Biofuels from Microalgae: A Promising Alternative and Sustainable Energy Source.

Sunil Kumar Srivastava[1] and Anju Mehra[2]

[1] Department of Microbiology, Swami Shraddhanand College, University of Delhi, Delhi and [2]Omics of Algae lab, International Centre for Genetic Engineering and Biotechnology (ICGEB), New Delhi

ABSTRACT

The human population is expected to rise by 50% or more by 2030, which is going to lead to a huge rise in energy consumption. The consumption rate of natural fossil fuels is estimated to be 105 times higher than what nature can provide. In addition, utilization of fossil fuels causes a lot of problems by producing greenhouse gases that lead to increase in global warming. Therefore, finding an alternative energy with less carbon prints has become one of the most challenging tasks with a lot of research impetus. In this context, biofuels or fuels derived from living creatures is a good option with their renewable nature along with the reduced CO_2 emission. Many current biofuel options are based on the usage of produce of traditional farming which can be used as food also. In addition, there is a land usage competition regarding the use for fuel crops or food crops. After a long time, researchers proposed a solution with microalgal biofuels where microalgae convert CO_2 and water in the presence of sunlight into valuable biomass for biofuels. The purpose of this study is to condense recent research on the potential of microalgal species for biofuel production and to explore prospective implementation strategies. In addition, some specific microalgal species and their benefits for biofuels are emphasized in this paper. The latest initiatives and successes in increasing production of micro-algal biofuels using different techniques are also discussed. Other applications that can be combined with biofuel generation, such as wastewater treatment and CO_2 reduction, are presented. The benefits and drawbacks of algae for the biofuel sector are also discussed.

Keywords: Microalgae · Renewable · Biomass · Production.

INTRODUCTION

Human activities use lot of energy and the demand is continuously increasing. This results in a higher consumption rate of fossil fuels[Maness *et al.*[1]]. It is clear that this energy demand can't be met by using fossil fuels alone. Besides the gap in supply, a lot of environmental changes are occurring due to the use of these fossil fuels such as increasing CO_2 concentration in the air, increase in the environmental temperature, global warming, melting of glaciers etc.[Chisti[2], Medipally *et al.*[3]]. As a result, the search for an alternative energy has become one of the most daunting problems[Medipally *et al.*[3], Mata *et al.*[4]].Following that, many alternative energy sources, such as solar energy, hydropower, geothermal, wind, and biofuels, are being researched and deployed. Among these possible energy sources, biofuels are seen as a viable way of reaching the aim of replacing fossil fuels in the short term[Chisti[2]].

Biofuels are biologically derived from living organisms where non-toxic, biodegradable, and renewable biofuels can be made from starch, vegetable oils, animal fats, waste biomass, or algal biomasses [Song *et al.*[5]]. Generally, biofuels are classified as first, second, third, and fourth generation biofuels based on the feedstock types used and its current/future accessibility [Bringezu[6]]. In addition, they help to improve the environmental situation with their low carbon foot prints [Popp *et al.*[7]]. Unfortunately, current biofuel statistics are based on feedstocks which are used as food also [Burrett *et al.*[8]]. According to Satyanarayana *et al.*[9] for the production of biofuel, there is a need of land which also can be used for food production. Therefore, a competition is created between land for food and land for fuel which becomes a detrimental factor.

Microalgae have garnered significant global attention in recent years due to their valuable biomass for biofuels along with the capacity to sequester CO_2 and cleaning of wastewater [Rittmann *et al.*[10]]. Algal fuels are also known as third-generation biofuel. This is the accurate decision for biofuel production since algae have great potential (such as a low-input, high-yield possibility) for renewable energy applications [Satyanarayana *et al.*[9], Hu *et al.*[11], Dismukes *et al.*[12]].

Therefore, it is now considered as a viable alternative renewable energy resource for biofuel production that overcomes the drawbacks of first- and second-generation biofuels [Chisti[2], Nigam *et al.*[13], Dragone *et al.*[14], Li *et al.*[15]]. Microalgae may be used to produce a variety of sustainable biofuels. Methane , biodiesel[Gavrilescu *et al.*[16]], and bio-hydrogen [Kapdan *et al.*[17]] are some examples. There are several advantages of creating biofuel from algae, including the fact that microalgae may generate 15 to 300 times more biodiesel per acre than conventional crops [Dragone *et al.*[14]]. Microalgae have a very short harvesting cycle and a very fast growth rate [Dragone *et al.*[14,] Schenk *et al.*[18]]. Furthermore, high-quality agricultural land is not required for the production of microalgae biomass [Scott *et al.*[19]].

