Bio-Diesel From Algae“Empowering The World of Energy: A Review”

Karande Sheetal R.[1], Wagh Mahesh M. [2]

[1] *Research Student, Energy Technology, Department of Technology, Shivaji University, Kolhapur, India*
[2] *Assistant Professor, Energy Technology, Department of Technology, Shivaji University, Kolhapur, India*

---***---

Abstract - ***The two forms of energy on which today's industrial and automobile world survive is the electricity and fossil fuel energy. Electricity in India is mostly generated with the help of dams and in some sense it is renewable. Depletion of oil resources & some environmental factors have been pushing automobiles makers & scientific communities to study on the use of alternative energy source in the automobiles. These oil reservoirs are limited and hence will be exhausted. Hence, today there is great need to look after development of Bio-Diesel which will carry forward the work of fossil fuel and save the world from disaster [1].. This paper highlights the on-going developments in biofuel feedstock selection and production technologies, evaluating and environmental and economic effect of biofuel.***

Key Words: *Fossil fuel, Oil extraction, Microalgae, Depletion.*

1. INTRODUCTION

Energy is one of the most important resources for mankind and its sustainable development. Today, the energy crisis becomes one of the global issues confronting us. Fuels are of great importance because they can be burned to produce significant amounts of energy. Many aspects of everyday life rely on fuels, in particular the transport of goods and people. Main energy resources come from fossil fuels such as petrol oil, coal and natural gas. Fossil fuel contributes 80% of the world's energy needs. Most industries use diesel machines for the production process. In the transportation sector, private vehicles, buses, trucks, and ships also consume significant amounts of diesel and gasoline. This situation leads to a strong dependence of everyday life on fossil fuels. However, the growth of the population is not covered by domestic crude oil production [2, 3]. Fossil oils are fuels which come from ancient animals and microorganisms. Fossil fuel formation requires millions of years. Thus, fossil oils belong to non-renewable energy sources. An increase of the oil price often leads to economic recessions, as well as global and international conflicts. Especially in some developing countries, the great development in the economy in fossil fuel resources will be consumed in only 65 more years. In addition the emission produced by the combustion of fossil fuels also contributes to the air pollution and global warming. Hence, renewable and clean alternative fuels have received increasing attention for current and future utilization. In the era of technological advancement & scientific development we are facing problems like Air Pollution, Global Warming (Green-House Effect) and Ozone Depletion etc. In order to counteract these problems we have to take some very efficient measures like Use of Biofuels such as Bio-Diesel. Microalgae are currently the most promising source of biofuels for total substitution of fossil fuels. Distinct benefits of microalgae compared to terrestrial feedstock include, but are not limited to, their higher photosynthetic efficiencies [4], and higher productivity which can potentially produce substantially greater biomass yields per day and per unit cropping area [5, 6]. The numbers of studies that have evaluated the potential of using raw algal oil in an engine are insufficient to gain a full understanding of the likely performance of this fuel [7]. The use of raw algal oil can overcome problems related with the use of expensive chemicals and procedures during the transesterification reaction necessary to produce Bio-Diesel. The aim of this study was to evaluate the potential of using algae oil as the alternative fuel for diesel engines following controlled cultivation, harvest and oil extraction.

2. PROBLEM DEFINITION

Further fuel of energy come in the broad sense which includes different kind of energy produced from an ever obtained material. There are many type of renewable source like sun, wind, biomass, etc. But as we consider the current stage we realized the at most need for the substitution of fossil fuel energy. Fossils fuels are the largest source of energy for today's vehicles. Thus the need of their substitution is obligatory. And the best substitute for this is “BIO-DIESEL”. The following important points will be discussed to give you a clear idea and necessity about bio-diesel from algae.

i. What is Bio-diesel?

ii. From what it can be extracted?

iii. The best ways of extracting bio-diesel from algae. (i.e. its preparation and purification)

iv. Research on algae strain to get maximum algal oil.

3. LITERATURE REVIEW

The purpose of this literature review is to outline in some detail literature relevant to study the detail information of' "Bio-Diesel from algae".

Raphael Slade et al. investigated conceptual and often incomplete nature of algae production systems together with limited sources of primary data for process and scale-up assumptions, highlights future uncertainties around micro-algae biofuels production [8].

