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Algae as a Biofuel: Renewable Source for Liquid Fuel

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Abstract: Biofuels produced by algae may provide a feasible alternative to fossil fuels like petroleum sourced fuels. However, looking to limited fossil fuel associated with problems, intensive efforts have been given to search for alternative biofuels like biodiesel. Algae are ubiquitous on earth, have potential to produce biofuel. However, technology of biofuel from algae facing a number of hurdles before it can compete in the fuel market and be broadly organized. Different challenges include strain identification and improvement of algal biomass, both in terms of biofuel productivity and the production of other products to improve the economics of the entire system. Algal biofuels could be made more cost effective by extracting other valuable products from algae and algal strains. Algal oil can be prepared by culture of algae on municipal and industrial wastewaters. Photobioreactors methods provide a controlled environment that can be tailored to the specific demands of high production of algae to attain a consistently good yield of biofuel. The algal biomass has been reported to yield high oil contents and have good amount of the biodiesel production capacity. In this article, it has been attempted to review to elucidate the approaches for making algal biodiesel economically competitive with respect to petrodiesel. Consequently, R & D work has been carried out for the growth, harvesting, oil extraction and conversion to biodiesel from algal sources.

Keywords: Biofuels, Algae, Algae oil, Photobioreactor

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1. Introduction: Over a past few decades the world is entering a period of diminishing non-renewable energy resources, while energy demand is increasing and decades the world's oil and fuel production is expected to decline [1]. As a result of this future energy crisis, both governments and private industry as well as research institute are examining alternative sources of energy. Other non-renewable sources of energy (such as coal and uranium) exist, however, these sources are limited and will also predictably decline in availability. Non-renewable sources like coal are the likely immediate candidate for replacing oil as an energy supply. It is energy rich, can be converted to liquid fuel, and is still very abundant. It is particularly plentiful in the China, United States, and India. These three countries are heavily industrialized and have ever-increasing energy demand day by day. Our dependence on fossil fuels has caused release carbon dioxide in the atmosphere, which one is the primary contributor to the global warming. For this, alternative stable energy sources will meet world demand while mitigating climate changes, it is necessary to develop renewable clean fuels. Now a day, most renewable energy initiatives are focused on electricity generation, while the majority of world consumption of energy is derived from liquid fuels [2]. The need for liquid fuel (renewable sources of energy) is starting to receive greater attention and has been focused on biomass-derived liquid fuels, or biofuels [3, 4]. Government and private organizations think about the beginning to seriously invest in the biofuels market, in both research and commercial production; however, many existing alternatives such as hydrogen, ethanol, and conventional biodiesel fail to be cost competitive with petroleum [5]. Now a day algae have been the center of research attention as an emerging feedstock for biodiesel production. Algal biodiesel research is now one of the top notch research topics mainly in the context of rising petrofuel prices and climatic changes. Algae have an usually fast growth rate in comparison to terrestrial energy crops and additionally a significant percentage of their weight is comprised of oil. This algal oil resulting from extraction can directly be converted into biodiesel which is renewable and an environmental friendly biofuel. Theoretically algae offer strong contention as a promising feedstock for biodiesel production **[6]**. Algae have been proposed to be the only source of renewable biodiesel that is capable of meeting the global demand for transportation fuels **[7]**. This research paper examines the feasibility of biodiesel as a potential replacement for petroleum-based liquid fuels. In particular, the use algae as a source of biomass for fuel production are reviewed.

2. Biofuel: A biofuel are the fuel derived from a renewable biological source, as opposed to a fossil-based source (coal, oil, natural gas). Those biological sources can include used food waste, vegetable oil, wood waste, sewage sludge and livestock manure. The materials produced specially for fuel production such as sugarcane and corn (processed for ethanol) and peanut, soybean, sunflower and other vegetable-based oils (processed for biodiesel). The advantages of biofuels over fossil fuels are there renewablity, they reduce dependence on non-renewable fossil fuels, and it can be produced domestically so that it reduce dependence on foreign sources of oil, which helps increase energy security. Biodiesel can be made from nearly any source of organic oil which includes restaurant waste oil, animal fats, and seed oils. The waste oil supply is very limited; however, it is a popular source for small scale, independent producers. For large commercial producers mainly use seed oils such as soybean, palm, corn oils, and rapeseed. However, biodiesel produced from seed oil diverts from the food supply and the increasing competition for seed causes the oil and resulting biodiesel to become increasingly expensive. Christi (2007), reported that biodiesel would be to replace all petroleum fuels **[8]**. Neither seed oil nor waste oil can come close to meeting the requirement for that much fuel, thus, if biodiesel is to become a true replacement for petroleum, a more oil productive source is needed **[5, 8]**.

