A CRITICAL REVIEW: MICROALGAE AS A RENEWABLE SOURCE FOR BIOFUEL PRODUCTION

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Abstract

Biofuel production from renewable sources is widely considered to be one of the most sustainable alternatives to petroleum based fuels and a viable means for environmental and economic sustainability. Algae is a very promising source of biomass in this context as it sequester a significant quantity of carbon from atmosphere and industrial gases and is also very efficient in utilizing the nutrients from industrial effluents and municipal wastewater. Algae are among the fastest-growing plants in the world, and about 50% of dry algae weight is oil. Microalgae produce about ten times more oil than oleaginous plants and it can be grown in systems like open ponds and photo bioreactors. Algae-based biofuel definitely has the potential to revolutionize the energy industry and will play a leading role in fight against greenhouse gas emissions, and climate change. So biofuel production from algae could be one of the surprising competitors on alternative energy market in not so long future, especially if oil's price continues to grow. In this review, present an overview about microalgae use for biodiesel production, including their cultivation, harvesting, and processing.

Key Words:
Biofuel, Renewable sources, Biodiesel, Algae, Photo bioreactors.

1. Introduction

The increases of world energy demand and greenhouse gas emissions have been concerning all sectors since last decades. Fossil fuels are starting to reveal their limitations as an energy source; both literally, as resources are depleted, and through their contributions to climate change. The result of this revelation is that the search for clean renewable fuels has been gathering momentum, in a bid to continue to meet our huge population's energy demands in the future. One of the most attractive responses regarding the alternative sources is biofuels. Biofuels are quite adequate to provide an alternative to fossil fuels and can also lowering emissions of greenhouse gases (GHG), mainly carbon dioxide (CO_2) and methane (CH_4), and meeting rural development goal because, they are more ecologically acceptable energy source compared to fossil fuels [1].

Biofuels are referred to solid, liquid or gaseous fuels derived from organic matter. They are generally divided into primary and secondary biofuels (Fig. 1). While primary biofuels such as fuelwood are used in an unprocessed form primarily for heating, cooking or electricity production, secondary biofuels such as bioethanol and biodiesel are produced by processing biomass and are able to be used in vehicles and various industrial processes. The secondary biofuels can be categorized into three generations: first, second and third generation biofuels on the basis of different parameters, such as the type of processing technology, type of feedstock or their level of development [2].

The first generation production systems have considerable economic and environmental limitations. The most common concern related to the current first generation biofuels is that as production capacities increase, so does their competition with agriculture for arable land used for food production [3].

The advent of second generation biofuels is intended to produce fuels from lignocellulosic biomass, the woody part of plants that do not compete with food production. Sources include agricultural residues, forest harvesting residues or wood processing waste such as leaves, straw or wood chips as well as the non-edible components of corn or sugarcane [4].

Therefore, third generation biofuels derived from microalgae are considered to be a viable alternative energy resource that is devoid of the major drawbacks associated with first and second generation biofuels [2]. Microalgae are able to produce 15–300 times more oil for biodiesel production than traditional crops on an area basis. This article focuses on microalgae as a potential source of biodiesel.

2. Algae biomass

The species of algae suitable for lipids production are the microalgae (phytoplankton or microphytes). The macroalgae or seaweed, on the other hand have many commercial values but not for lipid production. Other commercial values of algae include the making of food ingredients such as omega3 fatty acids, fertilizer, chemical feedstock, pharmaceuticals and bioplastics. A microalga is classified as diatoms (bacillariophyceae), green algae (chlorophyceae), goldenbrown (chrysophyceae) and blue-green algae (cyanophyceae). More than 200,000 microalgae species exist in the world and just a certain number can be considered for biodiesel production [5]. According to the Solar Energy Research Institute (SERI) rapport, the most promising species for fuel production are *Botryococcus braunii* due to its important quantities of hydrocarbons, *Nannochloropsis salina* with its high quantities of ester fuel production and *Dunaliella salina* due to its high quantities of fatty acids (Feinberg, 1984). The National Renewable Energy Laboratory (NREL) in United States affirms that *Spirulina*, *Dunaliella*, *Scenedesmus*, and *Chlorella* are the most popular strains that have been produced at commercial or large scale (>0.1 ha) [5].

