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An Evaluation on Algae as Biomass for the Production of Biofuels

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Abstract
The need for fuels of renewable origin is very essential for the countries that are in the development stages. The present condition is that the power generation is purely based on the fossil fuel thermal power plants which share a major source. Next to that is the nuclear power plant, which has its own limitations and problems associated to it. In the field of biofuels, various attempts has been carried out to blend a certain percentage of biofuels obtained from crops such as jathropa, cotton seed and many other varieties. In this review, a possibility of using Algae for the production of biofuels is discussed.

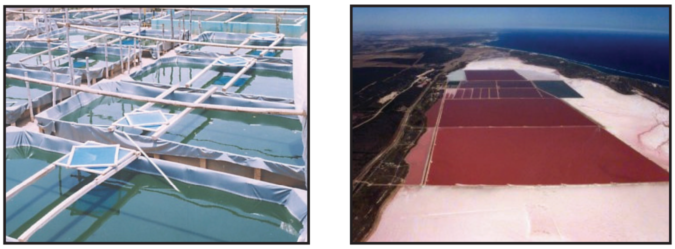
Keywords
Renewable Energy, Algae, Biofuels, Ethanol, Bio-Diesel

I. Introduction
In current scenario, Algae have received a great level of attention as a new biomass source for the production of bio fuels. Some of the important characteristics which keep algae apart from other biomass sources are that algae have a high biomass yield per unit area, can have a high oil or starch content, do not require fertile agricultural land, fresh water is not essential for cultivation and nutrients can be supplied by waste-water and CO_2 by combustion gas. At first, difference between macro algae (or seaweed) and microalgae needs to be understood. Microalgae have many different species with a variation in compositions a nd live as single cells or colonies without any specialization. Although this makes their cultivation easier and more controllable, their small size makes harvesting more complicated [1]. Macro algae are less versatile, there are very fewer options of species to cultivate and there is only one main viable technology for producing renewable energy: anaerobic digestion to produce biogas.

II. Bio Energy from Algae
Algae have a great potential to be used as a raw material for the production of bio energy. In order to utilize algae for this purpose, the most common systems for cultivating them are looked into. Since there are many species of algae with varying characteristics, a variety of options for the production of algae-based energy have been studied. Ensuing, the inputs and conditions needed for growing algae are examined.

A. Algae Culture Systems
Culture systems are very different between macro algae (seaweed) and microalgae. Because of their small (μm) size, microalgae will be cultivated in a system designed for that purpose, usually placed on land or floating on water, while seaweed can be grown directly in the open sea. The first mention of seaweed culture dates back to 1690, in Japan. Japan and China are still the main producers of cultured seaweed. Seaweed is mainly used as a food product, either eaten directly, or used in many processed foods as stabilizers or emulsifiers. Besides culturing seaweed, part of the current seaweed production comes from harvesting natural populations or collecting beach-cast seaweed. Besides the disturbance of the ecosystem by these practices, they are clearly unsustainable for application on a very large scale. Therefore growing macro algae in a dedicated cultivation system is worth considering. For algae to grow, a few relatively simple conditions have to be met: light, carbon source, water, nutrients and a suitably controlled temperature. Many different culture systems that meet these requirements have been developed over the years, however, meeting these conditions for scaled systems is difficult. One important prerequisite to grow algae commercially for energy production is the need for large scale systems which can range from very simple open air systems on- or offshore which expose the algae to the environment, to highly controllable, optimized but more expensive closed systems. The necessary technology for developing profitable algae-based fuel generation is still in various states of development and the final configuration is yet to be determined and demonstrated at the industrial scale.

B. Land Based Open Culture Systems
The simplest open air algae cultivation systems are shallow, unstirred ponds. The sizes range from a few m^2 to 250 ha (Figure 1a and b). CO_2 is the carbon source for algae.



(a) (b)

Fig. 1: (a). Small Pond for Spirulinaculture. (b). Dunaliellasalina ponds of Cognis, Western Australia.

Its dissolution from air into water limits the growth rate, making the yield per hectare relatively low. Other negative influences are the slow diffusion of nutrients and flotation and sedimentation of dead and living algae, limiting the usage of available sunlight. This can be prevented by some form of agitation, which in practice is done in circular ponds with a mechanical arm stirring in a circular motion (Fig. 2:a), or more commonly in so-called raceway ponds (Figure 2:b), in which a paddle wheel (Figure 2:c) forces a circulating water flow through a long narrow pond. Blowing gas bubbles through the medium provides both agitation and part of the required CO_2. Air, compressed CO_2 or CO_2 containing combustion gases can be applied. The major bottlenecks of these open systems are that there is almost no possibility for temperature control, unless a source of cheap surplus heat is available, and that they are very susceptible to invasion of algal predators, parasitic algae or other algal strains that grow better at the applied conditions and therefore out-compete the desired species.

