Site Selection for Large-Scale Algae Cultivation towards Biodiesel Production

Vasudevan Tachoth[1*], Aleena Rose[2]

[1]Director, Narayani Institute of Fundamental Research, Coimbatore-641021, Tamil Nadu, India

[2]Research assistant, Narayani Institute of Fundamental Research, Coimbatore-641021, Tamil Nadu, India

(vasudevan@nifrindia.org, aleena@nifrindia.org)

[*]Corresponding Author; Vasudevan Tachoth, Narayani Institute of Fundamental Research, Premises of Nirvan Industries, Door No. 1 & 2, SIDCO, Kurichi, Coimbatore-641021, Tamil Nadu, India, Tel: +91 9361616688, vasudevan@nifrindia.org

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Abstract- Fuel deficiency is one of the severe threats confronted by the whole world. This foreshadows about a situation where the resources would be insufficient to meet the energy requirements of industries, automobiles, and household equipments. Biofuels have been attracting the scientific world with its properties similar to that of fossil fuels and the capability to get renewed. Alga is widely studied owing to its high lipid content and potential to produce larger quantity of oil than other crops. When compared to food crops and other raw materials, alga is the best feedstock for biodiesel. The requisites for algae cultivation can be met easily which are fewer than that for food crops. But some hurdles are inhibiting the high productivity of algae and profitable algae farming. Lack of suitable sites is the major sticking point that hauls the production of biodiesel to the lowest. This article discusses the survey conducted for the selection of sites pertinent for large-scale algae growth aiming at a high yield of biodiesel. Maps of surveyed locations and charts showing the importance of algae cultivation have been included. The manuscript elaborates the geographical features of each location and shows their aptness to be selected as algae farming sites. Comparison of oil yield from different crops has been shown through graphs. Information regarding algae, similarity of biodiesel to petroleum products, implementation of algae as the feedstock for biodiesel, different processing techniques available for biodiesel production via extraction of oil from algae etc is also comprised in the article.

Keywords Algae, biodiesel, fossil fuel, cultivation, barren lands, seawater.

1. Introduction

The revolutionary inventions conceived by human beings marked new epochs in the history. While we study the human life from Stone Age to this century we could perceive many developments which turned out as revolutions. Starting with tools made out of stones they created a lot of technologies and finally reached this computer era and still continuing the expansion. When the humankind progress on one side, some factors draw them to the rear. The foremost issue is fuel deficiency [1]. Most of the technologies rely on energy from fossil fuels. Fossils are the remnants of living beings, such as plants and animals, obscured within the earth above millions of years ago. These transformed into energy sources called fossil fuels through a prolonged process over mega-years. Thus, these fuels are non-renewable because of the above-mentioned extensive course of action. Coal, oil, and natural gas are the three major types of fossil fuels. Automobiles, industrial machinery, spaceships, household equipment etc need fuels for their good working condition [2]. Power plants for generating electricity, which is our prime requirement, also necessitate fossil fuels. Fundamental needs of a human being include water, food, cloth, and shelter. But with these, we just live instead of leading a quality life. Because energy acquired from fossil fuels is essential in every aspect of our life [3]. Just think about a situation of cooking food without liquefied petroleum gas or microwave oven. InterContinental communication which paved the way for modernization was caused by fastness of different means of transport. This rapid growth in transportation was achieved as a result of the implementation of fuels. From this, we can understand the importance of fossil fuels in our day-to-day life. If the current tradition continues without an alternative, once, these sources may finish off due to the higher usage rate. Then people may travel in bullock-carts and use firewood for cooking. That day is not so far.