3. Algae Cultivation System

The two main methods of growing algae are the open pond and closed system which includes Photo bioreactor. Algae can be cultured in open-ponds such as raceway-type ponds and lakes and Photo bioreactors.

3.1 Open Pond Cultivation

Cultivation of algae in open ponds has been extensively studied. Open ponds can be categorized into natural waters (lakes, lagoons, ponds) and artificial ponds or containers. The most commonly used systems include shallow big ponds, tanks, circular ponds and raceway ponds. Nutrients can be provided through runoff water from nearby land areas or by channelling the water from sewage or from water treatment plants. Some source of waste carbon dioxide could be efficiently bubbled into the ponds and captured by the algae for its faster growth [15]. Open pond systems are cheaper to construct as the minimum requirement is just a trench or pond. Open ponds have the largest production capacities relative to other systems of comparable cost. The biggest advantage of these open ponds is their simplicity, resulting in low production costs and low operating costs.

3.2 Closed Systems

A variation on the basic "open-pond" system is to close it off, to cover a pond or pool with a greenhouse. While this usually results in a smaller system, it does take care of many of the problems associated with an open pond system Closed systems are much more expensive than ponds. However, the closed systems require much less light and agricultural land to grow the algae. High oil species of microalgae cultured in growth optimized conditions of Photo bioreactors have the potential to yield 19,000–57,000 liters of microalgal oil per acre per year [6]. It allows more species to be grown; it allows the species that are being grown to stay dominant; and it extends the growing season and in cold region locations if the pond is heated cultivation can be carried out all year round.

3.3 Photo bioreactor

The Photo bioreactor (PBR) is a translucent bioreactor container incorporating a light source in which algae are grown. As opposed to an open pond system, the Photo bioreactor is usually a closed system. Since the system is usually closed all the nutrients must be provided by the cultivator. Farming can be in batch involving restocking the reactor after each harvest or continuous operation that requires precise control of all elements to prevent immediate collapse. For continuous operation correct amount of sterilised water, nutrients, air and carbon dioxide must be provided. As algae grow, excess culture overflows and is harvested [7]. The Photo bioreactor may be made in the form of a tank, polyethylene sleeves or even as a bag.

4. Algae Harvesting

After they are grown and matured, techniques such as flocculation, micro straining, filtering, sedimentation and centrifugation are usually employed in microalgae harvesting. Depending on microalgae sizes and the quality of the desired products, these techniques can be combined to have higher efficiencies.

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Chemical flocculation and bioflocculation are employed to create a dense mass of microalgae easier to remove. In bioflocculation, microalgaes start to attach themselves forming flocks as a certain conditions in the system are appearing. Also, it can be promoted by the use of non-algal microbial cultures. In chemical flocculation, chemicals like ferric chloride, aluminum sulfate, ferric sulfate, polymeric flocculants, chitosan are used to promote the formation of the flocs. The main disadvantage of chemical flocculation is the costs for acquiring chemicals [5, 8, 9]. Both flocculation techniques are usually followed by sedimentation, filtration or centrifugation. In sedimentation, suspended microalgae are deposited by the action of the gravity, creating a certain concentration of mass easier to remove [10].

Centrifugation is a common method used to recover microalgae in large volumes. Its efficiency depends on the type of microalgae, the settling deep and the residence time of the cell slurry. Usually a paste of 20% algae can be obtained. Compared to the other techniques, it has the highest energy consumption [8].

Filtration can be performed under pressure or vacuum if algae sizes do not approach bacteria sizes. Microstrainers (typically 25 to 50 µm openings) can be used for species like *spirulina* or *anabaena*, which are filamentous bacteria easier to remove. If flocculation is performed before, higher filtration efficiency will be reached [5, 8].