J.E. Andrade et al. reviews briefly the literature on transesterification reaction using homogeneous, heterogeneous and enzyme catalysts [17].

Panayiotis Tsaousis et al. investigated the potential of using raw oil from microalgal biomass as a direct substitute fuel in an internal combustion engine [18].

Eman M. Fakhry et al. discusses the physicochemical properties of fatty acids comprising Bio-Diesel were discussed [19].

Parag Saxena et al. reveals that there is great volume of work done in the process design and manufacturing of Biodiesel from various vegetable oils, there is experimental data and prediction models for thermodynamic properties of feed oils (vegetable oils) and other important properties of Bio-Diesel [20].

M. M. K. Bhuiya et al. introduces second generation Bio-Diesel to be used as biodiesel feedstocks. Several aspects of these feedstocks are reviewed and discussed in this paper [22].

4. WHAT IS BIO-DIESEL

Bio-diesel is nothing but the vegetable oil extract which can be used in the internal combustion engines as a substitute for Conventional, Limited, Exhaustible fossils fuels. This extract when purified can easily replace diesel hence termed Bio-Diesel. Technically speaking Bio-diesel is methyl ester of higher fatty acid.

4.1 ALGAL OIL DIFFERS FROM OTHER VEGETABLE OIL:

Any vegetable oil extracted from sun flower, coconut, groundnut, safolla etc. and also from animal fats. But as we know that sunflower, coconut, groundnut oils are edible oils and their cost also very high that is roughly 65 Rs/ lit. And if we decide to manufacture Bio-Diesel out of this vegetable oil then the method of preparation & purification will add to its cost making it around 80 Rs/lit. If we extract oil from algae we will get 6757 lb .oil/acre and 700 gallons Bio-Diesel /acre. This oil yield is higher than other oil seed.

4.2 CLASSIFICATION OF BIOFUELS

The classification of biofuels is shown in Fig. 1. These classifications are: a) Natural biofuels, b) Primary biofuels, and c) Secondary biofuels. Natural biofuels are generally derived from organic sources and include vegetable, animal waste and landfill gas. On the other hand, primary biofuels are fuel-woods used mainly for cooking, heating, brick kiln or electricity production. The secondary biofuels are bioethanol and Bio-Diesel produced by processing biomass and are used in transport sectors [1]. The secondary biofuels are sub classified into three so called generations, namely,

a) First generation biofuels,
b) Second generation biofuels, and
c) Third generation biofuels based on their different features such types of processing technology, feedstock and or their development levels [8].

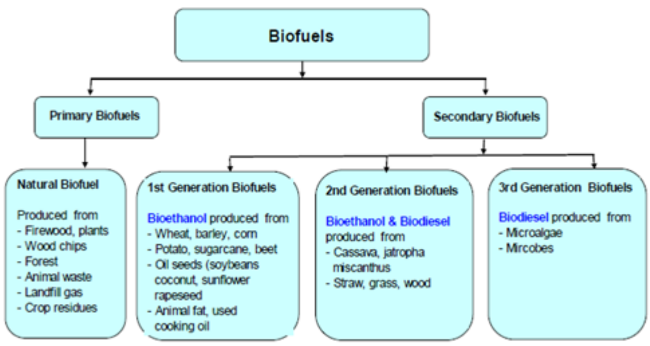


Fig.1 Biofuels production sources (biomasses) [8]

