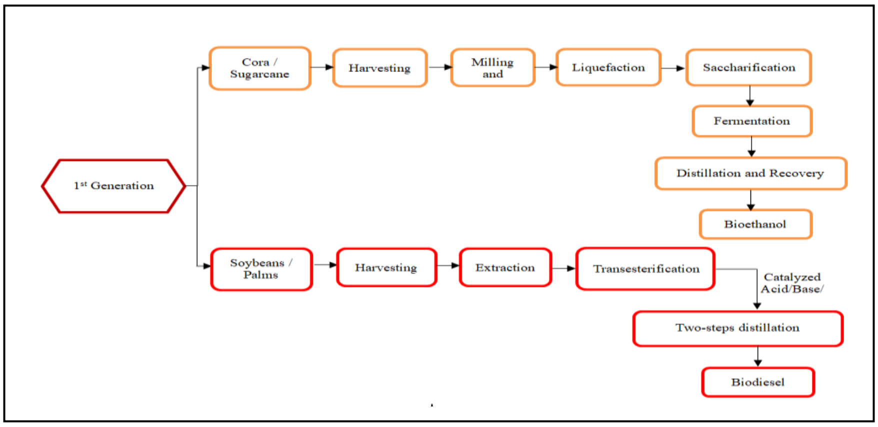

Fig. 9. Example of a figure caption. *(figure caption)*

Second-Generation Biofuel: Biofuel is produced from various shrubs, grasses, and trees, where carbohydrates can be extracted from agricultural plant parts, which are inedible materials such as cellulose, hemicellulose, and lignin. There are specific chemical methods by which lignin is extracted from cellulose and many biofuels, such as cellulose, ethanol, and alcohol, as shown in Fig. 10. [39].

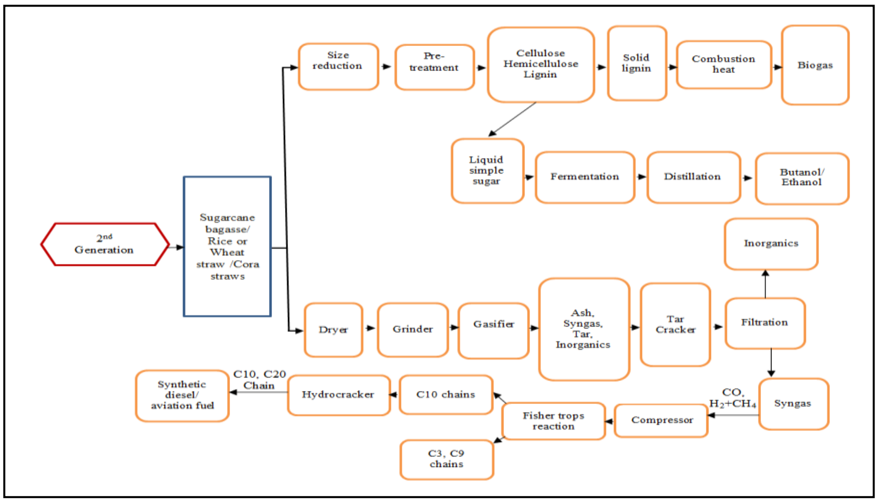

Fig. 10. Second-generation biofuel processing

Third-Generation Biofuel: Biofuel production is a promising future industry through algal oil esterification technologies and alcohol production through algal biomass fermentation. Algae are phototrophic microorganisms and a good source of food, fat, fuel, and oil; algae can produce biogas, bioethanol, and biohydrogen. Algae contain large amounts of fats, proteins, and carbohydrates, and these organic components can be used in biofuel production. Algae are the most widely used in biofuel production, and many methods are used for this, either through dark fermentation, biodegradation, or photo-fermentation. The technology of transesterification of algal or vegetable oil is considered more efficient than using fermentation technology to produce ethanol, as shown in Fig. 11.[40], [41].

