IOSR Journal of Biotechnology and Biochemistry (IOSR-JBB)
ISSN: 2455-264X, Volume 9, Issue 2 (Mar. – Apr. 2023), PP 07-13
www.iosrjournals.org

Microalgae as potential Sustainable Source for Biofuels: A Review

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Abstract
The term biofuels *usually apply to liquid fuels and blending components produced from biomass materials called* feedstocks*. The alarming rate of consumption of fuels is a major economic issue in the context of increasing energy demand all over the world. It has become increasingly obvious that continued reliance on fossil fuel energy resources is unsustainable, owing to both depleting world reserves and the greenhouse gas emissions associated with their use. Therefore, there are vigorous research initiatives aimed at developing alternative renewable and potentially biofuels as alternative energy resources. In recent years, bioenergy has drawn attention as a sustainable energy source because of a combination of growing energy needs in developed countries Microalgae-based bio-fuels are viewed as an alternative source and hence gaining attention as renewable energy source. Microalgae that grow in marine and freshwater environment have emerged as a potential feedstock for biofuel production as many strains accumulate higher amount of lipid with faster biomass growth and higher photosynthetic yield than their land part counter part*

Keywords: Microalgae; Biofuels , Bioenergy, Biodiesel

Date of Submission: 02-03-2023 Date of Acceptance: 14-03-2023

I. Introduction:

Biofuels are fuels produced directly or indirectly from organic material – biomass – including plant materials and animal waste. The alarming rate of exhausting biofuels andconcerned global climate change have challenged the researchers for finding an alternative source of sustainable bioenergy.Microalgae are abundant in the environment in seawater, freshwater, and wastewateris a promising feedstock to produce biofuel since they are capable of mitigating CO_2 emission and accumulating lipids for their high biomass productivity. Many microalgal species contain high content of lipids and require a simple cultivation process than other plant crops for the production of biofuels. Microalgae can produce several biofuels such as biodiesel, biomethanol, biohydrogen, bioethanol, etc. [Shobana et. al 2021]. The production of biofuels from microalgae is a potential process to encounter future energy demand since microalgae are cultivated year by year. Renewable energy, often called clean energy, is derived from natural sources with continuity e.g. sunlight or wind continue to shine and blow even if their presence depends on time and weather. Non-renewable some time labelled as "dirty" energy includes fossil fuels such as oil, gas and coal. Non-renewable energy sources exist only in limited quantities and take a long time to regenerate (NRDC, 2021). Recently, one of the preferred renewable energy sources is biofuels of biological origin that depend on agricultural production. The fact that biofuel production is at the expense of greater use of earth and ecosystem services (Susan et al., 2010) has led to some debates

Biofuel is renewable and sustainable alternative energy, which is regarded not as substitute but as supplementary to fossil fuels. Sustainable production of renewable energy is being vehemently debated globally and documented that 1st Generation biofuels, primarily produced from food crops and mostly oil seeds have limitations in their ability to achieve targets for biofuel production, climate change mitigation and economic growth. The 1stGeneration biofuels leads to 2ndgeneration biofuels but criticizershave raised question how2nd generation biofuels will solve all the problems the 1stgeneration biofuels possess [Mooreet.al 2008]. In order to increase the efficiency of 1stGeneration biofuels, the theories of industrial collaboration can be applied to integrate production systems and other industries to improve energy efficiency and environmental performance[Chertow 2000 , 2007]. By integrating biofuel production systems, the by-products of biofuels can be used in consequent processes. By making use of by-products, excess heat, etc. the energy efficiency can be improved and allow for more benefits including economic and environmental performance[Chertow 2005]. In addition to this, microalgae can be cultured without requirement of agricultural land or ecological landscapes and offer opportunities for mitigating global climate change including waste water treatment and greenhouse gases sequestrations.

The main reasons why is the microalgae biomass preferred for the production of biofuels are : (i) Its potential to achieve high biomass, (ii) Its ability to produce high fats, (iii) The ease of growth on soil unsuitable for agriculture, (iv) Capture carbon dioxide in large quantities, and (v) It's ability to grow on wastewater. The chemical composition of microalgae varies from one species to another, and the conditions for microalgae cultivation also affect their chemical composition. In general, microalgae cells consist of 20–40% fat, 30–50% proteins, 0–20% carbohydrates, 0–5% nucleic acids [Chang2018].