4.3 BIOFUELS PRODUCTION PROCESSES FROM MICROALGAE

The production of microalgae biomass for extraction of biofuels is generally more expensive and technologically challenging than growing crops. Photosynthetic growth of microalgae requires light, CO_2, water and inorganic salts. The temperature regime needs to be controlled strictly. For most microalgae growth, the temperature generally remains within 20°C to 30°C. In order to reduce the cost, the Bio-Diesel production must rely on freely available sunlight, despite daily and seasonal variations in natural light levels [7, 17-20]. A number of ways the microalgae biomass can be converted into energy sources which include: a) Biochemical conversion, b) Chemical reaction, c) Direct combustion, and d) Thermochemical conversion. Fig. 2 illustrates a schematic of Bio-Diesel and bioethanol production processes using microalgae feedstock [10]. As mentioned previously, microalgae provide significant advantages over plants and seeds as they: i) synthesize and accumulate large quantities of neutral lipids (20 50 % dry weight of biomass) and grow at high rates; ii) are capable of all year round production, therefore, oil yield per area of microalgae cultures could greatly exceed the yield of best oilseed crops; iii) need less water than terrestrial crops therefore reducing the load on freshwater sources; iv) cultivation does not require herbicides or pesticides application; v) sequester CO_2 from flue gases emitted from fossil fuel-fired power plants and other sources, thereby reducing emission of greenhouse gas (1 kg of dry algal biomass utilise about 1.83 kg of CO_2). In addition, microalgae offer wastewater bioremediation by removing of NH_4, NO_3, PO_4 from wastewater sources (e.g. agricultural run-off, concentrated animal feed operations, and industrial and municipal wastewaters). Their ability to grow under harsher conditions and reduced needs for nutrients, microalgae can be cultivated in saline/brackish water/coastal seawater on non-arable land, and do not compete for resources with conventional agriculture. Depending on the microalgae species other compounds may also be extracted, with valuable applications in different industrial sectors, including a large range of fine chemicals and bulk products, such as polyunsaturated fatty acids, natural dyes, polysaccharides, pigments, antioxidants, high-value bioactive compounds, and proteins [2, 8, 10, 21-28].

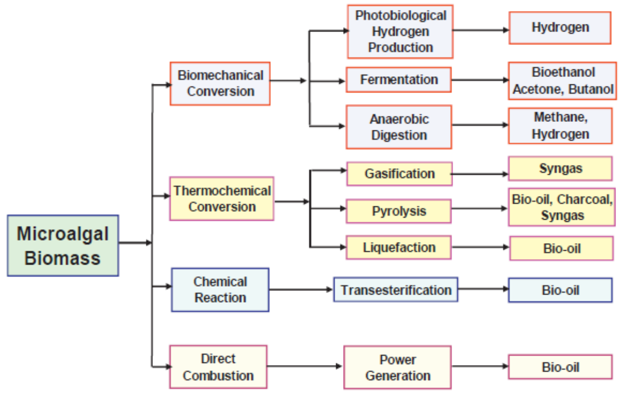


Fig.2 Biofuels production processes from microalgae biomass [2, 11]

There are different ways microalgae can be cultivated. However, two widely used cultivation systems are the open air system and photobioreactor system. The photoreactor system can be sub-classified as a) tabular photoreactor, b) flat photoreactor, and c) column photoreactor. Each system has relative advantages and disadvantages. More details about these cultivation systems can be found in [2-3, 7].

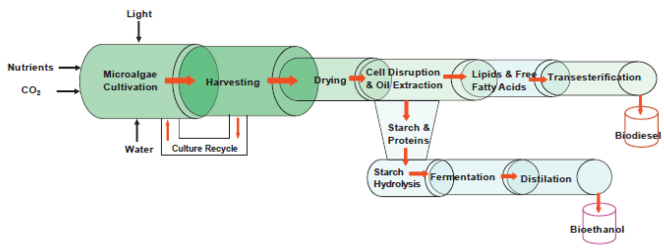


Fig.3. Biodiesel and Bioethanol production processes from microalgae [2]

The production of biofuel is a complex process. A schematic of biofuel production processes from microalgae is shown in Fig.3 The process consists of following stages:

a) stage 1- microalgae cultivation,

b) stage 2-harvesting, drying & cell disruption (cells separation from the growth medium),

c) stage 3- lipid extraction for biodiesel production through transesterification and

d) stage 4- starch hydrolysis, fermentation & distillation for bioethanol production. However, these processes are complex, technologically challenges and economically expensive. A significant challenge lies ahead for devising a viable biofuel production process [2].

4.4 Significance of various Properties of Biodiesel

There are various thermodynamic and physical properties of feed oils which are very important for the process modeling and simulation tools. Thermophysical properties of Bio-Diesel are used for the characterization of Bio-Diesel and they are also required for the combustion modeling. Physical properties of Bio-Diesel and their values or range are given below in the Table. 1.

