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Biodiesel: A Review

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Abstract
Energy is considered as one of the most important factors for economic and industrial growth. With the increased use and depleting problem of fossil fuels there is a huge demand for an alternative and better source of energy. This demand promoted the emergence of biofuels among which biodiesel is considered to be the most accepted and best alternative for the depleting energy resources. Many methods like transesterification, BIOX process, super critical process etc., have been employed to produce biodiesel more efficiently from variety of sources like edible oils, non edible oils and algal oil etc. Biodiesel is environment friendly, non toxic, biodegradable, renewable as well as a neat biofuel and hence plays a significant role in meeting the energy demands.
Keywords: fossil fuels, biofuels, biodiesel, renewable, transesterification, BIOX process, supercritical process, microalgal oil.

I. Introduction

Energy is the chief mover of economic growth, and plays a vital role in sustaining the modern economy and society. Our future economic growth considerably depends on the long-term accessibility of energy from the sources that are easily available, safe and affordable. The global economic growth has seen a dramatic increase in the energy demand of the world. Energy consumption is expected to increase by 84 percent by 2035 in most of the developing countries. India faces a dreadful challenge in meeting its energy needs and in providing sufficient energy of preferred quality in various forms in a sustainable manner and at competitive prices. If India has to eradicate poverty and meet its human development goals, then it has to sustain an 8% to 10% economic growth rate, over the next 25years. For delivering a sustained growth rate of 8%, India needs to increase its primary energy supply by 3 to 4 times. New sources of energy like biofuels may play a significant role in meeting the energy demands.

Biomass sources have turned out to be more effective in the recent days because of the insufficiency of conventional fossil fuels, their price hike and increased emissions of pollutants generated during combustion. The petroleum-based fuel reserves are concentrated in only some parts of the world and these resources are depleting day by day. The likelihood of producing biofuels from locally grown sources and using them as an alternative for various petrol products is one of the best attractive method to overcome the energy crisis. Any investments in biofuels will lead to a considerable boost in economic development. It is expected that with suitable production process, biofuels will produce significantly lesser greenhouse gas emissions than are produced by fossil fuels.

II. History of biodiesel

The diesel engine came into its existence in the year 1893 when the paper titled "The theory and construction of a rational heat engine" was published by a great German inventor Dr. Rudolph Diesel [1]. The use of vegetable oil was first started by Rudolph Diesel. He developed the first diesel engine working on peanut oil at the World's Exhibition in Paris, 1900 [2]. The main focal points for biodiesel production to expand were the oil seed crops. Until 1920s vegetable oils were utilized as the source of energy in the diesel engine. The factors like profitability, availability, low sulfur content, low aromatic content, biodegradability and renewability makes vegetable oils more advantageous over diesel fuel [3]. At present higher market values for challenging uses restricted the utilization of crops for biodiesel production.

III. Why biodiesel?

The reasons behind choosing biodiesel as an alternative fuel are several. This fuel has various numbers of advantages over fossil fuels. Biodiesel can be used as a very good alternative fuel for diesel engine. Its low carbon content makes it as an alternative to heating oil. With the help of biodiesel we are cycling carbon instead of releasing stored carbon into the atmosphere. Sunlight and carbon dioxide are the two essential components necessary for the growth of a plant and the necessary carbon that is stored in the plant during its growth is same as that released during the combustion process. This results in a positive energy balance. Energy balance is defined as the ratio of comparison of energy stored in the fuel to the energy required to grow, process and distribute that fuel. The energy balance ratio of biodiesel is no less than 2.5 to 1. Bio diesel is an efficient carrier of solar energy and hence has a positive energy balance ratio. As well it degrades rapidly in the environment and is non-toxic [3]. The rate at which biodiesel degrades is same as that of sugar. Pure biodiesel degrades 85 to 88% in water within 28days. Its biodegradability can be further accelerated by blending it with diesel. Many companies have reported the use of biodiesel to breakdown and degrade oil spills. Storing biodiesel is also very safe. Virtually it has same storing and handling requirements as that of diesel storage except the use of copper, brass, lead, tin, and zinc storage containers. The well-organized storage of bio-diesel resources can provide energy security to our country [4]. Sufficient information is not available on the storage of bio diesel and its blend but based on experience it can be stored up to a maximum of 6 months. The best part of biodiesel is that it can be used in any ratio in any diesel engine with little or no necessary engine modification. Significantly, there is no change required for the existing internal combustion engine technology and infrastructure. Since billions of dollars of investment have been spent in the present engine technology, any change to that will not be acceptable and the use of bio diesel will allow the world with the continued use of the present infrastructure. The necessary infrastructure to distribute biodiesel is already in place and it basically uses the existing fossil fuel network.