Bioethanol is an alcohol-based adjunct for gasoline that reduces the emissions in internal combustion engines. In an industrial-scale production conducted by Algenol, the production cost of bioethanol was estimated to be almost $0.79/L [150]. Combining algae cultivation with wastewater treatment has been recognized as a promising pathway for cost-effective and sustainable biofuel production**.** Biotechnological interventions can make major advances in strain improvement for the commercial scale production of bio fuels .

Table 1 Typical microalgal species for biofuels production

Microalgal species	Targeted biofuels	Microalgal growth and/or biofuels	Cultivation/reaction conditions	References
Microalgal consortium	Biochar	45.0 ± 5.9% solid biochar	Hydrothermal liquefaction	Roberts et al. (2013)
Nannochloropsis salina *Chlorococum* sp. *Spirulina* sp.	Biogas Bioethanol Biomethanol	0.70 L biogas/g 38 wt%	Photobioreactor, large scale, 35 °C Fermentation Gasification/anaerobic fermenta-	Quinn et al. (2014) Singh and Gu (2010) Rodionova et al. (2017)
C. protothecoides *S. obliques*	Biodiesel Biohydrogen	55% of lipid 300 μmol H_2/(mg Chl*h)	Heterotrophy; nitrogen limitation Indirect proces	Xu et al. (2006) Appel and Schulz (1998)

All microalgae species are not equally attractive or feasible for biodiesel production. Chlorophyceae is the most promising microalgae species due to its relatively high growth rate, high lipid content as well as its relatively easy culti-vation. Bacillariophyceae, Eustigmatophyte, Chrysophyceae, Haptophyceae and Cyanophyceas are other microalgae classifications that are important for biofuel production [Sajjadi et. al 2018]. Lipid contents of microalgae vary significantly for different microalgae strains. Thought implementation of biochemical strategies improve the lipid content but simultaneously decreases the growth rate in microalgae species [Aziz et. al 2019]. *Scenedesmus obtusus* microalgae strains with a higher lipid content have a low growth rate when cultivated under biochemical stress [Aouida et. al. 2017]. The microalgal biofuel production is a well-established practice in small-scale systems, its industrial-scale production is not economically viable this is attributed due to low lipid content and slow growth rate of microalgae strains [Chen et al., 2017]. Scenedesmus dimorphus accumulated 53.7 w/w carbohydrate contents which on hydrolysis with sulfuric acids produced 80% fermentable sugars, indicating its feasibility for bioethanol production 11.7 g/l final ethanol yield was reported from Chlorella vulgaris[Chng et al. 2017] while recently reported 93% of ethanol yield from fermentation of Scenedesmus sp. derived sugars[Sivaramakrishnan et al. 2018]. Sustainability is key to natural resource management or exploitation and it involves operational, environmental and socio-economic considerations; all of which are interdependent.

Genetic engineering offers a wide range of options to enhance the lack of industrially competent strains by several approaches, such as transcription and targeted expression of key proteins involved in microalgal lipogenesis[Bharathiraja et al., 2015, Tan et. al 2018]. The available research works on biofuels shows that most of the research to date mainly focuses on 2nd &3rd generation biofuel.

Temperature: Temperature is another important factor in the growth of microalgae and directly effects the biochemical processes including photosynthesis, in the algal cell factory. Each species has its own optimal growth temperature. Increasing temperature to the optimum range exponentially increases algal growth, but an increase or decrease in the temperature beyond the optimal point retards or even stops algae growth and activity [Bechet *et. al*2017]. The optimum temperature range for most algal species is 20–30 °C [Singh *et al* 2015]

This review outlines the state-of-the-art in biofuel production from microalgae and also demonstrate the integrated process and its interdependencies from algal biomass production, biofuel and co-products recovery processes, and algae-based CO_2 mitigation and wastewater treatment. It identifies the knowledge gaps within each area which can be targeted for focused research and innovation aimed at sustainable development of algae-based biofuel technologies. As an effort to develop affordable and sustainable energy sources, algae-derived biofuels have attracted considerable interest.