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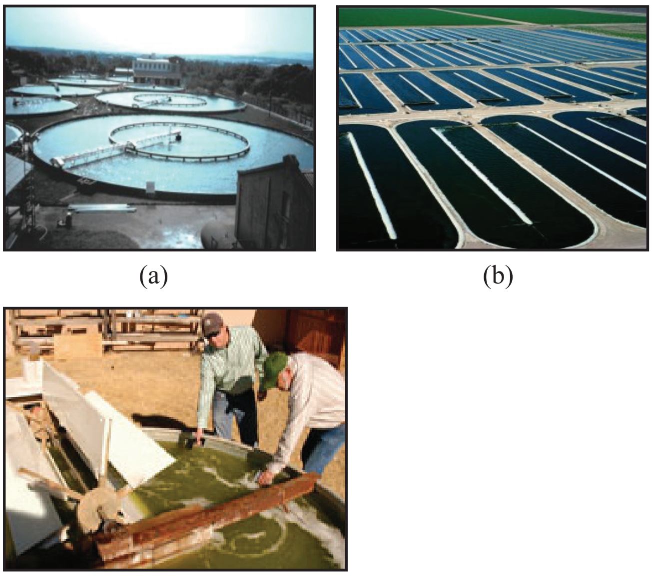

(a) (b) (c)

Fig. 2:(a). Centre-Pivot ponds for the culture of Chlorella in Taiwan, (b). Open raceway-type culture ponds of Earthrise in California, US. (c). Paddle wheel of a raceway pond.

Temperature, gas exchange and competition problems can be alleviated through closing an open system by covering it with transparent material or a greenhouse, but this is expensive for large surfaces [2]. Another simple, but inexpensive example is using polyethylene bags or sleeves (Figure 3:a) for batch culture.

Fig. 3:(a) 'Big Bag' Culture of Microalgae

Sizes go up to 1000 liters, but sensitivity to environmental conditions and short life expectancy make this system inappropriate for outside use. Several more advanced systems have been developed based on more durable transparent materials: glass, polyethylene and polycarbonate. These reactors offer continuous operation, a high level of controllability and elevated biomass concentrations, which results in lower space requirements and lower harvesting costs per ton of algae. One example is the bubble column (Figure 4:a), a vertical tubular reactor.

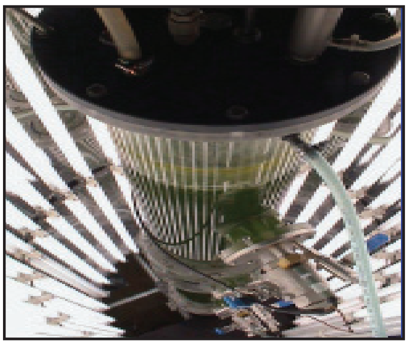

Fig. 4(a): Bubble Column Reactor

C. Algal Products

Since there are so many different algal species, algae as a group can produce a wide variety of products. The algal energy products which are relevant from a renewable energy perspective is looked below.

D. Complete Cell Biomass

It is possible to dry algal biomass and combust it directly to produce heat and electricity, or use high-temperature high-pressure processes like pyrolysis, gasification and hydro-thermal upgrading (HTU) to produce fuel gas or fuel oil respectively. These technologies require dry biomass. Drying requires a great deal of energy, which has a strong negative effect on the energy balance and capital costs of required equipment (drying with solar heat would compete for solar light with algae production). Thermochemical liquefaction is a high temperature, high-pressure treatment in which a wet biomass stream can be applied but this technology is still under development and is likely to require at least five years before it can be commercially applied. A biochemical way to process the whole biomass is anaerobic digestion. This produces biogas from the wet stream and requires much less energy input than the thermo-chemical options. There is 55-75 percent methane in biogas, which can be combusted to produce heat and/or electricity, or upgraded to replace natural gas.

E. Unique products

There are many initiatives on energy generation from algae, some ideas have been around for many decades, some are currently at the pilot-stage, but so far there is no commercial implementation. Alga culture however, is performed worldwide to produce products with a higher economic value than energy. Sometimes the entire alga is the product, but often compounds are extracted which are very difficult or impossible to produce in other ways. Some examples of these so-called "unique products" include food, food-additives and health-food, feed for fish, shrimp and shellfish, colorants and omega-3-fatty acids.

