CUTTING-EDGE BIOFUEL TECHNOLOGIES FOR ENVIRONMENTAL MANAGEMENT AND SUSTAINABILITY

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Highlights

The article explores advanced biofuel technologies that enhance environmental management and promote sustainability.

Abstract

Researchers focus on finding Renewable Energy Sources (RES) and green energy for a sustainable future owing to ecological sustainability standards, growing power demands, depletion of traditional energy resources, and ecological damage caused by global warming and climate change. Bioenergy is a very viable option as it may be used for various energy needs via appropriate conversion methods. This analysis focuses on the promise and problems of producing biofuels using different feedstocks and advancements in process technology. The use of biofuels, such as biodiesel, ethanol, bio-oil, syngas, Fischer-Tropsch Hydrogen, and methane ($CH4$), generated from agricultural crop left-overs, micro- and macroalgae, and other biological waste via thermo-bio-chemical procedures, has been determined to be an environmentally beneficial option for energy production. Developing and implementing biofuels in industry and transportation significantly reduces reliance on petroleum and coal. The literature study indicated that biofuels derived from crops and microalgae have the potential to be the most effective and appealing method. The area of biofuels has made significant advancements via genetic engineering, which has opened up new possibilities for large-scale production for commercial use. However, the process of

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producing biofuels on a big scale remains difficult. Therefore, it is crucial to address this issue by converting biomass into biofuels using innovative technology to meet present and future energy demands.

Keywords
renewable energy sources; biodiesel; thermo-bio-chemical procedures; sustainability; biomass.

Introduction

The continuous growth of the population and industrialization has expedited global energy needs. Energy use is anticipated to increase by about 54% during the next 15 years [1]. China, the USA, and India are now consuming the highest total global energy consumption, accounting for around 24%, 18%, and 11% respectively [2]. Coal, petroleum, and natural gas have traditionally been the primary power sources to meet increasing demands. Conventional fossil fuels now fulfill around 85% of the overall energy demands [31]. However, they present several significant concerns [3][20].

The finite nature of fossil fuels leads to their depletion, which in turn produces a significant energy crisis. The scarcity of energy sources increases their pricing, a significant economic issue, particularly in impoverished countries [36]. According to the International Energy Outlook 2018 (IEO-2018), India and Africa, along with China, have the highest population densities in the world. Their economies jointly account for almost one-third of global energy consumption, and their energy use is projected to increase significantly compared to other regions [33]. Consequently, any alterations in these economies have a detrimental impact on the global energy sector. China has the title of being the greatest energy producer globally, as well as being the primary manufacturer of energy-intensive goods [5]. By approximately 2040, the industrial sector will continue to be the primary end-use sector that consumes the most energy [4][6].

The first and most difficult problem is the irreparable environmental harm caused by using traditional fuels. The combustion of fossil fuels results in the release of detrimental gases such as carbon dioxide (CO2), methane (CH4), sulfur oxides (SOx), nitrogen oxides (NOx), and others. These emissions contribute to acid rain, global warming, and Earth climate alterations [7]-[9]. If emissions are not reduced, the current level of CO2, which is 394.5 ppmv (parts per million volume), is projected to increase to 500 ppmv by around 2050 [4]. Various techniques have been used to collect CO2, including adsorption using amines, carbonates, and ammonia. However, pre-combustion approaches like chemical looping combustion and oxy-fuel capture are inadequate in controlling the rapid increase in environmental CO2 concentration. These barriers have intensified the emphasis on the need for clean and renewable energy to achieve long-term sustainability [11]. Scientists have been developing extremely efficient technology to meet energy needs without causing severe environmental effects [18][23] [25].

Hydro, wind, solar, and biomass are alternatives and RES that may effectively enhance energy reliability while being economically and environmentally favorable [4]. Among several RES, bioenergy stands out since it can be stored and used via various energy-conversion techniques to meet various energy needs. Bioenergy may meet various energy needs, including producing solid biomass, liquid biofuels, or gaseous biogas or biomethane. Bioenergy may also contribute significantly to improving the financial condition of remote and underdeveloped regions by generating employment prospects [12]. It may produce electricity and heat simultaneously using combined heat and power (CHP) facilities. Biofuel may be derived from live creatures or natural feedstocks and used for transportation. The primary biofuels manufactured worldwide are ethanol, biodiesel, and biobutanol. Ethanol is a fuel that contains oxygen and has a high degree of evaporation. It also has a higher-octane amount, a low cetane quantity, and an elevated combustion temperature compared to fossil fuels [35]. Mixing bioethanol with gasoline decreases the release of GHG emissions and other detrimental gases [14].

