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Third Generation Biofuel from Algal Products- A Review

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Abstract

Presently, the main source of energy is non- renewable, which are once gone have very little chance of recovery or production or synthesis. Their quantity is fixed/ limited on the earth. The non- renewable sources of energy include coal, petroleum, diesel and natural gas which are derived from the fossil remains of organic matter found deep in the earth. Nuclear power is also a non- renewable source of energy and their reserves are also limited. These naturally available resources are at the brink of extinction. These fossil fuels contribute to a lot of air pollution in the atmosphere. The growing consumption of fossil fuels is also attributing to health problems among populations. It is deteriorating the environment day by day and also causing global warming as these are major contributors of greenhouse gas emissions. Therefore, the present need of the hour is an alternative fuel which is renewable, clean and can be easily extracted. Unfortunately, biodiesel from oil crops, waste cooking oil and animal fat cannot realistically satisfy even a small fraction of the existing demand for transport fuels. It can be obtained from a variety of plant materials including algae. Microalgal species can be cultivated to produce 15-300 times higher energy sources than plants, which also reduce the land area for cultivation and continuously increase the yield per unit area. Algae have long been recognized as potential feedstock to produce oils and have been considered as promising feedstock for the production of liquid biofuels.

Keywords: Biodiesel, Environment, Fossil fuel, Algae, Organic matter.

Introduction

Environmental quality is degrading very fast due to increasing population, industrialization and overexploitation of non- renewable natural resources. Fossil fuels are being used without giving a thought.

They are in finite quantities which are depleting very fast and will vanish one day. The process of its formation is very slow which could not fulfill our demand with the rate we are utilizing the fuel. Moreover, these fossil fuels also increase air pollution and global warming. CO_2 level in atmosphere is increasing due to burning of fossil fuels and the carbon locked within the earth's crust is released into the atmosphere as exhaust gases. Though fossil fuels are plentiful, but it is required to find a renewable alternative source. Fossil fuels are sure to finish eventually. So, it is the demand of the day to find an alternative which can convert plant material to biofuel. Biofuels are referred to solid, liquid or gaseous fuels derived from organic matter. It would explicit green chemistry principle of using plant source as starting material. Presently, renewable sources of energy are best alternative for sustainable power supply with the aim of reducing contaminants in the atmosphere (Gao *et al*., 2010; Richardson *et al*., 2012 and Rashid *et al*., 2014).

Concept of using vegetable oil as a fuel dates back to 1895, when Dr. Rudolf Diesel developed the first engine to run on vegetable oil. He demonstrated his engine at World Exhibition in 1900, which runs on Peanut oil as a fuel. Before World War II, biodiesel was introduced in South Africa to power heavy duty vehicles. Of late, environmental and economic concerns have renewed the interest in biodiesel throughout the world, especially in Europe, where it is in use since 1990s.

Biodiesel is a diesel fuel derived from animal or plant lipids (oils and fats). Biodiesel is monoalkyl esters of long chain fatty acids. It is synthesized through a process called transesterification between fatty acids or triglycerides with short chain alcohols mainly ethanol or methanol in presence of suitable catalyst (Rawat *et al*., 2013 and Garlapati *et al*., 2017). It can be obtained from a variety of plant materials including algae. Biodiesel derived from oil crops is a potential renewable and carbon neutral alternative to petroleum fuels.

Necessity of Biofuel

Algae can be converted into various types of fuels depending on the the part of cells used. Unfortunately, biodiesel from oil crops, waste cooking oil and animal fat cannot realistically satisfy even a small fraction of the existing demand for transport fuels. It can be obtained from a variety of plant materials including algae. But, microalgae, the only source of renewable biodiesel that is capable of meeting the global demand for transport fuels *(Chisti, 2007)*. In 1942, Harder and Von Witsch were the first to propose that microalgae can be grown as a source of lipids for food or fuel. The need for alternative transportation fuel had subsided after World War II and the research was diverted towards algal culture for the food production and wastewater treatment (Borowitzka, 2013). Interest in the application of algae for biofuels was rekindled during the oil embargo and oil price surges of the 1970s, leading the US Department of Energy to initiate Aquatic Species Program in 1978. The final report suggested that biodiesel could be the only viable method by which to produce enough fuel to replace current world diesel usage (Negoro *et al*., 1991). Thus, the study is aimed to consolidate the information on biodiesel production from algae as a potential source for future.