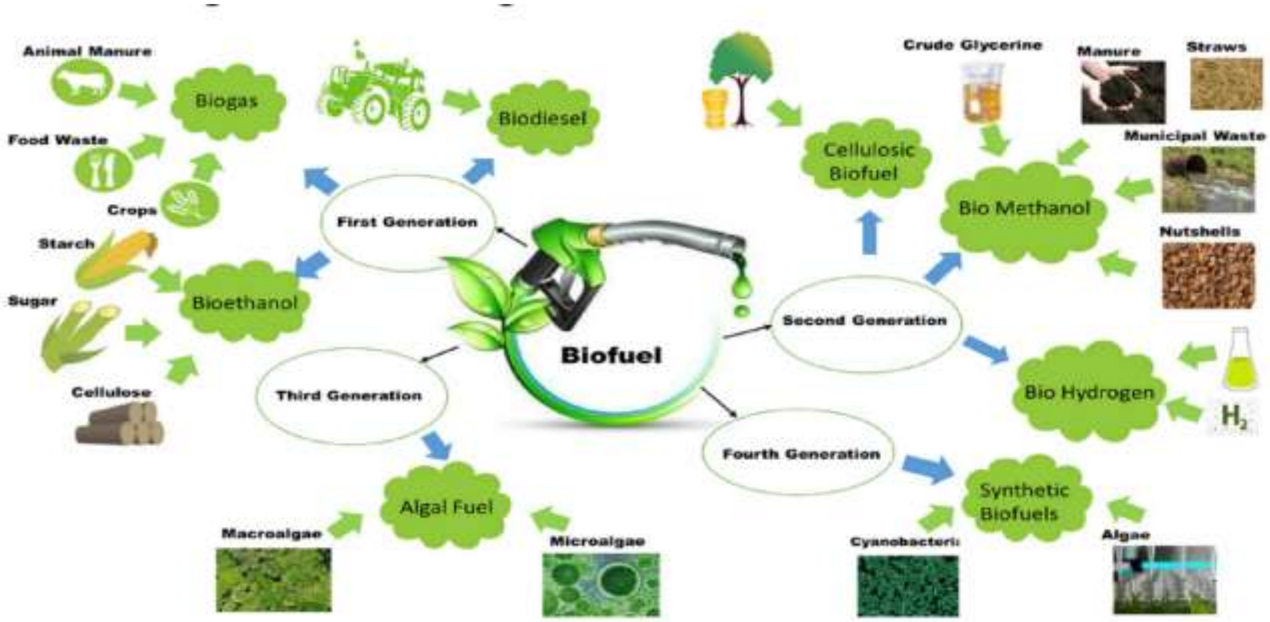

Figure 1. Types and different generation of biofuels depending on their source (Source-Wikipedia)

BIOFUELS FROM MICROALGAE

Microalgae are small single-celled organisms, found in both fresh water and marine water. Microalgae have around 300,000 species[Scott *et al.*[19]] and they can efficiently convert the CO_2 and solar energy into valuable biomass [Chisti[2,] Dragone *et al.*[14]] Table 1 shows the current biofuel outputs from various biomasses.

Table 1. Comparison of Microalgae with crops for oil yields. (adapted from http://scu.edu.au/teachinglearning/index.php/79 andMatta *et al* [4]).

Oil Yields	Liter/Hectare/Year	Barrels/Hectare/Year
Soybeans	400	2.5
Sunflower	800	5
Rapeseed	974	8.6
Canola	1,600	10
Castor	1307	11.6

Jatropha	2,000	12
Palm Oil	6,000	36
Microalgae	60,000 – 240,000	360 – 1,500

The oil content of diferent species of Microalgae in proportion to their dry weight, demonstrates a huge potential of their use as biofuels (Table-2).