Furthermore, biodiesel has more O2 than diesel fuel, leading to more efficient combustion. Consequently, it reduces the release of fine particles, carbon monoxide, and inert hydrocarbons [15]. The manufacture of biodiesel from fats from livestock, vegetable fats, and both edible and non-edible plant-based oils has been thoroughly researched as an environmentally friendly alternative to traditional fuels [16].

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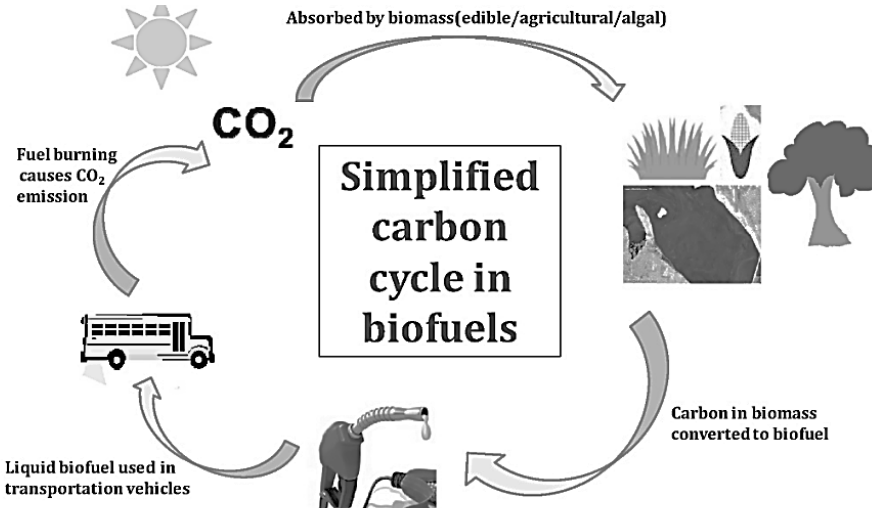

Figure 1. Simplified carbon cycle when biofuels are employed in the transport sector (reproduced from [4])

Figure 1 illustrates the simplified carbon cycle that occurs when biofuels are employed in the transportation sector. The generation of biofuel is increasing quickly, prompting some governments to recognize its importance and initiate the development of alternative fuel sources for transportation to reduce reliance on traditional fossil fuels. In 2019, worldwide biofuel output increased by over 8% compared to 2018, reaching a total of 155 billion liters (equal to 4.2 EJ). China is expected to see the most rise in biofuel production from 2019 to 2024, followed by Brazil and the USA [6].

From 2013 to 2023, ethanol production in India has increased, as reported by the Renewable Fuel Association of the USA (Figure 2). The increasing recognition of bioenergy has prompted governments to take significant measures and establish objectives. Indonesia aims to replace 15% of gasoline with ethanol and 20% of diesel with biodiesel by 2025. Meanwhile, Thailand is installing 12 bioethanol plants expected to produce around 2.6 million gallons of ethanol per day [17]. The United States has set a goal to substitute 20% of its road transport gasoline with biofuel by 2022, while the European Union has established a target of 10% biofuel use for transport by 2020.

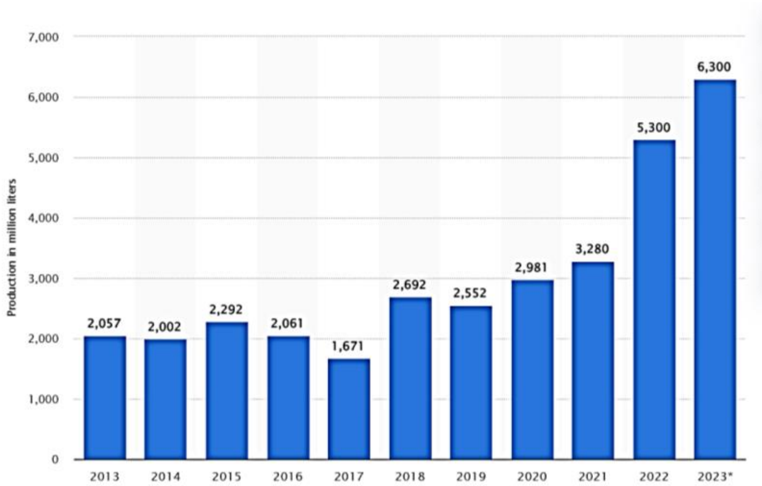

Figure 2. Ethanol production in India from 2013 to 2023

This study specifically examines the latest developments in biofuel technology, namely in producing bioethanol, biodiesel, and biobutanol, using the biochemical process. Significant attention has been focused on the role of nanotechnology, energy-efficient distillation processes, and bioengineering methods to enhance biofuel output and ensure the manufacturing process's economic viability and ecological sustainability [13].