Light : Light intensity is one of the major restrictive factors in microalgae cultivation. The duration of Lighttime and intensity directly affect photosynthesis of microalgae and has impact on the biochemical composition of microalgae and biomass yield [Krzemińska et al 2014]. In modelling of the outdoor or indoor algal culture system, growth rate and biomass productivity are predicted as a function of light [Huesemann et al 2013]. Light intensities vary inside the culture and reduce in culture depth this should be taking in consideration for modeling of the bioreactor or open pond system. Algae species vary in terms of their light requirements for maximum growth and biomass accumulation. At very low and very high light intensities, microalgae cannot grow efficiently [Mata et al 2010 ,Ye *et. al*2012].

Cultivation and harvesting of microalgae for biofuel production: Microalgae are photosynthetic microorganisms that need light and CO_2 as energy and carbon sources, respectively. Microalgae grow under different culture conditions of autotrophic, mixotrophic or heterotrophic [Shokravi et. al 2019 ,Kamalanathan et . al 2017]. Autotrophic microalgae cultivation is a sunlight-driven system that converts CO_2 into lipids and other valuablecomponents. The cultivation of algae requires few relatively simple conditions: light, water, carbon source, micro- and macronutrients and optimum temperature. Over the years, different culture systems have been developed keeping in mind the optimum conditions for microalgal growth, although it is a challenging task. The cultivation system for the growth of algae is an important requirement to aid in enhanced production of biofuels which includes open air ponds and closed controlled systems. The development of profitable algae-based fuel generation technology is yet in transition state wherein the final configuration is still to be explored and demonstrated at the industrial scale. The cultivation of microalgae is a significant factor leading to enhanced biofuel production.

All microalgae species cannot be modified using genetic engineering due to several constraints, such as the availability of the genomic data, the complexity of transgenesis and the difficulty of maintaining a balance between metabolic and energy storage pathways. Cyanobacteria are of particular interest in the production of a variety of biofuels, such as ethanol, biogas, hydrogen and biodiesel, due to their simple genetic structure, low nutrient demand and broad environmental tolerance. The choice of cultivation system has to be emphasized because the phytoremediation efficiency and the yield of biofuelslargely depend on it. Broadly speaking the cultivation system meant for microalgae are either open systems or closed systems. Moreover, hybrid systems which are combination of open and closed system can be used to achieve high biomass with high nutrient removal [Shaikh Abdur et. al 2017] .

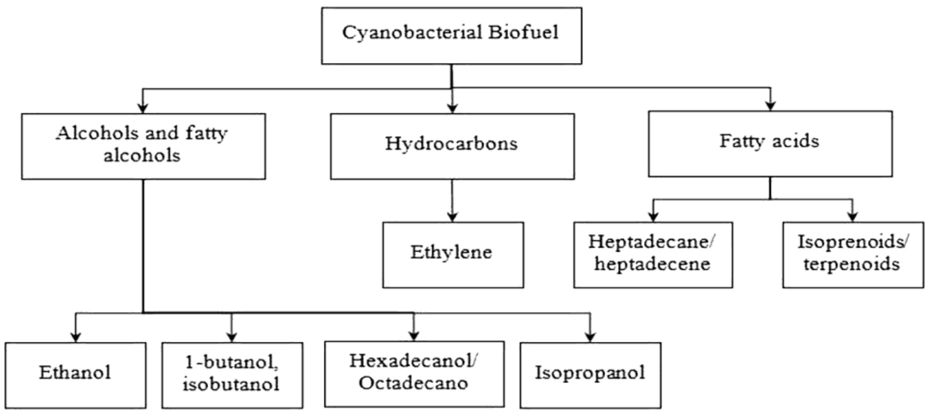

Figure 1 The chemical type and the biofuels produced from cyanobacteria.

