

BIOFUELS

Abstract

Biofuel is a fuel that is derived from or produced using organic material, such as plants, agricultural waste, or microbial sources, such as algae. The depletion of petroleum-derived fuels has necessitated the exploration of sources and methods for obtaining biofuels. Biofuels possess immense potential as a renewable energy source due to their capacity to mitigate carbon emissions, contribute to water body remediation, exhibit reduced pollution levels, and effectively combat greenhouse gas emissions. This chapter provides an overview of the sources of biofuels, the processes involved in their production, and the global scenario pertaining to the demand for biofuels. The challenges encountered in biofuel production and the future prospects of biofuels are also emphasized.

Keywords: Biofuels, sources, global scenario, future prospects.

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I. INTRODUCTION

Energy is a critical aspect of a high standard of living and sustainable economic development. The International Energy Agency (IEA) mentions that 70 to 75% of the global energy demand is set to come from developing countries, namely; India, China, and Southeast Asia. (CNBC, 2023). This demand has been ever-increasing for years. Due to this, we have been facing the threat of fossil fuel depletion which has driven the need for alternative energy sources. In the last few years, there have been technological advancements in the use of renewable energy sources and scientists have devised different ways to use them. According to the IEA's Electricity Market Report, renewable energy sources such as solar and wind power, along with nuclear, will meet more than 90% of the increase in global demand by 2025. (WEFORUM, 2023). But we cannot neglect the fact that the excessive use of fossil fuels generates more carbon emissions and that of the renewable energy sources causes exploitation of natural resources. This scenario is making it difficult to sustain these traditional resources. That is one of the reasons why worldwide scientists have started exploring biofuels as alternative energy sources. Collative effects to reduce carbon emissions and replace fossil fuels to preserve our natural resources have led to more use of biofuels. Biofuels are renewable sources and show potential prospects in developing countries.

A biofuel refers to a category of fuel derived from organic matter, including plants, as well as agricultural, residential, or industrial biowaste. It encompasses mainly bioethanol, biodiesel, biogas, and biohydrogen (NREL, 2006). In terms of agriculture, biofuels can be taken from crops, forestry, and animal by-products. Technology has enabled the production of solids, liquids, and gases from biomass sources such as wood, crops, and refuse. These are frequently used as alternatives to fossil fuels like petroleum, propane, coal, and natural gas.

The use of biofuels is a rational preference to reduce greenhouse gas emissions (GHG) and combat global warming. The utilization of alternative fuels will improve competitiveness due to this change in energy sources. Biofuels play a critical role in decarbonizing means of transport by offering a low-carbon solution for challenging sectors such as trucking, shipping, and aviation, and their use is expected to increase significantly by 2030. (IEA, 2023) If countries can use biofuels globally in the coming years, that will have a big impact on both the environment and the global economy.

This chapter offers some useful information regarding the various types of biofuels, their sources, as well as the production and demand for them. In addition to this, it discusses the effects that these biofuels have on the environment and provides an overview of how futuristic technology might be used to create a sustainable future.

II. SOURCES AND TYPES OF BIOFUELS

Biofuels encompass a range of fuels that are obtained and manufactured from organic matter, including plants, agricultural crops, and their residues (Mahapatra, S.*et al*, 2021). These fuels have the potential to serve as viable alternatives to petroleum-based fuels. From a conceptual standpoint, biofuels present a potential avenue for substituting fossil fuels, which, through their ongoing combustion, contribute to the continual release of carbon dioxide into the environment(Kumar, S. *et al*,2015).

1. Sources of Biofuels: The manufacture of biofuels can make use of a wide range of biological sources, and these fuels can be categorized according to the biological source from which they are derived.

- Algae (Hannon, M. et al, 2010):** Algae can grow in aquatic environments such as stagnant freshwater ponds with a rapid biomass production. Algae have the advantage of being able to use CO₂ very efficiently, thereby fixing more than 40% of the global carbon. Most algae species can produce energy-rich oils, resulting in high oil levels in total dry biomass. The algal growth is rapid compared to the terrestrial crops, reducing the time period of biomass production to few months in comparison to years taken by crops. Algae are also efficient at removing nutrients from water which makes it applicable for remediation of waste streams. The algae have potential to be bioengineered and are economically competent with petroleum. Table 1 depicts the different types of biofuels produced by the various microalgae.

Table 1: Different Species of microalgae used in the production of biofuel

Microalgae	Cellular Content	Type of Biofuel
<i>Spirulina maxima</i>	60 -71% proteins	Biodiesel (Poudyal RS. et al., 2015)
<i>Porphyridium cruentum</i>	40- 57% carbohydrates	
<i>Schizochytrium limacinum</i>	50-77% lipids	
<i>Synechococcus elongates</i> PCC 7942		Isobutyraldehyde and butanol (Atsumi S. et al., 2009)
<i>Botryococcus braunii</i>	terpenoid hydrocarbons and glyceryl lipid	converted into shorter hydrocarbons as major crude oil (Biodiesel) (Tran NH. et al., 2010)
<i>Chlorella protothecoides</i>	terpenoid hydrocarbons and glyceryl lipid	
<i>Anabaena cylindrica</i> <i>Scenedesmus obliques</i>		Biohydrogen

- Plant Based Sources:** There are a variety of plant based materials which can be used in processed and used as a source of biofuel. These include carbohydrate rich biomaterials, oil rich sources and agricultural wastes. Cellulosic biomass conversion

of inedible energy crops, which is both abundant and renewable, is also seen as a good approach for biofuel production.