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Advancements in New Technologies for Improving the Generation of Biofuels

Worldwide extraction of biofuels is on the rise, thanks to the use of diverse bioresources and the implementation of numerous cutting-edge technologies and biological procedures. Utilizing residue from biomass and crop leftovers for biofuel production can decrease the ecological impact and address several environmental concerns, such as waste management [34]. Currently, a growing amount of research is being conducted on the manufacture of biofuels using various plants and biomass materials derived from microorganisms. This is due to their environmentally favorable properties and their ability to be carbon-neutral resources. Furthermore, these plants and algae can amass biomass as a result of the process of photosynthesis. As a result, there is an increased focus on researching sophisticated technologies for producing biofuels as an energy source.

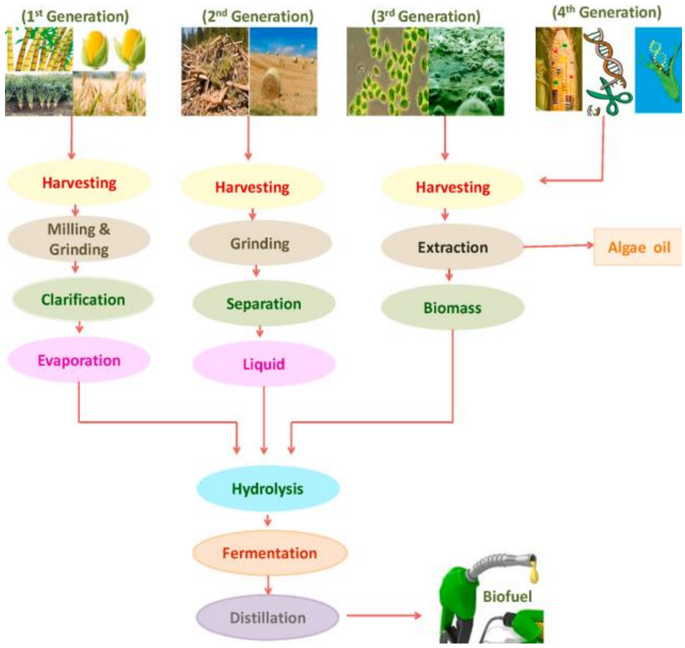

Figure 3. Schematic for converting biomass to biofuel (reproduced from [19])

Biofuels are classed into several generations depending on the kind of biomass-based materials they use. These generations are referred to as 1st, 2nd, 3rd, and 4th generation biofuels, as seen in Figure 3. The primary stages in the biochemical conversion of biomass include enzymatic hydrolysis, which breaks down carbohydrates into basic sugars that may be fermented to produce ethanol/butanol. The cultured broth is then distilled to extract the ethanol. Figure 3 provides a comprehensive breakdown of the procedure.

The first iteration of biofuels, including biodiesel and bioethanol, were derived from consumable food crops such as sugarcane, wheat, sunflower, and soybean. Ethanol, derived from raw maize and sugarcane using fungal mycelia as an enzyme in fermentation, was the first biofuel to harness chemical energy [30]. A significant quantity of bioethanol from starch is being generated on a wide scale using early enzymatic hydrolysis techniques in the first generation. The term "2nd-generation" pertains to the production of biofuels using lignocellulosic materials and other organic waste products, such as wood, straw, and oilseeds-bearing plants, which are readily accessible [21]. Algae are used as feedstock in 3rd generation biofuels, contributing a significant quantity of lipids for the production of biodiesel and other biofuels. Nevertheless, the production of 4th-generation biofuels relies on genetically engineered organisms and altered metabolic pathways, the enhanced capacity for CO_2 fixation, and the use of post-genome technologies in microalgae.

