BIOFUELS: A REVIEW ON EMERGING TRENDS AND APPLICATIONS

Abstract

A biofuel is defined as any fuel derived from organic materials like plants, agricultural crops, their waste products, and by-products. Due to depleting oil sources, energy security issues, and growing environmental concerns from rising greenhouse gas emissions and climate change, biofuels have gained a lot of attention recently. Modern technology is causing a significant rise in energy demand, which is resulting in an excessive use of fossil fuels. As a result, renewable energy is being examined as a potential replacement and is becoming more and more significant due to its effects on the environment, society, and economy. The biofuels are categorized into solid, liquid and gaseous biofuels based on the biomass used in their production. Biofuels are derived from biomass, which absorbs a substantial amount of CO2 from the atmosphere, their production and utilization are often considered carbon-neutral. Biochemical conversion and thermochemical conversion are the two main methods used to convert biomass into energy. Through the use of these processes, the biomass is transformed into three main categories of products: biofuels, heat, and power for the production of electricity. Globally, there is an increase in the generation of biofuels employing various developing technologies and biological processes from various bioresources. Waste disposal difficulties could be resolved and environmental burdens reduced if biomass waste and agricultural crop leftovers are used to make biofuels Economic sustainability is just unsustainable in the current environment. By contributing to local and national energy security, fostering economic growth, diversifying rural economies, creating employment opportunities,

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substituting imports with direct and indirect trade balance effects, enhancing energy supply, and promoting diversification through new industry creation, biofuel production and utilization offer opportunities for sustainable solutions.

Keywords: Biofuels, Production, Biomass, Generation, Biochemical

I. INTRODUCTION

A biofuel is defined as any fuel derived from organic materials like plants, agricultural crops, their waste products, and by-products [1, 2]. The growing demand for energy, driven by advancements in technology, has led to the overconsumption of fossil fuels [3].Because of its positive social, economic, and environmental effects, renewable energy is being seen as a potential replacement. The concept of using biofuels has existed for centuries. Biological materials were used to produce energy earlier in human history. But because they were readily available and commercially viable, humans continued to use fossil fuels as their primary energy sources [4] rather than plant resources. Among all sectors, transportation has experienced a notable surge in greenhouse gas (GHG) emissions, contributing to 15% of global GHG emissions and 23% of energy-related CO_2 emissions worldwide [5] .The transportation industry heavily depends on fossil fuels, constituting 96.3% of its fuel sources in 2018 [6]. Biofuels are widely acknowledged as promising alternative transportation fuels capable of diminishing the dependence on petroleum-based counterparts and mitigating climate change. Due to depleting oil sources, energy security issues, and growing environmental concerns from rising greenhouse gas emissions and climate change, biofuels have gained a lot of attention recently. Any fuel developed and produced from organic material, such as plants and their wastes, agricultural crops, and byproducts, is referred to as biofuel [7, 8] Biofuels can be a suitable replacement for fuel derived from petroleum. Modern technology is causing a significant rise in energy demand, which is resulting in an excessive use of fossil fuels [9]. As a result, renewable energy is being examined as a potential replacement and is becoming more and more significant due to its effects on the environment, society, and economy. The concept of biofuels has existed for a very long time. Biological materials were used to produce energy earlier in human history. However, because fossil fuels are readily available and commercially viable, humans have chosen to use them as their primary energy source rather than plant resources [10]

II. TYPES OF BIOFUELS

Additionally, the biofuels are categorized based on the biomass used in their production which are

1. **Solid Biofuels:** These biofuels originate from solid, organic, non-fossil biomass sourced from living organisms, which serve essential roles in generating heat, energy, and electricity[11] .They are produced from renewable industrial waste materials, including charcoal, fuel wood, wood pellets, wood remnants, and animal waste, with biochar being a notable illustration [12] .

2. **Liquid Biofuels:** These biofuels comprise all liquids derived from natural biomass or a biodegradable component [11] .In many aspects, liquid biofuels are preferable than solid and gaseous biofuels because of their high energy density, which makes them the ideal option for storage, transportation, and retrofitting[13] .Liquid biofuels include bioethanol, biodiesel, and bio oil, which are among the most significant types. Other liquid biofuels are included in the group of

    - Triglycerides based biofuels, which comprise biomass like vegetable oil, pyrolytic oil, biodiesel, hydrogenated oil, and bio-gasoline.

- Biofuels feedstocks including bio-oils, BTL diesel, and drop-in biofuels are all examples of lignocellulosic-based biofuels[14] .