Nowadays, scientists are researching for cost effective and highly productive renewable energy sources [1,4]. Solar energy, which can be converted to electrical energy, is utilized for many purposes like streetlights, traffic signal lights, cooking, water heater etc but it cannot replace other types of energy since it is very expensive. Also, this method is not applicable when the atmosphere is cloudy and at night times. Likewise other renewable energy types-wind energy, tidal energy, and geothermal energy- also have particular limitations [5]. Owing to these reasons search for a substitute continued and it ended in biofuel. Biofuels are renewable, nontoxic energy resources that are formed by carrying out different processes on agricultural, domestic, or industrial wastes and plants [1]. Bioethanol, biodiesel, vegetable oil, biofuel gasoline, green diesel, biogas etc are the biofuels available today [6]. Petroleum products are the widely used fuels for energy consumption in automobiles and industrial machinery [4]. An alternative to petroleum products, which has more advantages and capability to overcome the existing drawbacks, is biodiesel [7,8]. It is biodegradable and harmless. Compared to petroleum-based diesel, biodiesel has a favorable combustion emission profile [5]. That means it does not emit carcinogenic gasses like carbon monoxide and hydrocarbons [8]. Biodiesel can be obtained from oils synthesized using crops such as soybean, corn, sugarcane, rapeseed, mustard, jojoba, jatropha, palm, sunflower, coconut etc, algae, and animal fats [7]. Among these, algae are broadly studied for biodiesel production because of its fewer demands [9,10]. Most of the terrestrial crops need fresh water, specific climatic conditions, and chemical fertilizers for high yield. Vegetable oils are promising feedstocks for biodiesel, but use of this raw material may cause competition with the edible oil market which may increase both the cost of edible oil and biodiesel [2,4]. The requisites of algae are contradictory to those of other crops. Any kind of water-fresh, briny, wastewater- is suitable for algae cultivation [11,12]. Nitrogen and phosphorous are primarily required nutrients and these can be acquired from wastewater [13]. Thus, factors leading to high costs like fresh water and chemical fertilizers are not necessary for algae growth [14]. Any type of weather is apposite for its farming. The experiments conducted in laboratories, as well as algae farms, show the ability of this plant to effectively capture carbon dioxide (CO_2) and thereby to balance the CO_2 content in the atmosphere [3,15]. Thus, biodiesel production from algae is accompanied with two major benefits: (1) recycling of wastewater and (2) reduction of toxic gasses which then directs to pollution control [16,17]. Algal biodiesel exhibits almost similar properties as that of petroleum-based diesel and biodiesel from other plants. If the idea of making biodiesel from algae is executed with hundred-percentage competence, fuel deficiency will be avoided. But most of the companies fail to achieve this value due to some problems [18]. Research on algae-based biodiesel production has been started over years ago. But the difficulties involved in the synthesis processes have not been solved. The major problem is the requirement of a large amount of water and nutrients. Research shows that approximately 6000 liters of water is consumed when 1 liter of algal oil is produced [22]. Although algae cultivation is possible in wastewater, some factors inhibit the growth of algae thereby affecting the biomass and lipid productivity. Influence of each type of wastewater on the algae growth has been studied in an article [12]. An excessive amount of nutrients present in the agricultural wastewater and metal particles there in the industrial wastewater are the important factors that slow down the algae growth. Another crisis is the high capital desired for carrying out the whole procedures. Particular methods employed for harvesting and extraction phases are highly expensive. Techniques like centrifugation and coagulation are examples for this [5,13]. Cost effective methods can be utilized to settle this problem, but they result in low lipid productivity and reduced quality. Most of the modes have their own disadvantages such as greenhouse gas emission, time consumption, energy consumption etc. and hence, new ideas to be introduced to overcome these drawbacks. The two main approaches for cultivation, open and closed systems, have some negative aspects. An open system is not resistant to contamination and this may affect the quantity of output. There is also a chance of water loss through evaporation. Closed systems are high-priced and the production is extremely energy consuming. The photobioreactor is a good exemplar for this. Their cleansing process is also very difficult. These are the key problems included in the biodiesel production from algae.