Conversion of Biomass into Biofuels by Mechanical Processes

The transformation of biomass into biofuels via mechanical methods is crucial in advancing sustainable energy solutions. Biomass, including organic substances like agricultural leftovers, wood chips, and specific energy crops, is a plentiful and sustainable energy source. Mechanical procedures used to convert biomass into biofuels include a range of physical techniques to alter raw biomass into a more practical state, such as solid, liquid, or gaseous fuels [22].

1. Biomass Pre-treatment: To enhance biomass's physical and chemical characteristics for effective biofuel conversion, it is often subjected to pre-treatment. Examples of mechanical pre-treatment processes include grinding, milling, and chopping. These procedures decrease the biomass particles' size, enhancing their surface area and making them more suitable for future conversion procedures. Reducing the size is essential for improving the effectiveness of the conversion process, regardless of whether it utilizes pyrolysis, gasification, or fermentation.
2. Densification: It is a crucial mechanical procedure that transforms loosely packed biomass resources into compact, high-energy fuels. This procedure involves pelletization and briquetting techniques. Pelletization involves biomass compression into compact, cylindrical pellets while briquetting results in biomass compression into bigger, solid blocks. These compacted products possess greater energy densities and are more convenient to manage, transport, and store than unprocessed biomass. Utilizing densification as a fuel enhances combustion efficiency and decreases emissions.
3. Extraction and pressing: Mechanical extraction procedures manufacture liquid biofuels, namely biodiesel. Biomass resources, such as oilseeds like soybeans and rapeseed, are subjected to mechanical pressing to extract oils. Screw presses or expellers exert significant pressure on the biomass, extracting the oil and leaving behind a solid residue called cake or meal. This residue may be used as animal feed or subjected to further processing to produce biofuels. Before chemical or enzymatic treatments, mechanical extraction is often used as the first stage to transform the extracted oils into biodiesel.
4. Pyrolysis and Torrefaction: Thermal decomposition and heating in the absence of oxygen, known as pyrolysis, and roasting biomass at high temperatures, known as torrefaction. Thermal conversion procedures such as pyrolysis and torrefaction also rely on mechanical processes. Pyrolysis is the process of subjecting biomass to high temperatures without the presence of oxygen, resulting in the production of bio-oil, syngas, and biochar. Mechanical systems are used to introduce biomass into pyrolysis reactors and to manage and convey the resultant products. Torrefaction is a thermal treatment process that occurs at lower temperatures and produces a solid bio-coal. This bio-coal may serve as a renewable alternative to coal for generating electricity. Both procedures are enhanced by mechanical pre-treatment to guarantee uniform feedstock quality and size.
5. Gasification: It refers to the process of converting a substance into a gas by the use of heat or chemical reactions. Gasification is a method that transforms biomass into syngas, which is a combination of hydrogen, carbon monoxide, and other gases. This process requires partially burning the biomass at elevated temperatures. Mechanical systems play a crucial role in the transportation of biomass into the gasifier and in the management of ash and other by-products. Syngas may be processed further to generate liquid fuels such as methanol or synthetic diesel. The efficiency and efficacy of gasification are greatly influenced by the mechanical pre-treatment of the biomass, which involves achieving a consistent particle size and moisture content.
6. Mechanical Separation: It refers to the process of physically separating substances or components based on their different physical properties, such as size, shape, or density. Mechanical separation procedures, such as centrifugation and filtering, are essential in the post-conversion phase. After anaerobic digestion, which generates biogas, separating the resulting digestate into solid and liquid components is necessary. Mechanical separators, such as centrifuges, remove essential nutrients from the digestate, which may be utilized as fertilizers. Simultaneously, the biogas can be refined and harnessed as a sustainable energy source.

Advantages and Challenges: Mechanical techniques in biomass conversion provide a significant benefit by enhancing the efficiency and output of biofuel generation. These procedures are often simple, need little chemical input, and may be adjusted in size based on the biomass's availability. Nevertheless, there are still obstacles to overcome, such as the high energy consumption of mechanical pre-treatment, the need for uniform feedstock quality, and the substantial upfront investment in mechanical processing equipment.

Converting Biomass into Biofuels by Thermochemical Transformation

Various thermo-chemical methods may be used to produce electricity from lignocellulosic biomasses and also to acquire extra power by-products such as heat, syngas, oxygenated bio-oil (liquid biofuels), biochar (solid), and polymers [21]. The primary methods of thermal energy generation may be categorized into five main routes: combustion, torrefaction, pyrolysis, liquefaction, and gasification.