Table. 1 Physical Properties of Biodiesel [9]

Common chemical name	Fatty Acid Methyl Ester (FAME)
Chemical Formula Range	C14-C24 methyl ester
Kinematic viscosity range (mm^2/s, at 313 K)	3.3-5.2
Density Range (kg/m^3, at 288 K)	860-894
Boiling point range (K)	>475
Flash point range	420-450
Distillation range (K)	470-600
Vapor pressure (mm Hg, at 295 K)	<5
Solubility in water	Insoluble in water
Physical Appearance	Light to dark yellow, clear liquid
Odor	Light musty/ soapy odour
Biodegradability	More biodegradable than petroleum Diesel
Reactivity	Stable, but avoid strong oxidizing agents

4.5 THERMODYNAMIC PROPERTIES

The critical properties, vapor pressure and heat of vaporization of feed oils are very important for the process modeling and simulation studies which can be carried out for various types of feed oils [13]. These include critical Temperature (T_c), critical Pressure (P_c) and critical volume (V_c). There is a dearth of thermodynamic properties for various feed oils as the experimental data is not available because of the decomposition of oils at higher temperature. This gives rise to the growing importance of accurate prediction models for these properties. Many models have already been reported, but a systematic study is not done to evaluate the models for the predictions of various thermodynamic properties.

4.5.1 KINEMATIC VISCOSITY

Viscosity is a measure of resistance to flow of a liquid due to internal friction of one part of a fluid moving over another. This is a critical property because it affects the behavior of fuel injection. In general, higher viscosity leads to poorer fuel atomization. High viscosity can cause larger droplet sizes, poorer vaporization, narrower injection spray angle, and greater in-cylinder penetration of the fuel spray. This can lead to overall poorer combustion, higher emissions, and increased oil dilution. The viscosity of Bio-Diesel is typically higher than that of petroleum diesel often by a factor of two [11].

4.5.2 DENSITY

The air–fuel ratio and energy content within the combustion chamber are influenced by fuel density. In general, densities of Bio-Diesel fuels are slightly higher than those of petroleum diesel, and increasing the level of Biodiesel blends increases the blend's density. Fatty acid methyl ester (FAME) density is strongly affected by the degree of unstauration, with higher unsaturation leading to increased density. It has been reported that Bio-Diesel density is also affected by chain length, with higher chain length leading to lower fuel density [3],[9-12].

4.5.3 CETANE NUMBER

Cetane number (CN) is a measure of a fuel's auto ignition quality characteristics. Since Bio-Diesel is largely composed of long-chain hydrocarbon groups (with virtually no branching or aromatic structures) it typically has a higher CN than petroleum diesel. The CN of pure FAME molecules increases with chain length, but this effect is masked when considering complex mixtures of FAME fuels. On the other hand, the CN of FAME fuels clearly vary with average degree of unstauration. The literature also reports that increasing degree of unsaturation leads to decreasing CN [3], [9-13].

4.5.4 CLOUD POINT, POUR POINT AND CLOUD FILTER PLUGGING POINT

Two important parameters for low-temperature applications of a fuel are cloud point (CP) and pour point (PP). Cloud point is defined as the temperature below which wax in diesel or biowax in biodiesels form a cloudy appearance. The presence of solidified waxes thickens the oil and clogs fuel filters and injectors in engines. Pour point is the temperature at which the amount of wax out of solution is sufficient to gel the fuel. Bio-Diesel has a higher CP and PP compared to conventional diesel. Cold filter plugging point (CFPP) is the lowest temperature, expressed in 1°C, at which a given volume of diesel type of fuel still passes through a standardized filtration device in a specified time when cooled under certain conditions. It is important as in cold temperature countries, a high CFPP will clog up vehicle engines more easily [2], [6],[12].

4.5.5. FLASH POINT

Flash point is inversely related to fuel volatility. The biofuel specifications for flash point are meant to guard against contamination by highly volatile impurities principally excess methanol remaining after product stripping processes [3]. The flash point values of vegetable oil methyl esters are much lower than those of vegetable oils. An increase in density from 860 to 885 kg/m^3 for vegetable oil methyl esters or Biodiesels increases the viscosity from 3.59 to 4.63 mm^2/s and the increases are highly regular. There is high regression between the density and viscosity values of vegetable oil methyl esters. The relationships between viscosity and flash point for vegetable oil methyl esters are irregular [9],[10].