3. **Gaseous Biofuels:** Gaseous biofuels with low density are by their very nature gaseous. Among the noteworthy examples are biosyngas, biogas, and biohydrogen[15] .The biowastes are converted into gaseous biofuels via pyrolysis or gasification. These biofuels are later used in Otto engines connected to an electricity generator to produce heat or power.

III. SOURCES OF PRODUCTION

Researchers and experts worldwide are closely monitoring the development of environmentally friendly biofuels derived from biomass resources [16] .The production of various gaseous and liquid biofuels from biomasses has gained momentum [17-22] .These biofuels encompass biodiesel, ethanol, methanol, methane, bio-oil, and Fischer-Tropsch H_2. As emphasized by Choi et al. [23] ,these biofuels hold significant promise for future energy supply and the achievement of sustainable energy security. According to Prasad et al. [24-26] ,the utilization of biofuels as a renewable energy source leads to a reduction in air pollution emissions, including greenhouse gases, particularly CO_2 during combustion, thus mitigating overall pollution levels and other environmental consequences. Because biofuels are derived from biomass, which absorbs a substantial amount of CO_2 from the atmosphere, their production and utilization are often considered carbon-neutral.

Depending on the feedstock they are classified as the following

1. **First-Generation Biofuels:** Other food items or crops used as animal feed are the main sources of the first-generation biofuels [27] .Because they are made utilizing a number of well-known technologies and processes, such as fermentation, distillation, and transesterification, these biofuels are also referred to as "conventional biofuels"[27] .Since the process focuses largely on producing fuel and discards the leftover non-fuel elements as garbage, membranes are not required in these methods[28] .

2. **Second-Generation Biofuels:** All of the non-food feedstocks used to make second-generation biofuels, including lignocellulosic plants, agricultural waste, forestry waste, and waste products, are used to make them [27]. The second generation of biofuel production is an advancement over the first generation and focuses on both increased fuel recovery and the creation of secondary raw materials. It is an economically viable technology because, in contrast to the first generation process, it concentrates on creating valuable fuels while lowering the cost of energy overall and the amount of trash produced. For these reasons, researchers frequently support methods like membrane filtering and the integration of several biorefineries to increase biofuel yield. In batch and continuous operations, a range of thermophilic and mesophilic organisms are utilized to produce organic acids, biofuels, and amino acids[28] .

3. **Third-Generation Biofuels:** By trans-esterifying or hydrotreating the algal oil, third-generation biofuels are produced from microalgae [27]. Compared to first generation biofuels that employ conventional crops, these techniques can effectively improve the biofuel yield annually[29]. The second and third generation biofuels are collectively

referred to as advanced biofuels because they are still in the development and research stages [27]. The main sources consist of workable, easily accessible, and adaptable to environmental parameters resources that don't damage the food chain. Microalgae, animal oils, fish oils, used cooking oil, and other sources make up the majority of these sources. Another important development is the ability to reduce waste handling plant load and water pollution [30, 31].

4. **Fourth-Generation Biofuels:** Fourth-generation biofuels are produced using photobiological sun fuels, electro-fuels, and genetically modified (GM) algae [31, 32] .Light penetration, photosynthetic efficiency, and the production of biofuels are all enhanced by the GM algal biomass [32] .Fourth-generation solar panels have infinite, widely available raw ingredients that are also more advantageous economically. Microalgal biomass can be genetically altered to produce autolysis in cells and product secretary systems, which could have uses in oil extraction processes. Zinc-finger nuclease (ZFN), transcription-like effector nucleases (TALEN), and clustered regularly interspaced palindromic sequences (CRISPR/Cas9) are examples of bioinformatics techniques used to modify genomes.[32,33]

IV. BIOMASS AVAILABILITY FOR BIOFUEL PRODUCTION

A easily available renewable resource, biomass can be converted into another type of bioenergy that is typically used as feed stocks or used directly as a biofuel. The possible and sustainable feed stocks for the manufacture of biofuels are biomass leftovers and waste products from agriculture, waste produced by agroindustries, forest byproducts, and municipal solid waste. Since pelletizing wood chips, straw, and post-harvest residue provides significant value to the final biomass product, issues including land availability, water accessibility, environmental stability, and biomass production prices all have an impact on the stability of energy crop production. Waste oils from restaurants, lodging establishments, and food processing plants that have been fried and boiled are alternative sources of lipid and fatty acid methyl esters (FAME). According to Talebian-Kiakalaieh *et al*.,[34] using used cooking oil as feed stocks for trans esterification could cut the cost of producing biodiesel by up to 60–90%. Additionally, recovering used cooking oil for the creation of biodiesel is preferable than just discarding it, which frequently has negative environmental effects[35]. Due to their significant lipid accumulation, macroalgae (seaweeds) and often developing microalgae in ponds are also a readily available and promising source of oil. They also don't compete for resources like agricultural land or water [36] .