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Biomass differs from coal in terms of its chemical composition and energy content due to the significant concentration of oxygen trapped in the polymers made from carbohydrates of crops and plants. Biomass is an intricate glucose polymer consisting of 3-11% inorganic elements, biological extracts, 35% lignin, and often 60-80% cellulose and hemicellulose. The chemical extracts, carbohydrate polymeric components, and moisture levels found in biomass may be converted into many forms of thermal power supplies, including gas, bio-oil, and biochar [32].

Combustion is a well-established and advanced method of using biomass. The technique described is an exothermic reactive process in which biomass is combusted at a temperature ranging from 850 to 1000 ◦C, using the ideal quantity of oxygen. Throughout the operation, the temperature can reach a scorching 1400 ◦C—biomass burning accounts for almost 92% of the energy consumption [24].

Typically, the capacity of combustion plants ranges from small-scale (local, 100–MW) to large-scale (3000–MW) for industrial use. An inherent drawback of this method is the production of secondary substances, including soot, dust, ash, nitrogen oxides (NO_x), carbon monoxide (CO), and carbon dioxide (CO_2). Studies suggest combining biomass and coal combustion, especially in power plants that use coal-fired technology, is a compelling option for achieving an ecologically sound transition to renewable energy. Globally, co-combustion is the favored method for converting biomass to biofuel because of its high conversion rate. European nations such as the Netherlands, Spain, and Germany are at the forefront of using biomass co-combustion with coal-fired techniques [29]. Research has shown that using highly compacted, high-quality pellets as fuel in combination with coal-fired techniques may result in a significant increase of around 42% in power effectiveness. Additionally, it aided in reducing investment expenses and achieving immediate emission reduction.

Pyrolysis, or thermal decomposition, is a long-standing method used to thermally decompose biomass into three distinct forms of fuel: solid fuel (charcoal), liquid fuel (py-oil/bio-oil), and gas (syngas/fuel gas). This process occurs in a vacuum or without air or oxygen using heat. Pyrolysis may be conducted under various operating circumstances and classified as slow, rapid, and flash. The composition of the pyrolytic product is greatly influenced by the pace of heating, the amount of time it stays in the system, and the temperature. Operating conditions include reducing the temperature, gradually increasing the heating rate, prolonging the dwell time, and increasing the amount of char produced. When comparing, higher temperatures and shorter dwell times result in an increased production of syngas.

Furthermore, it has been determined that using intermediate temperatures, high heating rates, and short dwell times may optimize pyrolysis oil/bio-oil production. During the slow pyrolysis procedure, some volatile compounds in biomass undergo evaporation, leaving behind 80% char. Fast pyrolysis involves subjecting biomass fragments smaller than 0.99 mm to regulated temperatures within a certain range. This process utilizes a quick heating rate and a short dwell period of 0.5-10 seconds. It is carried out in the absence of oxygen, resulting in the production of producer gas and pyrolysis oil (Py-oil). Py-oil may be used as a fuel source for powering turbines, cars, and electric generators and producing other chemicals. Nevertheless, some limits, particularly the stability of temperatures and rusting, are significant issues [26]. To enhance the production and characteristics of py-oil, it is necessary to progress in upgrading bioprocessing techniques and finding more efficient methods, such as hydrogenation and various fracturing forms.

Converting biomass waste into gas by gasification is an endothermic action. During this procedure, biomass is transformed into syngas by subjecting it to incomplete oxidation with either oxygen or steam at temperatures ranging from 850 to 1000 ◦C. The gasification process starts by combining biomass with hot air and O_2-enriched air and undergoing thermochemical degradation to produce CH_4, H_2, CO, CO_2, C_2H_4, and C_2H_6, in addition to water and tar. The gasification process is represented by the equation (1):

$$Biomass\ traces \rightarrow CO + H_2 + CO_2 + CH_4 + Tar + H_2O + H_2S + NH_3 + Char + traces \quad (1)$$

The unified biomass gasification/combined cycle method is currently considered a viable option for converting syngas into electricity using gas turbines. If Fischer-Tropsch synthesis is the subsequent biomass treatment stage, the gathered syngas upon gasification often have an undesirable ratio of CO to H_2. This is because Fischer-Tropsch

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synthesis requires an H_2:CO ratio of 2. Therefore, the water-gas shifting process is conducted before the Fischer-Tropsch synthesis. The syngas is purified in this process, CO + H2O→CO2 + H2.

