Chapter 10

Microalgae as a promising feedstock for biofuel production

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1. Introduction

The worldwide continuous use of fossil fuels in all sectors of life and development led to their depleting supplies and, at the same time, the increase of carbon dioxide emission in the atmosphere causing climatic changes and global warming. Biologically produced fuels are potential renewable alternative energy sources that can mitigate greenhouse gas (GHG) emissions and reduce the world dependence on petroleum-derived fuels [1,2].

Even though many fossil fuels have their origins in ancient carbon fixation, they are not considered biofuels by the general opinion since they include carbon that has been "out" of the carbon cycle for a long time. Because of factors such as growing oil costs, the necessity for augmented energy security, worries about GHG emissions from fossil fuels, and government subsidies, biofuels are gaining favor among the public and scientists [3]. Biofuels made from renewable resources are regarded as one of the most environmentally friendly substitutes fossil fuels.

Plants grown for crop production made up the first generation of biofuel; these plants are no longer restricted by the need for arable land to cultivate crops for the production of both food and energy. To solve this problem, scientists were directed toward lignocellulosic plants and their residues (as the second-generation biofuel), which are grown far from arable lands.

Microalgal biomass is a reliable and sustainable source of biofuels such as bio-oil, biodiesel, bioethanol, and biogas. One of the side effects of incorporating microalgal technologies into the business is that these species have a high ability to collect CO_2 throughout the application and biomass generation stages, resulting in lower CO_2 emissions [4,5].

Algae, the primary producer in aquatic ecosystems, undergo photosynthesis using CO_2, inorganic nutrients in the water, and solar energy to metabolize complex organic compounds such as proteins, carbohydrates, and lipids. Different algal species show variable lipid content, which may reach more than 50% of dry biomass under certain stress culture conditions [6,7].

Microalgae are a third-generation biofuel feedstock (Fig. 10.1) that do not compete with crops for land and food. The feedstock for the first generation of biofuels is edible oil, such as palm, soybean, corn, wheat, moringa, and vegetable oil [8]. However, the challenge with algae-based biodiesel is strain selection. There are millions of algal strains on the planet, but just a few are now being examined by scientists.

According to Harrison et al. [9], the microalgal lipids can be transesterified to biodiesel and biomass fermented to alcohols to be applied in different engines as spark-ignited engines, compression ignition engines, and aircraft gas turbine engines.

In comparison to agro-based fuels, the production of biofuels from microalgae is gaining widespread acceptability due to its economic viability and environmental sustainability. Algae-derived biofuels are currently considered the third-generation biofuel feedstock as algae grow rapidly, producing renewable, eco-friendly, biodegradable, and sustainable biomass that is not in competition with food crops and can be cultured on abandoned or not agriculture lands [10−13], on wasteland, or artificial ponds with treated wastewaters [14,15].

The current review focuses on the methods of algae cultivation and the pretreatment process for algal biomass for biofuel production in addition to illustrating the economic impact of algal fuels.

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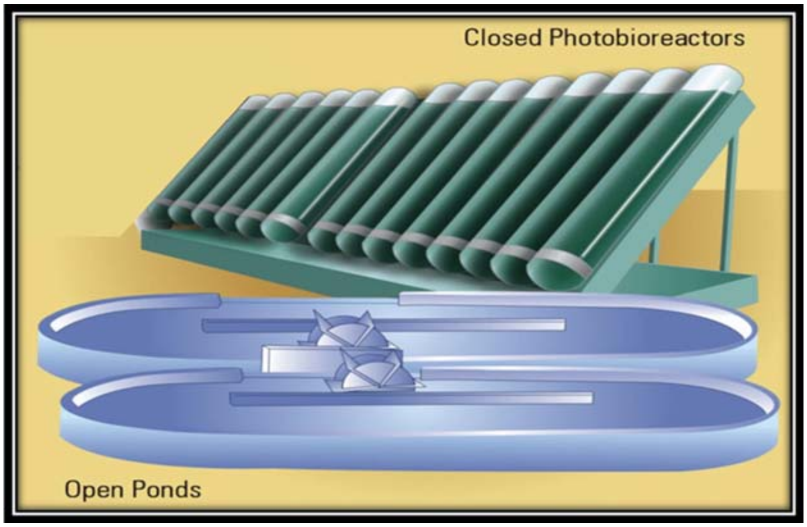

FIGURE 10.1 Photoautotrophic algal production unit (open and closed systems).

2. Microalgal biomass production

In the aquatic ecosystem, algae grow under natural conditions, absorbing sunlight and assimilating carbon dioxide (CO_2) from the air and nutrients in the ecosystem to synthesize complex organic compounds such as lipids, proteins, carbohydrates, pigments, enzymes, growth regulators, and other secondary metabolites of great importance.