V. TYPES OF BIOMASS

1. **Biodiesel:** Biomass stands out as the exclusive source capable of being converted into liquid biofuels such as ethanol and biodiesel, rendering it the sole renewable energy resource with this capability. Countries like Sweden, Austria, and the United States employ gasification techniques to manufacture biofuels, which find use in fueling vehicles. High-carbohydrate biomass varieties, such as sugarcane, wheat, or corn, undergo fermentation to yield ethanol, while biodiesel results from the blending of ethanol with vegetable, recycled, or animal fats. It's worth noting that the efficiency of biofuels is comparatively lower than that of gasoline. While they don't produce the pollutants commonly associated with fossil fuels, biofuels can be effectively employed in machinery and vehicles when mixed with gasoline. The production of ethanol necessitates

the cultivation of biocrops, primarily maize, over extensive farmland areas. Additionally, ethanol has gained popularity as a replacement for wood in residential fireplaces. When burned, it generates heat in the form of flames and releases water vapor instead of smoke.

2. **Biochar:** Biochar is an important byproduct of pyrolysis with uses in environmental and agricultural fields. Methane and carbon dioxide are released into the atmosphere by burning or decaying biomass, which can occur naturally or as a result of human activity. In contrast, when biomass is burned, its carbon content is sequestered or stored. The soil can continue to absorb carbon if biochar is added again. This will create substantial subterranean carbon sinks and reservoirs of stored carbon, which can lower carbon emissions and improve soil health. Additionally, biochar enriches the soil. Yes, it is porous. When biochar is added back to the soil, it takes up and retains water and nutrients. Biochar is used in the slash-and-char method used in Brazil's Amazon rainforest. The practice of slash-and-burn agriculture, which temporarily increases soil nutrients but gradually depletes them, is mimicked by slash-and-char agriculture.

3. **Black Liquor:** A hazardous, high-energy liquid known as "black liquor" is produced when wood is processed to make paper. Until the 1930s, black liquor from paper mills was considered waste and dumped into nearby water sources. Conversely, black liquor retains almost 50% of the wood's biomass energy. The mill could be powered by reclaimed black liquor thanks to the invention of the recovery boiler in the 1930s. The US forest industry is one of the most energy-efficient in the nation since paper mills there run almost entirely on black liquor. More recently, Sweden has been experimenting with gasifying black liquor to produce syngas, which can be used to generate electricity.

4. **Hydrogen Fuel Cells:** It is possible to chemically separate hydrogen from biomass and use it to power vehicles or generate electricity. In remote locations such as wilderness areas, stationary fuel cells generate electricity. For example, Yosemite National Park in the U.S. state of California uses hydrogen fuel cells to power and heat its administration building. Hydrogen fuel cells have even greater potential as an alternative energy source for cars. The U.S. Department of Energy claims that 40 million tons of hydrogen can be produced yearly from biomass. This would fuel 150 million automobiles. At the moment, hydrogen fuel cells are utilized to power buses, forklifts, boats, and submarines in addition to being examined on aircraft.

VI. COMPOSITION OF BIOMASS

Because biomass is a flexible energy source for biofuels, it is important to comprehend its main chemical structure because it has a significant impact on biofuel productivity. The plant cell wall is made up of cellulose, hemicellulose, lignin, and trace amounts of inorganic material. Thus, it is known as lignocellulosic biomass; nevertheless, the mass balance and biochemical makeup of this biomass vary depending on the kind of plant. The biochemical balance and structural stability of the biomass component, in addition to this composition, determine how much of the biomass decomposes during pyrolysis and hydrolysis[37].For instance, according to Ahorsu *et al*.,[38] hemicellulose or cellulose can yield more oil during pyrolysis than lignin can. In a different study, Yang *et al*.,[39] described the pyrolysis of hemicellulose, cellulose, and lignin and discovered that cellulose lost about 94.5% of its weight at 400 °C and hemicellulose lost 80% of its weight at 268 °C, but only

54% of lignin lost weight at 900 °C. It should be noted that the biomass production is what caused the change in the pyrolysis temperature and oil yield.

VII. METHODS OF BIOMASS CONVERSATION

Biochemical conversion and thermochemical conversion are the two main methods used to convert biomass into energy. Through the use of these processes, the biomass is transformed into three main categories of products: biofuels, heat, and power for the production of electricity.