Carbohydrate (sugars) rich biomaterial (Panahi, H. K. S. *et al.*, 2022): The carbohydrate rich feedstock generated due to the inefficient food processing and management of leftover food can be converted into bioethanol as well as mitigate the emission of greenhouse gases. It can thus provide a sustainable and ecofriendly method to dispose waste food. In the year 2018, about 108.14 billion L of bioethanol were produced through fermentation using food commodities (sugarcane and corn) as main feedstock.

There is a great deal of interest in shrubs and tree oil plants to eliminate competition with food crops. (Durrett *et al.*, 2008) Thus, plant-based biofuels promise a suitable second generation alternative for fossil fuels, but their widespread production demands more efficient and economical conversion processes. These challenges could be addressed, and the promise of plant-based biofuels as a feasible, sustainable energy source could be achieved through advancements in enzyme technology, such as protein engineering, enzyme combos, and process management. If adding these plant-derived liquids to fuel tanks lowers carbon emissions by lowering the need for fossil fuels, it will aid in addressing the climatic changes that harm biodiversity and humanity.

Oil as biomaterial (Demirbas, A.*et al.*, 2016): A variety of oil rich sources such as vegetable oils, soybean, rapeseed, sunflower, palm oils, animal fats and waste cooking oils can be used to derive biodiesel. According to Pahl (2008), amongst the total biodiesel raw material sources, rapeseed oil accounts to 59% followed by soybean (25%), palm oil (10%). Sunflower oil (5%) and other (1%). The extensive use of vegetable oils as biodiesel feedstock may cause competition with food supply over the time, hence non-edible plant oil can be a significant source as these plants can grow in waste lands and cost of cultivation is much lower (Mahanta *et al.*, 2006; Fatah *et al.*, 2012). Another advantage of non-edible plants is that they are adapted to arid, semi-arid conditions with low fertility and moisture demands (Atsumi,*et at.* 2013).

Agriculture waste: The wastes such as molasses, sugarcane juice, starch based materials such as corn, rice, wheat, lignocelluloses (cellulose, hemicellulose, lignin, etc.) from plants are alternative sources for the production of ethanol (Pragati, A.*et al.*, 2015). Sweet sorghum has higher fermentable sugar content as compared to sugarcane and requires less water for growth. The ethanol produced from sweet sorghum is free of Sulphur and cleaner when mixed with gasoline (Kumar S. *et al.*, 2015). The tuberous roots of cassava are rich in starch (about 70-85% by dry weight basis) making it a suitable source for ethanol production (Kumar S. *et al.*, 2015).

The latest agricultural operations using diesel-powered tractors and natural gas-based fertilizers resulted in the emission of nitrogen oxide. It is a greenhouse gas (GHG) that is generally 300 times more harmful than carbon dioxide and is released by fertilizers. Even farm soils have a tendency to release carbon that has been stored there and is vital to their fertility and stability. Farmers have to devote close attention and acquire knowledge as to which crops grow best where and in what conditions so

as to make agriculture smarter. Regenerative agricultural procedures, such as less frequent tilling of the soil, may contribute to maintaining nutrients and carbon in the soil. The same scenario applies to establishing a new crop of winter oilseeds that can be cultivated seasonally in between cycles of food crops. This would create income that might be used to pay for a soil-saving technique known as cover cropping that only a very few farmers have adopted up until now. (Rodionova MV. *et al.*, 2016) The switch to switchgrass cultivation (*Panicum virgatum*), a common feedstock for cellulosic ethanol, from food crops or pastures produced the best results.

2. Classification of Biofuels: Biofuels can be broadly categorized into four generations based on the type of source used in manufacturing, as indicated in figure 1.

