Biofuel From Algae

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Abstract: The species of algae suitable for lipids production are the microphyites or phytoplankton. One of the key reasons why microalgae are considered for lipids production is the rapid growth rate. Some algal strains are capable of doubling their mass several times in the day. There are certain factors that are beneficial for healthy growth of algae and these include the right nutrients, light and temperature range. There are two main methods in algaculture and these are the open and the closed systems. The prevalent closed system in use is the photobioreactor. Open pond cultivation is limited to strains that are resistant to contamination by other micro organisms. When matured, the algae are harvested by the use of either microscreens, centrifugation, flocculation or froth flotation. Oil extraction is accomplished either by mechanical press or the use of chemical solvents.
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1. Introduction:

The realisation that fossil fuels are fast depleting has accelerated the search for an alternative energy source that is renewable, economical, and environmentally friendly. The situation has been exacerbated by global warming which has brought it home to all that there is a need to conserve energy and reduce collectively man's global carbon footprint. The instability in the regions from which the fossil fuels are sourced is another cause for concern. High oil price threatens the independence and security of nation states and it is unacceptable to have the threat of being held to ransom hence the frantic search for more stable alternative sources of energy. In addition to algae fuel, other candidate alternative and renewable energy options do exist and they include solar and wind energy (Achara 2011A and 2011B). Perhaps, there may be no single candidate alternative energy source that can on its own replace the fossil fuels completely, in which case, the likely outcome may be that each of the individual candidate sources contributes fractionally to make up the whole.

The species of algae suitable for lipids production are the microalgae (phytoplankton or microphytes). The macroalgae or seaweed, on the other hand have many commercial values but not for lipid production. Other commercial values of algae include the making of food ingredients such as omega3 fatty acids, fertilizer, chemical feedstock, pharmaceuticals and bioplastics.

Biofuel is nothing new. The more familiar biofuels are those sourced from plants such as palmoil, soybeans, corn and the most recent addition, jatropha. With the exception of jatropha, the others serve as feedstock as well as food crops and there lies the dilemma, whether is morally right to divert food crops to biofuel feed stock. Algae especially the species for lipid production, is not competing as a food stock. Biodiesel may be sourced from renewable biological materials such as vegetable oils and animal fats. Biodiesel can be used in its pure form (B100) or may be blended with petrodiesel at any concentration.

One of the key reasons why these single cell photosynthetic organisms, the microalgae are considered as feedstock for oil is their rapid growth rate, high energy content and hence high oil yield. Some algal strains are capable of doubling their mass several times per day. In some cases, more than half of that mass consists of lipids or triacylglycerides—the same material found in vegetable oils. The DOE (Department of Energy, US) has reported that algae can yield 30 times more energy per acre than land crops such as soybeans. In addition to keeping the environment clean and free from pollution, these algae feed on CO_2 a waste product from fossil fuel combustion and a contributor to global warming, to produce lipids for biodiesel fuels.

This study is interested in the processes involved in growing and extracting biofuel from algae.

2. Algae Growing Environment

Algae cultivation is an environmentally friendly process for the production of organic material by photosynthesis from carbon dioxide, light energy and water. The water used by algae can be of low quality, including industrial process water, effluent of biological water treatment or streams of other waste water.

Algae can be grown either as mono or mixed culture. In monocultural algaculture a wild or a laboratory sample of the desired species is diluted and small aliquots introduced into large number of small growing containers. In mixed culture, algae that are too large may be filtered out and nutrients added for storage outdoors or in the greenhouse for about two days ready for the larvae. Mixed culture requires minimal maintenance.

In algaculture, different algae have different requirements but the basic reaction during photosynthesis of the single celled phytoplankton in water has been given in (Biology Resources, 2011) as:

carbondioxide + light energy + water = glucose + oxygen + water.