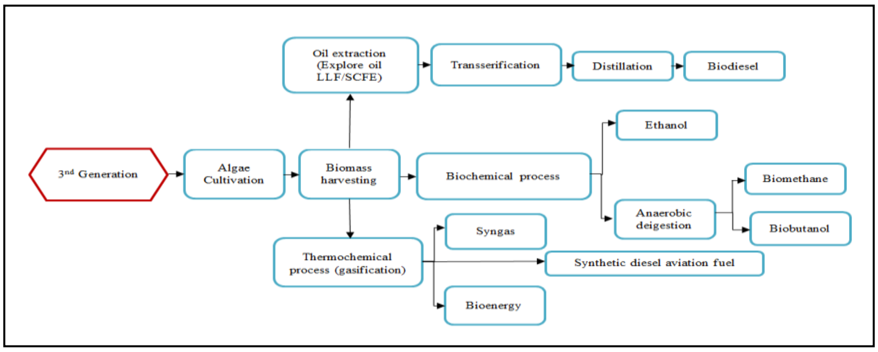

Fig. 11. Third-generation biofuel processing

Fourth-generation biofuel: The raw materials for this generation are derived from genetically modified biomass from second, third-generation sources. These modifications allow for the extraction of CO_2 and the mitigation of emissions into the environment [42]. Unlike third-generation fuels, biofuels are produced using non-arable land, which does not require the destruction of biomass. This type of biofuel includes the production of solar biofuels and electric fuels, and some of these types of fuels are carbon-free, as shown in Fig. 12.[43].

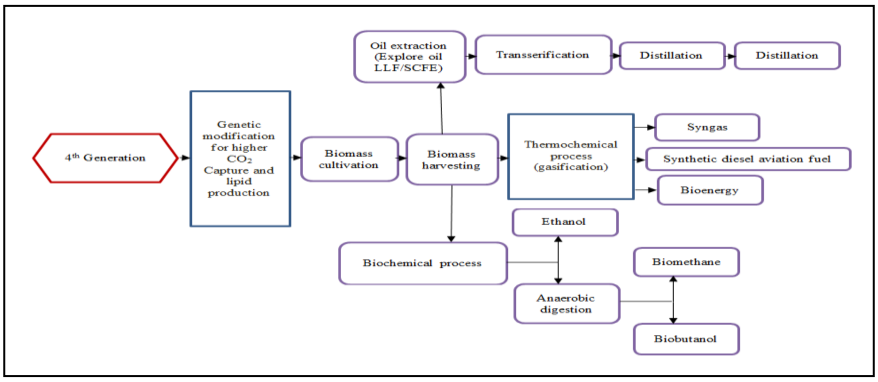

Fig. 12. Fourth-generation biofuel processing

6. Biomass Conversion Technologies

There are many biomass conversion technologies for producing different forms of energy and value-added chemicals, fertilizers, and functional materials. The choice of a particular product for conversion relies on several factors, such as the desired goal, associated environmental impacts, available technologies, and its state of maturity [44]. Table 1 shows the production of different bioenergies from bulk raw materials and the method of carrying out these processes [45].

Table 1. Biomass to biofuel conversion technologies

Thermochemical	Biochemical	Biological	Physical
Pyrolysis	Transesterification	Aerobic composting	Drying
Gasification	Hydrolysis	Anaerobic digestion	Extraction
Hydrothermal	Supercritical water	Fermentation	Crushing
Torrefaction			Distillation
Liquefaction			Grinding
Combustion			Briquetting
Incineration			

7. Biomass Conversion Technologies

Many studies have dealt with how to convert biomass into biofuel, as follows:

Limayem and Ricke [46] reviewed large-scale biofuel production and noted that interest in biomass-derived biofuels increases every time oil prices rise. Jacobson et al. [47] reviewed technologies for developing the production of gas, diesel, and chemicals from waste biomass and concluded that there is great potential for converting it into transportation fuel. Sheldon [48] reviewed the potential for converting biomass using various technologies into chemicals and fuels. He found that the amount of lignocellulosic waste, estimated at ($2x10^{11}$t) per year, is classified into two groups: the first is related to residual waste, and the second is related to product processing. He described some uses beyond energy valuation, especially bulky chemicals such as surfactants, industrial solvents, and lubricants. Passos et al. [49] converted sewage sludge by anaerobic digestion to biofuel and recovered 181 ml for CH_4/g at 35°C, pH=7.