F. Lipids and Biodiesel

Lipids are one of the main components of microalgae; depending on the species and growth conditions 2–60 percent of total cell dry matter, as membrane components, storage products, metabolites and storages of energy. These lipids can be used as a liquid fuel in adapted engines as Straight Vegetable Oil (SVO). Tri-glycerides and free fatty acids, a fraction of the total lipid content, can be converted into biodiesel. In comparison with SVO, algal oil is unsaturated to a larger degree making it less appropriate for direct combustion in sensitive engines. In order to efficiently produce biodiesel from algae, strains have to be selected with a high growth rate and oil content. If an open culture system is used, the selected strain must have the ability to remain dominant under the applied conditions. Because of environmental conditions such as temperature, this means in practice that using a locally occurring strain is preferable in most cases. In a closed photo-bioreactor, competition from other algae can be prevented to some extent and optimal growth conditions can be more easily maintained. Lipid accumulation in algae usually occurs during periods of environmental stress, culture under nutrient-deficient conditions is most often referred to. This implies a tradeoff; rapid growth but low lipid content under nutrient sufficient conditions, decrease or near-zero growth but lipid increase under nutrient-deficient conditions. To the contrary, a fairly unique result by showed an almost consistent productivity and almost doubling of the lipid content to 60 percent after switching to nutrient-deficient conditions in an outdoor pilot reactor under natural light. From all energy carriers produced from algae, biodiesel has received the most attention and is the only initiative which is on the border of pilot-scale and full-scale deployment.

G. Carbohydrates and Ethanol

Bioethanol can be used as a biofuel which can replace part of the fossil-derived petrol. Currently bioethanol is produced by fermenting sugars, which in the case of corn are derived from hydrolyzing starch. Algae species starch contents over 50 percent have been reported. With new technologies, cellulose and hemicellulose can be hydrolyzed to sugars, creating the possibility of converting an even larger part of algal dry matter to ethanol. Algae have some beneficial characteristics compared to woody biomass, the traditional target for this technology. Most notable is the absence of lignin in algae, making its removal needed for woody material redundant. Furthermore, algae composition is generally much more uniform and consistent than biomass from terrestrial plants, because algae lack specific functional parts such as roots and leaves. Algal cell walls are largely made up of polysaccharides, which can be hydrolyzed to sugar. Another algae-specific technology for ethanol production is being developed, in which green algae are genetically modified to produce ethanol from sunlight and CO2. Ethanol production from or by algae has very interesting prospects, but is currently only in the preliminary phase of research. More development is needed to analyze a full-scale production system.

H. Hydrocarbons

One species of algae, Botryococcusbrauniiis well known for its ability to produce hydrocarbons which have been loosely described as equivalent to the "gas-oil fraction of crude oil." Like petroleum, these hydrocarbons can be turned into gasoline, kerosene and diesel. While other algal species usually contain less than 1 percent hydrocarbons, in B. brauniithey typically occupy 20-60 percent of its dry matter, with a reported maximum of 80 percent. Depending on the strain, these hydrocarbons are either C30 to C37 alkenes or C23 to C33 odd numbered alkenes. These hydrocarbons are mainly accumulated on the outside of the cell, making extraction easier than when the cell wall has to be passed to reach the organics inside the cell. B. brauniilives in freshwater, but can also adapt to large range of (sea) salt concentrations. At present, the highest known salt concentration that a Botryococcusspecies can survive is 3 M NaCl, the optimum salinity being around 0.2 M NaCl (seawater contains about 0.6 M NaCl). Salinity manipulation may be used as a tool to yield algal biomass containing the desired lipid composition. Other factors affecting B. brauniigrowth and hydrocarbon production include availability of nitrogen and phosphate, light intensity and pH.B. braunii's main disadvantage is that it grows very slowly: it's doubling time is 72 hours, and two days under laboratory conditions. This is >20 times slower than fast-growing algae, therefore only low-investment growth systems like raceway ponds are interesting. In such a system B. brauniiwould have to compete with natural occurring algae. Using saline water could give B. brauniia strong competitive position. There are parts in the world with brackish water or salty groundwater, which makes the land unusable for agriculture. Specifically for these regions, further investigation on large-scale B. brauniiculture is certainly warranted, but in the scope of this research not treated further.