The temperature range of the water must be right to support the specific algal species being grown. The water must not be too deep to enable light penetrate to the bottom of the pond especially if the water is not agitated. Direct sunlight may be too strong for algae cultivation, only about one-tenth of sunlight is needed by the algae. Light may be placed in the tank using *glow plates* made from plastic or glass for proper control of light intensity. Paddle wheels or compressed air may also be used to agitate the tank to ensure not one group remains on top of the pond. Odours near stagnant waters may be due to oxygen depletion caused by decay of deceased algae. The bacteria inhabiting algae cultures with oxygen depletion, break down the organic material to produce hydrogen sulphide and ammonia which can be the cause of the odour. Some living algae do also produce odours especially certain blue-green algae and may be responsible for taste and odour in drinking water treatment and distribution. It has been noted in (The Plant Fertilizer, 2011) that the most common odour causing chemicals produced by these algae are MID (2-methylisoborneol) and geosmin.

3 Methods for Growing and Harvesting Algae

3.1 Nutrients

For healthy growth and bounty harvest, nutrients such as nitrogen (N), phosphorus (P), and potassium (K) serve as fertilizer for algae. Silica and iron, as well as several trace elements, may also be considered important marine nutrients as the lack of one can limit the growth of, or productivity in, a given area. In a microalgae study, (Venkataraman, 2007) presented in tabular form detail growth potential for Spirulina platensis in digested cow dung slurry effluent, with and without added bicarbonate (18 9 NaHCO3/l). The study clearly shows that the addition of the bicarbonate aids the algae growth with the growth rate increase peaking at about 7% of the bicarbonate. There are however several other factors that help to determine the growth rate of algae. Light is needed for photosynthesis, the temperature range must be ideal and the composition of the water (including salinity, pH, nutrients etc.) must be right. The ideal range of values for these factors is given in table 1.

The two main methods of growing algae are the open pond and closed system which includes photobioreactor. Algae can be cultured in open-ponds such as raceway-type ponds and lakes and photobioreactors. Raceway ponds are however less expensive.

Table 1. A Generalized Set of Conditions for Culturing Micro-Algae

Parameters	**Range**	**Optima**
Temperature (°C)	16-27	18-24
Salinity (g.l-1)	12-40	20-24
Light intensity (lux)	1,000-10,000 (depends on volume and density)	2,500-5,000
Photoperiod (light: dark, hours)		16:8 (minimum) 24:0 (maximum)
pH	7-9	8.2-8.7

Source: http://www.fao.org/docrep/003/w3732e/w3732e06.htm

3.1 Open Pond Cultivation

Cultivation of algae in open ponds has been extensively studied. Open ponds can be categorized into natural waters (lakes, lagoons, ponds) and artificial ponds or containers. The most commonly used systems include shallow big ponds, tanks, circular ponds and raceway ponds. One of the major advantages of open ponds is that they are easier to construct and operate than most closed systems. However, major limitations in open ponds include poor light utilization by the cells, evaporative losses, diffusion of CO_2 to the atmosphere, and the requirement potentially of large areas of land. Open ponds are highly vulnerable to contamination by other microorganisms, such as other algal species or bacteria and open to the elements. Furthermore, contamination by predators and other fast growing heterotrophs have restricted the commercial production of algae in open culture systems to only those organisms that can grow under extreme conditions. Also, due to inefficient stirring mechanisms in open cultivation, the mass transfer rates are very poor resulting to low biomass production.

The ponds in which the algae are cultivated are usually what are called the “raceway ponds”. In these ponds, the algae, water and nutrients circulate around a racetrack. With paddlewheels providing the flow, algae are kept suspended in the water, and are circulated back to the surface on a regular basis. The ponds are usually kept shallow because the algae need to be exposed to sunlight, and sunlight can only penetrate the pond water to a limited depth. The ponds are operated in a continuous manner, with CO_2 and nutrients being constantly fed to the ponds, while algae-containing water is removed at the other end.

Open pond systems are cheaper to construct as the minimum requirement is just a trench or pond. Open ponds have the largest production capacities relative to other systems of comparable cost.

