**ENVIRONMENTAL IMPACTS OF BIOFUELS**

Deepti Ashwini Lakra\*, Shivangi Sinha, Rupa Verma

M.Sc Biotechnology, University Department of Botany, Ranchi University Ranchi, Jharkhand, 834008

\*Corresponding Author: [deepti90210@gmail.com](mailto:deepti90210@gmail.com)

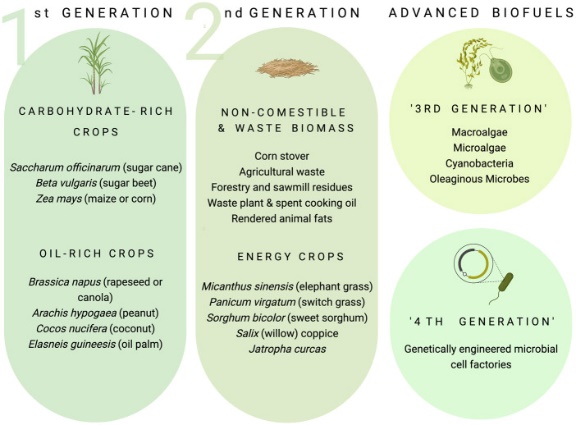
**Abstract**

The review examines the environmental impact of biofuels, focusing on their potential to replace fossil fuels. Life cycle assessments are utilized to quantify the overall net environmental impact of using biofuels instead of fossil fuels.These assessments consider energy requirements and direct greenhouse gas emissions and include the impact of land conversion for biofuel cultivation, such as deforestation. Additionally, the review discusses how biofuels have higher environmental impacts, such as ecotoxicity, eutrophication, and biodiversity loss, compared to fossil fuels. The article emphasizes the importance of considering the full life cycle of biofuels, including the indirect effects of land transformation and the associated carbon and biodiversity losses. Furthermore, the review highlights the need for certification schemes to ensure biofuels' sustainable production and mitigate their negative environmental impacts.