Algal growth can follow three distinct production mechanisms, photoautotrophic, heterotrophic, and mixotrophic.

2.1 Photoautotrophic algal production

For long-scale algal production, only the photoautotrophic method is technically and economically feasible using either open ponds or closed photobioreactors techniques (Fig. 10.1) to harvest a large number of algal biomasses.

Selections of the algal species and optimization of the growth conditions are of basic and great importance before starting either technique.

2.1.1 Open pond production system

It is the most cost-effective way of producing huge amounts of algal biomass. It may be applied in any region with fewer energy input requirements and easier maintenance and cleaning, so it does not compete for land with existing crops [16].

Lakes and lagoons are examples of natural water ponds, while raceway ponds are the most typical manmade system [17,75]. It is normally made of concrete, but compacted earth-lined ponds are also popular (where white plastic may be used). To stabilize algae growth and productivity, they are made of closed-loop, oval-shaped recirculation tubes with mixing and circulation. In front of the continuously operating paddlewheel, algal broth and nutrients are supplied and circulated through the loop. The majority of CO_2 is absorbed from the surface air [18].

The chosen algal strain, climatic conditions, and land and water costs all influence the technical viability of any system [76]. *Dunaliella salina* (adapted to high salinity), *Spirulina* sp. (highly alkaline medium), and *Chlorella* sp. (adapted to nutrient-rich medium) are the commonly cultivated algal strains in the open pond system. *D. salina* was cultured for β-carotene in halophilic water of Hutt Lagoon.

An open pond system needs or requires an extremely selective environment to avoid contamination by other algal species.

Open ponds may be considered less efficient in biomass productivity when compared with closed photobioreactors [7,17]. This may be due to several determining factors that are uncontrollable as temperature fluctuations, evaporation losses, CO_2 deficiencies, light limitation, and inefficient mixing.

2.1.2 Closed photobioreactor system

It is used to produce high-value products from microalgae to be used in the cosmetics and pharmaceutical industry, and the photobioreactor technique avoids the risk of pollution and contamination that occurs in open pond systems as reported by Ugwu et al. [16].

Closed photobioreactors are composed of many arrays of straight transparent tubes in glass or plastic materials that can be deposited horizontally or vertically or as a helix [19].

An airlift system allows the O_2 to go out and CO_2 to go into the system in addition to a mean for biomass harvest. The second section is the solar receiver with a large-surface illuminated platform for algal growth. Algal cultures are circulated with a mechanical pump or airlift system, agitation, and mixing that cause gas exchange (O_2 and CO_2) in the tubes [16].

Tubular photobioreactors are more convenient for outdoor and massive algal cultivation and have the benefit of natural sunlight.

Column photobioreactor is compact and easy to operate with low cost. For the vertical column, aeration comes from the bottom and illumination either through the transparent wall or internally [20].

2.1.3 Hybrid production systems

It consists of two-stage cultivation, where the first is through a photobioreactor with controlled conditions and minimum contamination, and the second is the open ponds. Here, environmental stresses naturally stimulate algal production by transferring algal culture from the photobioreactor to the open pond [21] [77].

2.2 Heterotrophic algal production

In this process, algal growth can be achieved using an original carbon source as glucose in either photobioreactors or fermenters. Higher algal cell densities are achieved, and the step-up and harvest costs are minimal [22]. There is reported large-scale biodiesel production by heterotrophically cultivated *Chlorella protothecoides*. Also, Miao and Wu [23] studied the same species and found that heterotrophically cultured cells produced lipid content four times higher (55%) than autotrophic cells (15%) under the same conditions. It was concluded that heterotrophic cultured cells could produce higher biomass production that accumulates greater lipid content in cells [24].

2.3 Mixotrophic algal production

Light is not an absolute limiting factor of algal growth in many algal species that can grow either autotrophically or heterotrophically. This means that they can undergo photosynthesis as well as absorb organic carbon substrate material (i.e., mixotrophic) [78] as in the case of the cyanobacterium *Spirulina platensis* and the green *Chlamydomonas reinhardtii*. Photosynthetic metabolism uses light for growth, while aerobic respiration uses an organic carbon source. The addition of glucose to the medium during light and dark phases influences algal growth.

The growth of mixotrophic algae is higher than those cultured in the open pond but lower than for heterotrophic ones.

Chojnacka and Noworyta [25] compared the growth of *Spirulina* sp. in photoautotrophic, heterotrophic, and mixotrophic cultures. They found that mixotrophic cultures enhanced growth rate over both heterotrophic and autotrophic algae, allowing the integration of both photosynthetic and heterotrophic components during dark respiration and decreasing the quantity of organic carbon substance employed during growth.

