Renewable Energy from Microalgae: Third Generation Biofuel with Integrated Approach

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Abstract— Continuous depletion of petroleum based fossil fuels and their negative impact on environment in terms of CO_2 accumulation have led to development of alternative, renewable and carbon neutral biofuels. Biodiesel has attracted intensive attention as an important biofuel. Biodiesel from microalgae appear to be the most promising renewable biofuel that can potentially completely substitute petroleum based fossil fuels. Microalgae are one of the most efficient photosynthetic plants on the earth with lipid-rich composition and rapid rate of reproduction. In comparison to other energy crops like soybean, rapeseed, sunflower, Jatropha, neem etc. Several species of algae have many advantages like higher per acre productivity, higher oil content and can grow in non-productive and non-arable lands. However, several other biofuels can be produced from microalgae which include methane produced by anaerobic digestion of the algal biomass, photobiologically produced biohydrogen and carbon-neutral electricity by burning of algal coal (dried algal biomass) with fossil coals in conventional power plants. Different factors like the light of proper intensity and wavelength, CO_2 concentration, temperature, nutrient composition, salinities and mixing conditions, the choice of cultivation systems, photo bioreactors etc. influence the efficiency of microalgae biomass production that need to be studied for making the microalgae biodiesel economical and sustainable. Huge efforts are being made to address these issues in developed countries. India in spite of being one of the major producers of algae is yet to start such type of research and development activities on algal biofuel. This paper reviews the potential of microalgae to produce a variety of biofuel including biodiesel and biogas with integrated approach for energy, environment and agriculture.

Key words: Renewable Energy from Microalgae, Biodiesel From Algae, Biofuel

I. INTRODUCTION

With the limited reserves of crude oil and the need to reduce CO_2 accumulation in the atmosphere, liquid fuels derived from plant materials i.e., biofuels are becoming an attractive source of energy. Presently bioethanol from corn, sugarcane or sugarbeet and biodiesel from different oil crops like soybeans, canola, palm, sunflower and jatropha are the most widely available form of biofuels. These sources of biofuel are not sustainable in long term (Patzek and Pimentel 2005) as the sources currently used are either food/feed crops or tree crops. The food crops are not suitable for biofuel as world's food requirement is increasing with increase in world population. The no edible oil crops like Jatropha and Pongamia, presently used in several parts of the world, show long gestation period of 4–5 years. Moreover the growth of these crops would compete for arable land with food crops.

These problems may be solved by increasing the application of microalgae for the production of biodiesel and other biofuels. In the recent past biodiesel production from algae has become an area of considerable interest. In the aspect of alternative fuels, microalgae is a miniature factory that in the process of photosynthesis, transform carbon dioxide and light into biomass rich in mineral components (Banerjee et al., 2002; Lorenz and Cysewski, 2003 Spolaore et al., 2006). Additionally, those photosynthesizing microorganisms are useful in bioremediation of polluted environments (Kalin et al., 2005; Munoz and Guieysse, 2006) and play an important role as "biofertilizers", through binding atmospheric nitrogen (Vaishampayan et al., 2001).

India being densely populated country with poor food security and limited arable land finds it difficult to completely depend on crop-based biofuels. In this regard algae may be a feasible solution to India for replacing petro diesel. Algae have higher productivities than most of the oilseed plants and some species of algae can build up very large amounts of triacylglycerides which is the major feedstock for biodiesel production. However several challenges have to be tackled before commercial production of diesel from algae at a sufficient scale to make a significant contribution to our energy needs.

II. MICROALGAE AND ENERGY CHAIN

First generation bio-fuels are produced from organic matters like starch, sugars, animal fats and vegetable oils. These are essentially food materials and if too much fuel is produced from these raw materials, the food prices may rise drastically. An ideal solution to this problem is to produce bio-fuels from cellulose products such as wood, straw, grasses and wastes from the wood processing industry. However, there is a doubt that the second generation raw materials can partially satisfy the requirement of sustainable, environment friendly fuel in an inexpensive manner. Third generation bio-fuels, mainly fuel cells use hydrogen as primary source of energy. Recently algae have been identified as the main source of such biofuels that can be produced more efficiently with low investment cost.

