MICROALGAE: A SUSTAINABLE AND RENEWABLE SOURCE FOR BIOENERGY PRODUCTION.

Abstract

Microalgal biomass has been proved to be a sustainable source for bio-oil, biodiesel, bioethanol, biomethane, and so on. One of the guaranteed advantages of coordinating the utilization of microalgal advancements in the business is microalgae's capacity to catch carbon dioxide during the application and biomass creation process and thus decreasing carbon dioxide discharges. In spite of the fact that microalgae are a plausible wellspring of biofuel, modern microalgae applications face energy and cost difficulties. To defeat these difficulties, analysts have been keen on applying the bio-treatment facility way to deal with removing the significant parts exemplified in microalgae. Various studies found that reasonable microalgae species are chosen in view of their sugar, lipid, and protein contents, and choosing the appropriate species is essential for top-notch biofuel and esteem-added items creation. Microalgae species contain sugars, proteins, and lipids in the scope of 8% to 69.7%, 5% to 74%, and 7% to 65% separately which showed their capacity to be utilized as a wellspring of significant worth added wares in numerous enterprises including farming, animal cultivation, medication, culinary, and beauty care products. In addition, new emerging technologies such as algal interactions for enhancement of microalgae growth and lipid production are also explored. This chapter describes the advantages of microalgae for the production of biofuels and various bioactive compounds and discusses culturing parameters.

Keywords: microalgae, biofuel, renewable source, sustainability, feedstock, photobioreactor.

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I. INTRODUCTION

Due to increasing population and environmental deterioration, any nation can face the challenge of sustainable development. Renewable energy sources must be discovered in order to support population increase and development. While it is essential that energy is produced without harming our environment [1]. In the past fifty years, the population of the world has more than doubled, which is expected to raise living standards and gradually boost economic output. Due to this, there has been a substantial rise in the demand for primary energy, primarily from fossil fuels. Considering that the world population is expected to increase by 1.4 billion people by 2030 and that real world revenues are anticipated to increase by 100% [2], an upwards trend in energy utilization is likely to continue. Currently, the world consumes roughly 15 terawatts of energy annually, with renewable energy making up about 7.8% of this total. Nevertheless, roughly 85,000 terawatts of sunlight reach the surface of the globe annually. Scientists and engineers are exploring into a number of alternative energy sources due to the continually rising global demand for fuels for motors and power generation and environmental concerns over greenhouse gases (GHGs) [3]. As a result, there is rising interest in eco-friendly alternatives that reduce the reliance on fossil fuels and greenhouse gas emissions, notably bioenergy production [4]. In recent years, a lot of attention has been paid to understanding how algae could be used as a source of bio-oils and bio-gases for energy production. [5].

Algae have the potential to be used as biomass feedstocks since they can grow in both salt and fresh water environment and they can do so without requiring any land for their cultivation. Algae would also be a completely renewable option with significant potential to supply the world's energy needs because water makes up two-thirds of the surface of the earth [6, 7]. As a result, the production of ethanol, methane, triglycerides from vegetable oils, hydrogen, and hydrocarbons from microalgae for biofuels has been addressed for many years. The first investigations on microalgae biofuel production focused on methane, and microalgae were mostly taken into consideration for wastewater treatment applications [5].An industrial scale bioreactor that uses microalgae to capture CO_2 and NO_2 is currently being developed in the United States. Microalgae were employed as a nutritional supplement in Mexico. Therefore, protein- and lipid-rich microalgae may one day prove to be a competitive alternative to petroleum. The Department of Energy (DOE) and the National Renewable Energy Laboratory (NREL) have been working together to create commercially viable fuels from microalgae high in algae [6].