**Keywords**: Biofuels, Feedstock, Land use changes, Greenhouse gases, Environmental sustainability

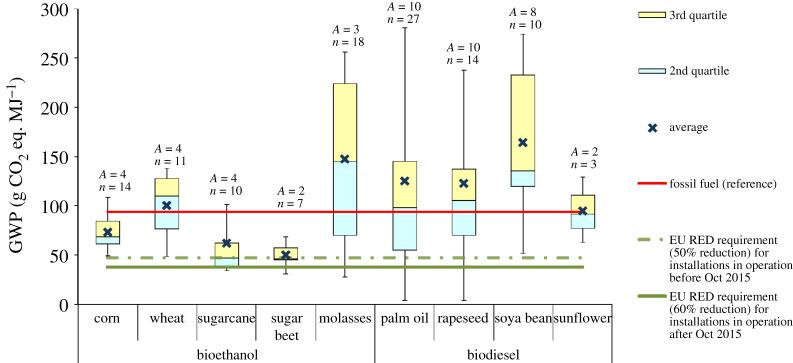
**Introduction**

Biofuels are a low-carbon alternative to fossil fuels which are derived from various kinds of biological materials, present mainly in a variety of plants, microorganisms, animals, and wastes, and could help to reduce the greenhouse gas (GHG) emissions and other related climate change impacts caused by transportation[1,2,34]. Biofuels can be differentiated based on theseveral key characteristics including feedstock type, conversion process, technical specification of fuel, and its use. Depending on the starting place and manufacturing of these biofuels, they are generally appertained to as first-generation biofuels, second-generation biofuels, and third-generation biofuels (according to the EASAC report 2012), while the fourth-generation biofuels are just arising at the elementary exploration position. On the way towards a sustainable economy, the development of effective biofuel products strategies based on the inexhaustible source of energy i.e., solar energy is of immense significance. Most of the primary-period biofuels are received from the different food crops as energy-containing granules like sugars, oil, and cellulose [34]. They yield very less biofuel and hurt food security. Since the first-era biofuels are produced through well-installed technology and under hygienic and controlled processes, likedistillation,fermentation, and transesterification, they are typically mentioned as ‘traditional/conventional biofuels'[36]. Efforts are highly neededin order to boost the technology as well quality of the superior biofuels by figuring out and by engineering powerful non-food feedstocks, enhancing the universal performance of conversion technology and the high-quality biofuels for multiple transport sectors that could possibly bringing down the costs (EASAC 2012). The second-generation biofuels are an enhancement in the production of biofuels from a feedstock of the lignocellulosic, non-food stuff that includes straw, bagasse, timbre residues, and crops on marginal lands. Projects are required to increase the quantity along with quality of renewable carbon and hydrogen that can be further converted to usable form of energy from “second generation” biomass. The 3rd generation technology biofuels are primarily based on algal biomass production [34].Biodiesel attained from these microalgae through traditional transesterification or hydro-remedy of algal oil is usually called 3rd generation biofuel. The second and the third-technology biofuels are cited as ‘superior biofuels’ as they are synthesized from the organic residues and microbes [36]. Presently, they are under immense expansive exploration to enhance both the metabolic yield of fuels and the Separation procedures in bio-oil manufacturing so that non-fuel components can beremovedand thereby reduce manufacturing costs. The fourth-generation biofuels (i.e.,Photobiological solar fuels and electro fuels) are being predicted to deliver essential advancements in the field of biofuel manufacturing. Technology and skills for manufacturing such solar biofuels is a rising field of interest attracting multiple companies, and is primarily based on the direct conversion of solar energy into non-pollutant form of biofuel by using inexhaustible raw materials which are reasonable and easily available [2,34].

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**Figure 1: Classification of transport biofuels.[33]**

Changes in land use pattern for production of raw materials and disposal of the residue is needed as first-generation biofuels can possibly have lower GHG effluence than fossil fuels, but the reductions for most feedstocks are deficient to meet the GHG savings needed by the EU Renewable Energy Directive (RED). Yet, second-generation biofuels have much higher potential to reduce the GHG effluence, at the condition that there is no change in land use patterns [38].Third-generation biofuels no longer constitute a viable alternative for improvement as it has been observed that their GHG emissions are comparatively better than the ones observed in case of fossil fuels[1] discharge of Greenhouse gas (GHG) from transportation have been amplifying at an immense rate as compared to any other sector alone [3]. This sector is dependent on the fossil fuels, which is regarded for 96.3% of the total transportation fuels as in 2018 [4].Transportation is likewise responsible for approximately 15% of the world's GHG effluences and also 23% of general energy-associated CO2 emissions [3].To lessen dependence on fuels that are based onpetroleum, and to alleviate changes in the climate, biofuels are considered much promising alternative source of transportation fuels [36]. The use of biofuels has both advantages and disadvantages in various aspects such as land use pattern, region, economic value feedstock, and environmental sustainability. A lot of other factors have been studied in various research, but they cannot be considered universal due to differences in soil pattern, economic development of a place, requirement of fuel, cropland, etc.

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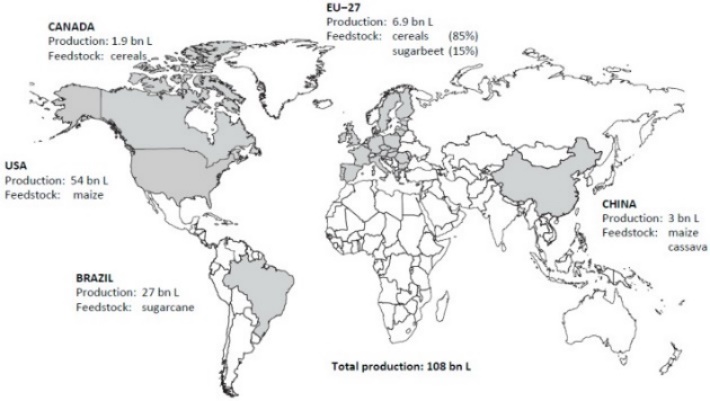
**Figure 2: GWP of first-generation biofuels with land-use change [1,36]. ‘*A*’ refers to the number of LCA papers found in the literature and ‘*n*’ denotes the total number of analyses**