Open microalgal systems: The open microalgal pond systems are commonly used for cultivation of microalgae as they have good opportunity to utilize the atmospheric carbon dioxide readily available in the atmosphere. There are several configurations of microalgae cultivation systems for biomass production and enhanced phycoremediation of industrial, domestic and agricultural wastewater. The open ponds can be natural or artificial in nature which include natural lagoons, circular ponds tanks. Cultivation of Chlorella sp. Is traditionally carried out in circular ponds made up of concreate. The raceway ponds comprise race track or oval channel made up of concrete, and they are meant to circulate nutrients and carbon dioxide regularly to algal cultures [Brennan et. al 2010]

Closed Algal System : The closed systems (photobioreactors (PBRs)) have well-controlled growth conditions. Generally, these reactors are designed to increase the light accessibility. They also allow perfect mixing to permit the light to be within an optimum value for cell growth and to improve gas exchange. Since photobioreactors solve many problems of the open cultivation, researchers have focused on designing photobioreactors for large microalgal biomass production [Brennan et. al 2010]. There is a wide variation in the design of the photobioreactor depending upon their geometry and construction. Photobioreactors can be built as bags tanks, and towers. Photobioreactors can be plates or tubular and made up of plastic or glass. Tubular photobioreactors seem to be the most suitable. Bubble columns and airlift photobioreactors can also be considered since they produce a relatively high concentration of microalgal biomass product [Ugwu et. al 2008]. An auxiliary tank is used to separate the oxygen produced from the photosynthesis. This is important considering that excessive oxygen can negatively affect the microalgae growth [Rawatet .al 2013]

Potential role of biofuels from microalgae: The microalgae cover all unicellular and simple multi-cellular microorganisms, including both prokaryotic microalgae(cyanobacteria) and eukaryotic microalgae, e.g. green algae, red algae. The advantages of using microalgae-derived biofuels are :(i) Consume less fresh water for their growth than the terrestrial crops [Dismukes et. al 2008], (ii) microalgae require less space as such minimising the associated environmental impacts[Searchinger et al 2008], (iii) Better Yield as the growth of microalgae in independent of seasons [Schenk et. al 2008].

Energy-saving approaches for harvesting and dewatering of microalgae : Harvesting and dewatering of microalgal biomass are regarded as a major holdup to microalgae-based biofuels due to their energy-intensive feature, and the pro-cesses may account for 20–30% of the total production costs (Mata et al. 2010; Uduman et al. 2010). Thus, finding energy-saving approaches is very important to offset the production cost of microalgae-based biofuels. In general, microalgae can be harvested by two steps of bulk harvesting and followed by thickening (Chen et al. 2011).

Table 2 Approaches for harvesting and dewatering of microalgae

Types	Approaches	Examples	References
Primary harvesting	Flotation	Electro-/dissolved air/suspended air flotation	Pragya et al. (2013) and Chen et al. (2011
	Flocculation	Chemical/biochemical/electro-flocculation	Mubarak et al. (2019)
	Centrifugation	Decanter; centrifuge; hydrocyclones	Knuckey et al (2016)
	Sedimentation	Gravity/centrifugal sedimentation	Uduman et al. (2010)
	Drying	Steam/spray/drum/freeze/oven/sun drying	Shelef et al. (1984
	Others	Screening; ion exchange; ultrasonic separation; electrophoresis techniques; magnetic separation	Cerff et al. (2012), Cheng et al. (2011), Hwang et al. (2013), Laamanen et al. (2016), Singh and Patidar (2018) and Uduman et al. (2010)
Secondary dewatering	Filtration	Forward osmosis; Belt/micro-/ultra-/rotary/ pressure/cross-flow/vacuum drum filtration	Buckwalter et al. (2013)

As shown in Table 2, technologies of primary harvesting generally consist of coagulation and flocculation, flotation, filtration, screening, ion exchange, gravity sedimentation, precipitation, centrifugation, and other tech-niques[Chengetal.2011;Laamanen et al. 2016; Singh and Patidar 2018; Uduman et al. 2010; Buckwalter et al. 2013]. The secondary dewatering methods include filtration, drying, and others such as microwave and fluid bed [Buckwalter et al. 2013; Laamanen et al. 2016; Shelef et al. 1984]. Advanced approaches such as a combined method of Pulsed Electric Field (PEF) and hydrothermal liquefaction (HTL) has been proposed as a promising and suitable pre-treatment for wet extraction of microalgal residual biomass.