Table 2. Oil content of different microalgae in proportion to their dry weight. Several species of microalgae have adequate amount of oil that can reach up to 80% of their dry body weight under specific environmental conditions. [adapted from Third generation biofuel from algae (http://creativecommons.org/licenses/by-nc-nd/4.0/)].

	Name of microalgae	**(% of dry weight)**
1	*Botryococcus* sp.	25 - 75
2	*Chlorella* sp.	28 - 32
3	*Crypthecodinium* sp.	20
4	*Cylindrotheca* sp.	16 - 37
5	*Dunaliella* sp.	23
6	*Isochrysis* sp.	25 - 33
7	*Nannochloris* sp.	20 - 35
8	*Neochloris* sp.	35 - 54
9	*Nitzschia* sp.	45 - 47
10	*Phaeodactylum* sp.	20 - 30

MICROALGAL BIOMASS PRODUCTION

Growing strategies of traditional crops are easy and economical in comparison to microalgae cultivation. Although microalgae requirements are very basic light, CO_2, water, and inorganic salts but some other factors can easily influence the growth such as temperature and light. Temperatures in the 20°C to 30°C range are ideal for most of microalgae cultivation. Biofuel production must rely on freely accessible sunshine to decrease costs, despite daily and seasonal fluctuations in natural light intensity [Chisti[2], Chaumont[20], Michael A Borowitzka[21, 22], Pulz *et al.*[23]]. The inorganic components that make up the algal cell must be supplied all nutrients through the growth media. Nitrogen (N), phosphorus (P) and, in rare instances iron (Fe), silicon (Si) are all essential elements.

Microalgae can grow in a in versatile environments such as fresh waters, marine waters, municipal waste waters, industrial waste waters, and animal waste waters, as long as adequate amounts of carbon (organic or inorganic), nitrogen (urea, ammonium, or nitrate), and phosphorus and other trace elements are present [Zhou *et al.*[24]]. In addition, some microalgae are mostly cultivated in sea water combined with nitrate and phosphate fertilizers, as well as a few additional micronutrients [Grima *et al.*[25]]. In comparison to fresh and marine waters, waste fluids have a distinct chemical composition and physical characteristics.

Recent studies have revealed a significant potential for large production of algal biomass for biofuel using wastewater. However, there are still many uncertainties and challenges in wastewater-based algae cultivation, such as discrepancies in wastewater composition according to source, environmental conditions, and pre-treatment methods, improper nutrient ratios (e.g., C/N and N/P), high turbidity due to the presence of suspended solid particles, which affects light transmission, and the presence of compaction.

Microalgae can be grown with different techniques. However, the two most common are a) suspended cultures, which include open ponds and closed reactors, and b) immobilized cultures, which include matrix immobilized systems and biofilms. Open raceway ponds are widely used for large scale production systems and they are open and shallow, with a paddle wheel that circulates algae and nutrients. The advantage of these, are the low-cost but productivity is typically low [Chisti[2,] Matta *et al.*[4]]. Tubular photobioreactors are the closed systems employed in large-scale algae production [Jerney and Spilling[26]]. There are different types of photobioreactor cultivation system: a) vertical photoreactors, b) flat or horizontal photoreactors, and c) helical photoreactors. Tubular photobioreactors can provide some advantages such as pH and temperature control, greater protection against culture contamination, better mixing, reduced evaporative loss, and higher cell densities than open ponds [Mata *et al.*[4]].