**History and early use of biofuels**

Biofuels have been used by automotive industries ever since the discovery of the engine. For instance, the first diesel engine developed by Rudolph Diesel was also tested on peanut oil after finding out that pulverized coal was unsuitable. Until the 1940s, biofuels were widely used as viable transport fuels and as blend of bioethanol. As a result,Monopolin,Discol, andArgol were extensively used in theEurope, USA, and other regions [[5](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7735313/#RSPA20200351C3)].The manufactureof bioethanol gradually decreased and eventually stopped as World War broke.The Second World War led to a hike in the prices of all the necessities as most of the food supplies were being transported to the military camp formen fighting at the front, and women were left to cope with the household. As a result, the prices of food-derived fuel, in other words biofuel, also rose andfuel derived from petroleum became relatively cheaper [36].

During the oil crisis in the 1970s, which was witnessed due to the Yom-Kippur War of 1973 and The Iranian Revolution of 1979, large numberof oil supplies were disrupted, creating problems for countries that were dependent on oil exports from the war-struck regions. As a result, multiple countrieshave once again started to show interest in the production of marketable biofuels. Nevertheless, Brazil turned out to be thefirst country to start the production of ethanol on a huge scale and marked it as the National Ethanol Programme also known as ‘Proálcool’ [[6](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7735313/#RSPA20200351C4)]. Brazil began to produce anhydrous alcohol from sugarcane which was blended with upto25% gasolineto manufacture biofuel. During the late 1990s, the prices of the crude form of oil rose along with concerns that were related toenergy security of the country. The USA and some European nations came up with policies to support the domestic biofuel industries due to rising concerns over energy exploitation [[7](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7735313/#RSPA20200351C5),36,37].

The interest in biofuel production was later rediscovered in the last decades after policies were developed to reduce the environmental harshness and strategies for the reduction of GHG effluences from transportation sector. Sincethen, biofuel programs have been launched in more than 60 countriesand they have pledged to achieve the target of blending of the biofuels into their fuel pools [[8](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7735313/#RSPA20200351C6)]. The most momentous of allare the Renewable Energy Directive (RED) in Europe and Renewable Fuel Standard (RFS) [[9](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7735313/#RSPA20200351C7)] in the USA [[10](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7735313/#RSPA20200351C8),36,37].

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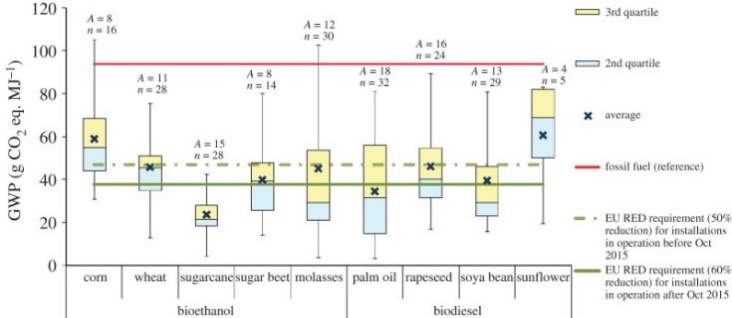
**Figure 3: World fuel ethanol production, 2012-2014 [31].**