- **First Generation:** The biofuels produced in this category are also referred to as conventional biofuels as the manufacturing of these biofuels uses processes such as fermentation, distillation and transesterification. The major source for production purpose is animal feed (Jeswani, H. K. *et al.*, 2020). Starch-based (such as potatoes, corn, barley and wheat) and sugar-based (such as sugarcane and sugar beetroot) feedstocks are the primary components used in the production of first-generation biofuels. These feedstocks have the distinct benefit of being readily available, and their conversion methods are also simple. (Neupane, D, 2022). Enzymes and microorganisms extract bio alcohols from cellulose, glucose, starches, carbohydrates, and other sugars through alcohol fermentation. Biodiesels are diesel made from renewable feedstocks, such as lignocellulosic biomass containing long-chain fatty acid esters (Obergruber, M.*et al.*, 2021). Biodiesels are made by reacting lipids like tallow, soybean oil, or other vegetable oils with alcohol to form methyl, ethyl, or propyl ester. The catalyst usually utilised in biodiesel manufacturing is NaOH or KOH (Hajjari, M *et al.*, 2017; Salehi *et al.*, 2020). Hydrotreating triglycerides with hydrogen produces green diesel from vegetable oils wherein the process involves three primary reactions: hydrodeoxygenation (HDO), decarbonylation (DCO), and decarboxylation (DCO₂) (Faungnawakij, K. & Suriye, K., 2013). Biogas is produced through anaerobic digestion with microbial consortiums, without oxygen, and produces nutrient-rich digestate (Neupane, D, 2022). Solid biofuels are often made from raw resources such wood, wood chips, leaves, sawdust, charcoal, and animal manure.
- **Second Generation:** This category mainly focuses on the utilization of non-food feed-stocks such as lignocellulosic plants, energy crops and agricultural wastes for production of biofuels. The techniques like membrane filtration and various integrated biorefineries are used to improve the yield of biofuels with reduced energy cost and waste product generation. The microorganisms are also used for carrying out the reactions required to produce biofuels, organic acids and amino acids (Oumer, A. N. *et al.*, 2018). The fermented sugars from lignocellulose polyose and cellulose compounds are utilised to produce cellulosic ethanol, which can boost rural economies and agricultural sustainability (Neupane, D, 2022). Algae can be used to produce biofuels including biodiesel, biogas, and hydrogen through centrifugation, aggregation, floatation, purification, and flocculation (Ho, S. H., *et al.*, 2011).

- Third Generation:** Biofuels belonging to this category are derived from microalgae by carrying out the esterification or hydrotreatment of the algal oil. This category is also beneficial in the remediation of the water bodies thus helping in reducing the water pollution (Jeswani, H. K. *et al*, 2020). Microbes can produce Biosynthetic Natural Gas (Bio-SNG) through anaerobic digestion. Bio-SNG is utilised either as CNG or LNG in automobiles and for natural gas cylinder refills (Zhang, W. *et al*, 2015). A study found that algal lipid may be turned to biodiesel using the same way as vegetable oil. Transesterifications, enzymatic, wet extraction, alcoholysis, and acidolysis produce algae biodiesel (Ganesan, R, 2020). Blending algal oil with diesel fuel at a 20% ratio reduces hydrocarbon exhaust and improves emission characteristics, although complete combustion emits more NO_x due to the presence of nitrogen (5-8%) (Neupane, D, 2022).
- Fourth Generation:** In this category, genetically modified algal biomass is used for the production of biofuels. The aim of genetic modification is to improve photosynthetic efficiency and light penetration. The photobiological solar fuels and electro-fuels are also used for the processing of biofuels and are cheaper as well as inexhaustible sources (Abdullah. B.*et al*, 2018). To improve biofuel production, molecular biology, genetic engineering, and multidisciplinary physicochemical methods are used, including CRISPR/Cas9 with guided RNA for genetic change in algae (Godbole, V. *et al*, 2021). This technique produces fourth-generation biofuel.

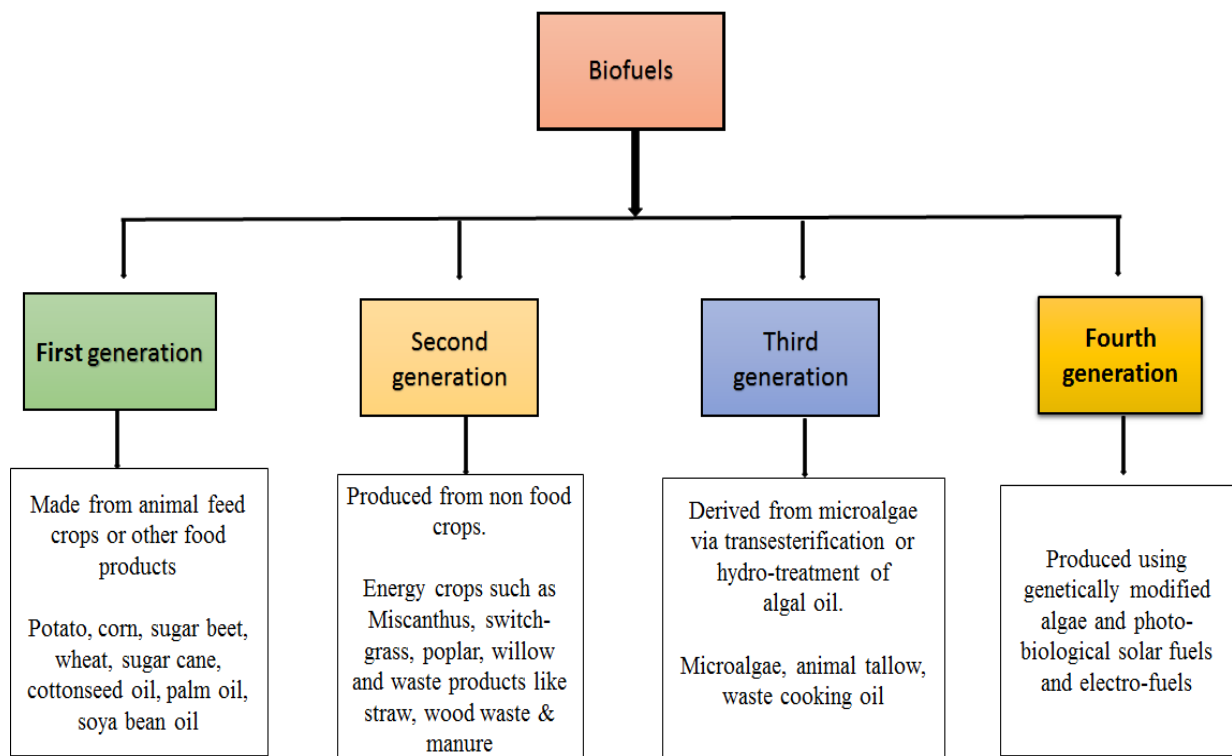


Figure 1: The different categories of the biofuels based upon the sources used for its production (Mahapatra, S. *et al*, 2021)