II. MICROALGAE AN EMERGING SOURCE OF BIOFUEL

Microalgae are microscopic plants that play a key role in the aquatic environment's organic matter synthesis. They grow their cells significantly more quickly than land plants, have a high surface area to volume ratio, and quickly absorb nutrients and carbon dioxide (CO_2) [7].Microalgae can thrive in a wide range of environmental conditions, including heat, cold, drought, salt, photo-oxidation, anaerobic life, osmotic pressure, and UV radiation. Microalgae are highly productive in terms of area, can grow on seawater or leftover nutrients, are rich in oils, proteins, and carbohydrates, and may be separated by biorefineries into bioenergy and food [8]. Algal biomass is being used more frequently as a source of bioenergy. Even though the number of species of algae in the globe is thought to exceed 50,000, only around 30,000 have been discovered and investigated so far [9]. The green algae such as *Chlorella, Spirulina, Scenedesmus obliquus, Chlorella vulgaris, Tetraspora* sp., *Chlamydomonas reinhardtii*, *Botryococcus braunii*are among the most often utilized algae for the generation of biofuels [10].For the production of biofuel, microalgae with a minimum of 30% lipids in their cells can be employed. Microalgae can absorb a significant amount of CO2 and turn it into carbohydrates and oxygen through photosynthesis. Afterwards when, sugars are converted into lipids, proteins, carbohydrates, and similar compounds to generate biofuels [9]. The following is the equation for a photosynthetic reaction. Figure 1 shows an illustration of the use of microalgae in the production of biodiesel.

$6CO_2 + 6H_2O$ + sunlight energy $\rightarrow C_6H_{12}O_6$ (sugars) + $6O_2$

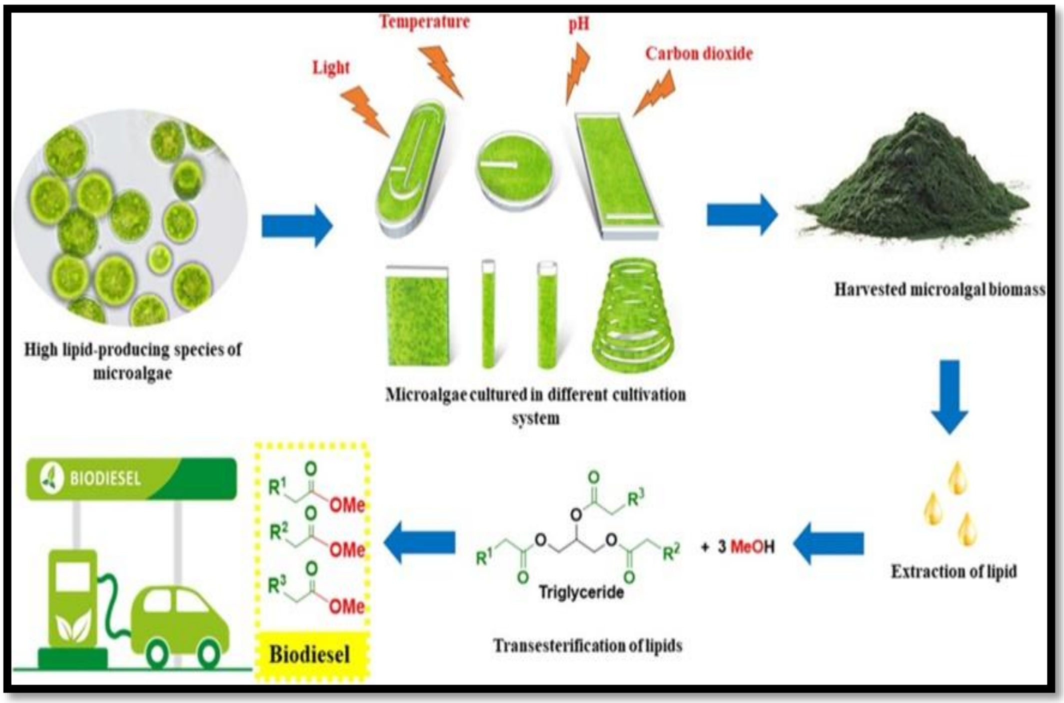

Figure 1: Utilization of Microalgae in the Biodiesel Production [26].

III. CLASSIFICATION OF BIOFUELS

Biofuels are substances produced from living organisms or metabolic waste. For generating biofuels, a range of sources have been taken into account. A fuel must contain at least 80% renewable raw resources to be categorized as a biofuel. A biofuel is classified as:

1. **First generation algal biofuels:** In the United States, corn and soybeans, as well as sugar cane in Brazil, are the major sources of first-generation biofuels. These biofuels have a number of drawbacks. First, only about 10% of the demand for liquid fuel in developing nations could be met by arable land. Furthermore, using first-generation biofuels increases the cost of animal feed, which in turn raises the price of food. Biodiesel is currently made from palm oil, soybean oil, and canola, while bioethanol is currently made from corn and sugar cane [11].