IV. Significance of biodiesel

Biodiesel refers to a processed fuel resulting from the biological sources and it is equivalent to petro-diesel. Biodiesel acts as a safe alternative fuel for substituting traditional petroleum diesel. It is a clean burning fuel with high lubricity. Biodiesel produced from renewable sources acts like petroleum diesel but produces significantly less air pollution. It is bio-degradable and very safe for the environment. Biodiesel production can be achieved in different methods. Biodiesel is a mono alkyl ester of fatty acids produced from both edible and non edible vegetable oils or animal fat and various other bio fuels such as methanol, ethanol etc. [3,4].

4.1 Properties of biodiesel

Properties	Values
Specific gravity	0.87 to 0.89
Kinematic viscosity @ 40°C (mm^2/s)	3.7 to 5.8
Cetane number	46 to 70
Higher heating value (Btu/lb)	16,928 - 17,996
Lower heating value (Btu/lb)	15,700 - 16,735
Sulphur wt %	0.00 - 0.0024
Cloud point °C	-11 to 16
Pour point °C	-15 to 13
Iodine number	60 – 135
Flash point °C	120-130

Reference: [5, 6, 7]

V. Sources for biodiesel production:

In recent times biodiesel has been produced from sources like vegetable oils, animal fats, soap stock and also recycled frying oils. In order to know which vegetable oil is best suited for the production of biodiesel, certain factors like geography, climate, and economics must be considered. Vegetable oils are considered as the renewable forms of fuel and they are more attractive in environmental benefits as they are made from renewable resources. Vegetable oil potentially forms the unlimited source of energy; with an energy content equivalent to that of diesel fuel. Direct use of vegetable oil in diesel engines gives rise to many problems such as jamming and gumming of filters, lines and injectors; engine knocking; starting problem during cold weather; coking of injectors on piston and head of engine; extreme engine Wear; carbon deposition on piston and head of engine [8]. Vegetable oils are of high viscosity and in order to reduce their viscosity and to overcome their problems to enable their use in many diesel engines, a process called transesterification must be carried out. The product so formed after transesterification is called as biodiesel. Biodiesel has relatively higher heating values. Biodiesel is 100% pure and hence it is referred as “neat fuel” or “B100”. The high heating values (HHV’s) of biodiesel ranges from 39 to 41MJ/kg. Biodiesel can be utilized by blending with petrol diesel and those blends are referred as BXX where XX represents the amount of biodiesel in the blend. Pure biodiesel can be denoted as B100.

5.1 Edible sources

Biodiesel is produced from various biolipids which includes vegetable oil feedstock, waste vegetable oil, soybean oil and non-edible oils such as jatropha oil, neem oil, castor oil, etc. [9]. Algae are considered as a significant source for the production of biodiesel. The yield of biodiesel from algal oil is over 200 times the yield from that of vegetable oils [10]. Rapeseed oil, canola oil and vegetables sources such as soybean oil, sunflower oil, palm oil and animal sources are also being used. Few other biodiesel sources are tobacco seed, sorghum, jatropha, pongamia, microalgae (Chlorella vulgaris), oat, piqui (Caryocar sp.), Cynara cardunculus, fish oil, groundnut almond, andiroba (Carapa guianensis), babassu (Orbignia sp.), barley, and wheat [11]. Raw materials generally accepted for biodiesel include the oils from Coconut (copra), corn (maize), cottonseed, canola (a variety of rapeseed), olive, peanut (groundnut), safflower, sesame, soybean, sunflower seed oils, nut oils, almond, cashew, hazelnut, macadamia, pecan, pistachio and walnut. Other edible oils can be obtained from amaranth, apricot, argan, artichoke, avocado, babassu, bay laurel, beech nut, ben, borneo tallow nut, carob pod (algaroba), cohune, coriander seed, false flax, grape seed, hemp, kapok seed, lallemantia, lemon seed, macauba fruit (Acrocomia sclerocarpa), meadowfoam seed, mustard, okra seed (hibiscus seed), perilla seed, pequi, (Caryocar brasiliensis seed), pine nut, poppy seed, prune kernel, quinoa, ramtil (Guizotia abyssinica seed or Niger pea), rice bran, tallow, tea (camellia), thistle (Silybum marianum seed), and wheat germ.