Enhancingtheconversionofmicroalgaetobiofuels : Microalgal biomass can be converted to renewable fuels (e.g.,power,heat,andfuels)andenergysourcethroughvarious technologies including : transesterification (Skorup-skaiteetal.2016), thermochemicalcombustion, pyrolysis,gasification,thermochemicalliquefaction, and biochemical/biological conversion in terms of anaerobic digestion, fermentation, and photobiological hydrogen production (Asada et al. 2012; Sharma and Singh 2017). Biomass for power (electricity) and heat can be achieved by combustion direct-firing in a boiler, where high-pressure steam is produced and introduced into a steam turbine, to make the turbine and electric generator rotate and thereforethe electricity isproduced

(ClimateTech Wiki2006). Fermentation aims to convert the cellulose of microalgalbiomassintobioethanol,withconsecutivestages of dewatering, milling, liquefaction, saccharification, fermentation, distillation and eventually the fuel products of bioethanol is obtained (Lee and Lee 2016).

Anaerobic digestion is a process of obtaining methane fromthedelipidizedalgalbiomasswithcarbonandnitrogen content via the consecutive stages of hydrolysis, fermentation,acetogenesis,andmethanogenesis(LeeandLee2016; Sirajunnisa and Surendhiran2016). This method converts organicbiomass into biogas (Appx. 60% CH_4&40% CO_2), following thismanydevelopingcountriessuchasChina,India,Nepal, Thailand, South Korea, and Brazil have installed small-scalebiogasdigesters(ESMAP 2005).

Environment and Sustainability: Microalgae-derived biofuel is one of the most promising renewable energy sources, not only due to its lower GHG emissions but also owing to itsCO_2 sequestration which is 10–50 times more than many terrestrial plants, while a higher concentration of CO_2 results in a higher yield of lipids [Zhuet . al 2017]. Algal-based wastewater treatment offers an efficient and cost-effective tool to eliminate organic and inorganic contaminant wastes from wastewater. The domestic wastewater contains organic and inorganic compounds, along with phosphate ($PO_4^{-3)}$&ammonia (NH_3). Recent studies have been reportedthat municipaland industrial wastewater can be successfullytreated through the cultivation of microalgae [Francisci et al 2018, [Komolafe et al. 2014].

II. Conclusion

Microalgae are tiny factories and renewable, sustainable and economical sources of biofuels, bioactive medicinal products and food ingredients. The development of eco-friendly fuels such as biofuels to solve the conflict crisis of limited fossil fuel resource microalgae-based biofuels have been regarded as one of the promising feedstocks for the new generation of biofuels. Many efforts have paid on exploring enormous advances in the development of upstream and downstream technologies, to offset the cost of obtaining high biomass concentration and high content of anticipated fuels. Some appropriate microalgal strains have been screened or modified to guarantee high microalgal biomass production, and win–win strategies such as two-stage of cultivation have been demonstrated the possibility of obtaining both high biomass production and lipid content or other fuels. Furthermore, advanced technologies applied in harvesting and biomass-to-fuels conversion make microalgae-based fuels more promising. However, some significant challenges remain in the scale-up of microalgal farming systems, and the constraints should be tackled in the future.

The results for the meta-analysis show that “strain selection” and “genetic modification” have the greatest number of studies, whereas the “environmental and sustainability” and “industrialization and economy” have the least. The genome editing techniques play an important role in expansion of the studies on gene editing. It has enhanced efficiency, simplicity and performance of the process, and there is hope for further improvement in developing more safe methods for genome editing in the future.

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Anamika, et. al. "Microalgae as potential Sustainable Source for Biofuels: A Review."*IOSR Journal of Biotechnology and Biochemistry (IOSR-JBB)*, *9*(2), (2023): pp. 07-13.