3. Algae: Algae are ubiquitous on earth, have a diverse group of marine and aquatic organisms. Like plants, algae also carry out photosynthesis, using sunlight to convert carbon dioxide, water and nutrients to oxygen and biomass (carbohydrates, oils and proteins). It can also grow in the dark, by consuming sugars. Algae are adapted to diverse environments and have greater photosynthetic CO_2 fixation efficiencies than terrestrial plants when comparisons are made based on land productivities. Microalgae known as single celled algae are habitually grown in open ponds or in enclosed systems known as photo bioreactors. Microalgae including seaweed and can be grown at sea or in tanks. Algae mainly seaweed, are a potential source of renewable fuel, food and chemicals. Principal energy processes being developed for aquatic biomass are shown in figure (1). Algae can provide a variety of fuels for electricity generation and transport including biodiesel, biogas and aviation fuel. The prospects of commercial algal biofuels production are strengthened by this diversity, versatility and efficiency. Microalgae are sunlight-driven cell factories that convert carbon dioxide to potential biofuels, foods, feeds and high-value bioactives **[9]**. In addition, these photosynthetic microorganisms are useful in bioremediation **[10]** and as nitrogen fixing biofertilizers **[11]**. The existing large-scale natural sources are of algae are: bogs, marshes and swamps - salt marshes and salt lakes. Micro-algae contain lipids and fatty acids as membrane components, storage products, metabolites and sources of energy. The algae that are used in biodiesel production are usually aquatic unicellular green algae. This type of algae is a photosynthetic eukaryote characterized by high growth rates and high population densities. Under good conditions, green algae can double its biomass in less than 24 hours **[8]**. Figure (2) represent the biodiesel process from algae. Additionally, green algae can have huge lipid contents, frequently over 50% **[2]**. This high yield, high density biomass is ideal for intensive agriculture and may be an excellent source for biodiesel production.