I. Hydrogen

As an energy carrier, hydrogen offers great promise as a fuel of the future, since it can be applied in mobile applications with only water as exhaust product and no NOx emissions when used in a fuel cell. One major bottleneck for the full-scale implementation of hydrogen-based technology is the absence of a large-scale sustainable production method for hydrogen. Currently, hydrogen gas is produced by the process of steam reformation of fossil fuels. Large-scale electrolysis of water is also possible, but this production method costs more electricity than can be generated from the hydrogen it yields. Biological hydrogen production is possible; several bacteria can extract hydrogen from carbohydrates in the dark, a group called purple non-sulphur bacteria can use energy from light to extract more hydrogen gas (H2) from a wider range of substrates, while green sulphur bacteria can make H2 from H2S or S2O32-. These options are only interesting if a wastewater with these compounds is available. Other algae can make hydrogen directly from sunlight and water, although only in the complete absence of oxygen. In practice, this means that hydrogen formation is only possible under conditions that either cost a great deal of energy, or prevent storing solar energy, and a closed culture system is required. At the moment, it is only possible to produce a fraction of the theoretical maximum of 20 g H2/m2/d, making bulk-scale hydrogen production by algae not yet viable. For this to change in the future, more knowledge of the organisms that can produce hydrogen (only a few have been investigated) and the required conditions is necessary, as well as optimization of the biological route of solar energy to hydrogen, through genetic modification. If these improvements prove to be possible, this would constitute a profitable and renewable hydrogen production.

III. Conversion of Algal Biomass into Bio-fuel

There are several ways to convert micro algal biomass to energy sources, which can be classified into biochemical conversion, chemical reaction, direct combustion, and thermochemical conversion (Figure 5). Thus, microalgae can provide feedstock for renewable liquid fuels such as biodiesel and bioethanol.

A. Production of Bio-diesel and Bio-ethanol

Basic species of Green Algae include Chlamydomonasreinhardtii, Dunaliellasalina, and various Chlorella species, as well as Botryococcusbraunii, which usually are slow growing, can house large quantities of lipids.

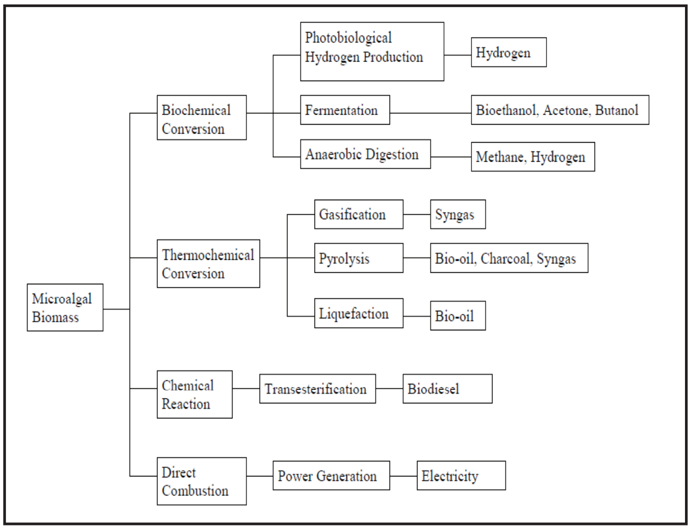

Fig. 5: Conversion processes for biofuel production from micro algal biomass

While many microalgae strains naturally have high lipid content in them, it is possible to increase the concentration of lipid content by optimizing the growth determining factors such as the nitrogen level control, light intensity, temperature, salinity, CO_2 concentration and procedure of harvest [4]. However, increasing lipid accumulation will not result in increased lipid productivity as biomass productivity and lipid accumulation are not necessarily related to each other. Lipid accumulation refers to increased concentration of lipids within the microalgae cells without consideration of the overall biomass production. Lipid productivity takes into account both the lipid concentration within cells and the biomass produced by these cells and is therefore a more useful indicator of the potential costs of liquid biofuel production. An integrated production of biofuels from microalgae (Figure. 6) includes a micro algal cultivation step, followed by the separation of the cells from the growth medium and subsequent lipid extraction for biodiesel production through trans-esterification.

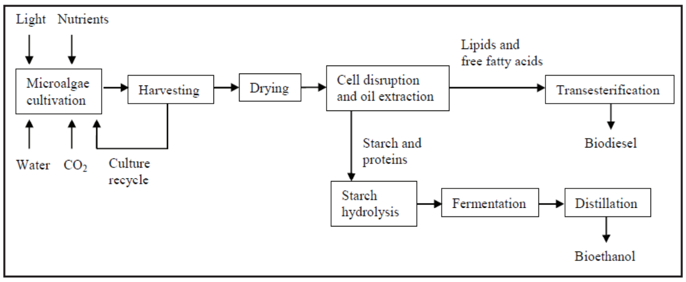

Fig. 6: Integrated process for biodiesel and bio-ethanol production from microalgae.