III. BIOFUEL PRODUCTION AND DEMAND: GLOBAL SCENARIO

The potential of biofuels as a prospective contender for technological improvement has drawn increasing attention (Msangi S et al., 2007). The commercial expansion and advancement of biofuels are primarily driven by their lower carbon emissions as compared to traditional fuels, their positive effects on rural development, and the current high prices of oils. Given the benefits of biofuels compared to fossil fuel-based fuels, it's important to understand the current worldwide situation regarding biofuel production and consumption. Graham-Rowe D (2011) proposed that there is an anticipated 84% surge in fuel demand in emerging economies, wherein biofuels are projected to contribute approximately one-third of the total fuel supply. According to the Food and Agriculture Organisation (FAO, 2005), a significant majority of the global population, exceeding 50%, heavily depends on biofuels as their primary energy source. Furthermore, these biofuels contribute to over 90% of the total energy consumption in less developed nations. In the realm of transportation, biofuels emerge as a significant contender to oil when juxtaposed with alternative technologies such as hydrogen. This is mostly due to their current state of scientific advancement, widespread accessibility, and global availability (Dufey A, 2006).

The current global demand for bioethanol, biodiesel, renewable diesel, and bio-jet has experienced a notable rise (Fig 3), mostly driven by the objective of reducing the reliance of energy-driven economies on finite fossil fuel sources (IEA, 2021). Bioethanol is the predominant alternative fuel to petrol, but renewable diesel and biodiesel are both capable of being blended with conventional diesel fuel. Conventional diesel engines may operate well on both fossil fuel and renewable diesel due to their chemical similarities. Nevertheless, it is important to note that biodiesel and fossil diesel possess distinct chemical compositions, hence necessitating careful consideration while combining the two fuels. Aircraft are pushed through the utilization of bio-jet fuel, which is classified as a form of biofuel.

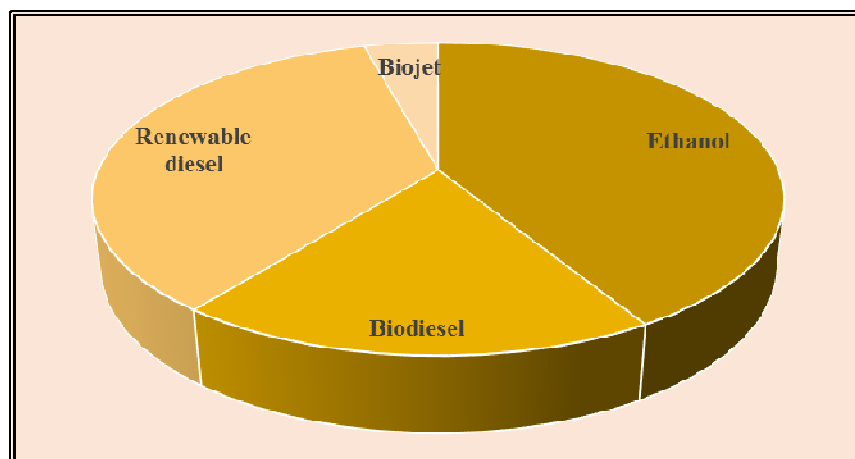


Figure 2: Biofuel demand growth by type, 2021-2026 (adapted from IEA, 2021)

It is projected that the demand for biofuel will experience a significant increase, expanding by 41 billion liters from 2020 to reach a total of 186 billion liters by 2026 (Fig 3). This growth is anticipated to occur at an average annual rate of 4% over the whole projected period. Figure 3 depicts the trajectory of biofuel consumption within specific regions, spanning the period from 2018 to 2026 (IEA, 2021).

The United States and Brazil remain the primary markets for biofuels. According to the estimated data, it is anticipated that ethanol and biodiesel will comprise around 87% of the global biofuel demand by the end of the specified time (Fig 2). During the projected time frame, it is estimated that around 33% of new production will originate from Asian countries. The primary factor contributing to this increase can be attributed to the implementation of ethanol laws in India and Indonesia, alongside the blending targets set for biodiesel in Indonesia and Malaysia.