4.5.6 HEATING VALUE

Due to its high oxygen content, Bio-Diesel has lower mass energy values than petroleum diesel. As the fatty acid carbon chain increases (for a constant unsaturation level) the mass fraction of oxygen decreases, so the heating value increases [11], [12].

5. METHOD OF EXTRACTION OF BIO-DIESEL

There are three well-known methods to extract the oil from oilseeds, and these methods should apply equally well for algae too:

1. Expeller/ Press
2. Hexane solvent oil extraction
3. Supercritical fluid extraction

5.1 EXPELLER/PRESS:

Expression/Expeller press-When algae is dried it retains its oil content, which then can be "pressed" out with an oil press. While more efficient processes are emerging, a simple process is to use a press to extract a large percentage (70-75%) of the oils out of algae.

5.2 HEXANE SOLVENT METHOD:

Hexane solvent extraction can be used in isolation or it can be used along with the oil press/expeller method. After the oil has been extracted using an expeller, the remaining pulp can be mixed with cyclo-hexane to extract the remaining oil content. The oil dissolves in the cyclohexane, and the pulp is filtered out from the solution. The oil and cyclohexane are separated by means of distillation. These two stages (cold press & hexane solvent) together will be able to derived more than 95% of the total oil present in the algae.

5.3 SUPERCRITICAL FLUID EXTRACTION:

This can extract almost 100% of the oils all by itself. This method however needs special equipment for containment and pressure. In the supercritical fluid/CO_2 extraction, CO_2 is liquefied under pressure and heated to the point that it has the properties of both a liquid and gas. This liquefied fluid then acts as the solvent in extracting the oil.

5.4. OTHER LESS WELL-KNOWN EXTRACTION METHODS:

-Enzymatic extraction
-Osmotic shock
-Ultrasonic-assisted extraction

5.5 REACTIONS:

5.5.1 TRANSESTERIFICATION:

Transesterification is the process that the algae oil must go through to become Bio-Diesel. It is a simple chemical reaction requiring only four step and two chemicals. Mix methanol and sodium hydroxide create sodium methoxide. Mix sodium methoxide into algae oil. Allow to settle for about 8 hours. Drain glycerin and filter biodiesel to 5 microns. Fig.4 shows output and input of the process.

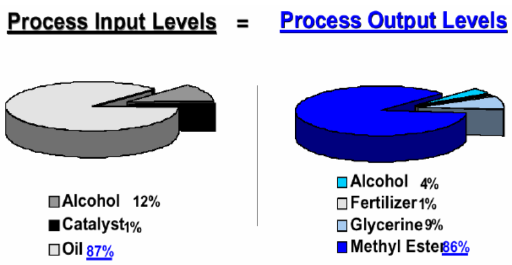
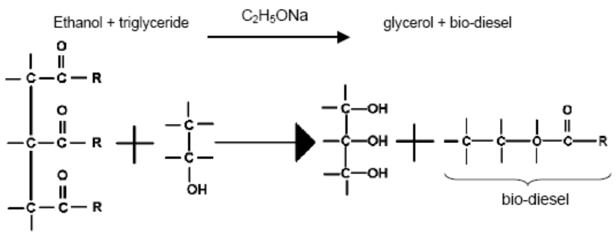


Fig.4 Output and input of the process.

5.5.2 REACTION

$$C_2H_5OH + Na \longrightarrow C_2H_5ONa$$



This biodiesel is also called as methyl soyate or methel Tallowate. Let the mixture of biodiesel glycerol settle down in a well ventilate room temperature for at least 8 hours . And what we are having now is light colored Bio-Diesel floating over the top of the glycerol and soap. By using small pump having diesel filter, the biodiesel can be separated. Now this is ready Bio-Diesel which can be directly use in diesel engine. But it is necessary to purify it further so as to reach the ASTM standard (American society of testing and material). Purification of Bio-Diesel is much simpler than its manufacturing. It's purification is known as washing as the water is the only main requirement for it.