5. Oil Extraction

Harvested algae is dried (from 10 kg of wait algae we get 1 kg of dry algae). Three techniques are commonly found for oil extraction: mechanical pressing, solvents and supercritical fluid extraction. Using mechanical pressing, algal oil can be extracted in a range from 70 to 75%. Chemicals like n-hexane, benzene, ethanol, chloroform and diethyl ether can be used as solvents to extract the fatty acids. The most common solvent used is n-hexane, which first is added to the algae paste and then is distilled to obtain the algal oil [11]. If n-hexane is added after mechanical pressing, 95% of algal oil can be obtained [12]. Another example is the extraction of hydrocarbons from *Botryococcus sp*. using ethyl acetate.

In supercritical fluid extraction, CO_2 is first heated and compressed until it reaches the liquid-gas state. Then, it is added to the harvested algae, acting like a solvent. This technique has been used to obtain hydrocarbons from *Botryococcus braunii* and lipids from *Skeletonema* [13].

6. Biodiesel from Algae Oil

After the extraction processes, the resulting microalgal oil can be converted into biodiesel through a process called transesterification. The transesterification reaction consists of transforming triglycerides into fatty acid alkyl esters, in the presence of an alcohol, such as methanol or ethanol, and a catalyst, such as an alkali or acid, with glycerol as a by-product [14].

Biodiesel is defined as the mono-alkyl esters of vegetable oils or animal fats. Biodiesel is produced by transesterifying the parent oil or fat to achieve a viscosity close to that of petrodiesel. The chemical conversion of the oil to its corresponding fatty ester (biodiesel) is called transesterification. Biodiesel is a biofuel commonly consisting of methyl esters that are derived from organic oils, plant or animal, through the process of transesterification. The biodiesel transesterification reaction is very simple [15].

$$\text{Triglyceride} + 3\ \text{Methanol} \xleftrightarrow{\text{Catalyst}} \text{Glycerine} + 3\ \text{Methyl Esters (Biodiesel)}$$

An excess of methanol is used to force the reaction to favour the right side of the above equation. The excess methanol is later recovered and reused. The energy density of biodiesel is comparable to petroleum diesel. The higher heating value of petroleum diesel is 42.7 MJ/kg. Values for biodiesel vary depending on the source of biomass (Table 2). Typically, biodiesel derived from seed oils, such as rapeseed or soybean produces, 39.6 MJ/kg, while biomass derived from algae yields 39.5 MJ/kg [15].