Molinuevo-Salces et al. [50] converted algae biomass and obtained methane amounting to 325 ml/g of solid mass by anaerobic digestion at 35 and a reaction time of 14 h. Hwang et al. [51] converted microalgae biomass to biofuel and recovered ethanol amounting to 0.18 Kg/Kg of biomass, and the process was carried out at 37°C by pretreatment and hydrolysis method. Sengmee et al. [52] converted algae (*Chlorella Sp.*) to biofuel by the Biological H2-Production method at 30°C, pH=6.8, and fermentation time 24 h. Lu et al. [53] converted Jatropha Curcas seed to Crude bio-oil with a yield of

41.5% using a liquefaction technique at 250°C and a reaction time of 40min. Couto et al. [54] converted domestic sewage to crude bio-oil with a yield of 44.4% using a liquefaction technique at 300°C and a reaction time of 15min. Jahromi and Algblevor [55] converted pinyon wood chips (HDO) to bio-oil using the pyrolysis technique at 350°C and in the presence of a nickel/red clay catalyst.

Cho et al. [56] converted coffee waste (coffee syngas) to bio-fuel using the pyrolysis technique at 700°C and in the presence of a catalyst, and the reaction lasted for 110 minutes. Liu et al. [57] produced fuel from Rice straw by gasification technique at 600-800°C with an O_2 content of 33% and airflow of 0.6 Nm^3/hr. Martin-Pascual et al. [58] converted olive tree waste to biofuel by torrefactions technique at 275°C and reaction time of 30 min. Liu et al. [59] converted sorghum straw powder and pellets to biofuel by torrefactions technique at 280°C for 5 min. Prasad et al. [60] were able to convert pretreated and saccharified rice straw to biofuel by pretreatment of alkali NaOH and microwave, and the reaction was catalyzed using P. Stripitis NCIM3499 and the catalyzed time took about 72 hr.

Shi et al. [61] produced biochar, bio-oil, and syngas from gumwood and bamboo using microwave pyrolysis technology at 600-800°C. The production process was very successful, as biochar yielded 22.2-14.5%, bio-oil 11.4-3.2%, and syngas yield 81.1-66.7%. Foong et al. [62] explained that biomass waste is an alternative to fossil fuels, and the best process used for conversion is pyrolysis rather than chemical conversion due to lower pollutant emissions and less waste formation. Different types of pyrolysis were also explained: solar pyrolysis as a heating source and vacuum pyrolysis, carried out under repeated vacuum conditions in an inert atmosphere. Cho et al. [63] also reviewed the application of biochemical processes to different types of biomass wastes generated from agricultural activities. They concluded enzyme technology is more efficient for converting biomass into valuable products used in the pharmaceutical, chemical, food, and cosmetic sectors.

In general, many technologies are used to convert biomass into biofuel, and each technology has advantages and disadvantages. Still, one thing is agreed upon, which is the use of biomass to generate energy from a bio-economy perspective, which is related to understanding the sustainable performance of biomass as a biofuel resource.

8. Biomass Conversion Technologies

8.1. Thermochemical Method

Pyrolysis: Technology is the decomposition of biomass at temperatures ranging from (200-600oC) to produce medium-energy gas, solid residues, and liquid materials. The solid residue is called biochar, a porous carbon compound, while the liquid materials include pyrolysis oils and aromatic compounds, which may be valuable as chemical raw materials. The advantages of this technology are that it is highly efficient and flexible, but its disadvantage is its high operating cost. Fig. 13. illustrates the pyrolysis process [64].