The biggest advantage of these open ponds is their simplicity, resulting in low production costs and low operating costs. The cost of using the open and closed systems have been given in table 2 and of interest is the column dealing with capital cost where it can be seen that the closed system is comparatively more expensive. While the open pond is indeed the simplest of all the growing techniques, it has some drawbacks owing to the fact that the environment in and around the pond is not completely under control. Bad weather can stunt algae growth. Contamination from strains of bacteria or other outside organisms often results in undesirable species taking over the desired algae growing in the pond. The water in which the algae grow also has to be kept at a certain temperature, which can be difficult to maintain. Another drawback is the uneven light intensity and distribution within the pond. Despite all these, various US government sponsored studies (Sheehan et all, 1998) still favour the open ponds on the basis of low cost. However, there are many organisations that are today studying the closed pond systems including the more expensive photobioreactors.

3.2 Closed Systems

Enclosing a pond with a transparent or translucent barrier effectively turns it into a greenhouse. This solves many of the problems associated with an open system. It allows more species to be grown; it allows the species that are being grown to stay dominant; and it extends the growing season and in cold region locations if the pond is heated cultivation can be carried out all year round.

3.2.1 Photobioreactor:

The photobioreactor (PBR) is a translucent bioreactor container incorporating a light source in which algae are grown. As opposed to an open pond system, the photobioreactor is usually a closed system. Since the system is usually closed all the nutrients must be provided by the cultivator. Farming can be in batch involving restocking the reactor after each harvest or continuous operation that requires precise control of all elements to prevent immediate collapse. For continuous operation correct amount of sterilised water, nutrients, air and carbon dioxide must be provided. Maximum production occurs when the time to exchange one volume of liquid matches the time to double the mass or volume of the algae. Algae grown in this controlled mode is said to be of higher nutrient content. The photobioreactor may be made in the form of a tank, polyethylene sleeves or even as a bag.

3.3 Harvesting

After they are grown and matured, the algae must be harvested and the methods of harvesting include using microscreens, centrifugation, flocculation and froth flotation. The algae can flocculate on their own by interrupting CO_2 supply and this is referred as autoflocculation. Chitosan derived from the shells of crustaceans is a commercial flocculant though used mostly for water purification. The use of chitosan is far more expensive. Other chemical flocculants include alum and ferric chloride. For large operations the use of flocculation may turn out to be too expensive. In froth flotation, the cultivator aerates the water into a froth, and then skims the algae from the top (Gilbert et al, 1961). In their study of froth flotation of algae have noted that the cost of froth flotation harvesting and drying exceeded the 35 to 40 dollar per ton mark often cited as required (at 1961 prices) to make the operation commercially viable.

3.4 Oil extraction

Algae oils have a variety of commercial and industrial uses, and are extracted through a wide variety of methods. By assuming that the biomass contains 30% of oil by weight, (Chisti, 2007) has estimated that it would cost about \$1.4 and \$1.81 per litre to produce algal oil from photobioreactor and raceways techniques respectively. In another study, based on the use of synthetic nutrients, Venkataraman estimated the cost of production of algae at \$2-\$3/pound and advised the use of industrial waste for the production of algal protein feed.

Oil extraction from various biomass systems have been compared (Oilgae, 2011) and summarised in the table 3. In this table, it is interesting to note that microalgae oil yield is more than ten times that of palm oil the nearest competitor.

Table 3: A Summary of Comparison of Oil and Biodiesel Yield from Main Energy Crops

Oil Source Biomass	(Mt/ha/yr)
Soy	1-2.5
Rapeseed	3
Palm Oil	19
Jatropha	7.5-10
Microalgae	14-255

Note: Mt – metric tons, ha – hectare (Source www.oilgae.com)