Conversion of Biomass into Biofuels Using Biochemical Processes

The conversion of biomass into biofuel largely relies on Anaerobic Digestion (AD), fermentation, esterification, and photo fermentation. Biochemical transformation utilizes microorganisms such as bacteria, fungi, and yeast. The enzymes these microorganisms synthesize have a crucial function in decomposing the complex biopolymers of biomass into biofuels in the form of gases or liquids, such as biogas, H2, and ethanol. Biodiesel is produced via a well-established biochemical method referred to as transesterification. AD is a well-accepted and established technique for producing biogas. The sequential instructions of the AD technique are shown here. During the first stage, cellulose ($C_6H_{10}O_5$), a biopolymer composed of basic sugars, undergoes hydrolysis by adding H_2O. This process yields glucose as the principal result, which serves as the main source of nourishment for hydrophilic bacteria. These bacteria then transform the glucose into aqueous organic substances. In the second stage, acidogenic bacteria convert soluble molecules ($C_6H_{12}O_6$) created in hydrolysis's first step into CO_2 and H_2. CH_3COOH, commonly known as acetic acid, is generated and serves as an energy source for CH4-generating microorganisms.

During the third phase, known as acetogenesis, the organic acids generated in the second phase undergo a conversion process to create CH_3COOH and H_2. Acetogenic bacteria have a significant impact in this context. Methanogenic bacteria, known as methanogenesis, are crucial in the fourth step of the AD procedure since they convert CH_3COOH and H_2 into CO_2 and CH4 [27]. For biogas generation, organic matter with an 80-90% moisture level is an excellent feedstock when using AD. Biological waste products, including agricultural and botanical waste, metropolitan waste, and effluent, may be effectively employed with animal and cow manure. Biogas is a gas comprising about 60% CH4 and 40% CO_2. Methane is a flammable component found in biogas. Biogas may be used for illuminating gas/petromax and directly burned for heating and culinary purposes. Extensive research has shown the use of biogas in combustion engines for producing electrical or mechanical power, including the operation of equipment and agricultural implements. The residual sludge from the biogas plant may be consistently used as a natural fertilizer for crops, making AD an exciting technology with broad potential in the agricultural sector [28].

The light-dependent method for H_2 synthesis involves both primary and secondary biophotolysis processes, which occur via cyanobacteria and green algae and are further facilitated by photosynthetic bacteria. These microorganisms possess an important enzyme called hydrogenase, which plays a key role in regulating the creation of H_2. Equations (2) and (3) comprehensively describe the biological events and processes that occur during hydrolysis and fermentation.

$$\text{Hydrolysis: } (C_6H_{10}O_5)_n + nH_2O \rightarrow n\, C_6H_{12}O_6 \quad (2)$$

$$\text{Ethanol fermentation: } C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 + \text{Energy} \quad (3)$$

Biodiesel is a fuel from biomass materials, including lipids, seed oil, vegetable oil, rapeseed methyl ester (RME), animal fats, and other feedstocks. This production process involves a chemical reaction called transesterification, depicted in Figure 4. It is a compound formed by combining long fatty acid chains with a single alkyl group, making it an excellent alternative to fossil fuels, particularly diesel.

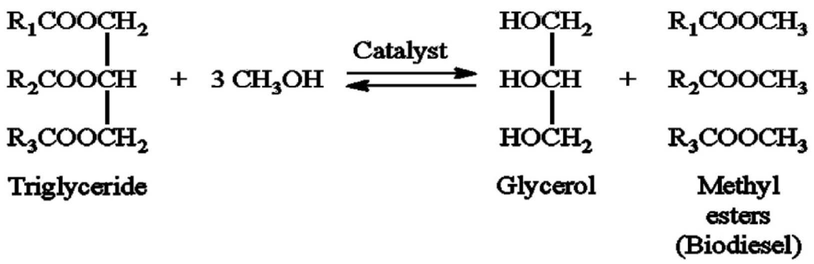

Figure 4. The method of transesterification to derive biodiesel from triglycerides

In recent decades, many microalgae strains have been chosen for their substantial lipid content, which holds significant promise for biodiesel production. Hotels, commercial organizations, and companies that produce a large volume of cooking oil residue may be viable resources for obtaining biofuel feedstock. This is because this biomass is readily accessible and can be obtained at little to no cost. Their effective application for making biodiesel may address the significant issue of disposing of this remaining biomass.