5.5.3 WHY BIODIESEL FROM ALGAE?

Table.2 Production Averages for Common Oil Crops

Production Averages for Common Oil Crops		
Plant	**Lb. oil /acre**	**Gallons of biodiesel/acre**
Algae	6,757	700
Coconut	2,070	285
Jatropha	1,460	201
Rapeseed	915	126
Peanut	815	112
Sunflower	720	99
Soyabean	450	62

Micro algae have much faster growth-rates than terrestrial crops. The per unit area yield of oil from algae is estimated to be from between 5,000 to 20,000 gallons per acre, per year (4.6 to 18.4 l/m^2 per year); this is 7 to 30 times greater than the nest best crop. Algae can grown in CO_2-enriched air can be converted to oily substances. Such an approach can contribute to solving two major problems: air pollution resulting from CO_2 evolution, and future crises due to a shortage of energy sources.

According to some estimates, the yield (per acre, say) of oil from algae is over 200 times the yield from the best-performing plant/vegetable oils.

5.5.4 RESEARCH ON ALGAE AND BIO-DIESEL FROM ALGAE:

The idea is that carbon dioxide from coal fired power station is used to produce algae, which is used to make Bio-Diesel and natural gas. Lipid accumulation in algae typically occurs during periods of environmental stress, including growth under nutrient-deficient conditions. Biochemical studies have suggested that acetyl-CoA carboxylase (ACCase), a biotin-containing enzyme that catalyzes an early step in fatty acid biosynthesis, may be involved in the control of this lipid accumulation process. Therefore, it may be possible to enhance lipid production rates by increasing the activity of this enzyme via genetic engineering. Research into cloning the gene that encodes ACCase from the eukaryotic alga Cyclotella cryptica has been undertaken, by isolating this gene. Research found that the amino acid sequence of ACCase deduced from this gene exhibited a high degree of similarity to the sequences of animal and yeast ACCases in the biotin carboxylase and carboxyltransferase domains, but less similarity exists in the biotin carboxyl carrier protein domain. Comparison of the genomic nucleotide sequence to the sequences of cDNA clones has revealed the presence of two introns in the gene. Research teams are currently constructing expression vectors containing this gene and developing algal transformation protocols to enable over expression of ACCase in C. cryptica and other algal species. Some estimates of biodiesel production from algae using CO_2 from coal-fired power stations:

- Algae yield 100 tones/ha.
- 2.2 tonnes carbon dioxide needed / 1 tonnes algae
- Water needed $4m^3/m^2$. Most of the water is lost due to evaporation, some is consumed by the algae, and some is lost in the harvesting of the algae.
- A 500 MW coal fired power station produces 3.67x106 tones of carbon dioxide
- 3.5 barrels of biodiesel per ton algae produced

- 6 MJ methane per tone algae generated
- Energy density of LNG is 15.2 kWh/kg and density is 448 kg/m^3
- One of the more well-researched species of algae is the diatoms.

6. RESULTS & DISCUSSIONS

Many countries including the European Union (EU) have adopted policies on certain percentage of renewable energy use for transport and other relevant sectors. In December 2008, the EU signed a directive that requires 10% of member to come from renewable sources biofuels, hydrogen and green policy towards mitigation of climate change effect and global warming. The EU directive also obliges the bloc to ensure that biofuels offer at least 35% carbon emission savings compared to fossil fuels and the figure should rise to 50% in 2017 and debates among governments, policymakers, scientists and environmentalists as currently most commercially produced biofuels are derived from sources that compete with or belong to feedstock for human and animal consumption.

In terms of greenhouse gas emission, the biofuels produced from microalgae is generally carbon neutral. The CO_2 emitted from burning biofuel is assumed to be neutral as the carbon was taken out of the atmosphere when the algae biomass grew. Therefore, biofuels from microalgae do not add new carbon to the atmosphere. Biofuels can be a viable alternative to fossil fuels on short and medium terms. Additionally, advanced biofuels made from residues or waste have the potential to reduce CO_2 emissions with 90% compared to petrol/diesel.