1. **Thermo-chemical processes:** High-pressure liquefaction and quick pyrolysis are two additional categories for the thermo-chemical conversion of biomass [40]. The biomass plays a significant role in the fuels industry as alternate sources of fuels and chemicals, primarily bio-oils derived following thermo chemical conversion.

2. **Pyrolysis:** Pyrolysis is a primary technique employed in the conversion of biomass into biofuels [40] .This process utilizes heat in the absence of oxygen to break down long-chain molecules into their shorter-chain counterparts [41] . Fast pyrolysis has shown significant promise in yielding biofuels with medium-low calorific values and producing concentrated fuel oils [40] .Typically, biomass or waste materials serve as the primary feedstock in this process to generate syngas and various liquid fuels, and an advantageous feature is the transformation of solid materials into more manageable gases and vapors, easing handling, transport, and storage. Nevertheless, it's worth noting that a substantial amount of heat is required for the chemical reactions essential to syngas production, which represents one of the notable challenges.[41].

3. **Carbonisation:** Carbonization is the term for the process of slow pyrolysis that is mostly used nowadays to create charcoal. [41]. There are three main ways to accomplish these:

   - Hot circulating gas for chemical production in the retort or converter gas;
   - External heating using fuel wood or fossil fuel;
   - Internal heating of raw materials with regulated combustion. [43].

4. **Combustion:** Combustion is the process of burning biomass in the atmosphere, which is then used to transform chemical energy into mechanical power, electrical power, or heat. The combustion process is carried out using a range of process equipment, including as boilers, steam turbines, turbo-generators, furnaces, and stoves [44] .Through a series of homogeneous and heterogeneous reactions, the primary combustion products are heat, power, or CHP [45] .The temperature, combustion environment, and particle size of the feedstock all have a major impact on biomass combustion. The combustion process's primary drawback is its significant emissions of nitric oxide and carbon dioxide, as well as its release of particulate matter and ashes.[46].

5. **Gasification:** Gasification is another thermo chemical process that employs biomass fuel to produce gaseous products with a high energy content [40] .Combustion produces two main byproducts: fuel gas and syngas. Syngas synthesis also yields hydrogen and methanol, which are widely used as fuels for transportation [44].One of the main concepts

of BIG/CC Biomass Integrated Gasification/Combined Cycle Plant systems is also connected to gasification conversion systems. It has a wonderful function in that it can purify the gas prior to combustion in the turbine. The gas is cleaned and compressed, resulting in a considerable reduction in volume. [44, 47].

6. **Liquefaction:** Liquefaction, carried out under conditions involving low temperature and high hydrogen pressure, is a process that transforms biomass or other organic materials into stable liquid hydrocarbons [44] .In the high-pressure liquefaction of air-dried wood, bio-oils are generated, comprising a complex mixture of volatile organic acids, alcohols, aldehydes, ethers, esters, ketones, furans, phenols, hydrocarbons, and non-volatile components [40] .For producing substances with a higher energy density in the liquid phase, catalytic liquefaction represents an efficient approach. The use of a catalyst or operation under high hydrogen partial pressure can facilitate catalytic conversion. Nevertheless, it's important to note that this technology presents significant technical challenges, which have limited its widespread adoption [41] .

7. **Bio-Chemical Processes:** The use of bacteria in bio-chemical (or biological) conversion processes results in the production of gaseous compounds with a wide range of commercial and industrial uses from biomass [46] .Anaerobic digestion and fermentation are the two primary methods employed.

   - **Fermentation:** Commercially, ethanol is made from sugar and starch crops like sugarcane, sugar beet, and wheat using an anaerobic process. Saccharides must first be broken down before being converted to ethanol by yeast and enzymes. Later, distillation is used to complete the purification. Instead of being thrown away, the solid waste products are either gasified or utilized as cattle feed or boiler fuel (a product of sugarcane). Because of its high productivity and great potential for energy in the residue, sugarcane is mostly employed as a preferred feedstock [41]. The lignocellulosic biomass, such as wood and grasses, is also divided into more basic components. But the longer-chain polysaccharides in these compounds give them a more complicated structure. Hence, it is subjected to acid or enzymatic hydrolysis and then fermented to form ethanol [44] .

   - **Anaerobic Digestion:** Anaerobic bacteria digest microbial feedstock in the absence of oxygen, resulting in the production of heat, carbon dioxide, methane, and hydrogen sulfide. This process takes place in large tanks under optimal conditions and spans several days. Once digestion is complete, the remaining solid digestate is employed as fertilizer, while the released gases (biogas) are processed into fuel [41]. This method is widely regarded as the most eco-friendly and energy-efficient approach for generating biogas, which can be utilized for heat and/or electricity production, as well as for producing biosolids for soil improvement and liquid fertilizer. [48].