The purpose of this manuscript is to study the limiting factors of algae cultivation and provide feasible solutions for overcoming those issues. A literature survey has been carried out in order to study the problems faced during algae farming. Shortcomings associated with each type of cultivation system are particularly discussed in the article.

2. Methods

Open systems, closed systems, fermentation, hybrid systems, integrated systems, and excretion processes are the methods used for algae growing. In an open system, algae are cultivated in natural or manmade pools. These pools should be shallow (approximately one-foot depth) or else sunlight deficiency occurs and it leads to inefficient photosynthesis [6]. Also, there is a possibility of contagion in open farming [14]. Open ponds are arranged like racetracks for the better movement of nutrients and motors are used for the circulation of algae [13]. Biomass from the pools is processed for producing biodiesel and the leftovers can be used as animal feeds [6]. In a closed system, photobioreactors are used for the farming purpose. They have transparent tubular structure and possess the advantages such as preventing contamination of algae and evaporation of water, balancing pH value, controlling carbon dioxide and light intensity entering into the reactor [11,18]. Even though closed systems have many pros, high processing cost limits the application of this method. Another trouble is oxygen production as a result of algal photosynthesis. This is not a restraint in an open system because there the produced oxygen moves to the atmosphere. Sometimes the photobioreactor may get intensely heated and reduce the productivity. Implementation of a heat exchanger keeps the equilibrium state of the temperature inside the reactor [19]. This also increases the operating cost of closed systems. Fermentation is a method in which algae are grown on sugars without exposure to sunlight. Here algae exhibit heterotrophic behavior i.e. they convert sugar into biomass and from that fuels can be synthesized. Next is hybrid system where combination of various methods is carried out. For example the grouping of an open pond and photobioreactor or fermentation and open pond results in a method possessing advantages of each system. In an integrated system, the ability of algae to remove the wastes (toxic gasses or nutrients) is exploited. Nutrients and toxic pollutants in wastewater are absorbed and utilized by algae as food. Thus, dirty water is recycled and biomass is produced in the integrated system. In excretion process as the name indicates algae excrete certain chemicals into the culture in which they are grown. Instead of biomass which stores the oil content, these chemicals are used to synthesize fuels. Here cultivation over large areas and harvesting are not needed and thus excretion method reduces the operating cost. The technical details of the open, closed and hybrid systems are discussed below.

An open system is a mostly used mean for algae cultivation owing to its low cost and ease of operation. Even though there is a possibility of contamination and water loss, the above-mentioned factors attract the manufacturers. Commonly implemented structure for open pond system is raceway rather than regular circular ponds. The depth of the raceway ponds will be around 0.5meter. Either concrete or plastic lining is used to avoid the raceway ponds' contact to earth. It is necessary because this contact may pollute the culture with redundant materials from the earth. Use of paddle wheels is important for the system. Mixing of algae and nutrients, circulation of the mix through the loop and prevention of sedimentation are achieved by this paddle wheel. Extra rotating structures can also be employed in the channel bends. Algae and nutrients are provided in front of the paddle wheel in order to start the movement and collected at the end of the raceway.

Closed systems are photobioreactors where a biological reaction takes place in consequence of exposure to light energy. Photobioreactors can be in tubular, flat or column structure according to the quantity required. For large-scale cultivation, flat plate reactors are suitable because of the huge area exposure to light. Column structured photobioreactors are cost effective and simple when compared to other configurations. But the tubular structure is commonly used for the closed system. Transparent plastic or glass tubes are arranged in vertical or horizontal arrays for the flow of algae and nutrients. The diameter of a tube will be approximately 0.1 meter. Movement of algae and nutrients can be attained using mechanical pumps. For locations not having adequate amount of solar energy, artificial illumination is utilized. In desert areas, since the tubes are transparent, sunlight is enough for the cultivation.

The hybrid system combines the positive features of open and closed systems and provides a quality synthesis method. The problem of contagion in open ponds is rectified here by the photobioreactor. In the second phase, algae are brought to the open pond for nutrient mixing and supply of CO_2 from the atmosphere. Further operations like harvesting and extraction are similar to that of other systems [23,24].