B. Bio-diesel Production

After the initial extraction process, the resulting micro algal oil will be converted into biodiesel by a process called Trans-esterification. In the trans-esterification reaction, transformation of triglycerides into fatty acid alkyl esters, in the presence of an alcohol, like methanol or ethanol, and a catalyst, like an alkali or acid, with glycerol being the byproduct. For acceptance of user, micro algal biodiesel needs to comply with existing standards, like ASTM Biodiesel Standard D6751 (United States) or Standard EN14214 (European Union). Micro algal oil contains a high degree of polyunsaturated fatty acids, with four or more double bonds, when compared to vegetable oils, which makes it vulnerable to oxidation in storage and therefore reduces its acceptance for use in biodiesel. However, the degree of unsaturation of micro algal oil and its content of fatty acids with more than four double bonds can be reduced easily by partial catalytic hydrogenation of the oil, the same technology that is commonly used in making margarine from vegetable oils. Nevertheless, micro algal biodiesel has similar physical and chemical properties to petroleum diesel, first generation biodiesel from oil crops and compares favorably with the international standard EN14214.

C. Bioethanol Production

The current trend in producing bioethanol are focusing on microalgae as a raw material for the fermentation process. Microalgae provide carbohydrates, which is in the form of glucose, starch and other polysaccharides, and proteins which can be used as carbon sources for the process of fermentation by bacteria, yeast or fungi. For example, Chlorella vulgaris has been considered as a potential raw material for production of bio-ethanol because it can accumulate high levels of starch. Chlorococumsp. are also used as a substrate for bioethanol production under different fermentation conditions. Results have showed a maximum bioethanol concentration of 3.84 g/l obtained from 10 g/l of lipid-extracted microalgae debris [7]. Production of bioethanol by using microalgae can also be performed through self-fermentation. Studies have that dark fermentation in the marine green algae Chlorococcumlittoralewas able to produce 450 µmol ethanol/g at 30ºC. Even though there are limited study materials on micro algal fermentation were observed, a number of advantages were found in order to produce bioethanol from microalgae. Fermentation process need less consumption of energy and process is simple as compared to biodiesel production system. Besides, CO2 produced as by-product from fermentation process can be recycled as carbon sources to microalgae in cultivation process thus reduce the greenhouse gases emissions. However, the production of bioethanol from microalgae is still under research and this technology has not yet been commercialized.

VI. Conclusion

Microalgae offer great potential as a sustainable raw material for the production of biofuels, such as biodiesel and bioethanol. However, there are many important scientific and technical obstacles that are needed to be overcome before the production of microalgae derived biofuels in large scale can become commercially viable. Technological developments, including advances in design of land culture systems, micro algal biomass harvesting, drying, and processing are important parameters that may lead to increased cost-effectiveness and therefore, effective commercial implementation of the biofuel from microalgae strategy.

References

[1] Aresta, M., Dibenedetto, A., Barberio, G.,"Utilization of macro-algae for enhanced CO_2 fixation and biofuels production: Development of a computing software for an LCA study." Fuel Process.Technol. 86(14-15), pp. 1679-1693, 2005.
[2] Bai, Z. G., Dent, D. L., Olsson, L., Schaepman, M. E., "Global assessment of land degradation and improvement: Identification by remote sensing GLADA report", Rome/ Wageningen, FAO/ISRIC, 2008.
[3] Banerjee, A., Sharma, R., Chisti, Y., Banerjee, U. C., "Botryococcusbraunii: A renewable source of hydrocarbons and other chemicals." Crit. Rev. Biotechnol. 22(3), pp. 245-279, 2002.
[4] Chisti, Y.,"Biodiesel from microalgae", Biotechnol. Adv. 25(3), pp. 294-306, 2007.
[5] Harun R, Danquah MK, Forde GM. Microalgal biomass as a fermentation feedstock for bioethanol production. Journal of Chemical Technology & Biotechnology.2010; 85, pp. 199-203.
[6] Ueno Y, Kurano N, Miyachi S.,"Ethanol production by dark fermentation in the marine green alga, Chlorococcumlittorale", Journal of Fermentation and Bioengineering.1998; 86, pp. 38-43.
[7] Vasudevan P, Briggs M.,"Biodiesel production—current state of the art and challenges", Journal of Industrial Microbiology and Biotechnology, 2008, 35: pp. 421-430.

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