This means that mixotrophic algal cultivation can be an important part of microalgae to produce biofuel.

2.3.1 Wastewater used for microalgal cultivation

Wastewater is rich in nitrogen, phosphorus, and organic contaminants. The use of treated wastewater for microalgal growth allows for a faster production rate, reduces the nutrient levels in the wastewater, reduces harvesting costs, and improves lipid production. Many applications of wastewater have been reported in literature using different microalgal species [26,79].

Sawayama et al. [27] used the microalga *Botryochoccus braunii* to absorb nitrate and phosphate from the primary treated sewage to produce rich carbohydrate biomass. While Marting et al. [28] used urban wastewater for the growth of *Scenedesmus obliquus*, where elimination of phosphorus and ammonium reached 98% and 100% in 94 and 183 h. On the other hand, Hodaifa et al. [80] used concentrated or diluted industrial wastewater from olive oil extraction for the cultivation of *Scenedismus obliquus*, which recorded 67.4% and 35.5% elimination of BOD respectively.

Mostafa et al. [29] demonstrated the feasibility of a wastewater treatment method that combines nitrogen removal and algal lipid production for use as a biodiesel feedstock. This study also provided information on the culture of nine algal strains for lipid production on secondary treated residential wastewater, as well as the potential of microalgae lipids for biodiesel generation by transesterification. Overall, it can be stated that using microalgal culture nutrient media is a feasible and cost-effective way of producing sustainable biodiesel and glycerol when compared with traditional growing methods.

3. Harvesting of microalgal biomass

It includes flocculation, filtration, flotation, and sedimentation by centrifugation. The selection of the algal species and the most appropriate harvesting method are of great importance for the cost-efficient economic production of algal biomass [81].

The selection of the harvesting technique depends on the microalgal characteristics such as size, density, and the target product value.

The concentration of the biomass takes place by centrifugation, filtration, or ultrasonic aggregation, this step requires more energy.

Flocculation is the first step used for microalgal aggregation before the application of any other harvesting methods [30]. Multivalent metal salts such as ferric chloride, aluminum sulfate or ferric sulfate, or chitosan may be used as flocculants [31,82] to neutralize the negative charge on algal cells. Ultrasonic may be used to optimize the aggregation efficiency as reported by Bosma et al. [32].

Unlike flocculation and the need of adding chemicals, flotation methods are based on the application of micro air bubbles that allow algal cells to float at the surface of the culture media (especially when there are increased lipid contents in the algal cells).

The most common harvesting technique for algal biomass is centrifugal sedimentation that depends on both the density and algal radius (suitable for large algal cells) as well as on the centrifugation velocity [83], especially in the case of algal biomass cultured on wastewater.

Filtration of algal biomass is preferable for larger algal species (such as *Spirulina*) and not used in smaller-sized microalgae such as *Chlorella*, *Scenedesmus,* or *Dunalliella* where membrane microfiltration or ultrafiltration techniques are more convenient, as reported by Petrusevski et al. [84].

Electrophoresis can be used where an electric field directs microalgae to the external part of the solution. Electrolysis of the water produced H_2 that carries the microalgae to the surface. This method has a high cost.

4. Extraction and purification of microalgal biomass

Oils were easily extracted from freeze-dried biomass, while difficult extraction was known from wet biomass, but it is expensive as well as the spray drying method [33]. Higher temperatures (more than 60°C) decrease both the triacyl glycerate and the lipid yield.

Combined ultrasound and electromagnetic pulse cause rupturing of algal cell walls, and the addition of CO_2 induce a lowering of the pH and separation of oils from algal biomass [85]. Cell disruption by high-pressure homogenizer, autoclaving, or addition of NaOH, HCL, or the use of alkaline lysis to the cells can be performed.

5. Conversion techniques/methods of algal biomass to biofuels

There are two categories of conversion techniques utilizing algal biomass that depend on the type (as shown in Fig. 10.2), the quantity of biomass, and the desired form of conversion of energy to the thermochemical and biochemical.

5.1 Thermochemical conversion

This means the thermal degradation of different organic compounds in the algal biomass to biofuel products. This may be achieved by different steps/process such as direct gasification, combustion, liquefaction, and pyrolysis, as reported by Takahara and Sawayama [34].

5.1.1 Gasification

Hirana et al. [86] reported that oxidation of *Spirulina* sp. at a temperature of 850−1000°C produced methanol (1 gm biomass produced 0.65 gm methanol). Whereas Minowa and Sawayama [35] gasified *Chlorella vulgaris* (at 1000°C) in a nitrogen cycling system to obtain methane-rich fuel.