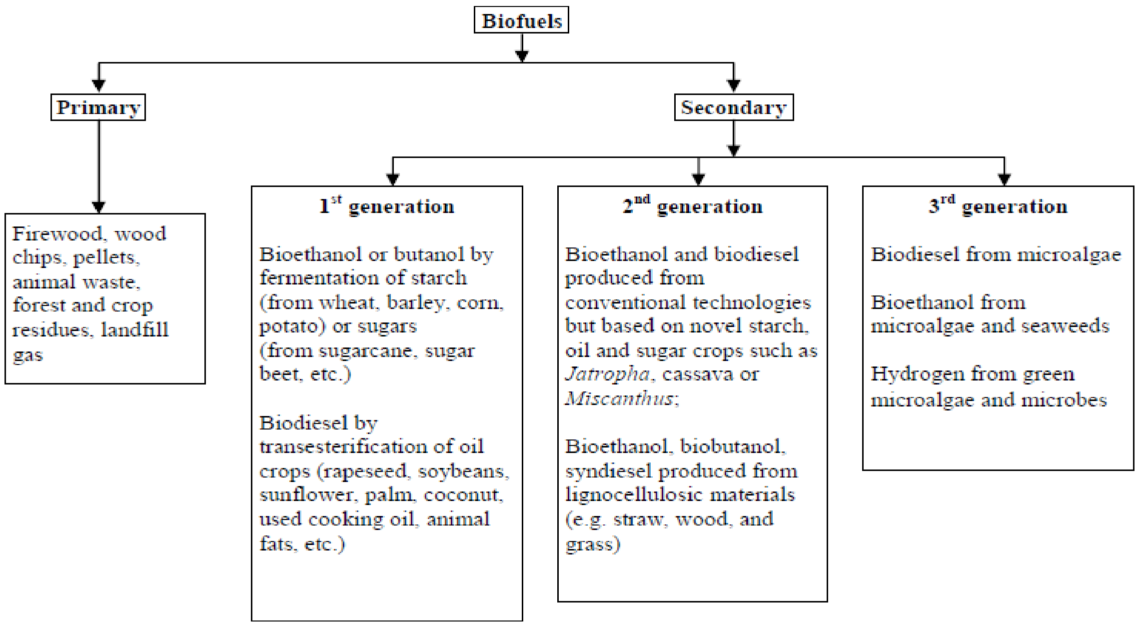

Figure 1: Classification of biofuels [2]

Table 1: Microalgae species considered for oil production

Species	Stress	% Lipids (dry weight)
Cyclotella Cryptica	Nitrogen deficiency[16]	18
Dunaliella salina	Osmotic stress and nitrogen deficiency[16,7]	18.5
	Nitrogen deficiency[16]	14.4
	Non environmental stress[18]	6
Nitzschia sp.	Non environmental stress[9]	45-47
Phaeodactylum tricornutum	Non environmental stress[8,9,19]	20-30
Botryococcus Braunii	Nitrogen deficiency[16,20]	54.2
	Non environmental stress[9]	25-75
Chlamydomonas sp.	Non environmental stress[16]	23
Chlorella sp.	Non environmental stress[16]	20.7
	Non environmental stress[9]	28-32
Chlorella vulgaris	Nitrogen deficiency[21,22]	18
	Non environmental stress[18]	14-22

Nannochloris sp.	Non environmental stress[9]	20-35
Nannochloropsis sp.	Nitrogen deficiency[22]	33.3-37.8
	Non environmental stress[9]	31-68
Nannochloropsis salina	Nitrogen deficiency[16]	54
	Non environmental stress[16]	28.6
Spirulina platensis	Non environmental stress[16]	16.6
Tetraselmis sueica	Nitrogen deficiency[22]	20-30
	Non environmental stress[9]	15-23
Isochrysis sp.	Nitrogen deficiency[16]	26-45
	Non environmental stress[9]	25-33

Table 2: Generalized Set of Conditions for Culturing Microalgae

Parameters	Range	Optimum
Temperature (□C)	16 – 27	18 - 24
Salinity (g.l^{-1})	12 - 40	20 – 24
Light intensity (lux)	1,000 – 10,000 (depends on volume and density)	2,500 – 5,000
Photoperiod (light : dark, hours)	---	16:8 (minimum) 24:0 (maximum)
p^{H}	7 - 9	8.2 – 8.7

Source: http://www.fao.org/docrep/003/w3732e/w3732e06.htm

Table 3: Comparison of Calorific Value of Diesel with Different Biodiesel [15]

Oil	Lower Heating Value
Diesel	42.7
Jatropha	39.7
Sunflower Oil	39.6
Soya bean	39.6
Karnja	38.8
Algae	39.5

7. Conclusion

This review underlines the existing technical viability for the development of biofuels from microalgae as a renewable energy resource. Microalgae have the potential for the production of profitable biodiesel that can eventually replace petroleum based fuel. Algal-biodiesel production, however, is still too expensive to be commercialized as no algal strains are available possessing all the advantages for achieving high yields of oil via the economical open pond culturing system. Current studies are still limited to the selection of ideal microalgal species, optimization of mass cultivation, biomass harvest and oil extraction processes, which contribute to high costs of biodiesel production from microalgae. Although algal biofuels still require a great deal of Research and development, the prospect of a highly productive process, able to use land and water resources not suitable for conventional crops, justifies a continuing investment into this technology. Future cost-saving efforts for algal biofuel production should focus on the production technology of oil-rich algae via enhancing algal biology and culture system engineering coupled with advanced genetic engineering strategies and utilization of waste.

8. References

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