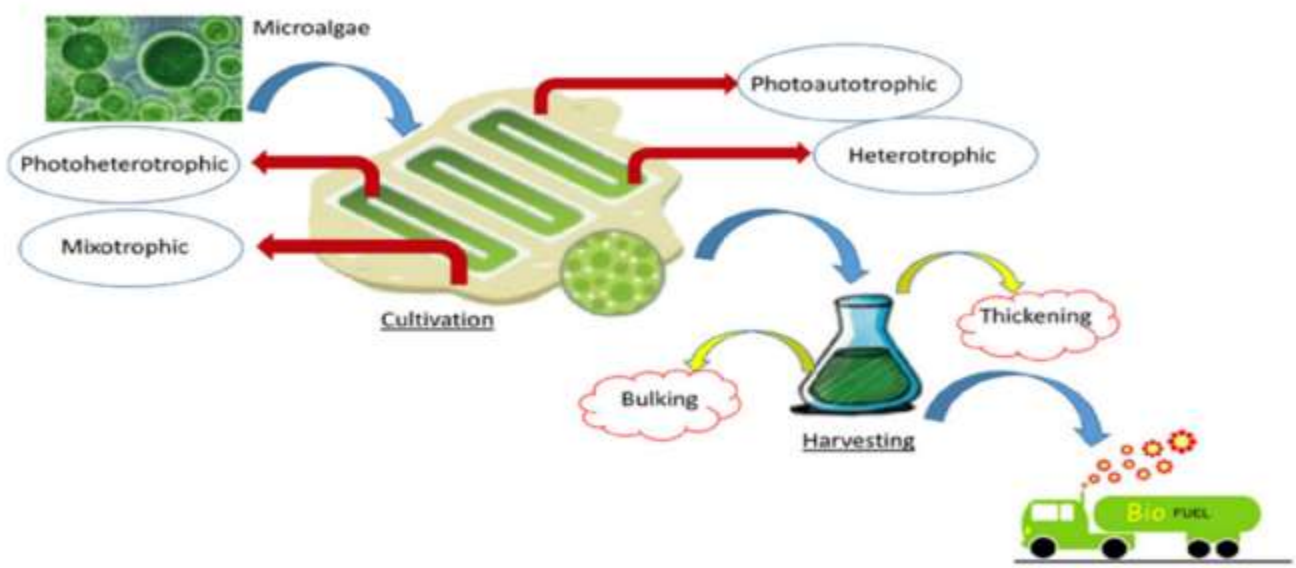

Figure 2. Biofuels from Microalgae, where different cultivation methods shown for microalgae, including photoautotrophic, heterotrophic, photoheterotrophic, and mixotrophic, and harvesting process by bulking and thickening techniques employed to concentrate the algal slurry (Source - Wikipedia)

However, every cultivation system has its own advantages and disadvantages and employing for cultivation according to the same.

Other than that, immobilized cultures or connected algal processes have helped to minimize some of the major problem to some extent [Hoffmann[27]]. Algal biofilms have the potential to play a significant role in addressing the primary problems associated with the development and harvesting of microalgae. Algae biofilm growth can be greater than suspended growth if appropriate surface area is supplied [Chisti[2,] Dragone *et al.*[14,] Scott *et al.*[19],Alam *et al*[28]].

PROMISES AND CHALLENGES IN THE ALGAE-TO-BIOFUEL INDUSTRIES

Microalgal biofuel production appears to be a good business to start because of its higher efficiency in converting solar energy into chemical energy (3–8%) and production of higher biomass and oil yield than conventional energy crops (only 0.5 % efficiency with 10 g/m^2 /day yield) [Lardon *et al* [29]]. Because of these promising characteristics of microalgae, there has currently been a surge in global interest in microalgae study and production. Many scientists and government leaders in a variety of nations have given the situation careful thought. Scientists are dedicating a significant amount of time to microalgal research, and several governments are giving large amount of funding for microalgal-related initiatives. Despite the fact that there are significant obstacles in producing microalgal biodiesel, more and more inventors are persuaded to think that the profits will ultimately exceed the dangers, and microalgae investments have reached over $900 million globally [Deng *et al*[30]].

Table 3. Solutions proposed to issues challenging microalgae-to-biofuel industries (adapted from http://dx.doi.org/10.1016/j.rser.2017.08.042)

Issue	Potential solutions
Light	Pulsing light-emitting diode (LEDs), micro lensed PBR
Temperature	IR glass/plastic, use extremophilic species, using cooling water
Nutrient	Wastewater, utilize flue
Dewatering	Filamentous species, self-flocculating/settling species
Oil extraction	Genetic Modifications of excretory pathways
Costs	Co-production of a valuable product, novel PBR designs

In this single-step extraction method, biomass harvesting, concentrating, and oil extraction, as well as separation of oil, water, and biomass, are all completed in less than an hour. [Smith-Baedorf[31]] identified many measures to be performed in order to solve feasibility concerns (Table 3) stated that airplanes run on algae biofuel, which is a significant promise/feedback to algal research efforts. One major point here is that using algal biofuel increased the aircraft's efficiency by 10% and reduced fuel consumption by 1.5 liter per hour when compared to conventional gasoline, which might be due to the relatively high calorie content per liter of algae biofuel. Although major improvements in algal research have enhanced their commercial significance, the application still faces a number of obstacles. Nonetheless, substantial scientific and engineering hurdles remain in efforts to fully commercialize microalgae-to-biofuel technology [Kumar *et al.*[32]].