5.1.2 Liquefaction

In this process, algal biomass under high temperature (300−350°C) and high pressure (5−20 Mpa) in the presence of hydrogen as catalyst can be converted to bio-oil as mentioned by Goyal et al. [87].

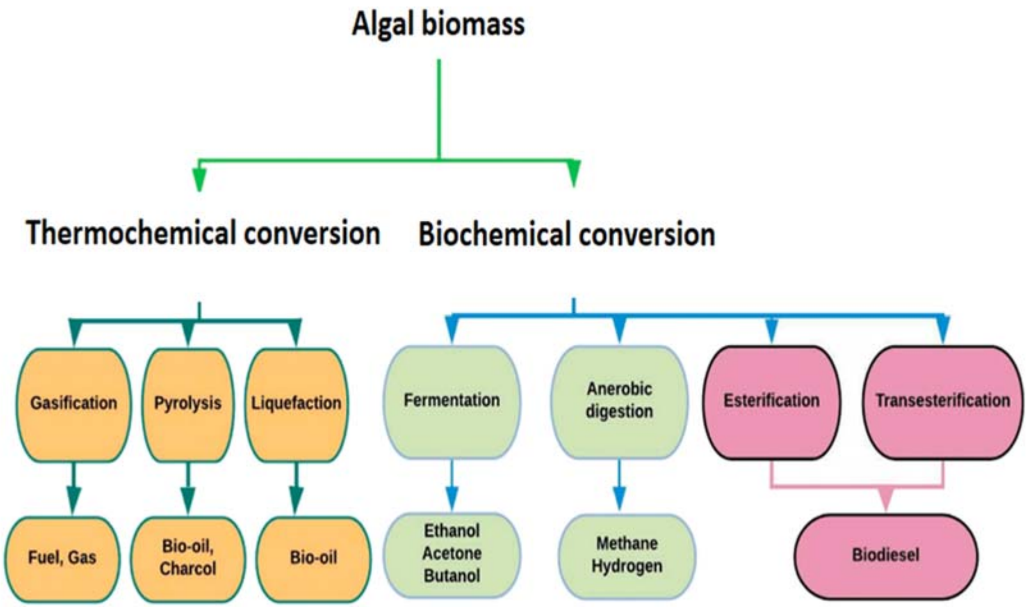

FIGURE 10.2 Biochemical and thermochemical conversion of algal biomass to biofuel.

Dote et al. [88] liquefied *Botryoccocus braunii* at 300°C, and *Dunaliella tertiolecta* was studied by Minowa et al. [36] to create liquid fuel.

5.1.3 Pyrolysis

In this process, algal biomass can be converted to bio-oil, syngas, and charcoal at a temperature range of 350−700°C in the absence of air. Flash pyrolysis at a moderate temperature of 500°C with short hot vapor exposure for 1 s, is the future technique to convert biomass to liquid fuels that can replace fossil fuels. Demirbas [37] and Miao and Wu [38] used the pyrolysis technique to convert *Chlorella protothecoides* and *Microcystis aeruginosa* to bio-oil. Results indicated that bio-oils from microalgae are of higher quality than those extracted from lignocellulosic materials [37,38].

5.1.4 Direct combustion

This process is concerned with the conversion of chemical energy in the biomass in presence of air to yield hot gases [87] in furnaces, boilers, or steam turbines at 800°C with a pretreatment process such as drying, chapping, or grinding.

5.2 Biochemical conversion

Biochemical conversion of algal biomass into biofuel includes anaerobic digestion, alcoholic fermentation, and photo-biological hydrogen production.

5.2.1 Anaerobic digestion of algal biomass

It involves the breakdown of organic substances (wet algal biomass) to produce a gas (methane, CO_2, H_2S). Generally, it occurs in three stages: hydrolysis, fermentation, and methanogenesis. Hydrolysis includes the breakdown of complex compounds (carbohydrates) into soluble sugars. Fermentation of these sugars by fermentative bacteria will produce alcohols, acetic acid, volatile fatty acids, and a gas (H_2 and CO_2), which is the second step [39,40,89,90]. Methanogenesis is the generation of methane (CH_4) and CO_2 as reported by Cantrell et al. [91].

5.2.2 Alcoholic fermentation

Defatted biomass rich in sugars, starch, or cellulose, which is left after oil extraction, is converted to alcohol (ethanol) where hydrolysis of starch and cellulose to sugars is followed by the addition of water and yeast in fermenters where yeast breaks sugars to ethanol, as reported by Mckendry [89,90] and as shown in Fig. 10.3.