All of the six methods discussed above have their own advantages and disadvantages. Hybrid systems which comprise of two methods eliminate each other's limitations but multiply the cost. While the comparison cost effective method is found to be excretion process, however, its productivity is less under the current situations. These situations include lack of a proper site, scarcity of water, transportation difficulties etc; the site is said to be perfect if problems of water scarcity and transportation have been solved [16]. According to the inferences, we have reached; some strategies are framed for high yield from algae. Alga being a less demanding plant, geographical factors is not an obstacle for its growth. Thus, it minimizes the competition with food crops. If we get infertile land somewhere near the sea, we can make artificial ponds by using seawater [20,21,22]. The problem is to find out a suitable location having desert or non-arable land nearby sea. By conducting a survey we have found out some sites appropriate for algae farming. Before that everyone should know the importance of algae cultivation or why alga is considered as a promising feedstock for biodiesel.

Figure 1 gives the comparison of the quantity of oil obtained from different types of crops. Alga is not included among these crops. From the graph it is clear about the capability of various crops in producing oil. Palm is the highest oil producing feedstock and it gives around 640 gallons of oil from one acre. With this rate of synthesis, we cannot meet the requirements of the whole world. Hence, use of biodiesel as a substitute for petroleum-based diesel will not be profitable. Here comes the significance of algae. It is possible to acquire 5000 to 100,000 gallons of oil from algae cultivated in a one-acre land. Figure 2 shows the oil productivity of algae and certain crops shown in the above graph (Fig. 1). Particular crops include jatropha, coconut, and palm those exhibited comparatively high productivity than others. But oil yield from algae is too higher than the productivity of these crops [5].

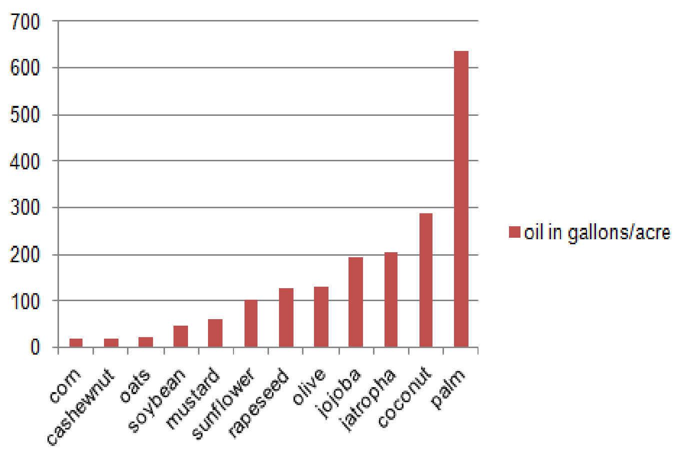

Fig.1.The quantity of oil obtained from different types of crops

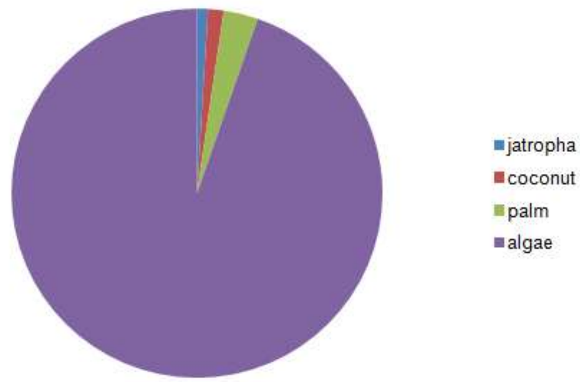

Fig.2. Oil productivity of algae compared to that of jatropha, coconut, and palm

3. Results and Discussion

Survey for sites was based on the idea that, operating cost can be reduced if we choose a barren land where the cultivation system gets the adequate amount of water and wind energy. Kutch district of Gujarat in India, Namib Desert of Southern Africa, and Saudi Arabia are some of the regions meeting the conditions.