**Current scenario**

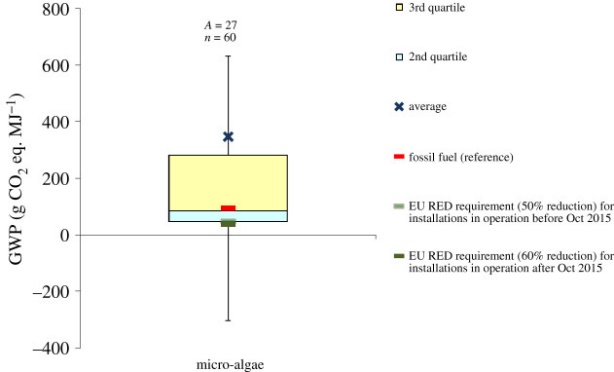
Worldwide bioethanol manufacturing has upgradedby 67%, i.e., rising from 67billion litres to 110.4 billion litres, over the last decade in the years 2008–2018 [4]. At the same time, biodiesel has witnessed more than threefold increase in their production, rising from 12billion litres to 41 billion litres. Presently, biofuels regard for roughly 3.4% of general transportation fuels around the world[4].The production of biofuelsworldwide is majorly dominated by America and Brazil, thereby generating around 69% of world’s biofuels as in 2018, followed by Europe (EU-28) with its 9% contribution in the run [11,36]. The exclusive source of bioethanol differs for each country depending on the crops supported by the soil type and climatic conditions of the region. For example, in the USA is corn is used for producing bioethanol, whereas, in Brazil, sugarcane is the major source. In Europe, the primary feedstocksfor yield of bioethanol are sugar beet, wheat, andcorn, while rapeseed and used cooking oil (UCO) are used for biodiesel yield [12,37].

The International Energy Agency (IEA) estimates that nearly 1/3rd of all gasoline that isused for transportation can be received from biofuels by 2050 [13]. Production of biofuels gives off several co-products, like variousbiochemicals, animal feed, electricity and heat. Thus, before the production of the desired biofuel, some important factors like impacts of the biofuels and its co-products are to be necessarily determine. The ISO 14040 and14044 standards propose that, if possible, allocation of the co-products should be avoided through subdivision of processes, or by expansion of system [2,36].

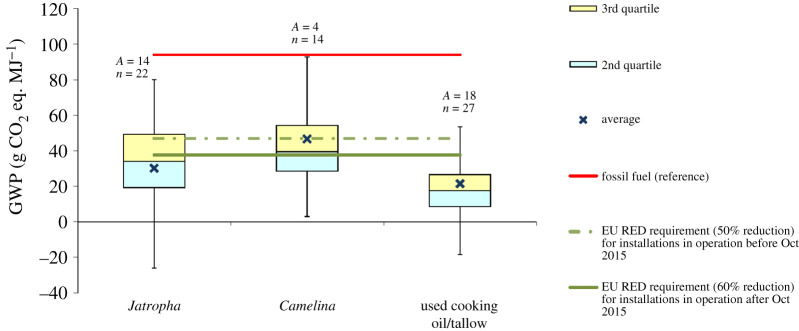
Contradictory results were obtained after careful observation of the LCA studies due to differences in the presumptions, data sources, allocation system and land use changes [1]. According to the data in the Figures 4,5,6, the Global Warming Potential (GWP) of the first-generation bioethanol from a variety of food crops range extensively, starting from 3g CO2 eq. MJ-1 to 162g CO2 eq. MJ-1. Figure 1 suggest that the common Global Warming Potential of bioethanol has decreased than that of petrol for all the feedstock (23-59 versus 94g CO2 eq. MJ-1) [36].

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**Figure 4: GWP of the firstgeneration biofuel without changes in the land use pattern. Based on data from [**[**1**](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7735313/#RSPA20200351C24)**,36]. ‘*A*’ represents the number of LCA articles found in the literature and ‘n’ symbolizes the total number of analyses.**

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**Figure 5: GWP of second-generation biodiesel. Based on data from [1]. ‘*A*’ represents the number of LCA articles found in the literature and ‘n’ symbolizes the total number of analyses.**

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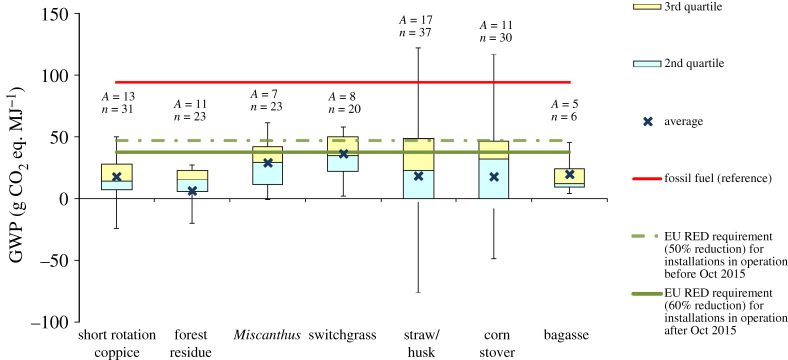
**Figure 6: GWP of second generation of biodiesel. Based on Data from[1]. ‘*A*’ represents the number of LCA articles found in the literature and ‘n’ symbolizes the total number of analyses.**