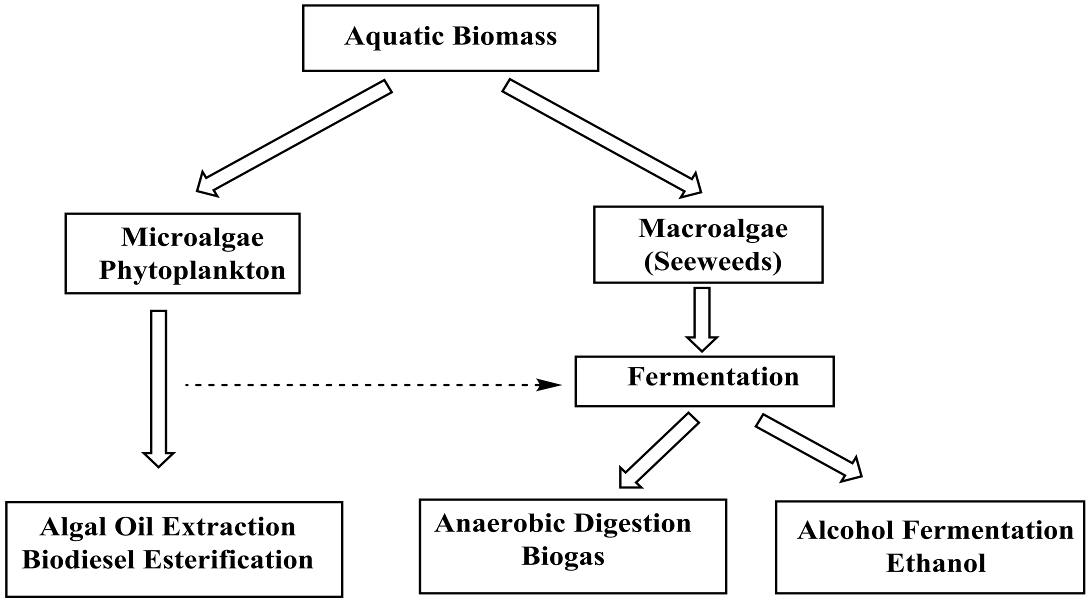

Figure (1): Principal Energy Processes Developed for Aquatic Biomass.

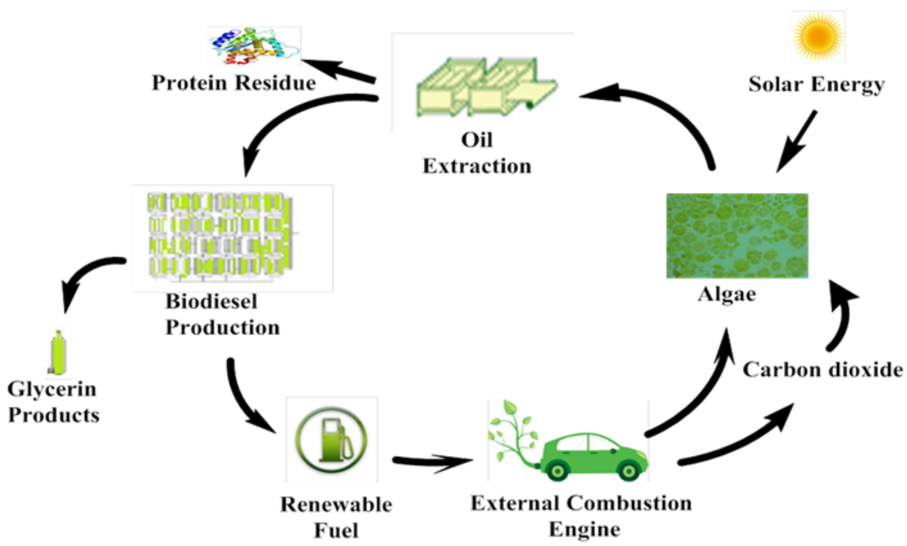

Figure (2): Biodiesel Production Process from Algae.

4. Algae Biomass Production: Algae has hugely diverse in form, they range in size and complexity from microscopic single-celled species (microalgae) to multi-cellular seaweeds such as the giant kelps, hundreds of feet in length (macroalgae). Large-scale production of algal biomass generally uses continuous culture where, fresh culture medium is fed at constant rate and the same quantity of algal broth is withdrawn continuously during daylight. Production rate ceases during the night, but while the mixing of broth must continue to prevent settling of the biomass [12]. About 25% algal biomass produced during daylight, production rate decrease during the night because of respiration. Production rate depends on the light level under which the biomass was grown, the growth temperature, and the temperature. The mainly two practicable methods of large-scale production of algae are raceway ponds and tubular photobioreactors. Raceway ponds for mass algae culture have been used since the 1950s. Now a day extensive experience exists on operation and engineering of raceways ponds. The largest raceway-based biomass production facility occupies an area of 440,000 m^2 [13]. Sheehan et al., (1998) evaluate production of algal biomass for making biodiesel in raceway ponds sponsored by the United States Department of Energy [14]. Raceways ponds are apparent to be less expensive than photobioreactors, as they cost less to build and operate. However raceways are low-cost, they have a low biomass productivity compared with photobioreactors. Photobioreactors involve cooling during daylight hours. Additionally, control of temperature at night is also useful. Therefore, loss of biomass production during night due to respiration can be reduced by lowering the temperature at night. Outdoor tubular photobioreactors are effectively and inexpensively cooled using heat exchangers. Photobioreactors have been successfully used for producing large quantities of algal biomass [12, 15 - 17]. Selecting a suitable method for algal biomass production for making biodiesel requires a comparison of capabilities of raceways and photobioreactors. Most common harvesting methods for algal biomass include sedimentation, filtration, centrifugation, ultra-filtration or combination of flocculation- flotation [18]. The various algal harvesting techniques are discussed in Table (1). Few of algae like cyanobacteria (are that are responsible for at least 50% of the photosynthetic biomass production on earth. With improvements in bioenergy research algae have expanded tremendous scientific attention as a bioenergy feedstock. Algae have been studied extensively on account of their various potential advantages for biofuel production when compared to terrestrial energy plants.