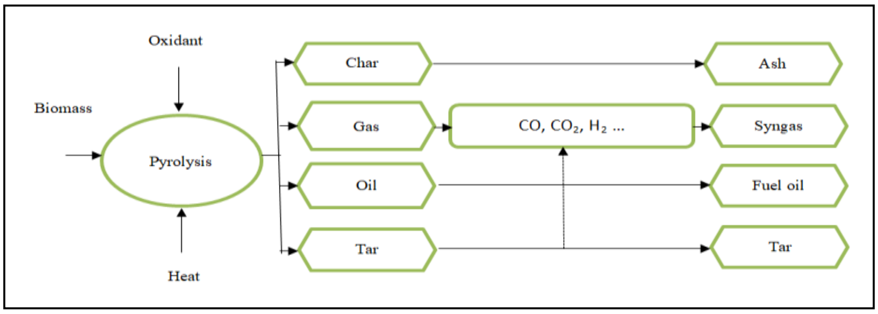

Fig. 13. Represents thermal decomposition

Gasification: The chemical process by which carbonaceous materials are converted into synthetic gas through molecular oxidation with oxygen, air, or steam at high temperatures (800-900°C). Gasification is a promising method for producing materials (energy sources) derived from agricultural waste. Synthetic gas consists of carbon monoxide, hydrogen in low proportions, carbon dioxide, water, hydrogen sulfide, methane, and ammonia under certain conditions. In gasification technology, it is preferable to use dry biomass compared to wet biomass because it does not require further drying. Its advantages include flexibility and reduced emissions, and the resulting industrial gas has various uses [65].

Liquefaction: Thermal liquefaction technology converts biomass into bio-oil with high quality and productivity, reaching about 33.5% with less oxygen content and water. However, this process uses high pressure, which leads to an increase in the cost of the equipment required for the procedures at the industrial level. Fig. 14. represents the liquefaction process [66].

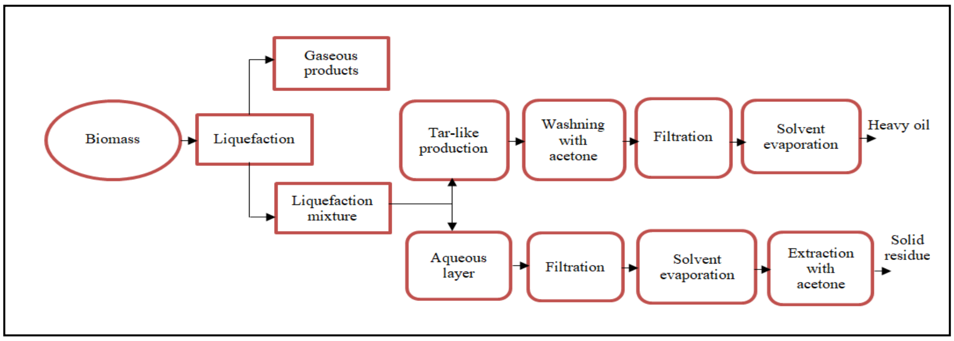

Fig. 14. Liquefaction process)

Torrefaction: This technology represents a thermal chemical treatment system (200-300 °C) in an inert environment, which produces solid char. The process is carried out in the laboratory using thermogravimetric analysis (TGA), a small tubular reactor, and a furnace. This technology has significant benefits. However, the technology needs to be solved before it can be commercialized. The pyrolysis technology is determined by the factors of temperature, heating rate, reactor bed height and type, pressure, residence time, feedstock type, and feedstock mixing ratio as factors that had the highest impact on yield, stability, and carbon content of biochar [67].

Combustion: Combustion is the only way to produce thermal and electrical energy. Three steps occur during biomass combustion: drying, pyrolysis, and reduction. Although this process can be used for most forms of biomass and has a high efficiency in heat production, making it economically viable, it has been found to require complex reactions and requires air, fuel, and heat [68].