A model biofuel system should have much higher net energy balance, should be more water efficient and should require much less arable land (Singh and Dhar, 2011). Microalgal cultivation on marginal lands can improve the economic benefits of non-arable, drought or salinity affected areas. Higher photosynthetic efficiency leads to reduced amount of fertiliser and nutrient inputs which consequently results in less waste and pollution. A good amount of fresh water can be saved if algal cultivation is done in closed bioreactors. Depending on the process microalgae harvesting cycle may vary from 1-10 days which allows multiple or continuous harvests with significantly increased yields.

A variety of bioenergy other than biodiesel can also be synthesized from algae. For ex- the microalgae biomass generated in bioreactors can also be gasified or pyrolysed to produce a range of bio fuels and can act as a complement in CO_2 sequestration strategy (Weissman and Tillett 1992; Zeiler et al. 1995). Dried algal biomass can be co fired with coal in conventional power plants to produce somewhat more clean "carbon neutral" electricity. Bio ethanol, bio methane, and bio-hydrogen are also the important bio energies obtained from microalgae.

III. BIODIESEL FROM ALGAE

Algae hold similar photosynthetic capacity as that of plants with higher efficiency of conversion of solar energy into natural oil. It takes place with a combination of more efficient access of water, carbon dioxide and other nutrients. Because of these exceptional abilities, microalgae can produce manifold oil per unit area of land, compared to other conventional energy crops (Table 1). Chemically algal biomass constitutes about 60 per cent natural stored lipids and rest protein, carbohydrate and other nutrients. Microalgae appear to be the only source of biodiesel that has the potential to completely replace the fossil diesel. Depending on species, microalgae produce many different kinds of lipids, hydrocarbons, and other complex oils (Banerjee et al. 2002; Metzger and Largeau 2005).