The main feature of algae in this direction is its biomass doubled very short time during exponential growth, atmospheric carbon dioxide is the source of carbon for growth of algae, as simple cellular structure algae have higher rates of biomass and oil production than plant or crops, salty or waste water can be used for the culture of algae, the lipid content in algae can be familiar through altering growth media composition, oil content in algae can exceed 80% by weight of dry biomass. Also, few algae species are known to produce many kind of hydrocarbons, lipids and other complex oils, biofuel production from algae can be together with fuel gas carbon dioxide mitigation and waste water treatment and production of high value chemicals [19, 20].

Table (1): Algae Harvesting Techniques

S. No.	**Algae harvest method**	**Relative cost**	**Algal species**
1	Foam fractionation	Very high	*Scenedesmus, Chlorella*
2	Centrifugation	Very high	*Scenedesmus, Chlorella*
3	Polyelectrolyte flocculation	High	*Dunaliella*
4	Filtration	High	*Spirulina, Coelastrum*
5	Microstrainers	Unknown	*Spirulina*
6	Tube settling	Low	*Micractinium*
7	Diecrete sedimentation	Low	*Coelastrum*
8	Phototactic autoconcentration	Very low	*Euglena, Dunaliella*
9	Autoflocculation	NA	*Micractinium*
10	Bioflocculation	NA	*Micractinium*

5. Biodiesel Production from Algae: Biodiesel is a biofuel consisting of monoalkyl esters that are derived from organic oils, plant or animal, through the process of transesterification, also called alcoholysis **[21]**. Transesterification is the chemical conversion of oil into its corresponding fatty ester (biodiesel).

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

It involves the displacement of alcohol from an ester by another alcohol in a process very similar to hydrolysis, but that an alcohol (mostly methanol) is employed in place of water **[22]**. The major product of the transesterification process is biodiesel and glycerine is another important byproduct produced which can be burnt for heat and can be used as a feedstock in cosmetic industries **[23]**. Conventionally, biodiesel is produced from algae by the transesterification process. The process of making biodiesel occurs as follows **[6].** Triglycerides, alcohol and catalyst are placed in a controlled reaction chamber to undergo transesterification; b) The initial product is placed in a separator to remove the byproduct, glycerol; c) The excess methanol (alcohol) is removed from the methyl esters via evaporation and d) The final biodiesel is rinsed with water, neutralized and finally dried. The transesterification reaction can be catalyzed by alkalis (KOH, NaOH, carbonates), acids (hydrochloric phosphoric and sulphuric). Alkali catalyzed trans-esterification reaction is about 4000 times faster than the acid catalyzed reaction and as such most frequently used commercially **[22]**. The chemically catalyzed trans-esterification (alcoholysis) reaction despite having appreciable conversion levels within short reaction time has numerous difficulties, it is energy intensive, recovery of glycerol is challenging, the acidic or catalyst has to be removed from the product, alkaline waste water requires treatment and moreover free fatty acids and water interfere with the reaction **[24]**. The comparison of different properties of diesel and biodiesel mention in Table (2) **[23, 24]**.

Table (2): Comparison of Different Properties of Diesel and Biodiesel.

Properties	**Fuel**	
	Biodiesel	**Diesel**
Density at 15°C (g/cm^3)	0.834	0.8834
Viscosity at 40°C(mm^2/s)	2.83	4.47
Carbon, %	86.2	76.1
Hydrogen, %	13.8	11.8
Sulfur, %	0.034	< 0.005
Oxygen, %	-	12.1
Cetane Number	47	56
Flash point	62	178
Lower calorific value MJ/kg	42.59	37.243

The oil content in some of algal species mention in Table (3) **[25]**. Although the lower energy biodiesels based on seed oils are the most common, they have enough energy density to make them a viable alternative to petroleum diesel. The interest the production of Biofuel from alage has been expressed through a booming market.