Incineration: Oxidative combustion process in aerobic conditions at high temperatures between 900-1100°C. The final products of this method are ash, combustion gas, and solids. The most critical steps of this process are evaporation, discharge, pyrolysis, and gasification. Still, its disadvantage is that it generates many harmful gases, leading to water and air pollution [69].

8.2. Biochemical

Biochemical processes allow the conversion of biomass by its decomposition into available carbohydrates into biogas and liquid fuels in addition to many other bioproducts. This is done using a combination of biological and chemical pathways, such as biological catalysts and microbes, which provide a high selectivity for converting biomass into final products [70]. Table 2 shows these techniques.

Table 2. Biochemical technologies

Technology	Biomass Type	Advantages	Disadvantages	Product	Ref.
Transesterification	Microalgal	low process temperature, environmentally friendly	purification of products requires high cost; the process time conversion is long	Biodiesel liquid fuel	[71]
Hydrolysis	Lignocellulosic such as softwoods, agricultural waste	The temperature used by the process is moderate; you do not need to use expensive enzyme materials	This leads to corrosion, dangerous, toxic	Ethanol Sugars	[72]
Supercritical Water Gasification	Waste plastics	Highly selective H_2, high efficiency	It causes corrosion because it operates under high-pressure	Hydrogen	[73]

8.3. Biological technologies

It is considered environmentally friendly, and it is enhanced to a specific chemical product through a set of reactions in the metabolic pathway. It has many advantages for using biological catalysts to convert carbohydrate raw materials into chemical products without intermediate separation processes. As for its disadvantages, it uses high-cost hydrolytic enzymes and some microorganisms' sensitivity to issues such as growth settings, nutrients, and inhibitors, which takes a long time [74]. Table 3 shows the biological techniques.

Table 3. Biological technologies

Technology	Biomass Type	Advantages	Disadvantages	Product	Ref.
Fermentation	Microalgae	Short processing time, high ethanol production, low production cost	Microorganism instability	Grain Alcohol	[75]
Aerobic composting	Organic waste	It kills microorganisms, reduces the amount of animal manure	This leads to environmental pollution	Heat	[76]
Anaerobic digestion	Livestock Manure Sewage sludge	Safe disposal of materials through digestion, its economic costs are low	Additional processing is required to produce refined products, and processing and storage problems	CO_2 CH_4	[77]

Fermentation: The series of biological reactions that convert monosaccharides into ethanol and carbon dioxide under anaerobic conditions using yeasts is called fermentation. The targeted raw materials for this type are sugars and starch. Carboxylic acids and Glycerin are produced as by-products with CO_2 and ethanol. The advantages of the process are that in addition to obtaining ethanol as a concentrated alcohol, solid residues are obtained that are used as fuel in production boilers [78].

Aerobic composting: C, N_2 compounds are easily converted into energy & protein sources by microbes, ammonia, organic acids, water, and improved compost products. This technology's advantages are reducing animal manure and converting waste into nutritious organic substances to enhance soil fertility. However, composting procedures contribute to additional environmental pollution [76].

Anaerobic digestion: An excellent benefit for generating renewable energy and proper waste management. This technology is carried out in four stages: Acidogenesis, hydrolysis, acetogenesis, and methanogenesis, and a set of chemical reactions in metabolic pathways. The raw materials used here include municipal solid waste, animal manure, and agricultural waste [79].

8.4. Physical technologies

This pre-processing process is carried out to convert biomass and includes size fragmentation, condensation, drying, and obtaining biomass with improved properties. Extraction, distillation, and molding are commonly used techniques. Table 4 represents the physical techniques.