While many years of research and development still lie ahead, if successful, algae-based fuels can help meet the world's growing demand for transportation fuel while reducing greenhouse gas emissions. However, a number of challenges remain before algae can be used for mainstream commercial applications as the uncertainty of cost constitutes the biggest obstacle. There is no doubt that research work on microalgae is still in primary stages. Currently, it is not clear that what kinds or families of algae would be most appropriate in order to produce commercially viable biofuels. Researchers are currently working on appropriate commercial cultivation processes of algae biomasses. At this point in time, there is no definitive answer to an open question if it is better to grow algae in photobioreactor system or open air (pond) system. As algae are micro-organisms of a size ten times smaller than human hair, it is a great challenge to harvest them. At present, microalgae harvestings are based on either centrifugation or chemical flocculation, which push all the microalgae together, but these processes associated with high cost [14].

Bio-Diesel or bioethanol production from algae biomass cannot be commercially viable unless by-products are optimally utilised. As mentioned earlier, the lipid or the oil part is around 30% of the total algae biomass and the remaining 70% is currently wasted which can be used as nutrients, pharmaceuticals, animal feed or bio-based products. The use of lipid as well as all by-products will allow exploring the full potential of microalgae towards sustainable environment and economy.

At present, 70-90% of the energy put into harvesting microalgae for fuel usually gets used into extracting the lipids (oil) they produce under current factory designs. It is obvious that new technologies are needed for reducing huge energy losses [15]. Microalgae have immense potentials for biofuels production. However, these potentials largely depend on utilisation of technology, input feedstock (CO_2, wastewater, saltwater, natural light), barren lands and marine environment. Based on energy content, available technology, land, it is hard to overemphasize that biofuels are a realistic short-term, but definitely not a long-term and large scale solution to energy needs and environmental challenges. Microalgae can be temporary sources of energy, and with the appropriate growth protocols they may address some of the concerns raised by the use of first and second generation biofuels [16].

7. SUMMARY & FUTURE SCOPE

The potential for production of algal biofuels has captured the attention of the nation and the world. Algal biofuels have the potential to replace a significant portion of the total diesel used today with a smaller environmental footprint. In addition, algal biofuels production can be carried out using marginal land and saline water, placing no additional pressure on land needed for food production and freshwater supplies. Finally, algal biofuels have the potential to mitigate the impact of CO_2 released from point sources. The rationale of taking up a major programme for the production of biodiesel in India for blending with diesel in context of -

- Support to agriculture sector.
- Part replacement of imported crude.
- Rural development program.
- Lubricity improver.
- Bio-Diesel being superior fuel from the environment point of view.
- Addressing global concern relating to containing carbon emission for mitigation of climate change.
- Providing nutrient to soil, by using oil cake as manure.
- Greening the country through Jatropha curcus plantation.
- Generation of gainful employment to the people.

Because of these properties it is superior to other fuels like hydrogen energy & nature dependant solar energy etc in country like India as future fuel which can make our place better in world & can reduce one cause to human Inexistence that is Global Warming.

7.1. FUTURE SCOPE.

It is likely that a significant amount of research and a number of breakthroughs are needed to make algal biofuels a commercial reality. This paper indicates that the major cost for fuel production comes from the growth and harvesting of the algal biomass.This is the main short coming of Indians.

We should not allow the foreign companies to step in our country as they will be the main profit owners and the dream of developed India will be restricted further more. We know that Bio-Diesel is capable of bringing revolution in future. And thus in spite of foreign companies stepping in our country it is time for us to establish our own international companies, and if this is done today, then tomorrow we will live in developed country like India.

REFERENCES

[1] Altinsoy AS.Biyodizel uretimi, Motorlarda Kullanimi ve Turkiye deki Kayanaklarin Incelenmesi Istanbul TeknikUniversitesi, Fen Bilimleri Enstitusu, Yuksek Lisans Tezi;2007.

[2] Demirbas, A. Biofuels securing the planet's future energy needs. Energy Conversion and Management 2009, 50,pp.2239-2249.

[3] Bull S.R. Renewable energy transportation technologies. Renewable Energy 1996, 9, pp. 1019-1024.

[4] Tang, D., Han, W., Li, P., Miao, X., Zhong, J. , CO_2 biofixation and fatty acid composition of Scenedesmus obliquus and Chlorella pyrenoidosa in response to different CO_2 levels. Bioresource Technology, 2011. 102(3):pp.3071-3076.

[5] Chisti, Y., Biodiesel from microalgae. Biotechnology Advances, 2007. 25(3): pp. 294-306.