Kutch is the largest district of India in the sixth largest state, Gujarat. Even though it is the largest district, population is only around two million. Southern and western regions of Kutch are surrounded by Gulf of Kutch and Arabian Sea respectively. Rann of Kutch and Little Rann of Kutch are located in the northern and eastern zones of this district. Kutch peninsula comprises miscellaneous types of landscapes such as grasslands, hills, salt marshes, and coastal areas. Figure 3 shows a map of Gujarat in which Gulf of Kutch, Rann of Kutch, and Little Rann of Kutch have been marked. A book titled "Memoirs on the Geology of Kutch" written by A. B. Wynne clearly explains about the sterility of Kutch. He points out it by highlighting the scarcity of trees, the presence of sandy plains, and absence of jungle. Thus, Kutch being an arid land in the vicinity of a large source of water (Gulf of Kutch and Arabian Sea), it can be utilized for algae cultivation. The method of an open system or hybrid system is suitable to be implemented in this location. By exploiting wind power, seawater can be pumped into the artificial ponds made in the barren lands. Algae, which do not need fresh water, would grow in seawater by absorbing the nutrients and recycling it.

Another site that can be suggested for same purpose is the Arabian Desert occupying the countries such as Kuwait, Oman, Qatar, Jordan, Iraq, Saudi Arabia, UAE, and Yemen. It covers an area of 2,330,000 square kilometers and consists of many hyper-arid regions.

Fig.3. Map showing the locations of Gulf of Kutch, Rann of Kutch, and Little Rann of Kutch

Boundaries to the northeast, east, southeast, south, west, and north of the Arabian Desert are the Persian Gulf, Gulf of Oman, Arabian Sea, Gulf of Aden, Red Sea, and Syrian Desert. Since water resources surround the above-mentioned countries, those places are suitable for algae farming. Rub al Khali or Empty Quarter, which is the largest sand desert, is a portion of the Arabian Peninsula stretching over Yemen, Oman, United Arab Emirates (UAE), and Saudi Arabia. Location of Rub al Khali is shown in Fig. 4. Although there are rich oil sources, algae cultivation also has to be taken seriously because we cannot rely on fossils for a long period.

Namib Desert of South Africa is another apposite location for algae cultivation for the reason that it is nearby an ocean, Atlantic Ocean. It is said to be the oldest desert in the world. Even if it is a barren land with particular climatic conditions the desert contains various types of plants and animals that are unique. Figure 5 shows the location of Namib Desert on the map of Southern part of Africa. The Namib Desert, which covers an area of around 80,950 square kilometers, stretches over the Atlantic coasts of Angola, Namibia, and South Africa. Availability of water resource makes this place suitable for algae cultivation towards biodiesel production. The three locations discussed above have the advantages of avoiding competition with food crops since they are non-arable lands and accessibility to a large source of water.

Algae grow much faster than other crops and produce a larger amount of oil per unit area than conventional crops such as jatropha, coconut, palm etc; also the harvesting cycle of algae is limited to a short period of 1 to 10 days. It can be grown on lands inappropriate for food crops and other oil crops. The factors that don't support the development of agriculture are not the limiting factors of algae farming.

Fig.4. Rub al Khali or Empty Quarter region and water sources nearby Arabian Peninsula

Alga can make use of infertile land and wastewater for its growth. It takes nutrients and uses toxic gasses for augmentation and thereby recycles the wastewater and purifies the atmosphere. So it is good to cultivate alga nearby power plants or industrial factories. Any time of year is suitable for the cultivation of algae. Alga has the capability to be grown in regions away from the farmlands and forests. Thus, it minimizes the damages to the ecosystem and food chain supply. However the present algal yields are not sufficient to meet the modern transportation and heating requirements.