Concept

Microalgae are presently being promoted as an ideal third generation biofuel feedstock because of its fast growing rate with the utilization of CO_2 and capable of producing lipids in high quantity. In the environment the CO_2 concentration is very high which is a main contributor for global warming. It can be trapped through the process of photosynthesis in plants. It is calculated that terrestrial plants can use only 3-6% of global CO_2 emissions whereas, microalgae can use 10-50 times higher because of their fast growth rate (Cuellar-Bermudez *et al*., 2015 and Yuan *et al*., 2019). Microalgal species can be cultivated to produce 15-300 times higher energy sources than plants, which also reduce the land area for cultivation and continuously increase the yield per unit area (Chisti, 2007 and Yun, 2015).

Algae have been used as food for human beings and animals since many years. Essential fatty acids derived from algae are used in the treatment and prevention of diseases. Some are also used as source of pigments as natural colourants. Algae have long been recognized as potential feedstock to produce oils and have been considered as promising feedstock for the production of liquid biofuels. Oil productivity of many microalgae greatly exceeds the oil productivity of the best producing oil crops. As algae do not have to produce structural compounds such as cellulose for leaves, stems, or roots, and because they can be grown floating in a rich nutritional medium, microalgae can have faster growth rates than terrestrial crops. Also, they can convert a much higher fraction of their biomass to oil than conventional crops, e.g. 60% versus 2-3% for soyabeans (Tornabene *et al*., 1983). Algal oil yield has been estimated to be from 58,700 to 136,900 L/ha/year, which is 10 to 23 times, as high as, the next highest yielding crop, oil palm, at 5950 L/ha/year (Atabani *et al*., 2012). It suggests that oil productivity of many microalgae greatly exceeds the oil productivity of the best producing oil crops.

Contribution of India is only 1% of total global biofuel production with biodiesel contribution of 45 million litres and 80 million litres of ethanol production (Garlapati *et al*., 2017). Requirement of biodiesel is five times more than gasoline in India. Hence, Government of India has implemented National Biodiesel Mission (NBM) in 2009 for commercialization of biodiesel. *Jatropha curcas* was most common substrate for biodiesel production earlier because of its potential to use wasteland efficiently (Chanakaya *et al*., 2012). Centre for *Jatropha* Promotion and Biodiesel made efforts for crop-based biodiesel production in India but the mission remained unsuccessful due to inadequacy of oil content and requirement of large area for cultivation of crops (Garlapati *et al*., 2017).

Frequently used biofuels are biodiesel, bioethanol and bio-hydrogen (Chia *et al*., 2017). Among all, biodiesel is commonly used as it is carbon neutral fuel (Show *et al*., 2017). There are many attractive features which encouraged scientists towards algae for its use as biodiesel. The most attractive characteristic feature is that they can be grown with minimal efforts in freshwater resources and even in harsh conditions like in saline and wastewaters (Sharma and Singh, 2017). They have a high flash point, biodegradable and relatively harmless to the environment if spilled (Demirabs, 2009,2011). Algal fuels are green in nature considered as sustainable and economic sources of energy.

Process of biodiesel production involves chemical reactions of trans-esterification and esterification. In above process oils and fats are being reacted with short chain alcohols (typically methanol or ethanol) with low molecular weight. But, microalgae-based biofuels are not yet economically feasible due to high operating costs and large energy demands. In spite of that algae are claimed to yield between 10 to 100 times more fuel per unit area than second generation biofuel crops (Greenwell *et al*., 2009). Experiments on *Chlorella pyrenoidosa* were performed and found that under nitrogen deficient conditions it can accumulate about 70% lipids of its dry weight (Aach, 1952).