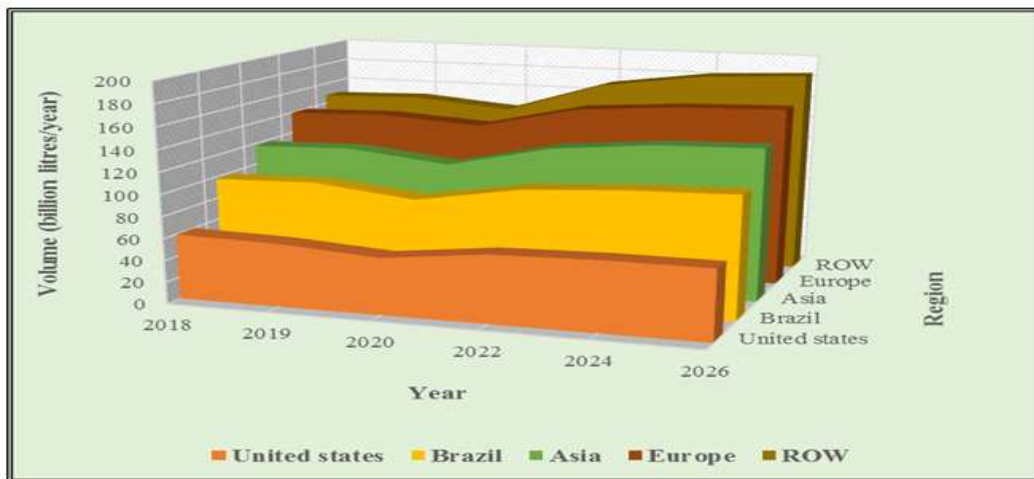


Figure 3: Biofuel demand growth by region, 2018-2026 (adapted from IEA, 2021)

The surge in renewable diesel and biojet's global market share is predominantly attributable to the implementation of policies in Europe and the United States. These policies have significantly increased the demand for these renewable fuel alternatives. The global market share of renewable diesel and biojet is projected to increase significantly from 5% in 2020 to 13% in 2026 (IEA, 2022). In contrast, Asian nations are actively promoting the growth of domestic consumption and increasing exports of biojet and renewable diesel to meet the rising demand in North America and Europe. From 2022 to 2026, the aggregate supply of Asian-origin goods is anticipated to increase by 40% (IEA, 2022). The escalating demand for liquid transportation fuel, the implementation of rules mandating the use of 27% ethanol and 15% biodiesel blends, and the voluntary purchase of ethanol by consumers in excess of mandated limits are the primary contributors to the increase in consumption (European Commission, 2021)

Asia has the greatest growth rate in demand for ethanol and biodiesel, whereas North America and Europe have the highest growth rate in demand for renewable diesel and biojet fuel (Figure 4). The United States and Europe account for virtually all of the demand for biojet fuel (Figure 4). In markets where regulations prioritise the reduction of greenhouse gas (GHG) emissions, both fuel suppliers and consumers highly value the performance characteristics of renewable diesel (IMO, 2021). In addition, the possibility of converting closed refineries to biofuel production further increases the competitiveness of renewable diesel. Certain governments have been reluctant to adopt a more assertive posture towards bioenergy development, primarily due to institutional, financial, or political constraints. Despite the obvious increase in demand for this fuel in regions such as Europe, the United States, Brazil, India, and Indonesia, this aversion persists.

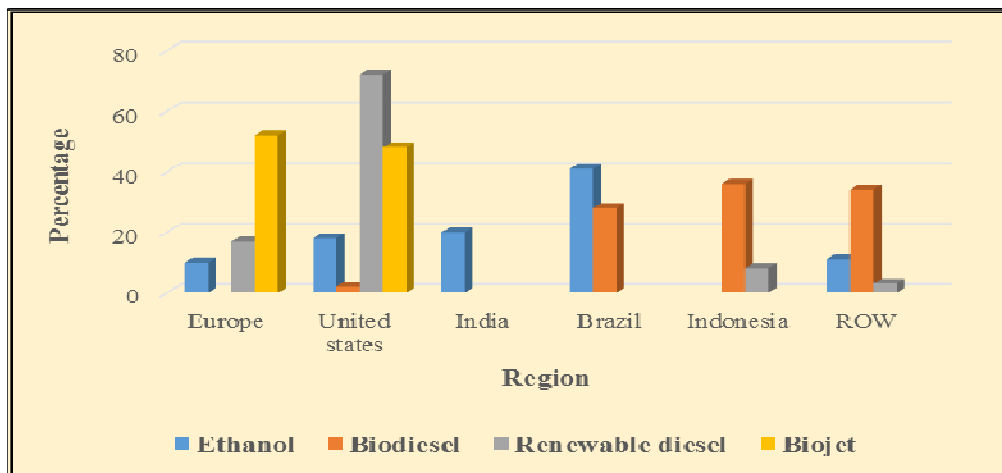


Figure 4: Region-wise biofuel demand growth by type, 2021-2026 (adapted from IEA, 2021)

According to the European Commission report, it is anticipated that the suggestions put out by the Commission will result in a twofold increase in the proportion of renewable energy in fuels by the year 2030, as compared to the current objective of 14%, as determined by the prevailing assessment method (Santoni de Sio F, 2021). Nevertheless, it should be noted that the increase in biofuel demand is not expected to double. According to the forecast, there is anticipated to be a moderate rise in the demand for biofuels in Europe. This increase is mostly attributed to the utilization of renewable diesel, which has the advantage of being mixed at higher concentrations compared to ethanol and biodiesel (Vignesh, P.*et al.*, 2021). Additionally, renewable diesel exhibits favorable performance in terms of Green House Gas (GHG) intensity and may be derived from various waste materials and residues (Vignesh, P., 2021). The proposed measures, which prioritize reductions in greenhouse gas (GHG) intensity, have the potential to enhance the competitiveness of biofuels in comparison to other viable methods for reducing emissions, including electric vehicles.