**Table1: An overview of the number of LCA studies by biofuel type, feedstock, location, and land-use change[1,36].**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | **location** |  |  |  |  | **land-use change** |  |  |
| **fuel type/feedstock** | **Australia** | **Africa** | **Europe** | **Asia** | **South America** | **North America** | **with** | **without** | **total** |
| *bioethanol—1st gen.* |  |  |  |  |  |  |  |  |  |
| corn | 0 | 0 | 6 | 1 | 0 | 23 | 14 | 16 | 30 |
| molasses | 4 | 3 | 4 | 25 | 0 | 12 | 18 | 30 | 48 |
| sugar beet | 0 | 1 | 19 | 0 | 0 | 1 | 7 | 14 | 21 |
| sugarcane | 0 | 1 | 0 | 1 | 32 | 4 | 10 | 28 | 38 |
| wheat | 0 | 0 | 39 | 0 | 0 | 0 | 11 | 28 | 39 |
| *bioethanol—2nd gen.* |  |  |  |  |  |  |  |  |  |
| bagasse | 0 | 0 | 1 | 1 | 3 | 1 | 0 | 6 | 6 |
| forest residue | 0 | 0 | 16 | 0 | 0 | 7 | 0 | 23 | 23 |
| *Miscanthus* | 0 | 0 | 14 | 0 | 0 | 9 | 7 | 16 | 23 |
| short rotation coppice | 0 | 0 | 29 | 0 | 0 | 2 | 14 | 17 | 31 |
| stover | 0 | 0 | 12 | 0 | 0 | 18 | 3 | 27 | 30 |
| straw/husk | 0 | 0 | 27 | 9 | 0 | 1 | 5 | 32 | 37 |
| switchgrass | 0 | 0 | 2 | 0 | 1 | 17 | 2 | 18 | 20 |
| *biodiesel—1st gen.* |  |  |  |  |  |  |  |  |  |
| palm oil | 0 | 0 | 0 | 56 | 3 | 0 | 27 | 32 | 59 |
| rapeseed | 0 | 4 | 19 | 0 | 2 | 13 | 14 | 24 | 38 |
| soya bean | 0 | 3 | 3 | 5 | 18 | 10 | 10 | 29 | 39 |
| sunflower | 0 | 5 | 1 | 0 | 2 | 0 | 3 | 5 | 8 |
| *biodiesel—2nd gen.* |  |  |  |  |  |  |  |  |  |
| *Camelina* | 0 | 0 | 1 | 0 | 0 | 13 | 0 | 14 | 14 |
| *Jatropha* | 0 | 7 | 0 | 8 | 7 | 0 | 4 | 18 | 22 |
| used cooking oil/tallow | 0 | 1 | 17 | 5 | 3 | 1 | 0 | 27 | 27 |
| *biodiesel—3rd gen.* |  |  |  |  |  |  |  |  |  |
| algae | 2 | 0 | 13 | 13 | 4 | 28 | 0 | 60 | 60 |
| total | 6 | 25 | 223 | 124 | 75 | 160 | 149 | 464 | 613 |

The huge difference in the Global Warming Potential of the first-generation biofuels as in theFigure2 is because of numerous reasons. Some of the examples are, in the LCA study on manufacture of soya bean biodiesel and corn ethanol in China discovered that the Global Warming Potentialof soybean biodieseland corn ethanol were 20% and 40% higher than petrol and diesel, respectively. The study also revealed greater use of chemicalfertilizers and increased levels ofenergy consumption during the manufacturing process [14]. South African sugar beet has been found to have minimal to no reduction (0–20%) in greenhouse gas emission when compare to fossil fuels.In Brazil, due to continuous growth of bioethanol the land dedicated to sugarcane cultivation has expanded [17,18]. If this results in the deforestation of tropical rainforests, the Global Warming Potential from bioethanol obtained by sugarcane can rise by almost 60% more than petrol [19,36].