Table 2: Cost of Drum Filtration

Capital Cost	Operation cost1	Operating Cost 2
Appx. \$0.2 per 1000 annual gallons	\$15,000-20,000/hectare/annum	\$27,000-35,000 per hectare/annum
Note: A 1,000,000 l / hr drum filtration system costs about 400,000 \$ (drum filter, pumps and measuring, equipments)		
Indicative Costs for Open Ponds		
\$125000 - \$150000 per annum	\$15,000-20,000 per hectare per annum	\$27,000-35,000 per hectare per annum
Indicative Costs for Closed Pond		
\$200,000 per hectare per annum	\$20,000-25,000 per hectare per annum	\$40,000-45,000 per hectare per annum
Cost of Extraction Using Oil Press		
0.5 \$ per annual gallon	\$ 35 / T (approx 12 c per gal)	\$50/T (approx 17 c per gallon)

Source: Oilgae

3.5 Physical extraction

In the extraction process, the oil must be separated from the rest of the algae and this could be achieved by mechanical crushing. When dried, the oil content is still retained in the algae and the oil can be recovered using an oil press. In the vegetable oil industry, many commercial manufacturers use a combination of mechanical press and chemical solvents in extracting oil. Since the strains of algae vary widely in their physical attributes, various press configurations (screw, expeller, piston, etc.) work better for specific algae types. Often, mechanical crushing is used in conjunction with chemical solvents.

The cost of extraction using oil press has been given in table 2 where the cost has been broken down into components covering capital and operation.

Osmotic shock is a sudden reduction in osmotic pressure, this can cause cells in a solution to rupture. Osmotic shock is sometimes used to release cellular components, such as oil.

Other harvesting and extraction methods that are under development include ultrasound (Bosma et al, 2011). In their study using this technique to harvest microalgae found that harvesting efficiency is improved as the biomass ingoing concentration increases. Cavitation bubbles are created in the solvent material by ultrasonic waves and the cell walls are forced to break and release their contents into the solvent when the bubbles collapse close to the walls.

3.6 Chemical extraction

The oil can be extracted using chemical solvents but the downside to using solvents for oil extraction are the dangers involved in working with the chemicals. Care must be taken to avoid exposure to vapours and skin contact, either of which can cause serious health damage. Chemical solvents also present an explosion hazard. The inexpensive chemical solvent called hexane is a common choice and it is widely used in the food industry. Benzene classified as a carcinogen and ether may also be used to separate the oil. In the Soxhlet extraction method, oils from the algae are extracted through repeated washing, or percolation, with an organic solvent such as hexane or petroleum ether, under reflux in a special glassware (Cyberlipid, 2011). This technique benefits from the fact that the solvent can be reused.

In enzymatic extraction, enzymes are used to degrade the cell walls with water acting as the solvent and this makes the fractionation of the oil much easier. The costs of this extraction process are estimated to be much greater than hexane extraction (Hielcher, 2011). The enzymatic extraction can be supported by ultrasonication. The combination "sonoenzymatic treatment" causes faster extraction and higher oil yields.

Supercritical CO_2 can also be used as a solvent. In this method, CO_2 is liquefied under pressure and heated to the point that it becomes supercritical (having properties of both a liquid and a gas), allowing it to act as a solvent (p2pays, 2011).

4. Algal culture collections

Specific algal strains can be acquired from algal culture collections, with over 500 culture collections registered with the World Federation for Culture Collections.

5. Conclusion

1). Algae fuel is a major candidate among the renewable energy sources that are expected to replace the fast depleting fossil fuel sources.
2). The macroalgae or seaweeds, although suitable for other commercial values but not lipids production.
3. By feeding on CO_2, a waste product of fossil fuel combustion and a contributor to global warming, the algae help to keep the environment clean and free from pollution as well as produce lipids for biodiesel fuel.
4). For healthy growth and bounty harvest the temperature range, lighting, water depth and nutrients must be right to support the specific algal species being grown.
5). The two main methods of growing algae are open pond and closed systems. The closed system such as photobioreactors are easier to control but more expensive to build.
6). For maximum production using the photobioreactor, the time to exchange one volume of liquid must match the time to double the mass or volume of the algae.
7). After maturity of the algae, common harvesting methods include using microscreens, centrifugation, flocculation[3] and froth flotation.
8). A combination of mechanical press and chemical solvents may be used to extract the oil.
9). Algae have the potential to yield many times more oil than other biofuel sources.

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