Future Perspective of Third Generation Biofuel

Microalgal products has been gaining importance in recent years as an alternative non- polluting fuel source for the production of biofuel. But the industry faces economic challenges. At present, many countries like Iran, Israel, Japan, Bulgaria, France, Greece, Italy, Netherlands, Portugal, Spain, United States of America, United Kingdom, Canada, Mexico, Australia and New Zealand are focussing on the production of algal based biofuel as green energy source. Algal biofuel is in great demand in Malaysia, Indonesia, Brazil and other European countries for its production.

Many companies are currently innovating algal biofuel technologies. Algenol biofuels, Blue marble production, Sapphire energy, Solazyme, and Diversified technologies Inc. are contributing in the production of biodiesel from microalgal products. Whereas, Solazyme, Sapphire energy and Algenol have begun commercial sale of algal biofuel in 2012 and 2013, and 2015, respectively. Most efforts had been abandoned or changed to other applications, with only a few remaining by the year 2017.

Algenol Biofuels was established in 2006. Algenol is a global, industrial biotechnology company that is commercializing its patented algae technology for production of ethanol and other fuels. In Southwest Florida, Algenol's patented technology enables the production of the four most important fuels (ethanol, gasoline, jet and diesel fuel) using proprietary algae, sunlight, carbon dioxide and saltwater. Reliance Industries in collaboration with Algenol, USA commissioned a pilot project to produce algal bio-fuel in the year 2014. *Spirulina* rich in proteins content has been commercially cultivated in India. Algae is used in India for treating the sewage in open/natural oxidation ponds This reduces the Biological Oxygen Demand (BOD) of the sewage and also provides algal biomass which can be converted to fuel.

Solazyme is one of a handful of companies supported by oil companies such as Chevron. It has developed a process to use up to 80% of dry algae as oil. This process requires algae to grow in a dark fermentation vessel and be fed by carbon substrates within their growth media. The effect is the production of triglycerides that are almost similar to vegetable oil (Nathan, 2013). Oil refineries can further take this algal oil and turn it into biodiesel, renewable diesel or jet fuels.

Sapphaire Energy is a leader in the algal biofuel industry backed by the Wellcome Trust, Bill Gates' Cascade Investment, Monsanto. After experimenting with production of various algal fuels beginning in 2007, the company now focuses on producing what it calls "green crude" from algae in open raceway ponds. In 2013, Sapphire began commercial sales of algal biofuel to Tesoro, making it one of the first companies, along with Solazyme, to sell algae fuel in the market (Andrew, 2013).

Diversified Technologies Inc. has created a patent pending pre-treatment option to reduce costs of oil extraction from algae. It developed a technology, called **Pulsed Electric Field (PEF) technology**. It is a cheap and low energy process that applies high voltage electric pulses to a slurry of algae. The electric pulses enable the algal cell walls to be ruptured easily, increasing the availability of all cell contents (lipids, proteins and carbohydrates), allowing the separation into specific components downstream. This alternative method to intracellular extraction has shown the capability to be both integrated in-line, as well as, scalable into high yield assemblies. The Pulse Electric Field subjects the algae to short, intense bursts of electromagnetic radiation in a treatment chamber, electroporating the cell walls. The formation of holes in the cell wall allows the contents within to flow into the surrounding solution for further separation. PEF technology only requires 1-10 microsecond pulses, enabling a high-throughput approach to algal extraction.

Preliminary calculations have shown that utilization of PEF technology would only account for $0.10 per gallon of algae derived biofuel produced. In comparison, conventional drying and solvent-based extractions account for $1.75 per gallon. This inconsistency between costs can be attributed to the fact that algal drying generally accounts for 75% of the extraction process (Gieskes, 2008). Although a relatively new technology, PEF has been successfully used in both food decontamination processes, as well as, waste water treatments (EPA, 2013).