Alcohol must be purified or distilled to remove water, condensed to liquid form, and used in cars to replace petroleum. The solid left after this process may be used either for gasification or cattle feed [41].

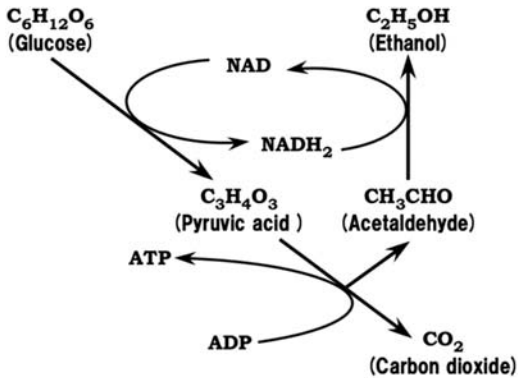

FIGURE 10.3 The chemical reaction for conversion of algal biomass to ethanol.

5.2.3 Photobiological hydrogen production

Photosynthetic H_2 production from water may be produced in two stages. In the first stage, algal photosynthesis occurs normally, while in the second stage, algae are grown in a sulfur-deficient condition that induces an anaerobic condition leading to hydrogen production [42].

6. Algal biofuel types

6.1 Biogas (biomethane production)

Anaerobic biochemical breakdown of all polymeric materials produces methane and CO_2. In the environment a diverse range of microorganisms coexist and interfere in the production of the end products as fermentative microbes. New digesters and advancements in the operation of several kinds of bioreactors are highlighted, as well as recent advances in the molecular biology of methanogens.

Methane fermentation is a multipurpose biotechnology able to convert virtually all forms of polymeric materials to methane and CO_2 under anaerobic circumstances. This is accomplished through the biochemical breakdown of polymers into methane and CO_2 in an environment where a diverse range of microorganisms coexist and produce reduced end products, including fermentative microbes (acidogens), hydrogen-producing, acetate-forming microbes (aceto gens), and methane-producing microbes (methanogens). At various stages of methane fermentation, anaerobes play a crucial role in generating a stable environment.

6.2 Bioethanol

Bioethanol is one of the most important renewable fuels due to its economic and environmental benefits. The increased use of bioethanol around the world as a renewable fuel may be due to (1) the depleting resources of fossil fuel and the emergence of biomass as a renewable energy. (2) Because of the use of fossil fuels, one of the most pressing concerns in this century is GHG emissions; biofuels may be a viable solution. (3) The price of petroleum is on the rise in the global market. (4) Petroleum reserves are limited, and some oil-importing countries have a stranglehold on them, putting the rest of the globe at risk. Recently El-Sheekh et al. [43] produced bioethanol from wastes such as wheat straw with the aid of fungi fermentation. They could produce and improve bioethanol by 3.6-fold after optimization conditions for commercial *Saccharomyces cerevisiae* on hydrolysate obtained from enzymatic saccharification of *Aspergillus niger* to 1% NaOH pretreated wheat straw. Furthermore, the produced bioethanol was blended with 10% and 20% in volume by diesel #1/wCO biodiesel commixture. Mixtures consisted of 50% diesel/50% biodiesel, 10% bioethanol/45% diesel/45% biodiesel, and 20% bioethanol/40% diesel/40% biodiesel that were tested as new fuel blends.

6.3 Biodiesel

Algal-based biofuels are gaining traction in the wake of expectations that crude oil prices may hit new highs. Transesterification of lipids to biodiesel is one of the sustainable, carbon-neutral fuel applications that use algal components [7].

Microalgae species with higher lipid content can be used to make sustainable energy products including jet fuel, biodiesel, and biogasoline [44,45]. Biodiesel is an environmentally friendly diesel fuel made from vegetable oils, animal