Once the biomass has been generated, the next difficulty is the dilute nature of microalgal cultivation, which necessitates the use of energy for dewatering. [Danquah *et al.*[33]] discovered that tangential flow filtration can concentrate up to 148 times while using just 2.06 kW h m3 of energy, which is superior to other techniques. [Matos *et al.*[34]] recently showed that combining electro-coagulation with centrifugation reduced energy usage by more than 97 percent. Nonetheless, significantly reduced energy-consuming approaches are required. Furthermore, because microbial oil extraction is very energy intensive and costly, extracting and purifying oil from algae remains a substantial barrier in the production of both microalgal bioproducts and biofuel [Mercer *et al.*[35,] Shuba *et al.*[36]] In this regard, establishing cost-effective and efficient oil extraction and purification procedures is a key issue for the microalgae and biofuel sectors.

CONCLUSIONS AND FUTURE PERSPECTIVES

Microalgal biofuels have the potential to replace fossil fuels due to their inherent efficiency in converting solar energy into chemical energy, as well as their considerably larger potential output of oils suited for biofuel production than terrestrial crops. Several accomplishments in genetic and metabolic engineering of algae strains to improve production costs have been recorded in recent years. Furthermore, several technological elements of algal biomass production and biomass processing procedures to generate biofuels have been improved. Nonetheless, the expense of manufacturing continues to be a barrier to the efforts of the algae-to-biofuel companies. Nonetheless, due to the present growing worry about fossil fuels, energy security, greenhouse gas emissions, and the ability of alternative biofuel feedstocks to compete for limited agricultural resources, there is increasing global interest in microalgal biofuels. Microalgal production may thus be scaled up to an industrial level by using transgenic strains in conjunction with effective harvesting and oil extraction techniques, as well as generating high-value products and exploiting leftover byproducts to enhance production economics. In addition, the abundance of sunlight and high temperatures in the tropics may promote the generation of hydrogen in a low-cost system using a closed photobioreactor. To enhance the economy, this would be a great opportunity, especially for landlocked nations like Ethiopia, which is still without petroleum-based fuels and has "thirteen months of sunshine".

REFERENCES

1. Maness P-C, Yu J, Eckert C, Ghirardi MLJM. Photobiological hydrogen production-prospects and challenges.4(6):659-667. (2009)

2. Chisti Y. Biodiesel from microalgae. *Biotechnology advances*.25(3):294-306. (2007)

3. Medipally SR, Yusoff FM, Banerjee S, Shariff MJBri. Microalgae as sustainable renewable energy feedstock for biofuel production.2015. (2015)

4. Mata TM, Martins AA, Caetano NS. Microalgae for biodiesel production and other applications: a review. *Renewable and Sustainable Energy Reviews*.14(1):217-232. (2010)

5. Song D, Fu J, Shi DJCJoB. Exploitation of oil-bearing microalgae for biodiesel.24(3):341-348. (2008)

6. Bringezu S. Towards sustainable production and use of resources: assessing biofuels: UNEP/Earthprint.(2009)

7. Popp J, Lakner Z, Harangi-Rakos M, Fari MJR, reviews se. The effect of bioenergy expansion: Food, energy, and environment.32:559-578. (2014)

8. Burrett R, Clini C, Dixon R, Eckhart M, El-Ashry M, Gupta D, *et al.* Renewable Energy Policy Network for the 21st Century. (2009)

9. Satyanarayana K, Mariano A, Vargas JJIJoer. A review on microalgae, a versatile source for sustainable energy and materials.35(4):291-311. (2011)

10. Rittmann BEJB, bioengineering. Opportunities for renewable bioenergy using microorganisms.100(2):203-212. (2008)

11. Hu Q, Sommerfeld M, Jarvis E, Ghirardi M, Posewitz M, Seibert M, *et al.* Microalgal triacylglycerols as feedstocks for biofuel production: perspectives and advances.54(4):621-639. (2008)