5.1.1 Biodiesel Production from Waste Cooking Oil

Biodiesel production can be achieved using waste vegetable oils due to their low cost. They are collected from large food processing units and service facilities. They include several chemical reactions such as hydrolysis, polymerization and oxidation during food frying process, which leads to increased efficiency of fatty acids [12].

5.1.2 Biodiesel Production from Soapstock

Soapstock is identified as the by-product of refined vegetable oils. It is an additional low value feedstock for biodiesel production which contains an extensive amount of water of about 44.2%. They are alkaline aqueous emulsion of lipids and hence they contained little free fatty acids. However they had fatty constituents such as soaps, mono, di, tri-glycerides and phosphatides which can be easily converted into fatty acid methyl esters [13].

5.2 Non edible sources

Edible vegetable oils and animal fats for biodiesel production have become more expensive as they compete with food materials. In recent years there is an increased demand for vegetable oils since they are edible and hence they are not preferred much for biodiesel production. Some of the sourses like Pongamia glabra, Lesquerella fendleri, Madhuca indica, Chlorella vulgaris, oat, rice, rubber seed, sesame, tobacco seed, Dipteryx odorata, Cynara cardunculus, fish oil, groundnut, wheat, almond, Carapa guianensis, barley, Camelina sativa, coconut, copra, jatropha, soapnut, algae, babassu tree, copaiba, honge, jatropha or ratanjyote, jojoba, karanja or honge, mahua, milk bush, nagchampa, neem, petroleum nut, rubber seed tree, silk cotton tree, and tallare are used as non-edible plant oil sources for biodiesel production [14, 15].

5.2.1 Biodiesel Production from Jatropha Oil

There is growing interest for biodiesel production from oil sources, like Jatropha curcas L (JCL). It is a non edible oil-bearing plant, widely spread in the tropical regions of the world. Jcl is having equivalent properties to biodiesel production due to its calorific value and cetane number [16]. As a result JCL is having concern to produce biodiesel. A study made by Azam et al., says that palm oil biodiesel when blended with Jatropha biodiesel at about 20-40% will improve oxidation stability and low temperature property [17]. Hence Jatropha biodiesel has good low temperature property and palm biodiesel has good oxidative stability and also it was initiated that antioxidant dosage could be reduced by 80-90%. According to Sarin et al. jatropa seed is capable of producing a significant amount of oil for biodiesel production [18]. This is a non-edible oil-bearing plant widespread in arid, semi-arid and tropical regions of the world. Jatropha is a drought resistant perennial tree that grows in marginal lands and can live over 50 years [19].

5.2.2 Biodiesel Production from Soap nut oil

Soapnut plant grows well in deep loamy soils and leached soils, so nurturing of soapnut in such soil evades probable soil erosion. As well as it helps to produce more seeds and this acts as a feedstock for biodiesel production [20]. Soapnut is a fruit of the soapnut tree found in tropical and sub-tropical areas in various parts of the world. Soapnut oil has been considered as non edible oil to produce biodiesel [21]. Soapnut has copious purposes in the field of medicine.