Table 4. Physical technologies

Technology	Biomass Type	Advantages	Disadvantages	Product	Ref.
Extraction	Seeds	Low energy consumption Safe, environmentally friendly	Widespread application problems	Oil	[80]
Distillation	Seeds	High yield, separate the components completely	Power consumption is high	Bio-oil	[81]
Briquetting	Agricultural waste	Its prices are reasonable, it has storage capability, and it can be transported long distances.	There is a great need for trained staff, expensive, high energy consumption.	Fuel	[82]

8.5. Ultrasonic

Ultrasound stimulates the response mixture to produce bubbles and break them up uniformly, forming what is called (cavitation). The use of this technique significantly reduces the reaction time, temperature, and energy input; heat is generated once a sufficient depth is applied throughout ultrasonic cell disruption, which enhances the efficiency of biomass cell disruption, which in turn is affected by the use of ultrasonic cavitation through the temperature of the liquid medium, viscosity and additional temperature [83].

8.6. Microwave

Microwave technology uses microwave energy to process materials, reducing processing time and conserving energy. This technology has received wide attention as a valuable technology as microwave irradiation provides excellent safety and convenience for heating reaction mixtures to achieve the required temperatures for the application [84].

8.7. Nanotechnology

Nanotechnology uses a variety of metal nanoparticles and metal oxides. There are many such materials, such as the use of iron oxide NPs to produce biodiesel from waste cooking oil, $Ca/Fe_3O_4@SiO_2$ to produce it from sunflower and soybean oil, and the use of Pd on C, Pd on alumina, and Fe_3O_4NPs to produce bioethanol from syngas [85], [86].

9. Biofuel Products

9.1. Biomethanol

Methanol production relies exclusively on biomass waste (old wood or biowaste) and is a costly chemical reaction procedure. It is likely to be used as fuel for internal combustion engines in the future because, during combustion, it does not cause carbon emissions [87].

9.2. Bioethanol

Bioethanol or (ethyl alcohol) is one of the sustainable renewable fuels due to its economic and environmental benefits. It is produced from lignocellulosic biomass by using advanced fermentation or hydrolysis techniques. It is used as fuel in vehicles, industry, and transportation, and its production reduces greenhouse gas emissions [87].

9.3. Biodiesel

Biodiesel is produced by converting fat sources (animal and lignocellulosic biomass such as (corn, vegetable oils, wheat), and edible fats) into mono-alkyl esters using transesterification technology. It can be used as a good alternative to petroleum diesel. This replacement has led to a decrease in CO2 emissions and a decrease in fuel use [88].

9.4. Biogas

Biogas is produced by anaerobic digestion of biomass, a complex biological process with a high energy efficiency and biomass conversion compared to ethanol. Biogas mainly consists of methane (CH_4) (40-75%), CO_2 (15-60%), and small amounts of H_2O (5-10%), H_2S (0.005-2%), NH_3 (less than 1%), and CO (less than 0.6%). There are two basic steps in processing biogas before its final use: cleaning and upgrading, and it cannot be used as vehicle fuel without making any modifications [88].

10. Conclusion

This review examined the utility of using biomass to produce different biofuels. The review showed that abundant waste and biomass residues are produced from various sources worldwide. Thermochemical, biological, and physical conversion technologies have been used to process multiple primary materials to produce different bioenergy sources. Both product specifications and the nature of raw materials determine the choice of appropriate production technology, and it can be concluded that biomass production technologies have significant potential for sustainable energy production despite the operational limitations that hinder their limited scalability and infrastructure challenges. Thermochemical technologies are the most widely used and are more efficient and commercially viable for biofuel production. Chemical and bio-biological technologies are environmentally friendly and economically feasible. These conversion technologies are known to rely on raw materials such as agricultural waste, solid waste, and animal manure, making them an excellent choice in developing countries, mainly rural areas where this type of biomass is available. Physical techniques have advantages in varying energy consumption from one method to another, but they have broad application problems. Emerging technologies such as Ultrasonic, nanotechnology, and microwave-assisted processing promise to improve biofuel production efficiency and selectivity. Still, their high costs and technical complexity currently limit large-scale deployment. With continued advancements in conversion technologies and supportive policy frameworks, biomass-based biofuels can be pivotal in transitioning to a low-carbon energy future.

Acknowledgment

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