2. **Second generation algal biofuels:** The second generation of biofuels is produced from non-edible plant materialssuch as, wood, waste streams and straw. Second-generation biofuel methods, however, can be just as energy-intensive as first-generation biofuels for woody lignocellulosic substrates. Before the biofuel production stage, lignocellulosic material may require a pretreatment step like steam blasting. As a result, second-generation biofuel processes are anticipated to have higher energy requirements than first-generation procedures [12]. Second-generation biofuels have the advantage of being plentiful and having no adverse effects on food production. On marginal land that would not generally be used for cultivation, the majority of these energy crops can be grown [11].

3. **Third generation algal biofuels:** Third-generation biofuels can be produced without utilizing any agricultural land. Algae are frequently the basis for third-generation biofuels and are claimed to require less land than terrestrial crops like corn, oilseed rape, and switch grass. Microalgae are more productive per hectare than crops, according to once [13]. Only bioethanol and biodiesel are now produced on an industrial scale [14]. Microalgae can complete an entire development cycle every few days and utilize photosynthetic mechanisms similar to those found in higher plants. In reality, microalgae only double their biomass once every 3.5 hours during exponential growth [15].

IV. TYPES OF BIOFUEL PRODUCTION FROM MICROALGAE

1. **Biodiesel from Microalgae:** Due to their faster growth rates than terrestrial plants, microalgae are viewed as a potential source for biodiesel production. The downstream costs of lipid extraction and the availability of water, CO2, and nutrients [9] limit the widespread use of algae biodiesel. While reducing sulphur and particulate matter emissions, biodiesel offers engine performance that is comparable to that of petroleum-based diesel fuel. A non-toxic alternative fuel made from renewable resources; biodiesel is biodegradable. Currently, the term "biodiesel" relates to a very specific chemical alteration of natural oils [16].The fact that biodiesel may be utilized in current diesel engines without requiring any modifications and can be blended with petroleum diesel at any ratio is one of its main benefits over many other alternative transportation fuels. Algal biomass can be transesterified to produce biodiesel directly from algae. They can also be made using a two-step procedure that involves first extracting the lipids and then transesterifying them, but both methods require extracting the lipids with solvents such methanol, isopropanol, petroleum ether, and alcohols. The direct transesterification method is a simple and cost-effective one [17].

   The majority of microalgal lipids are neutral lipids with low levels of unsaturation. Due to this, microalgal lipids have the potential to replace fossil fuel. The amount of unsaturated fatty acids is the biggest drawback of microalgae oil. For the manufacture of biodiesel, high quantities of unsaturated fatty acids are problematic because they may lead to the cross-linking of fatty acid chains, which results in the development of tar. Microalgae can contain up to 30% of their total fatty acids as unsaturated fatty acids [18].

Table 1: Comparison of Some Sources of Biodiesel [12]

Crop	Oil yield (L/ha)	Land area required (M ha)
Corn	172	1540
Soyabean	446	594
Canola	1190	223
Jatropa	1892	140
Coconut	2689	99
Palm oil	5950	45
Microalgae	136,900	2

2. **Bioethanol:** The current emphasis of ethanol production efforts is on using microalgae as a feedstock for the fermentation process. Proteins and carbohydrates found in microalgae can be used as carbon sources for fermentation. Protein and carbohydrate content varies based on the algal type. Under anaerobic conditions, ethanol is produced through the fermentation of sugars by bacteria, yeast, or fungus. CO_2 and water are produced as by-products in addition to ethanol, which is the main product. For the production of bioethanol, microalgae are also being studied. High levels of polysaccharides have been shown to accumulate in the complex cell walls of green algae, such as *Spirogyra* species and *Chlorococum sp.*, as well as starch. It is possible to exploit this starch accumulation to make bioethanol. According to research by Harun et al., the green alga *Chlorococum sp*. produces 60% more ethanol when samples are pre-extracted for lipids as compared to when they are dried as whole cells. This suggests that microalgae can be utilized to produce ethanol and lipid-based biofuels from the same feedstock, hence increasing their overall economic benefit [2].

    Two approaches are often used in the production of bioethanol from biomass. Fermentation is a biological process, while gasification is a thermo-chemical process, respectively. The biggest concern is that both types of feedstocks must be generated in huge amounts due to their high value for food applications. Due to this conflict with the food chain and land use, it is difficult to increase the production of these biofuels [19].