There is a growing need for the production of biofuels derived from renewable non-biogenic sources (Wachsmuth, J.,*et al.*, 2022). These sources rely on technologies that are now in the early phases of development. Additionally, there is a strong demand for biofuels derived from wastes and residues such as spent frying oil (Eguchi, S., 2015). The augmentation of both supply and demand for renewable diesel will result in increased prices for feedstocks that meet regulatory requirements, potentially leading to an escalation in costs. The augmentation of targets for road transport and aviation will also generate a heightened level of competition for fuel resources, particularly renewable diesel and biojet fuels (O'Malley, J, 2021). Therefore, it can be inferred that the continued dependence on petroleum-derived fuel in the future is no longer sustainable due to the growing emphasis on energy security and the imperative to mitigate greenhouse gas (GHG) emissions, which has resulted in a heightened use of biofuels.

IV. ISSUES WITH BIOFUEL PRODUCTION

In light of the unexpected surge in demand for biofuels across the globe, various economic and environmental concerns that suggest biofuels are not a particularly sustainable solution have come to light. Consequently, using biofuels necessitates extensive planning. The following are only a few of them:

- 1. Impact on Food:** The decision to allocate land for biofuel production or the choice of crops for this purpose has the potential to restrict food supplies, resulting in a subsequent rise in prices. This escalation can have a significant effect on developing nations especially where food scarcity is a serious concern. Use of food crops such as corn, soyabean, sorghum has the potential to significantly decrease the access to affordable food. The increasing demand for food based biofuel crops can attract crop producers for a higher price of their products. Hence, many environmental organizations have criticized the cultivation of plants like soybeans, sugarcane, oil palms for biodiesel production (Fairley, 2022).
- 2. Effect on Water Resources:** Large scale biofuel production of crops like sugarcane, corn consume large amounts of water for their cultivation, which could significantly contribute to the problem of water scarcity. In the production of algal biofuel, a third generation crop, a high amount of water is required for maximum growth. Sometimes high temperature leads to evaporation of water thus minimizing algal growth (Mohanty MK, 2023). The increased use of biofuels has thus put an increased pressure on water resources in two broad ways - water used for irrigation of these crops and water that is required in the production of these biofuels in refineries that involve processes like boiling and cooling.
- 3. Biodiversity Threats:** Though the production of biofuels have been proposed to have positive impacts like restoration of degraded lands, negative impacts are equally significant. Energy crop plantations can severely affect natural landscapes leading to loss of biodiversity. Most of the biofuel crops that are currently used are well suited for growth in tropical areas. This provides an economic advantage for the conversion of natural ecosystems into energy plantations causing loss of biodiversity in these areas. The genetic diversity of crops is compromised where large scale energy crop plantations are practiced as it causes excessive nutrient load, soil degradation and other forms of pollution. Most of the biofuel feedstock plantations practice monoculture where single species are cultivated that involve a narrow pool of genetic material with minimum use of traditional varieties. This leads to an increased susceptibility of crops to new pests and diseases (Tudge, S.J., *et al*, 2021). The potential effects of algal biofuels on biodiversity remain unresolved. The extensive production of algae on a wide scale can have a notable impact on coastal biodiversity due to the invasion of algal species in coastal shallow environments such as salt marshes, mangroves, and coral reefs.
- 4. Impact of Second Generation Biofuels:** Second generation biofuels are produced from non-food feedstock and agricultural residues comprising lignocellulosic material. Hence, cellulose degrading bacteria or genetically modified bacteria producing enzymes for cellulose conversion may be involved that could potentially harm existing agriculture. Plantation of these non-food feedstock like switchgrass provides a monetary advantage to farmers thus contributing to the problem of food scarcity (Ottinger, 2009). Removal of agricultural waste for biofuel production can also lead to deterioration of the land quality thus affecting productivity.
- 5. Impact on Global Warming:** Biofuel production takes into account the amount of CO₂ that is absorbed by the plants and released into the atmosphere. Nevertheless, this analysis fails to encompass the complete biofuel production cycle, as it neglects to take into account the costs associated with the growing and processing of biomass into

biofuels. According to reports by Hanaki *et al.* (2018), the tropical forests absorb substantially more carbon dioxide than the cultivated plants used to produce biofuels. Consequently, the use of biofuels derived from crops frequently fails to reduce carbon dioxide (CO₂) emissions. Carbon deposited in the soil is released into the atmosphere when forests or grasslands are converted into farmland for the production of energy crops. This emission could be substantial enough to negate the advantages of using biofuels. According to studies, reforestation and forest preservation could also result in improved carbon sequestration and increased fuel efficiency. The amount of fossil energy utilized for the cultivation and transportation of feedstock commodities, as well as within the biofuel manufacturing facility, is a crucial factor to consider when evaluating the contribution to greenhouse gas emissions. Studies indicate that more nitrous oxide, which is more potent than greenhouse gases like CO₂, is produced during biogas production than during the combustion of fossil fuels (Jeswani *et al.*, 2020).