Biofuel production from microalgae has been gaining importance in recent years as an alternative non-polluting fuel source, but the industry faces economic challenges. Producing algae biofuel is not yet a cost-effective replacement for gasoline, but alterations to current methodologies can change this. Carlos *et al*. (2014) presented a feasible technology of bio- oil production from microalgal biomass through fast pyrolysis which is cheap and simple/ easy in operation.

Since, terrestrial plant sources of biofuel production simply do not have the production capacity to meet current energy requirements, microalgae may be one of the only options to approach complete replacement of fossil fuels. Regional production of microalgae and processing into biofuels will provide economic benefits to rural communities.

Environmental impact of Biodiesel

Production of biofuel from algae offers an alternative feedstock to reduce dependency on fossil fuel and will assist in maintaining healthy global environment. There is clearly a demand for sustainable biofuel production, but whether a particular biofuel will be used ultimately depends not on sustainability but cost efficiency. Therefore, research is focusing on cutting the cost of algal biofuel production to the point where it can compete with conventional petroleum (Chisti, 2007). Algae can be easily grown on lands which are useless for ordinary crops with the use of water from salt aquifers which is non- potable and also can't be utilised in agriculture too. When used in a microalgal bioreactor, harvested microalgae will capture significant quantities of organic compounds, as well as, heavy metal contaminants absorbed from wastewater streams that would otherwise be directly discharged into surface and ground-water (Smith *et al*., 2010). Moreover, this process also allows the recovery of phosphorus from waste, which is an essential but scarce element in nature, the reserves of which are estimated to have depleted in the last 50 years (Kumar *et al*., 2010).

Another possibility is the use of algae production systems to clean up non-point source pollution, in a system known as an algal turf scrubber (ATS). This has been demonstrated to reduce nitrogen and phosphorus levels in rivers and other large bodies of water affected by eutrophication and systems are being built that will be capable of processing up to 110 million litres of water per day. ATS can also be used for treating point source pollution, such as the wastewater mentioned above, or in treating livestock effluent (Mark, 2010; Adey *et al*., 2011 and Dixner, 2013). This opens a new strategy to produce biofuel in conjunction with wastewater treatment, while being able to produce clean water as a byproduct.

It can also be grown on the surface of oceans in bags or floating screens. Most of the researchers and scientists emphasized on monoculture for the production of biofuel but researches have proved that polycultures/ heterocultures would give more yield of biofuel. Moreover, polyculture communities are more stable and will also reduce the environmental impact on algal biofuel industry (Groom *et al*., 2008). Algae is a cleaner source of energy and results in a much less significant footprint due to higher oil productivity than other oil crops (Smith *et al*., 2010). Algal cultures require no external subsidies of insecticides and herbicides but terrestrial crops need them thus prevent environment.

As compared to petroleum, it is much less toxic and can degrade more readily than petroleum- based fuels (EPA, 2013). Acién Fernández *et al*. (2012) studied algae and showed that replacing fossil fuels with renewable energy sources, such as biofuels, have the capability of reducing CO_2. An algae-based system could capture approximately 80% of the CO_2. Algal biofuel does not produce any sulphur oxides or nitrous oxides and produces a reduced amount of carbon monoxide, unburned hydrocarbons and reduced emission of other harmful pollutants (Hemaiswarya *et al*., 2012).

However, due to the flammable nature of any combustible fuel, there is potential for some environmental hazards if ignited or spilled. Algal biofuel is less hazardous as compared to fossil fuels, due to its ability to be produced in a much more localized manner and due to the lower toxicity overall, but the hazard is still there nonetheless. Therefore, algal biofuels should be treated in a similar manner to petroleum fuels in transportation and use, with sufficient safety measures in place at all times. Despite numerous reports are available on effective biofuel production from microalgae, the process scaling up and its commercialization is still not very easy.

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