    Fermentation of microalgae is a two-stage process. In the first stage, ethanol is produced through the fermentation of microalgae in a dark, anaerobic environment. The ethanol generated in this way can then be processed and used as fuel. In order to cultivate microalgae, the CO_2 formed during the fermentation process was recycled into algal culture ponds. The second stage required using the remaining algal biomass slurry from fermentation, which could be used in anaerobic digestion as long as the pH was kept around 6 and 9. Methane was produced as a result of this process, which can then be used to generate energy. Although there are a number of advantages to producing bioethanol from algae, the fermentation process requires less energy than biodiesel production and is much simpler. Moreover, CO2 produced as a by-product of the fermentation process can be recycled as a source of carbon for the growth of microalgae, thereby lowering greenhouse gas emissions [20].

3. **Biomethane:** The simultaneous production of biogas and bioethanol is facilitated by the fermentation of bioethanol. Consequently, methane fermentation technology is applied to

algae to produce useful byproducts like biogas. Methane and CO2 comprise the majority of the biogas created by anaerobic microorganisms during anaerobic digestion, which produces biogas from anaerobic microorganisms. Anaerobic digestion methane can be generated into power and used as a fuel gas. Anaerobic digestion residual biomass can possibly be further processed to create fertilizers. This would encourage sustainable farming practices by delivering greater efficiency and lowering the cost of algae production in addition to being renewable and sustainable. Microalgae exhibit significant process stability and high conversion efficiency for anaerobic digestion because they lack lignin and have reduced cellulose levels [21].

Table: 2 Methane Yield from the Different Algal Strains.

Biomass	**Methane yield (m^3kg^{-1})**
Laminaria sp.	0.26–0.28
Gracilaria sp.	0.28–0.4
Macrocystis	0.39–0.41
L. digitata	0.5
Ulva sp.	0.2

Biogas production from this anaerobic digestion process is primarily influenced by its organic loadings, pH, temperatures, and retention time in reactors. Methane yield from various microalgae (as feedstock) depends on these factors. The main factors that contribute to a high methane yield are a long solid retention time and a high organic loading rate. Anaerobic digestion can also operate in mesophilic (35 °C) or thermophilic (55 °C) conditions. *Ulva* sp. was anaerobically digested using a constant temperature, mesophilic process, and the methane yield was 180 ml/g (volatile solid based). However, the mesophilic environment promoted a slower rate of organic component breakdown during the anaerobic digestion process. However, it was claimed that the cost of producing methane from microalgae was higher than that of other biomass, such as wood and grass. The combined integrated processes.

4. **Bio-hydrogen:** A significant fuel with multiple uses, such as the liquefaction of coal and the upgrading of heavy oils, is biohydrogen (e.g., bitumen). A number of biological processes, such as the steam reformation of bio-oils, the dark and photo fermentation of organic materials, and the photolysis of water catalyzed by unique microalgal species are all capable of producing hydrogen [23].

V. MICROALGAE CULTIVATION SYSTEMS FOR BIOFUEL PRODUCTION

There are various methods for creating microalgae biomass, and they all have significant structural, functional, and economic differences. The two major types of microalgae mass cultivation systems are outdoor and indoor systems; due to the usage of sunlight, outdoor systems are more cost-effective. The different cultivation systems yield various amounts of biomass per unit of area: open systems produce 10 to 25 g m-2 d-1 of biomass, closed systems 35 to 40 g m-2 d-1, and thin-film systems 80 to 100 g m-2 d-1[12].

1. **Open pond cultivation systems:** Over the past few years, there has been a significant amount of research conducted on the cultivation of algae in open ponds. Open ponds can be divided into two categories: naturally occurring waterways (lakes, lagoons, and ponds) and man-made ponds or containers. Systems like shallow huge ponds, tanks, circular ponds, and raceway ponds are the most widely utilized ones. Open ponds have the key benefit of being simpler to construct and maintain than most closed systems. However, open ponds have number of disadvantages (Table 3), including a lack of choices for monitoring and controlling variables including pH, temperature, mixing, and light availability. Due to its extremely short residence time, sparged CO_2 has poor solubility and experiences significant losses. Seasonal fluctuations also impair the repeatability of the findings. Despite all of these drawbacks, open systems may still be preferable than closed ones [25, 12]. The low cost and ease of maintenance of open cultivation systems is a major advantage. Up scaling is simple because this also applies to the installation of raceway ponds. They are therefore used more frequently in large-scale approaches [12]. Much effort is now given to the development of suitable closed systems, such as flat-plate, to address the issues with open ponds.

A **B**

1. *H. pluvialis* production in raceway paddle wheel mixed ponds (Parry *Nutraceuticals,* India).