Biofuels Using Genetic Engineering

Genetic engineering methods have greatly advanced the development of biofuels. These techniques have empowered scientists to alter the genetic composition of organisms in order to augment their capacity to generate biofuels, therefore improving the process's efficiency, cost-effectiveness, and sustainability. Recent advancements in genetic engineering have mostly concentrated on enhancing the production of biofuels, refining the metabolic pathways of microorganisms, and creating novel biofuels from a broader array of raw materials.

1. ***Enhanced Biofuel-Producing Microorganisms***

A significant breakthrough in biofuels via genetic engineering is the creation of genetically engineered microbes capable of converting biomass into biofuels with greater efficiency. Researchers have genetically modified strains of bacteria and yeast to enhance their capacity to convert carbohydrates into ethanol via fermentation. By refining Escherichia coli and Saccharomyces cerevisiae's metabolic pathways, their alteration has enhanced ethanol production. These alterations include incorporating genes that enable the organisms to metabolize a wider variety of sugars derived from lignocellulosic biomass, often resistant to degradation.

2. ***Biofuels Derived from Algae***

Advancements in genetic engineering have greatly contributed to the development of biofuels derived from algae. Algae have great potential as biofuel producers because of their substantial lipid content and quick development rates. Researchers have effectively altered algal strains to boost lipid accumulation and improve the efficiency of photosynthesis. For example, the genetic alteration of microalgae like Chlamydomonas reinhardtii and Nannochloropsis species has resulted in increased bio-oil production, enhancing the feasibility of using algae as a source of biodiesel. Furthermore, progress in synthetic biology has facilitated the development of algae strains capable of directly synthesizing hydrocarbons, thereby imitating the characteristics of fossil fuels.

3. ***Biofuels Derived from Cellulose***

The intricate composition of cellulose and hemicellulose has posed a substantial obstacle in transforming lignocellulosic biomass into biofuels. Current advancements in genetic engineering have specifically targeted the development of enzymes with enhanced ability to effectively degrade complex polysaccharides into sugars that may be utilized for fermentation. Genetic alterations in fungi and bacteria have created cellulases and hemicellulases with enhanced efficacy and durability. For instance, by incorporating genes from thermophilic organisms into Trichoderma reesei, a renowned cellulase producer, its capacity to break down lignocellulose at elevated temperatures has been improved, resulting in advantages for industrial applications.

4. ***Enhanced Biofuels***

In addition to ethanol and biodiesel, genetic engineering facilitates the development of advanced biofuels, including butanol, isobutanol, and farnesene. These biofuels have improved characteristics compared to conventional biofuels, including increased energy densities and enhanced compatibility with current infrastructure. Engineering microbial strains to create advanced biofuels requires manipulating metabolic pathways to shift carbon flow towards the desired end-products. For example, scientists have modified Clostridium acetobutylicum to increase the amount of butanol it produces by improving its metabolic network and minimizing the creation of by-products.

5. ***CRISPR and Genome Editing***

CRISPR-Cas9 technology has completely transformed the field of genetic engineering, enabling accurate and effective alterations to genomes. This method has been used to augment biofuel production in several species. Scientists may use CRISPR to eliminate genes that hinder biofuel generation or introduce genes that enhance the metabolic capacities of the organism. For instance, CRISPR has been used to eliminate inhibitory pathways in

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yeast, leading to increased ethanol production. Moreover, this approach has been used to generate algae strains with enhanced lipid content specifically to produce biodiesel.

Conclusion and Future Scope

This review examines the potential and challenges of manufacturing biofuels utilizing various sources of raw materials and developments in process technology. Biofuels, including biodiesel, ethanol, bio-oil, syngas, Fischer-Tropsch Hydrogen, and methane (CH4), can be produced from agricultural crop residues, micro- and macroalgae, and other biological waste using thermo-bio-chemical processes. These biofuels are a favorable choice for energy production due to their environmental benefits. Using biofuels in industry and transportation greatly reduces dependence on petroleum and coal. The literature review revealed that biofuels obtained from crops and microalgae have the potential to be the most efficient and attractive approach. Genetic engineering has greatly advanced the field of biofuels, enabling the exploration of new opportunities for large-scale commercial production. However, the large-scale production of biofuels continues to pose significant challenges. Hence, tackling this matter by transforming biomass into biofuels using cutting-edge technology is essential and will enhance biofuel production to fulfill current and future energy requirements.

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