TheGlobal Warming Potential of second-generation biofuels is significantly lower as compared to fossil fuels. However, the variation among different research and feedstocks may be massive, and the values could be ranging from −115g CO2 eq.MJ−1 to 173 g CO2 eq.MJ−1 for bioethanol and −88g CO2 eq.MJ−1 to 150 g CO2 eq. MJ−1 for biodiesel [2]. The assessment of advanced biofuels is highly influenced by the uncertainties related to technologies, as these have not yet been fully implemented on commercial scale. As a result, the accuracy of these data isnot as correct as those obtained from the well-mounted data of first-generation biofuels [36].

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**Figure 7: GWP of second generation of bioethanol. Based on data from[1]. ‘*A*’ represents the number of LCA articles found in the literature and ‘n’ symbolizes the total number of analyses.**

Lignocellulosic bioethanol obtained from lignocellulosic biomass such as agricultural and forest residues has much lower Global Warming Potentialas compared to bioethanol obtained from energy plants. This is especially due to emission of nitrous oxide which is emitted throughout the cultivation of these energy crops, and is associated with the usage of fertilizers. The residual lignin from lignocellulosic bioethanol is expected to co-generate heat and power so that the energy requirements of the process can be satisfied with surplus power [1,36]. Similarly, in a study [20] altogether only 5% of biodiesel manufacturing yield, which could be very low as compared to more than approximately 90% taken into consideration in different studies.

Global Warming Potential of the third-generation biodieselobtained from algae was estimatedafter a total of 27 Life Cycle Assessment studies using various distinct approaches,methodologies, system boundaries, method designs, and assumptions for nutrient,feedstocks, and co-product management. These differences in the available choices have resultedin values ranging from −2400g CO2 eq. MJ−1 to 2880 g CO2 eq. MJ−1. This implies that emission of GHGcan either lead tosignificant reductionorincrease by use ofmicroalgal fuel ascompared to regular diesel. Nevertheless, most of these studiesemphasizes that withthe current of developmental state, biodiesel from algae has better lifecycle compared to fossil diesel. The principal reason for increased emissions is the result ofdecreased algal yield and increased usage of energy during the stages of cultivation, harvesting, and drying [25,26,27,28,29,36]. Some research studies claimthat the amount of greenhouse gas savings from using of GHGinstead of diesel is significantly higher, is based on the most probable assumptions that would not be viable for adoption by large-scale. These include utilization of carbon dioxide residues derived from small- and large-scalecement factories as a raw material [21], sugarcane as a nutrient/feedstock [22], and reutilization of necessary nutrients obtained from anaerobic digestion in plants [24] and instagnant and wastewater[23,36].

**Future scopes**

Reducing GHG emissions, rural improvement energy andconservation are important factors that influence the global adoptionof biofuels. However, increasing the biofuel production is a significant issue of concern [37]. Hike in food prices, risk of increasing GHG emissions due to change land-use-changes (LUC) and deterioration of land, forest, water resources, and as a result complete ecosystems pose a significant concern [30]. The cultivation of feedstock has entered a competition as agricultural land has been diverted from food-producing land to being used as fuel-producing land, thereby raising concerns about food security. The increasing requirement for food and other agricultural goods has led to increased chances of deforestation and the utilization of land rich in biodiversity. This has also resulted in the consumption ofsignificant amount of freshwater from various sources, fertilizers, and pesticides, leaving irreversible and irresistible consequences on the environment. The primary focus of most Life Cycle Assessment studies on biofuels involves examination of Green House Gas emission and the preservation of fossil fuel resources.In maximum LCA research on biofuels, fossilfuelconservation is an important matter of discussion that remains unsettled and has to be overcome with advanced knowledge. Additional categories of environmental impacts considered under biofuel’s Life Cycle Assessment research consist of hazards like photochemical smog,eco-toxicity,eutrophication, human toxicity, and acidification [1,36].