5.2.3 Microorganisms as a source for biodiesel production

Lipomyces starkeyi, Rhodotorula glutinis, Yarrowia Cryptococcus curvatus, Lipomyces lipofera, lipolytica, Rhodococcus, and Nocardia are capable of producing intracellular triacylglycerides [22, 23, 24]. These microorganisms contain fats up to 80% of the cellular dry weight [25]. Microorganisms comprises of a broad string of substrates like carbon source, sugars, organic acids, alcohols, oils, and different waste products, such as whey and agro-industrial waste for triacylglyceride synthesis [26].

5.2.4 Grease as a source for biodiesel production

Greases are regarded as cheap feedstocks for biodiesel production. They include triglycerides

(TG), diglycerides (DG), monoglycerides (MG), and free fatty acids (FFA) of about 8 to 40%. A grease with 8-12 wt% FFA is sorted as yellow grease, and a grease containing >35 wt% FFA is sorted as a brown grease [27, 28, 29].

5.2.5 Microalgae as a source for biodiesel production

Use of microalgae for biodiesel production has numerous advantages in contrast with other accessible feedstocks [30 31]. Microalgae also offer feedstock for quite a few types of renewable fuels such as biodiesel, methane, hydrogen, ethanol etc. Microalgae biodiesel acts well as petroleum diesel, at the same time it decreases the productions of particulate matter such as CO, hydrocarbons, and SOx [32]. Microalgae can be grown dynamically everywhere and throughout the year, certain species of it can be reaped daily, the presence of polyunsaturates makes it suitable for cold environment and hence it is preferred more as the best source of biodiesel production [33, 34].

Table 1: Biodiesel production methods applicable for different sources

Sources	Best applicable methods
Soybeans (Glycine max)	Pyrolysis, transesterification
Rapeseed (Brassica napus L.)	Enzymatic transesterification
Coconut	transesterification
Rice bran oil (Oryza sativum)	Lipase-Catalyzed Interesterification
Barley	Lipase-Catalyzed Interesterification
Wheat Abutilon	Lipase-Catalyzed Interesterification
Peanut	transesterification
Corn	Saponification and Hydrolysis
Olive oil	transesterification
Pea nut oil	Saponification and Hydrolysis
Sunflower	Catalytic Pyrolysis
Palm oil	catalytic cracking
Jatropha	transesterification

Reference: [35, 36, 37, 38, 39, 40, 41]

Table 2: Estimated oil content and yields of different biodiesel feedstocks

Feedstocks	**Oil content (%)**
Jatropha seed	35-40
Kernel	50-60
Linseed	40-44
Neem	20-30
Pongamia pinnata (karanja)	27-39
Soybean	15-20
Calophyllum inophyllum L	65
35 Moringa oleifera	40
uphorbia lathyris L.	12-29
Sapium sebiferum L.	12-29
Sapium sebiferum L.	38-46

Rapeseed	16-18
Tung	40-50
Pachira glabra	30-60
Peanut oil	45-55
Olive oil	45-70
Corn	48
Coconut	63-65
Cotton seed	18-25
Rice bran	15-23
Microalgae (low oil content)	30
Microalgae (medium oil content)	50
Microalgae (high oil content)	70

Reference: [42, 43, 44-55]

VI. Methods of biodiesel production

Biodiesel feedstocks require some conversions to meet their regulatory standards. Primarily used technologies for the conversion of vegetable oil, microalgal oils and other crops are Using the oil directly, Blending or mixing with petro-diesel, Formation of Micro-emulsion by utilizing alcohol or any solvent, Pyrolysis, Transesterification etc. Among these the most widely used process is transesterification.

6.1 Transesterification: catalytic process

The process of transesterification emerged when Rochieder illustrated glycerol preparation through ethanolysis of castor oil in the early 1846 period. Ever since that time many parts of the world started studying ethanolysis [56]. Vegetable oils have high viscosity and in order to enable their use in the diesel engines their viscosity has to be reduced. This can be done using many processes such as transesterification, pyrolysis, micro emulsification, or by blending with petrol diesel [57, 58]. Transesterification is the widely used process. The oil extracted along with any suitable alcohol from the seeds in presence of a catalyst is subjected to this reaction. The products formed will be alkyl esters and glycerol. The alkyl esters so formed is referred to as biodiesel.