12. Dismukes GC, Carrieri D, Bennette N, Ananyev GM, Posewitz MCJCoib. Aquatic phototrophs: efficient alternatives to land-based crops for biofuels.19(3):235-240. (2008)

13. Nigam PS, Singh AJPie, science c. Production of liquid biofuels from renewable resources.37(1):52-68. (2011)

14. Dragone G, Fernandes BD, Vicente AA, Teixeira JA. Third generation biofuels from microalgae. (2010)

15. Li Y, Horsman M, Wu N, Lan CQ, Dubois-Calero NJBp. Biofuels from microalgae.24(4):815-820. (2008)

16. Gavrilescu M, Chisti YJBa. Biotechnology—a sustainable alternative for chemical industry.23(7-8):471-499. (2005)

17. Kapdan IK, Kargi FJE, technology m. Bio-hydrogen production from waste materials.38(5):569-582. (2006)

18. Schenk PM, Thomas-Hall SR, Stephens E, Marx UC, Mussgnug JH, Posten C, *et al.* Second generation biofuels: high-efficiency microalgae for biodiesel production.1(1):20-43. (2008)

19. Scott SA, Davey MP, Dennis JS, Horst I, Howe CJ, Lea-Smith DJ, *et al.* Biodiesel from algae: challenges and prospects.21(3):277-286. (2010)

20. Chaumont DJJoAP. Biotechnology of algal biomass production: a review of systems for outdoor mass culture.5(6):593-604. (1993)

21. Borowitzka MAJJob. Commercial production of microalgae: ponds, tanks, tubes and fermenters.70(1-3):313-321. (1999)

22. Borowitzka MA. Culturing microalgae in outdoor ponds. Algal culturing techniques: Academic Press. 205-218. (2005)

23. Pulz OJAm, biotechnology. Photobioreactors: production systems for phototrophic microorganisms.57(3):287-293. (2001)

24. Zhou W, Chen P, Min M, Ma X, Wang J, Griffith R, *et al.* Environment-enhancing algal biofuel production using wastewaters.36:256-269. (2014)

25. Grima EM, Fernández Sevilla JM, Acién Fernández FGJEoibb, bioseparation,, technology c. Microalgae, mass culture methods.1-24. (2009).

26. Jerney J and Spilling K Large scale cultivation of microalgae in open and closed systems. Biofuels from Algae pp.1-8(2018).

27. Hoffmann JPJJop. Wastewater treatment with suspended and nonsuspended algae.34(5):757-763. (1998)

28. Alam F, Mobin S, Chowdhury HJPE. Third generation biofuel from algae.105:763-768. (2015)

29. Lardon L, Hélias A, Sialve B, Steyer J-P, Bernard O. Life-cycle assessment of biodiesel production from microalgae. ACS Publications; 2009.

30. Deng X, Li Y, Fei XJAJoMR. Microalgae: A promising feedstock for biodiesel.3(13):1008-1014. (2009)

31. Smith-Baedorf HD. Microalgae for the biochemical conversion of CO2 and production of biodiesel: University of Bath; 2012.

32. Kumar A, Ergas S, Yuan X, Sahu A, Zhang Q, Dewulf J, *et al.* Enhanced CO2 fixation and biofuel production via microalgae: recent developments and future directions.28(7):371-380. (2010)

33. Danquah MK, Ang L, Uduman N, Moheimani N, Forde GMJJoCT, Biotechnology: International Research in Process E, *et al.* Dewatering of microalgal culture for biodiesel production: exploring polymer flocculation and tangential flow filtration.84(7):1078-1083. (2009)

34. Matos CT, Santos M, Nobre BP, Gouveia LJBt. Nannochloropsis sp. biomass recovery by Electro-Coagulation for biodiesel and pigment production.134:219-226. (2013)

35. Mercer P, Armenta REJEjols, technology. Developments in oil extraction from microalgae.113(5):539-547. (2011)

36. Shuba ES, Kifle DJR, Reviews SE. Microalgae to biofuels:'Promising'alternative and renewable energy, review.81:743-755. (2018)