[6] Singh J., Gu S., Commercialization potential of microalgae for biofuels production. Renewable and Sustainable Energy Reviews, 2010. 14(9): pp. 2596-2610.

[7] Haik, Y., Selim, M. Y. E., Abdulrehman, T., Combustion of algae oil methyl ester in an indirect injection diesel engine. Energy,201136(3):pp.1827-1835.

[8] Raphael Slade, Ausilio Bauen, "Micro-algae cultivation for biofuels: Cost, energy balance, environmental impacts and future prospects", biomass and bioenergy 53, (2013)pp.29to38.

[9] Demirbas, A., 2009. Progress and Recent Trends in Biodiesel Fuels, Energy Conversion and Management 50, pp.14.

[10] Chang, A. F., Liu, Y. A., 2010. Integrated Process Modeling and Product Design of Biodiesel Manufacturing Ind.Eng.Chem.Res.49,pp.1197.

[11] Hoekmana S.K., Broch A., Robbins C., Ceniceros E., Natarajan M., 2012. Review of Biodiesel composition, properties, and specifications,Renewable and Sustainable EnergyReviews16,pp.143.

[12] Ramirez-Verduzco L.F., Rodriguez-Rodriguez J.E., Jaramillo-Jacob A.R., 2012.Predicting cetane number, kinematic viscosity, density and higherheating value of biodiesel from its fatty acid methyl ester composition, Fuel 91,pp.102.

[13] Yuan, W., Hansen, A.C., Zhang, Q., 2003. Predicting the Physical properties of biodiesel for combustion modeling, American Society of Agricultural Engineers Vol. 46(6), pp. 1487.

[14] Lardon, L., Hélias, A., Sialve, B., Steyer, J. P., & Bernard, O. (2009), Life-Cycle Assessment of Biodiesel Production from Microalgae, Environmental, Science & Technology, 43(17):pp.6475-6481.

[15] Harun R., Singh M., Forde G.M., Danquah, M.K. (2010), Bioprocess engineering of microalgae to produce a variety of consumer products, Renewable and Sustainable Energy Reviews,14:pp.1037-1047.

[16] Tredici M.R. (1999), Bioreactors, photo. In: Flickinger MC, Drew SW, eds. Encyclopedia of Bioprocess Technology: Fermentation, Biocatalysis, and Bioseparation. New York, NY: Wiley, pp. 395-419.

[17] J.E. Andrade, A. Pe´rez, P.J. Sebastian, D. Eapen,"A review of bio-diesel production processes", biomass and bioenergy35(2011)1008,pp.1020.

[18]Panayiotis Tsaousis, Yaodong Wang, Anthony P.Roskilly, Gary S. Caldwell, "Algae to energy: Engine performance using raw algal oil", The 6th International Conference on Applied Energy–ICAE2014,Energy Procedia61(2014)pp.656–659.
[19]Eman M. Fakhry, Dahlia M. El Maghraby, " Fatty Acids Composition and biodiesel Characterization of Dunaliella salina", Journal of Water Resource andProtection, 2013, 5, pp.894-899.
[20] Parag Saxenaa, Sayali Jawaleb , Milind H Joshipura, "A review on prediction of properties of biodiesel and blends of biodiesel", Procedia Engineering 51 (2013) pp. 395 – 402.
[21] Kao-Chia Ho, Ching-Lung Chen, Ping-Xuan Hsiao, Meng-Shan Wu,Chien-Chang Huang, Jo-Shu Chang, "Biodiesel production from waste cooking oil by two-step catalytic conversion", The 6th International Conference on Applied Energy –ICAE2014.

[22] M. M. K. Bhuiya, M. G. Rasula, M. M. K. Khana, N. Ashwathb, A. K. Azada, M. A. Hazrata, "Second Generation Biodiesel: Potential Alternative to-Edible Oil-Derived Biodiesel", The 6th International Conference on Applied Energy – ICAE2014, Energy Procedia 61 (2014) pp. 1969 – 1972.

BIOGRAPHIES

Research Student, Energy Technology Pursuing M.Tech. in Energy Technology from , Department of Technology, Shivaji University, Kolhapur, India-416004

Asst. Professor,
Energy Technology from ,
Department of Technology,
Shivaji University, Kolhapur,
India-416004