$$\text{Triglycerides} + \text{ROH} \xrightarrow{\text{catalyst}} \text{Diglycerides} + \text{R}'\text{COOR}$$

$$\text{Diglycerides} + \text{ROH} \xrightarrow{\text{catalyst}} \text{Monoglycerides} + \text{R}''\text{COOR}$$

$$\text{Monoglycerides} + \text{ROH} \xrightarrow{\text{catalyst}} \text{Diglycerides} + \text{R}'''\text{COOR}$$

In general, the catalysts used for transesterification process can be bases, acids or immobilized enzymes [59, 60]. For the Transesterification to give a high yield, the alcohol should be free of moisture and the free fatty acid content must be <0.5%. Transesterification is a reversible reaction but in the production of biodiesel, the backward reaction doesn’t take place or is negligible because the glycerol formed is immiscible with the product leading to a two phase system [61, 62]. Glycerol is removed from alkyl esters after the reaction has been carried out. The low solubility of glycerol in the esters makes its separation occur quickly and can be accomplished by settling or centrifugation processes [63]. To enhance the separation of glycerol, water is added to the reaction mixture after the transesterification process is complete. Once glycerol has been separated, the alkyl esters will enter a neutralization step and then excess alcohols will be removed and then water washing is done. Acids will be added to the biodiesel product for neutralizing the residual catalyst and to split out any soap that would have been formed during the reaction process. The soaps formed will react with acids and form water soluble salts and free fatty acids. Water washing process will remove the soluble salts and the free fatty acids will stay in the biodiesel. Neutralization step prior to washing decreases the amount of water needed and reduces the potential for emulsions to form when the wash water is added to the biodiesel [64]. Transesterification process depends on water content of fats or oils, temperature of the reaction, catalyst, reaction time as well as on the fatty acid content [65].

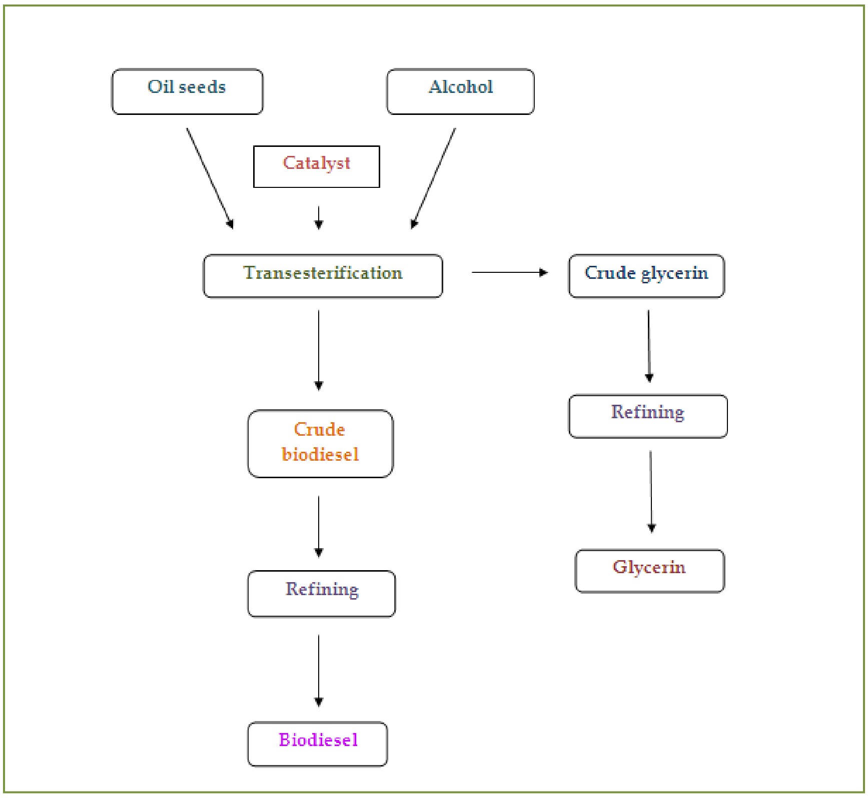

Fig 1. Production of biodiesel

Table 3: Transesterification by acid catalyst and base catalyst.