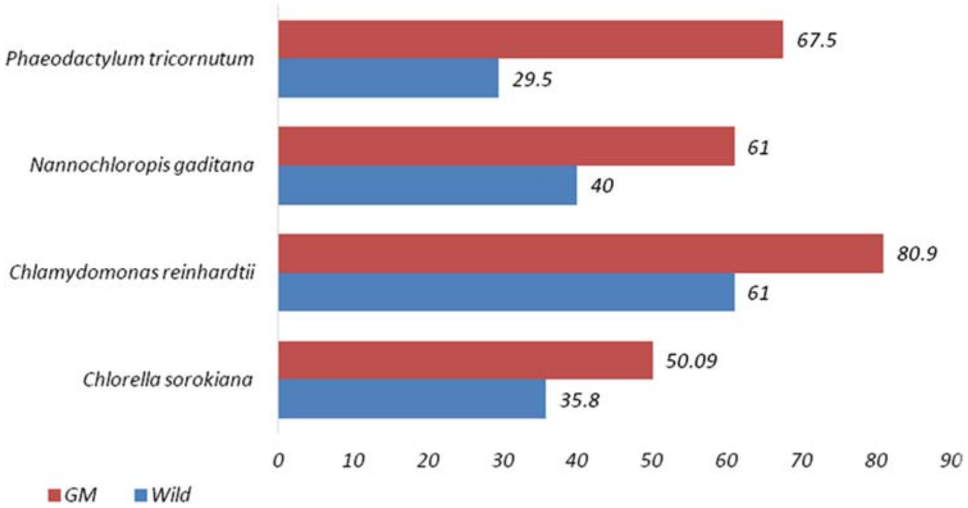

FIGURE 10.4 Comparison between some wild-type microalgae with genetically modified strains in bio-lipid production.

fats, or grease. It has a fatty acid alkyl esters chemical structure. Biodiesel emits far fewer hazardous pollutants into the atmosphere than fossil diesel. Furthermore, it burns cleaner and has less sulfur, resulting in lower emissions. It is more likely that since biodiesel is formed of renewable resources, it will compete with petroleum goods in the future [46,47]. To utilize biodiesel as a fuel, it must be combined with diesel fuel to make biodiesel-blended fuel (up to 20%). The "biodiesel" is made commercially by transesterification of triglycerides, the major components of l origin oils, in the presence of an alcohol (e.g., methanol) in addition to a catalyst (alkali or acid).

Lipids produced from oil crops (first generation) or nonfood lignocellulosic agricultural residues (second generation) or algal lipids (third generation) can be converted to biodiesel through a process called transesterification (as shown in Fig. 10.4), where a chemical reaction occurs between triglycerides and alcohol in the presence of a catalyst (acid or alkali) to produce the monoesters of the biodiesel, as reported by Sharma and Singh [92].

There are huge numbers of worldwide algal species, but only a few of them are currently investigated in researches. A few suitable microalgae strains for different biofuel generations and the fatty acid composition of their lipid content are illustrated in Tables 10.1 and 10.2.

TABLE 10.1 The main variation between the biofuel generations.

Biofuel generations		Main advantages and disadvantages	
First generation	**Food sources**	Require cultivable lands Negative impact on environment Negative effect on food security	
Second generation	**Nonedible sources**	No impact on food security No impact on biodiversity	
Third generation	**Algal species**	No impact on food security No impact on biodiversity Environmentally co-friendly Easily cultivated	
Fourth generation	**Genetically modified algae**	No impact on food security No impact on biodiversity Brackish and saline land can be used for cultivation	

TABLE 10.2 List of algae strains that are suitable for biofuel production.

Species	Lipid %	References
Scenedesmus bijuga	34.10−35.24	[48]
Chlorella saccharophila	41.71−44.73	[48]
Chlamydomonas reinhardtii	21−51	[49]
Chlorella sp.	19.28−28.79	[48]
Monoraphidium dybowskii	30.12−31.78	[50]
Chlorella vulgaris	24.28−31.04	[48]
Scenedesmus dimorphus	33.70−40.33	[48]
Chlorella pyrenoidosa	18.67−52.08	[48]

Algal biodiesel is considered a renewable, biodegradable, nontoxic alternative with similar physical and chemical characteristics to fossil fuel and comparable with the international standard EN!4214.

Algal biodiesel is considered more suitable for use in the aviation industry and reduces GHG emissions by up to 78% compared with those emitted by petroleum fuel.

All the world's scientists have directed their research to increase algal biomass production and especially the lipid contents through variable and optimized physical and chemical culture conditions, biomass collection, and trans-esterification of the produced lipids to obtain biodiesel of low cost and good quality that satisfies the international standards to replace the depleted fossil fuel in all sectors of life.

The quality and amount of lipids in the microalgae determine the quality of the biofuel produced [51]. Microalgae lipid quality and production are influenced by environmental factors such as growing time, nutrition availability, and illumination exposure [52]. These factors in the environment can be controlled. As a result, the microalgae strain chosen is the most important determinant of qualitative fatty acid profiles and lipid production rates. Indeed, previous research has revealed significant differences in the quantity and quality of lipids among microalgae strains. *Tetraselmis maculata*, for example, has a total lipid content of less than 4.5%, but *Schizochytrium* sp. has a total lipid content of more than 80%.