- 6. Variation in Biofuel Quality:** Many biofuel crops used to produce biofuel differ significantly in their oil content. During production of biofuels, the oil in their seeds is extracted and converted to fuel using chemical processes. Though different biocrops are processed into biodiesel using the same process, the resulting fuel varies significantly in its ability to produce power (Cunnigham, 2011). As the composition of these oils ranges from saturated to unsaturated fatty acids, this composition has a significant impact on the fuel viability of these oils. Oils high in saturated fatty acids may solidify at low temperatures, preventing their use as biofuels in frigid climates. Therefore, oils rich in unsaturated fatty acids are preferable, but they have an undesirable burning characteristic that leaves a gummy residue in the engine, thereby increasing processing costs.
- 7. Other Environmental Impacts:** Changes in land use and crop concentration have a significant impact on soil quality. The removal of plant residues during the production of biofuels of the third generation reduces the soil's organic matter, which would otherwise nourish the soil. In addition, many biocrops necessitate the use of fertilizers that have negative effects on the environment (Chonget *al.*, 2013). Utilizing algae as a biofuel of the third generation necessitates the use of substantial quantities of fertilizer and pesticides for crop protection. High biofuel production suggests an increase in the use of these fertilizers and pesticides, which indirectly affect the aquatic ecosystem (Mohanty, M.K., 2023). Land competition between cropland and natural ecosystems has resulted in a change in land use, which is a significant problem. However, the precise impact of biofuel production on deforestation is ambiguous. This is due to a dearth of information on feedstock being grown in the country, the location of biofuel plants worldwide, and biofuels that can also be used as food or animal feed.

In conclusion, with the rising price and increased demand for fossil fuels, research on waste, microbial, and microalgal focused oils as biofuels will continue to garner attention. The advantages of one biofuel over another, however, must be determined by taking into account a variety of interrelated aspects. Before considering biofuels as an efficient and secure choice in the near future, it is important to analyze their impact on the environment because not all biofuels perform equally in terms of energy production.

V. FUTURE PROSPECTS OF BIOFUELS

The utilization of alternative fuels will improve competitiveness due to this change in energy source. Biofuels play a critical role in decarbonizing means of transport by offering a low-carbon solution for challenging sectors such as trucking, shipping, and aviation, and their use is expected to increase significantly by 2030. (IEA, 2023) If countries can use biofuels globally in the coming years, that will have a big impact on both the environment and the global economy. A sustainable future and the management of climate change impacts depend on a global shift to renewable energy sources. Considering the multitude of concerns surrounding the detrimental effects of biofuel production, which render it unsustainable, the subsequent suggestions present potential avenues for addressing the aforementioned challenges and facilitating the sustainable utilization of biofuels.

1. Microorganisms for Biofuel Production: Apart from microalgae, there are various bacteria which are being employed in the production of biofuels as listed in table 2. The microorganisms can be exploited to enhance the productivity of biofuels in a shorter duration. Currently, various microorganisms have been found to generate biofuels effectively, including:

- Cyanobacteria that have been genetically modified to increase their ability to produce hydrogen (Lindberg P. *et al*, 2010).
- Optimizing hydrogen manufacturing and metabolic modification for the production of biofuels in bacteria (Carere CR. *et al*, 2012, Cha M. *et al*, 2012);
- Dark fermentation by bacteria to convert carbohydrates to biohydrogen and other biofuels;
- Photo-biological approaches for the generation of biohydrogen by microalgae
- Genetic engineering of the yeast to increase ethanol production by tolerating high alcohol concentrations; and
- Genetic engineering of microbes that can ferment carbohydrates to increase the amount of bioethanol and biobutanol.
- Screening the microalgae that can produce more oil for biodiesel production;
- Fermentation of plant cell wall carbohydrates by yeast or other microorganisms to produce biofuels

2. Nanotechnology in Microalgal Production: Due to its durability, recycling capacity, adsorption effectiveness, catalytic efficiency, stability, crystallinity, economic benefit, substantial storage capacity, beneficial biofuel production, and environmentally friendly attributes, nanotechnology has the potential to be applied at various stages, from growing microalgae to using the resulting biofuel in fuel engines. Implementation of nanotechnology improved microalgae production, increased the yield of many microalgae biofuels, and had ramifications for both engines powered by gasoline and diesel. (Hossain *et al.*, 2019). Physical or chemical approaches can be used to create NPs for biofuel enrichment. In this regard, the ball mill procedure (agitation rate: 450 rpm) was described as a physical approach for the preparation of NPs in the earlier research (Ganesh *et al*, 2011; Sabarish *et al*, 2018; Manibharthi *et al*, 2018), whereas the plasma-arc and sol-gel methods were presented as chemical methods.

Nano-structures increase the surface area of immobilization of enzymes and increase the enzymes' loading capacity and stability; they are being applied for enzyme immobilization. It is possible to immobilize enzymes using a variety of techniques, including electrospun nanofibers, covalently linked enzymes to nanofibers, and enzyme aggregate coatings on nanofibers.