Catalyst type	Examples	Problems
Acid catalyzed transesterification	Methanolic sulfuric acid, ferric sulfate, sulfonic acid, methanolic hydrogen chloride, methanolic boron trifluoride.	High alcohol content favors the formation of alkyl esters but the reaction is very slow and glycerol recovery becomes difficult if alcohol content is more.
Base catalyzed transesterification	KOH and NaOH	Potassium methoxide causes complete esterification compared to sodium methoxide but because potassium has high heat of reaction with methanol, sodium methoxide is preferred. The reaction proceeds slowly with high molecular weight alcohols.

Ref [66, 34, 61, 64]

6.12 Enzymatic Transesterification

Even though biodiesel have been effectively produced by chemical method, there are certain problems associated with it such as glycerol recovery and the necessity to use refined oils and fats as primary feed stocks [67]. To overcome all this, an enzyme called lipases has been used as a catalyst for the production of esters [68]. Unfortunately, the transformation of waste oils into biodiesel is highly complicated and cost effective with chemical catalysts so lipases were preferred [65, 67]. Favorable factors for the use of a specific enzyme are selected based on the origin and formulation of lipases [69]. In the synthesis of alkyl esters, lipase catalysis has many advantages over chemical methods. Some of them are the capability to esterify both glycerol and free fatty acids in a single step; reusing ability of the catalyst and production of glycerol side stream with minimum or no inorganic material and with very low water content. Lipases from fungi and bacteria are frequently used for transesterification process. Initially sunflower oil was used as a feed stock for biodiesel production using enzymatic methods. Among the lipases used the immobilized lipases obtained from *Pseudomonas* species gave better results. Almost 99% conversion was obtained when ethanol was used. Studies shows that when the reaction was carried out repeatedly only 3% product was obtained with methanol, 96% with absolute ethanol and 70-82% with 1-butanol. The rate of reaction also depends upon the amount of water added. To obtain maximum conversion with methanol, water should not be added but for other solvents addition of water is necessary as it increases the rate of reaction by 2-5 times [70]. Many lipases were studied for their capability to transesterify tallow with alcohols and according to that study an immobilized lipase obtained from *R.miehei* showed maximum ability to convert tallow to its subsequent methyl ester [71]. Nowadays because of the high cost of lipases the enzymatic method is not preferred much and other problems associated with it are the inactivation of lipases by the feed stock contaminants and by polar short chain alcohols [66].

6.2 Non-catalytic Transesterification

Non catalytic Transesterification doesn't require an additional purification process as it doesn't include any catalyst. Not only triglycerides but also free fatty acid can be converted into fatty acid methyl ester by this process. There are two types of non catalytic transesterification process. One is BIOX process and the other is supercritical process.

6.2.1 Biox Process

This process was developed by Professor David Boocock from the University of Torronto. BIOX process makes use of a co-solvent which helps to overcome the slow reaction time [68]. Tetrahydrofuran is used as the co solvent in this biox process which solubilizes methanol and brings about a very fast reaction. Catalyst residues are not found in the glycerol as well as in the ester phase. The reason to choose tetrahydrofuran as a co solvent is that it has a boiling point close to methanol. It is easy to remove excess methanol as well as tetrahydrofuran in a single step once the reaction is complete. This process needs an operating temperature of about 30°c. Nowadays many co-solvents like Methyl tert-butyl ether (MTBE) have been studied to carry out this process. There is a clean separation of glycerol and the ester. The products obtained finally are water and catalyst free. It is also very easy to recover and recycle the co-solvent [68].