7. Genetically modified algae

To overcome the constraints of the first two generations, scientists and researchers focused on the production of biofuel by the third and fourth generations, using photosynthetic single-cell microalgae. Microalgae have been identified as a viable source of biofuel production, offering a better choice to meet current fuel demands due to their rapid biomass productivity, doubling time, high oil content, and ability to be cultivated on abandoned agricultural land [53].

Various experiments have been conducted to modify algal species to boost lipid and fatty acid content using genetic engineering methodologies such as single/multiple gene/key enzyme overexpression and deletion strategies [54]. Due to the quick availability of genome sequence information through a combination of proteomics, genomics, transcriptomics, and metabolomics, DNA sequencing is becoming more important in microalgae species.

Engineering the wild gene to construct intensified productivity and to personalize the final product is an important way out for algae biotechnologists, considering the algal potential in meeting fuel and food demands through exponentiation population. Algal biotechnology is recently dealing with engineering the wild genes to increase algal biomass productivity that covers both fuel and food demands. In this strategy, algal strains are selected and genetically modified for optimized growth and environmental stress tolerance producing larger algal biomasses with higher lipid content of promising quality for fuel production (Fig. 10.4). Biofuel produced from transgenic algae are more compatible with diesel engines than those originated from either lignocellulosic plants or crops [55]. An important strain of microalgae, as well as its genetic manipulation, is critical for increasing biofuel production.

Microalgae cultivation in wastewater (as one kind of abiotic stress that leads to gene expression and effect on chemical contents) allows necessary nutrient uptake for growth and biomass production and is considered an option for algal long-term biofuel production. To examine the proposed nutrition approach's sustainability and economic performance, a comparative life cycle assessment method and a techno-economic analysis are used. Our research is validated using two circumstances. Scenario one is based on a source-separated nutrient delivery technique in tertiary treatment with microalgae-integrated wastewater. Scenario two is based on a policy of non-separated point nutrient distribution and the use of microalgae in secondary wastewater treatment. The findings demonstrate that using a source-separated nutrition method can help reduce environmental consequences while also enhancing productivity [56].

The PROMETHEE-GAIA approach is developed and applied by Mofijur et al. [57] for selecting microalgae strains from which aviation fuel can be generated. A total of 19 criteria are used in the evaluation, with equal importance given to the following three: biomass production, lipid quality, and fatty acid composition, and biodiesel characteristics. The approach is used to evaluate 17 potential microalgae strains in this paper. The most suited strain for aviation fuel production is *Chlorella* sp. NT8a. The findings also reveal that unmodified biofuel from the best strain could fall short of all airplane fuel requirements. Microalgae-based fuel, in particular, failed to meet the density, heating value, and freezing point requirements of international jet fuel standards. These findings underscore the need for a comprehensive action plan that includes improvements in biofuel processing and modification.

Toxic materials generated by various businesses could be remedied in the future by the introduction of genetically engineered algae species. The issues surrounding the use of genetically modified algal species should be carefully considered. If a genetically modified algal species is transplanted to a new environment, it may not be able to adapt to the changing conditions. When natural type algae are mixed with genetically modified algae, new breeding can occur, which can be damaging to other creatures. Even if there are significant concerns regarding the use of genetically modified organisms, the current situation necessitates the total establishment of biofuel production employing modern technology in algae species. The use of genetic engineering technologies on algae is not restricted to the generation of biofuels [55].

Using genetically engineered algae species, the production of a variety of commercially relevant products can be boosted. As a result, the works related to algae cultivation will have market worth. The cost of bioremediation employing genetically modified algae species will be lower than that of traditional approaches. Because of the increased production of biofuels, there are more prospects for direct and indirect employment.

8. Algal fuel properties

The transesterification of algal oils and the characteristics of the produced biodiesel clearly remarked its efficiency used biofuel. Its properties mainly depend on the feedstock used as well as the conversion method employed.

To evaluate the biodiesel derived from algae, different aspects must be considered:

- The acid number indicates the corrosiveness of the oil.
- The iodine value indicates the degree of unsaturation of the biodiesel.
- The specific gravity and density indicate the energy efficiency of the fuel.
- The flashpoint expresses the lowest temperature at which the biodiesel vaporizes to form an ignitable mixture.
- The pour point indicates the low temperature at which the oil turns semisolid and loses its flow characteristics.
- Viscosity refers to the fluid's resistance to flow.
- The heating value indicates the released energy in the form of heat after the combustion of a compound.
- Cetane number refers to the ignition quality of the diesel engines that can operate efficiently.
- Variable fatty acid composition of the algal oil is subjected to transesterification process. Higher percentages of saturated fatty acid methyl esters refer to higher both oxidative stability and cetane number but at the same time have poor cold flow characteristics, as reported by Harrison et al. [9]. On the other hand, higher percentages of unsaturation in the fatty acid profile design better cold flow properties but lower oxidative stability and cetane number. So, the fatty acid composition (fatty acid methyl esters), the percentage of carbon chain length, and the degree of unsaturation have the most valuable effects on the fuel properties [58].