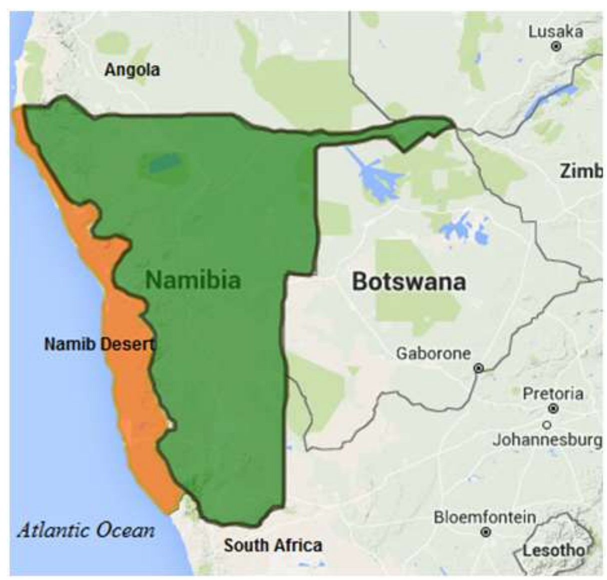

Fig.5. Location of the Namib Desert in Southern African region

So as to increase the productivity of biodiesel we have to expand the algae cultivation. Three locations were chosen for the large-scale cultivation of algae in order to produce biodiesel. Kutch district, Arabian Desert and the Namib Desert have wide areas of arid land and nearby water resources. Hence, water transportation cost can be avoided. Since these are coastal areas wind power is enough to pump water needed for algae growth.

Two of the chosen sites are desert areas and during summer the temperature rises up to 50-60℃ on daytime and decreases to 0℃ on nighttime. This huge variation is challenging to the algae cultivation but the trouble can be resolved through the synthesis method employed. All through winter, the daytime temperature is in a better range of 20-25℃. The coastal region of Namib Desert holds the best temperature range for algae growth. In summer it is 19-14℃ and so the temperature variation between day and night is less. The temperature of Kutch district varies from 30 to 48℃ throughout summer and 12 to 25℃ during winter. This range is good for open pond cultivation because evaporation will be less in the case of Kutch. Scientific names of algae that grow in seawater adapting to the desert conditions are as follows:

- Nannochloropsis Salina [25, 29]
- Phaeodactylum tricornutum [26]
- Skeletonema costatum [25]
- Chlorococcum Sp. [27]
- Thalassiosira [25]
- Tetraselmis Sp. [27]
- Chaetoceros [25]
- Pleurochrysis carterae [28]
- Dunaliella tertiolecta [30]
- Crypthecodinium cohnii [30]

Among these, Nannochloropsis Salina and Dunaliella tertiolecta are reported to be the best algae for cultivation in seawater towards biodiesel production [7]. Marine microalgae are suitable for the method presented here. But it is possible to make genetic changes in another type of algae and cultivate in seawater. In the proposed areas open pond cultivation is appropriate. The abundance of water, solar energy, and wind energy reduces the operation cost. The salinity of seawater prevents the contamination of culture thereby leading to quality products. Thus large-scale cultivation is possible and high lipid productivity can be achieved.

Conclusion

Biodiesel is equally imperative as petroleum because it is not safe to depend on fossil fuels for future energy requirements. Hence, algae must be cultivated in large scale for acquiring high yield of biodiesel. As presented in the article, Kutch district, Arabian Desert, and Namib Desert are suitable locations for extensive algae farming. Method of open system can be implemented in these types of locations. Hybrid systems are also executable here. Fewer requirements of algae such as water, nutrients, sunlight etc can be easily achieved if such regions have been chosen for cultivation. If the idea of utilizing coastal areas for algae growth is accomplished, then it will be possible to reduce operating cost and increase the productivity. Survey can be continued for searching more regions which have infertile land, sufficient wind, and accessibility to seawater.

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