Table (3): Oil Content in Selected Algal Species.

Algal Species	Oil Content (% dry weight)	Algal Species	Oil Content (% dry weight)
Ankistrodesmus sp.	28-40	*Nannochloris* sp.	31 (6-63)
Botryococcus braunii	29-75	*Nitzschia* sp.	28-50
Chlorella sp.	29	*Phaeodactylum tricornutum*	31
Chlorella protothecoides (autotrophic/heterothrophic)	15-55	*Scenedesmus* sp.	45
Cyclotella sp.	42	*Stichococcus* sp.	33 (9-59)
Dunaliella tertiolecta	36-42	*Tetraselmis suecica*	15-32
Hantzschia sp.	66	*Crpythecodinium cohnii*	20
Isochrysis sp.	7-33	*Neochloris oleoabundans*	35-54

6. Work Done in India: In India, some of the initiative was taken by government for promoting algal biofuel research. In 2008-09, government of India launched a "National Algae Biofuel Network" with the participation of 12 national institutes to work on algal biofuel with focusing on aspects, such as collection and characterization of algal strains from different ecological niches and deposition of the same in three repositories, development of different production systems, improved algal strains for more oil/lipid content and finally, design development and fabrication of low-cost and pilot-scale bioreactors for the cultivation of algae for biofuels and technology. Presently, algal biofuel research in India is mostly confined to only some of the Indian institutes (government funded research laboratories and a few other Private Indian universities). The Table (4) show status of R & D work on algae in India **[26]**. It's the need that scientists of India should join the global race for research and development on algae based biofuel whereby allowing the country to find a solution to its impending energy crisis. On a precedence basis the possible challenges in this favor should be addressed by initiating required R & D efforts. Cost of producing algal biodiesel can be reduced significantly by using a bio-refinery based production strategy **[26, 27]**, improving capabilities of microalgae through genetic engineering **[28, 29]** and advances in engineering of photo-bioreactors **[12, 30, 31]**.

Table (4): Status of R & D Work on Algae In India.

S. No	Institution/Organization	Algae species worked	R & D area
1	University of Madras, Chennai	*Sargassum*	Cultivation
2	University of Madras, Chennai	Seaweeds	Biogas production
3	University of Madras, Chennai	*Botryococcus braunii*	Cultivation in open raceway pond
4	Central Food Technological Research Institute (CFTRI), Mysore]	*Botryococcus braunii*	Isolation and characterization of hydrocarbon
5	Vivekananda Institute of Algal Technology (VIAT), Chennai	Microalgae	Development of technology to treat industrial waste water
6	Central Rice Research Institute (CRRI), Cuttack, Orissa	*Chlorella vulgaris*	Production

7	Vivekananda Institute of Algal Technology (VIAT), Chennai	Algae as Biofuel	production from diatom species
8	Indian Institute of Technology, Roorkee	Microalgae	Conversion of Microalgal oil to biodiesel

7. Conclusions: The algae are considered as one of the most promising feed-stocks for future bio-diesel production in India. Biodiesel from algal biomass is technically feasible because it is the only renewable and can potentially completely displace liquid fuels derived from petroleum. The advantages of algae are their wide- spread availability, higher oil yields and reduced pressure on cultivable land. The difficulty in efficient biodiesel production from algae lies not only in the extraction of the oil, but also developing an algal strain with a high lipid content and fast growth rate. Producing low-cost algal biodiesel requires primarily improvements to algal biology through genetic and metabolic engineering. Use of the biorefinery concept and advances in photobioreactor engineering will further lower the cost of production. Photobioreactors provide a controlled environment that can be tailored to the specific demands of highly productive microalgae to attain a consistently good annual yield of oil. For producing algal biodiesel, it need to improve significantly to make it competitive with petrodiesel, but the level of development necessary appears meager.

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