B. *Chlorella* production in circular ponds (Weissman and Goebel, 1987).

Figure 2: Open Pond Cultivation Systems.

2. **Closed systems cultivation systems using photobioreactors:** Among the closed systems several types of PBRs exist (Fig.4).Algal culture systems can be illuminated by artificial light, solar light or by both. Naturally illuminated algal culture systems with large illumination surface areas include open ponds, flat-plate, horizontal/serpentine tubular airlift, and inclined tubular photobioreactors. Some of these photobioreactors include bubble column, airlift column, stirred-tank, helical tubular, conical, torus, and seaweed type photobioreactors. Photobioreactors require much more energy for building and during processing compared to the increase in productivity. Assuming that the photosynthesis potential of a pond is equivalent to a 5-cm depth photobioreactor, growth-rates (expressed inday^{-1})for photobioreactor lead to productivity rate between 20 and 30 g $\cdot m^{-2} \cdot$ day^{-1}, which are in the range of usual performances of open raceways. For both culture methods and based on the culture conditions, nutrients and CO2 supply needed to generate 1 kilograms of algae are calculated [25].

Figure 3: Photobioreactors for Microalgae Cultivation

VI. MICROALGAE HARVESTING METHODS

One of the key challenges to be solved before microalgae may be used as a fuel source is efficient harvesting. In general, there are four ways to collect microalgae: centrifugation, flocculation, filtration, and sedimentation [7].

1. **Sedimentation:** Microalgae, which naturally have high sedimentation rates, are suited for the straightforward sedimentation system. This is done in thickeners or clarifiers, which are typical procedures in water treatment facilities. A flocculation agent can aid if the strain has problematic sedimentation characteristics. Economic factors dominate when determining the best flocculation and harvesting combination [7].

2. **Flocculation:** For microalgae, which naturally have high sedimentation rates, the straightforward sedimentation method is appropriate. These functions are carried out in thickeners or clarifiers, which are common procedures in water treatment plants. A flocculation agent can be useful if the strain has poor sedimentation qualities. The best combination of flocculation and harvesting should be made primarily for financial reasons [7].

3. **Centrifugation:** A centrifuge is used in the centrifugation process to separate mixtures using centrifugal force. The most popular harvesting technique currently being employed in the production of microalgae is centrifugation [9]. A process of accelerated sedimentation is centrifugation. In systems known as hydro cyclones, it can run with fixed walls or rotating walls (the latter being the more typical form). Although initial investment and ongoing expenses are frequently considerable, efficiency in comparison to natural sedimentation is substantially higher [7, 9].

4. **Filtration:** In industry, filtering is a relatively prevalent procedure. Simple screening or microstrainers, dewatering, or even sophisticated vacuum or pressure filtration systems can all be used in this process. The cost of the system increases with system complexity. Plugging is filtration's biggest drawback. Vibrating screens or tangential filtrations are employed to address this. To prevent blockage, deep bed filtration is also frequently employed, however it involves combining the solution with sand. Belts for pressing and

screening are used in some combination systems, which have the benefit of continuous operation [9].

VII. CONCLUSION

The idea of using microalgae as a source of biofuel is not new, but in recent decades it is been taken seriously because of the rise in price of petroleum products and more significantly, the emerging concern about global warming that is associated with burning of fossil fuels. Microalgae have the potential to be a significant source of bioenergy and functional foods. Through various conversion processes, microalgae can be used to produce many kinds of biofuels, such as biohydrogen, biodiesel, and bio-ethanol. Moreover, the large number of existing species of microalgae constitutes a unique reservoir of biodiversity, which supports potential commercial exploitation of many novel products. Microalgal farming can be coupled with flue gas CO_2 mitigation and wastewater treatment. Given that marine microalgal species are used, it can also be done using seawater as the medium, giving populated and dry coastal areas a viable alternative for producing ethanol.

More advancement is as yet required for the improvement of innovations which lessen costs while expanding the yields. Mechanical turns of events, remembering propels for photobioreactor plan, microalgal biomass collecting, drying, and other downstream handling advancements are significant regions that might prompt upgraded cost-adequacy and subsequently, compelling business execution of the biofuel from microalgae methodology. Subsequently, microalgal biofuels are a feasible energy asset, the test will be the financial aspects of creation. A couple of organizations are now in progress to accomplish business scale creation of microalgal biofuels.

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