VIII. RECENT PROGRESS IN TECHNIQUES OF BIOFUEL PRODUCTION

Globally, there is an increase in the generation of biofuels employing various developing technologies and biological processes from various bioresources. Waste disposal difficulties could be resolved and environmental burdens reduced if biomass waste and agricultural crop leftovers are used to make biofuels [21,22,36]. Due to their environmental friendliness and carbon neutrality, biomass materials derived from various plants and microorganisms are currently the subject of increased research. Additionally, photosynthesis allows these plants and algae to store biomass [49,50]. As a result, more research is being done on cutting-edge technology for producing biofuels as a source of energy. According to the usage of biomass-based resources, biofuels are divided into four generations: first, second, third, and fourth. In the beginning, edible food crop resources including sugarcane, potatoes, oilseeds, corn, barley, wheat, sunflower, and soybeans were used to make biofuels like biodiesel and bioethanol [51,52]. Thus, according to Hayashida *et al*.,[53,54] the first biofuel chemical energy to be produced from raw corn and sugarcane was ethanol. This process involved the use of a fungus called mycelia as an enzyme throughout the fermentation process. The similar outcome shown by Wang *et al*.,[55] demonstrates that ethanol fermentation may be produced with raw maize flour when starch-digesting microorganisms such *Rhizopus sp.* and *Saccharomyces cerevisiae* are used. Consequently, a massive volume of bioethanol was created today. The term "second-generation" describes the production of biofuels from readily available lignocellulosic materials and various organic waste products (such as wood, straw, and switch grass, as well as oilseed-bearing plants like jatropha). Algae are used as a feedstock in the third generation of biofuels, producing a significant number of lipids that are used to make biodiesel and other biofuels. However, the ability of organisms to fix more CO_2 and the post-genome technology of microalgae are required for the production of fourth-generation biofuels [56,57,58,59].Thus, numerous methods that can be utilized to convert biomass into biofuels using various mechanical, thermochemical, and biochemical conversion approaches, as well as 1st through 4th generation technologies.

IX. SOCIO-ECONOMIC ISSUES

Energy is a very important factor in both social and economic development [60], and biomass to bioenergy resources are particularly significant since they provide more value from already-existing items. Future liquid fuel demand is assumed to promote income and earnings as well as socioeconomic benefits, which is related to the social and economic elements of biofuels. To guarantee the rural and regional service from local biofuel production and its use, many nations diversify their energy mix. Even if economic factors are crucial in deciding which investments to make, scientific research is not constrained by them. In addition to the often used raw materials, research works to develop more environmentally friendly alternatives that are also commercially feasible. Finding free or inexpensive resources is important because the raw material represents the largest expense in the manufacture of biodiesel. There is a lot of used vegetable oil accessible, but it needs to be collected properly. Microalgae-based wastewater treatment could provide a solution to the untreated wastewater in addition to biodiesel generation. Municipal solid waste-volatile fatty acids and FOG-based (fat, oils and grease) technologies offer numerous benefits as well. Economic sustainability is just unsustainable in the current environment. The creation of biodiesel is strongly related to various aspects of life, including employment, nutrition, economics, feedstock production, chemistry, technology, and innovation[61].

X. CONCLUSION AND FUTURE PERSPECTIVES

This overview delves into the potential of biofuel production, addressing challenges associated with various feedstocks and advancements in process technologies. Biomass, characterized by its high energy density, serves as the primary feedstock for biofuel production. However, the conversion of biomass is contingent on operational conditions, the chosen conversion method, and the cost-benefit analysis. Addressing these challenges necessitates ongoing development and refinement of advanced technologies and novel strains created through genetic engineering. Among the most promising solutions are biofuels derived from energy crops and microalgae. Expanding biofuel production at a larger commercial scale through genetic engineering warrants further research and development. Biofuels offer notable environmental benefits compared to fossil fuels. Nevertheless, when establishing criteria for assessing the biofuel sector's implications, considerations regarding land use, water consumption, and biodiversity must be taken into account. This review underscores the crucial importance of the social and economic dimensions of biofuels. By contributing to local and national energy security, fostering economic growth, diversifying rural economies, creating employment opportunities, substituting imports with direct and indirect trade balance effects, enhancing energy supply, and promoting diversification through new industry creation, biofuel production and utilization offer opportunities for sustainable solutions.

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