6.2.2 Supercritical Process

Conventional transesterification process makes use of either acid catalyst or base catalyst but it consumes a lot of time and separation of catalyst and product becomes very difficult. Kusdiana, Saka and Demirbas have given a solution to overcome these problems. They told that biodiesel can be produced by a non catalytic, supercritical process using supercritical methanol [71]. The problems because of the two phase nature of oil mixtures/methanol can also be overcome by supercritical transesterification process. Since supercritical methanol has very low dielectric constant, there is formation of a single phase than the formation of two phase, methanol and oil mixture. Purification of the products is also easy with this method and the reaction time is less. Supercritical transesterification process is eco-friendly and consumes very less energy [72]. A fluid or a gas exhibits strange properties whenever they are subjected to temperature and pressure above critical points. At that point only fluid phase exists. According to this method the alcohol to oil ratio must be high. Studies reveal that when oil reacts with excess methanol at high temperatures and pressures, it gives alkyl esters at a very short period of time. This may occur within 3 to 5min and in order to avoid the products from decomposing the reaction must be quenched very quickly [73].

VII. Current status of biodiesel

The current research is on finding more appropriate crop sources and to enhance the oil yield for biodiesel production. With respect to the present yield, large amount of fresh water and land is necessary to produce sufficient oil in order to completely replace the use of fossil fuels. Almost 0.53billion m3 of biodiesel is necessary in order to replace all the transport fuel in US as per the present rate of consumption but sources like oil crops, waste cooking oil, soap stock, jatropha oil cannot meet this demand. Therefore by using microalgae this situation can be overcome. Microalgae grow well in the aquatic environment as it provides necessary water, CO_2 and nutrients. When comparing with land crops, Microalgae have simple structures and can be grown very abundantly throughout the year. They have high photosynthetic efficiency with a growth doubling time less than 24hrs. Valuable products such as animal feeds, proteins, pigments, polysaccharides, fertilizers etc can be produced by microalgae. The contribution of microalgae biodiesel to emit Carbon-di-oxide and sulphur into the atmosphere is nearly zero. This is the only microorganism that can completely replace the usage of fossil fuels [74]. They are not specific to climatic conditions or environmental conditions hence can be grown in all conditions. Microalgae have rich oil content about 20% to 50% than others. Dry biomass weight of some microalgae may exceed 80%. Open ponds, raceway pond and tubular photo bioreactors are some of the sensible methods used for the large scale production of microalgae [75, 76, 78]. When coming to the source as microorganisms, microalgae is preferred as the best source in production of biodiesel as it can easily synthesize lipids that can convert into biodiesel. Microalgae also removes nitrogen, carbon-di-oxide in air, phosphorous content in waste water and the concern about global warming makes the micro algal biodiesel more attractive. As there is techno-economic constraints microalgae-based biodiesel is not realized commercially particularly in areas of mass cultivation and downstream processing

[79, 80]. The biodiesel obtained from micro algae has many advantages. It's non-toxic, bio-degradable and doesn't contain any sulfur. Certain species can be cultivated daily. The oil extracts of algae can be processed into ethanol and can be used as live stock feed. The carbon emissions can also be reduced depending on where it's grown [77].

VIII. Development of microalgae biodiesel in India

Expertise from the field of biotechnology, chemical engineering and chemistry are very much required to develop the algal technology. In India, the department of biotechnology (DBT) has initiated many algal networks. Numerous projects on various aspects of algal technology were funded in Universities and R&D institutes. DBT has sponsored bio-energy centres like DBT- ICGEB centre, DBT-ICT Centre for Energy Biosciences; DBT-IOC Centre of Advanced Bio Energy Research has also been made a part of the algal network [81].

IX. Conclusion

Fossils fuels are non renewable forms of energy resources and they are depleting day by day so the production of biofuels such as biodiesel is increasing rapidly. Biofuels like biodiesel are renewable, eco-friendly and non-toxic energy resources. Biodiesel is similar to petroleum diesel in its properties but biodiesel emits very less amount of CO_2, sulfur and particulates compared to petroleum diesel. It can be produced by a simple transesterification process using acid or base catalyst or enzymes as catalyst. Enzymatic transesterification process using lipases gave high yield of biodiesel but because of the high cost of lipases, enzymatic transesterification is not much followed. But catalytic transesterification has several problems like removal of catalyst and product purification etc., so non catalytic transesterification such as BIOX process, supercritical process have become the most preferable method for biodiesel production. Recent studies show that microalgae are the best and an ever green source for biodiesel production as microalgae has many advantages over other conventional sources.

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