During the growing phase of microalgae in the photobioreactor (PBR), nanoparticles also improved light conversion and thus increased the photosynthetic efficiency, which led to an increase in the efficiency of absorbing carbon dioxide from the environment and its storage, which can accelerate the growth of biomass. (Zimmerman, W.B.,*et al*, 2009; Zimmerman, W.B.,*et al*, 2011)

Table 2: Different bacterial species used in the production of biofuels

Bacterial species	Fermentation Product
<i>Escherichia coli</i> <i>Bacillus subtilis</i>	bioalcohol, isoprenoids and fatty acids derivatives.(Gronenberg LS. <i>et al</i> , 2013)
<i>Clostridium acetobutylicum</i> <i>Clostridium beijerinckii</i> <i>Caldicellulosiruptor species</i>	acetone-butanol-ethanol fermentation (Hasnuma T <i>et al</i> , 2013)
<i>Thermococcus species</i> <i>Pyrococcus species</i> <i>Thermotoga species</i>	Biohydrogen (Carere <i>etal</i> , 2012)
<i>Thermoanaerobacter species</i> <i>Saccharomyces cerevisiae</i>	Bioethanol (Verbeke, T.J., <i>et al</i> , 2013)

3. Net Zero Emissions: A large increase in the production of biofuel is required if the aim of reaching "net zero emissions" (NZE) by the year 2050 and delivering the related emission reductions is to be achieved. The demand for biofuel reached an all-time high of 4.3 EJ (170,000 million litres) in the year 2022, surpassing the levels that were seen in 2019 before the COVID-19 epidemic began. There has been forward movement in the development of technology related to renewable energy, which is gaining momentum on a daily basis. The use of electric vehicles, nuclear power, heat pumps, electrolyzers, solar photovoltaics, and bioenergy combined with carbon capture and storage are among the key highlights.

- Electric vehicle sales have dramatically risen in recent years, owing to improved range, wider model availability, and improved performance. Electric vehicle sales have dramatically risen in recent years, owing to improved range, wider model availability, and improved performance. Because of the comparatively high purchase price of an electric vehicle and a lack of charging infrastructure availability, sales in developing and emerging economies have been slow. The Net Zero scenario anticipates the setup of 17 million accessible public charging stations by 2030.
- Nuclear energy is a significant low-emission source of electricity, making up roughly 10% of global electricity generation. It can complement renewable sources in

reducing power sector emissions while also making a contribution to power security as a dispatchable power source in countries where it is accepted. It can also be used to generate low-emission heat and hydrogen. Over the last 50 years, nuclear power has avoided nearly 70 metric tons of CO₂ emissions.

- Heat pumps are progressively being identified as a crucial technological means for heat decarbonization, with sales increasing by 11% in the last year in several countries. To meet the Net Zero Emissions by 2050 (NZE) target, the global heat pump stock would need to nearly triple by 2030 in order to cover at least 20% of global heating needs.
- Electrolyzer additional functionality increased by more than 20%, while manufacturing capacity increased by more than 25%. The bigger story, however, is still to come: based on the current pipeline of projects in development and their expected completion dates, electrolyser capacity could reach nearly 3 GW by the end of 2023, representing a more than four-fold increase in total capacity over 2022.
- Solar photovoltaics PV The installed capacity of solar photovoltaics (PV) is anticipated to exceed that of coal by 2027, making it the biggest renewable resource on Earth. Distributed solar PV, such as rooftop solar on tower blocks, is also projected to expand more rapidly as retail electricity prices rise and policy support grows. The increase in growth rate from 270 to 1300 TWh corresponds to the level expected from 2023 to 2030 in the Net Zero Emissions by 2050 scenario. Continuous growth in terms of economic development of PV, massive supply chain development, and increasing policy support, particularly in China, the United States, the European Union, and India, are expected to accelerate capacity growth in the coming years.
- Bioenergy is the world's largest renewable energy source, making up 55% of renewable energy and more than 6% of the global energy supply. To meet the NZE scenario, its use in a wide range of applications should indeed increase by 2030. Biojet kerosene, which is used in aviation, is expected to account for 10% of the demand in 2030. Biomethane, which is used in gas grids to heat buildings, saw tremendous demand. Liquid biofuels, which are primarily used in road transportation, are expected to account for 10 EJ of the demand in 2030.
- Bioenergy with carbon capture and storage (BECCS), which generates negative emissions by capturing and storing carbon-neutral bioenergy emissions, is also important. BECCS is the capture of CO₂ from large point sources, such as power plants or industrial facilities that use either fossil fuels or biomass as fuel.

There are a lot of challenges that need to be overcome before biofuel can become economically competitive with fossil fuel. It has been recommended by Zhang, X., *et al* (2014) that the production of biofuel should be combined with the treatment of CO₂-rich flue gases, nitrogen-rich municipal wastewater, or a combination of the two in order to achieve the goal of boosting both the sustainability and the efficiency of the process. It is necessary to combine a number of different genetic engineering approaches in order to both produce novel strains with the

potential for commercialization and maximize the production of biofuels. (Johnson, T.J. *et al*, 2016).

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