The utilization of the newly discovered information and advancement in technologies, called “synthetic biology”, enablesthe creation of series of biological systems. Shortly, this would enable theconversion of solar energydirectlyinto fuelvia inexhaustible raw materials (e.g.: sunlight, CO2, andwater). Production of such alternate sources like solar biofuels are anticipated to occur ingenetically advanced photosynthetic microorganisms or artificial dwelling factories which will be genetically engineered. The upcomingsystem of photobiological solar fuel production intends to employ photosynthetic microorganisms as “catalysts” toharvest solar energy and produce great amount of high-quality fuel [34].Unlike present methods which involve the production of fuel based on harvested biomass, in the future microorganisms will be tailored to secrete the fuel for continuous collection in a photo-bioreactor ensuring simultaneous production and collection of the fuel [2].

Biggest scientific discovery is of microbes that are involved in the natural breakdown of lignin for facilitated access to cellulose. Cellulose is referred to as a naturally occurring fibre found in the cell wall of plants; its function is to keep the cells together [34]. To convert it into a usable form, this first needs to be broken down into sugar, which is later converted to ethanol after fermentation or other liquids that could be used to produce fuel or bioethanol. Currently, this conversion of cellulose into sugar is being carried out using expensive enzymes. This ultimately leads to an urgent requirement for the development of tailored microbes that can ferment cellulose into sugar, thereby cutting the cost of expensive enzymes and making the process more economical.

**Conclusion**

Biofuels have emerged as a potential alternative to conventional fossil fuels, aiming to reduce greenhouse gas emissions and reduce the impacts of climate change. With concerns over energy demand, security, and the need to reduce CO2 emissions from fossil fuels, biofuels have gained attention as a promising solution for addressing these challenges. However, it is important to consider the impacts and environmentalpotential resources associated with biofuel production.

Despite having the potential in terms of reduction of greenhouse gas emissions as well as reducing dependence on fossil fuels, there are also concerns regarding the negative environmental impact of biofuels.

The production of biofuels requires the cultivation of biomass crops, which can lead to land use changes and potential habitat destruction, which have negative implications for biodiversity and ecological balance. Additionally, the production of biofuels requires significant amounts of water and energy, which can contribute to resource depletion and increase environmental pressures. Furthermore, the use of certain feedstocks for biofuel production, such as corn, sugarcane, soybeans, etc., can contribute to deforestation and loss of agricultural land. These concerns highlight the need for careful planning and sustainable practices in biofuel production to minimize environmental impacts. In conclusion, biofuels have the potential to play a crucial role in reducing greenhouse gas emissions and addressing energy challenges. However, it is essential to carefully assess and manage the environmental impacts associated with biofuel production. Considering the potential environmental impacts associated with biofuel production, it is crucial to carefully assess and manage the sustainability of these alternative fuels. To ensure the long-term viability of biofuels as a sustainable and environmentally friendly energy source, it is important to prioritize the use of feedstocks that have minimal impacts on land use, water resources, and biodiversity. In addition, certification schemes can be an effective approach to ensure that biofuels are produced sustainably, adhering to certain environmental and social standards. These schemes can help mitigate the negative environmental impacts of biofuel production by setting standards and guidelines for sustainable practices. Furthermore, the implementation of certification schemes can assure consumers and stakeholders that biofuels are being produced with minimal environmental impact. In general, although biofuels can potentially reduce greenhouse gas emissions and dependence on fossil fuels, there are concerns regarding their impact on the environmental.These concerns must be addressed through sustainable practices, careful land use planning, and the implementation of certification schemes. In conclusion, biofuels have the potential to be a possible substitute for fossil fuels in terms of decreasing greenhouse gas emissions and tackling energy issues. Nevertheless, it is crucial to overlook the environmental consequences associated with the production of biofuel in order to guarantee their sustainability in the future.

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