9. Economic importance of algae as biofuel sources

The depleting sources of fossil fuel together with the accumulation of GHG emissions in the environment, from its combustion, cause climate change and global warming. The search for renewable and sustainable energy from biomass starts with the seeded crop plants and then with the lignocellulosic plant residues, which do not require arable lands for cultivation and do not compete with the food crops.

Additional biomass-based fuels are necessary for liquid transesterification to biofuels used for transportation and to replace the depleted fossil fuels. Extreme treatment and production processes have been used for terrestrial feedstock. Initially, the outward benefits of such systems were favorable. Nonmarket benefits were intended to be the policy reinforcement (in the United States and Brazil, for example) [59]. However, the literature may exaggerate these benefits. The loss of significant carbon sinks due to ground clearance for crop cultivation, particularly in tropical places, results in a significant increase in GHG emissions.

Because of the influence of land clearance and conversion on food prices and supplies, the total social and economic gain of traditional biofuels is also unstable, resulting in the loss of nonmarket ecosystem services. These changes have far-reaching societal implications. Extra jobs and earnings from crop-based biofuel production, as well as increased access to gasoline, will compensate for higher food prices in impoverished areas in particular. Increased food costs frequently result in higher salaries for producers, especially those in low-income groups, of which there are many. However, because the benefits of feed crops cannot be distributed evenly throughout society, the distribution of revenue between net producers and net consumers of agricultural commodities remains an analytical problem that must be solved to determine the eventual impact on human well-being [60].

Algae, particularly microalgae, offer a new biofuel potential that does not appear to have the same level of negative development as other biofuels. Microalgae biodiesel, like most biomass-based biofuels, is not genuinely competitive with fossil fuels. However, the relative infancy of manufacturing and processing technologies may exacerbate this [61]. In addition to the possibility of advances that lower production costs, biomass could be used to produce other commodities, increasing financial profitability. However, only a few researches have been conducted on assigning viable organic fuel to determine the practicality of cultivating microalgae for biofuels. The produced algal biomass by advanced technologic techniques, in addition of biofuel production, can be used for many commodities and increasing financial profitability.

Microalgae production and transformation also have the disadvantage of being capital and resource intensive. Apart from the production and maintenance of artificial ecosystems, the facility needs a lot of electricity, water, and nutrients to generate enough biomass [62].

Microalgae have faster growth rates than terrestrial plants and can grow anywhere, in wastelands, in artificial ponds, raceways, or closed bioreactors using treated wastewater or saltwater and at the same time can benefit from solar energy in photosynthesis.

Biofuels from algal biomass are considered renewable and sustainable energy sources that can replace petroleum fuel. Algal biomass can be converted to different forms of energy using thermochemical transformation techniques generating gases, liquids, and solids fuels through liquefaction, gasification, and pyrolysis processes, as reported by Demirbas [63].

Energy conversion using thermochemical, chemical, and biochemical methods produces bio-oil, biodiesel, bioethanol, biomethane, and biohydrogen.

Intensive work and continual research are concerned with the optimal methods of algal culturing, biomass harvesting, oil extraction, and biomass conversion to different types of biofuels to optimize all the conditions affecting the large-size, low-cost, and good quality biofuels that can substitute fossil fuel in the newer future.

10. Applications of biomass

The algal cultivation followed by harvesting of the biomass, drying, and grinding of this biomass to powder can be utilized for many applications, including the drug industry, used as food supplements, pigments as natural coloring substances and antioxidants, anticancers, antivirals, biopolymers (bioplastic), biofuels (biohydrogen, bioethanol, biodiesel, bio-oil, biogas, biochar), and biofertilizers [64−74].

11. Conclusion

The world is entering a period of declining energy, and therefore there is a need for new and alternative energy sources. The algae are an auspicious substitute source for biofuel, including biodiesel, bioethanol, and biohydrogen. The researchers are looking for promising strains with high biomass, lipid, and fatty acids content. The cultivation conditions are the most significant factors that impact productivity and yield. In parallel with the screening for new algae strains, researchers are attempting to use genetic engineering techniques to improve the ability of algae to accumulate high content of lipids and fatty acids that are used for esterification to produce methyl esters (biodiesel). Another important factor that affects the efficiency and productivity of biofuel is the harvesting method. In conclusion, algae are a promising source of renewable energy that may compensate for the shortage of fossil fuel.

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