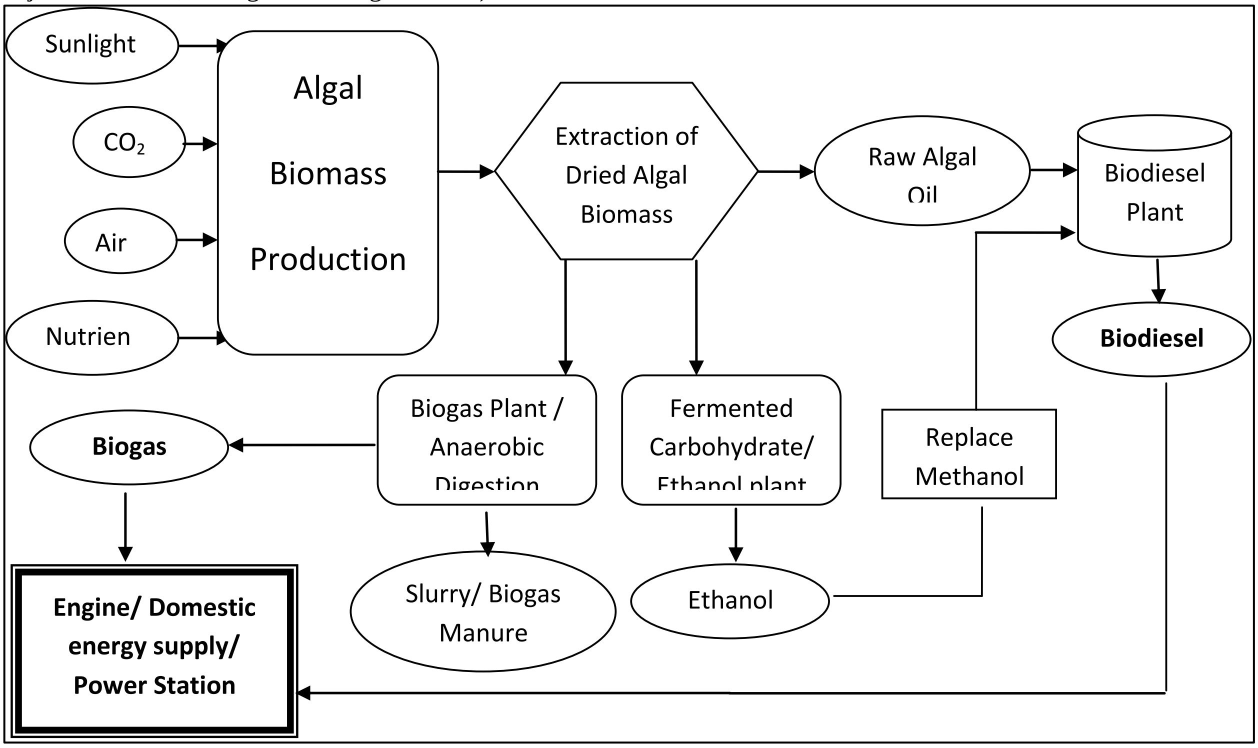

Fig. 1. A Model for Integrated Energy Generation from Microalgae

Crop	Scientific name	Oil content (%)	Oil yield (L/acre)
Soybean	Glycine max	18-22	181.68
Sunflower	Helienthus annuus	40-50	386.07
Rapeseed	Brassica napus	40-43	480.69
Jatropha	Jatropha Curcass	20-40	788.33
Karanja	Pongamia Pinnata	30-40	-
Neem	Azadirachta Indica	30-40	-
Microalgae		30-70	19000-57000

Generally, microalgae double their biomass within 24 h. The time required for doubling the biomass in experimental cultures, under optimum conditions, may even be reduced to only 3.5 h whereas, the oil content of algae may even exceed 80% of their dry mass (Spolaore et al., 2006). The amount of oil obtained from algae depends on the rate of their growth and on the level of biomass oil content. Microalgae with high oil content are especially desirable for biodiesel production. Table 2 enlists a number of algae species that have higher oil content.

Microalgae	Oil content (% dry matter)
B. brauni	25-75

Nitzschia laevis	69.1
Schizochytrium sp.	50-77
N. oleoabundans	35-54
Parietochloris incisa	62
Nannochloropsis sp.	31-68
C. vulgaris	40-56
Chlorella minutissima	57
Chlorella emersonii	63

Table 2: Oil content of some microalgae

Biodiesel production is called transesterification process in which highly viscous oils is transformed into alkyl esters with lower viscosity, similar to normal diesel fuel and glycerine. Transesterification requires 3 mol of alcohol for each mole of triglyceride to produce 1 mol of glycerol and 3 moles of methyl esters. This reaction is reversible in nature and arrives at equilibrium at a certain stage (Fukuda et al. 2001). The relative proportion of polar lipids to neutral lipids (triglycerides) and the high amount of long-chain polyunsaturated fatty acids (greater than C18) are common in microalgae but are not produced in significant quantities in higher plants. Both of these factors affect the efficiency of biodiesel synthesis, as well as influence the fuel properties. The production of methyl ester or biodiesel from algae starts with the site selection followed by culturing and harvesting of algae, processing of biomass, extraction of oil and finally synthesis of biodiesel by transesterification process.

A. Algal Biomass Production:

Practical methods of growing algae on a large scale include open ponds (Molina Grima, 1999) and photo bioreactors (Sanchez Miron et al., 1999). Open pond may vary in capacity, shapes and sizes depending upon the existing natural resources i.e., land and water. In open pond system for sufficient algal growth water depth of 15-30 cm is optimum as this depth facilitates the uniform distribution of sunlight to the bottom. Successful microalgae cultivation requires specific environmental conditions, which vary from species to species. The major parameters influencing biomass production include light of proper intensity and wavelength, temperature, CO_2 concentration, nutrient composition, salinities, and mixing conditions.

The problems that are associated with open ponds include contamination, uncontrolled environments, evaporation, limited species suitability, low volumetric productivities and the need for large land area. These problems led to development of a closed photo bioreactor system. Phtobioreactors are of different designs. For ex-tubular photo bioreactors, vertical bubble columns and airlift reactors, combined bubble column and inclined tubular reactors, helical photo bioreactors, and flat plate photo bioreactors (Tredici and Zittelli 1998; Sanchez et al. 1999; Berzin 2005; Ugwu et al. 2005). The closed photo bioreactor system offers better control over contamination, mass transfer, and other cultivation conditions. Photo bioreactors help the production of large algal biomass.

IV. CONCLUSION AND FUTURE PROSPECTS

Biodiesel derived from microalgae appear to be the only current renewable source that can potentially completely substitute fossil fuels because of their high productivity and high lipid content. The hurdles for the utilization of microalgae as a raw material for the production of bio fuels include the harvesting, oil extraction processes and the supply of CO_2 for high efficiency of microalgae production. However, the biggest challenge is that microalgae biodiesel are not economically competitive with fossil fuels at today's energy prices. To address this issue research dealing with improving production systems, identifying ideal microalgae and enhancing bio fuel production through genetic engineering and investigating the sustainability of microalgae bio fuel is necessary before large scale microalgae bio fuel operations.

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