Review Article

ALGAECULTURE: AN ALTERNATIVE TO SOLVING ENERGY SUSTAINABILITY CRISES IN DEVELOPING COUNTRIES

ABSTRACT

There is an impending need to reduce the dependency on fossil fuels in these areas of the world considering the ever depleting conventional oil resources and climate change, induced by greenhouse gas emissions. Algae are currently being prompted as a potential next generation bioenergy feedstock due to the fact that they do not compete with food or feed crops. They also produce much higher areal oil yields than the current agricultural crops. They can be produced on barren lands and have broad bioenergy potentials as they can be used to produce liquid transportation and heating fuels such as biodiesel and ethanol, or anaerobically digested to produce biogas. Algae are fast growing organisms capable of fixing high amount of carbondioxide through photosynthesis to produce biomass**.** Diverse technologies are currently being pursued to produce algae for bioenergy applications. The successful culture of algae could serve as a solution to the impending energy crises in both developed and developing countries.

KEYWORDS: **Algae, Biofuel, Greenhouse, Bioenergy, Feedstock**

INTRODUCTION

Escalating fuel prices, the emerging concern about global warming that is associated with burning fossil fuels, quest for economic growth, fighting poverty and the growing demand for petroleum products have spurred new interest in the search for alternative sources of natural oil for fuel (Abubakar *et al*., 2012). Microalgae are photosynthetic microorganisms that convert sunlight, water and carbon dioxide to algal biomass. Many microalgae are excitingly rich in oil (Yusuf Chisti, 2007) which can be converted to biodiesel using existing technology. Microalgae are fast growing unicellular or simple multicellular microorganism which have the ability to fix carbondioxide (CO_2) while capturing solar energy at an efficiency 10 to 50 times greater than that of terrestrial plants and higher biomass production compared to energy crops (Wang *et al.*, 2008). Microalgae are known for their rapid growth and high energy content. The main environmental factors influencing microalgal growth and chemical composition are light, nutrients, temperature and pH (Rousch *et al.*, 2003). Microalgae have several advantages, including higher photosynthetic efficiency as well as higher growth rates and higher biomass production compared to other energy crops. Several microalgae strains have been reported to have the ability to accumulate large quantities of lipids. It has also been observed that nitrogen limitation leads to an increase of lipid content in some chlorella strains (Reitan *et al.*, 1994). Previous studies have confirmed that lipid content in some micro algae strains could be increased by various cultivation conditions (Illman *et al.*, 2000), under stress conditions a lipid production of 30%-60% of dry cell weight has been reported, one can only imagine the yields under favourable conditions. Since fatty acid methyl esters originating from vegetable oils and animal fats are known as biodiesel, from an energetic point of view, lipids are the most desirable components of microalgae cells (Sostaric *et al.*, 2009). In addition the organic matter produced by photosynthetic microalgae can be transformed into a wide range of valuable products, such as biodiesel, food additives and health-care products (Pulz and Gross, 2004). Algal-oil processes into biodiesel as easily as oil derived from land-based crops. Algae have much faster growth rates than terrestrial crops. The per unit area yield of oil from algae is estimated to be from between 5,000 to 20,000 gallons (18,927 to 75,708 litres) per acre, per year; this is 7 to 31 times greater than the next best crop, palm oil (635 gallons *or* 2,404 litres). Many companies are pursuing the development of algae bioreactors for various purposes, including biodiesel production and CO_2 capturing (Veridium Patents Yellowstone, 2007). This paper highlights the potential of microalgae for sustainably providing biodiesel as an alternative to petroleum-derived transport fuels, such as gasoline, jet fuel and diesel; and in the long run solve energy sustainability crises in developing countries such as Nigeria.

Algae Cultivation

Raceway Ponds

A raceway pond is typically shallow (about 0.3m deep) and is structured in a closed looped system. Algae mass is usually not allowed to settle bellow by the application of a paddlewheel. Raceway ponds are constructed using concrete or compacted earth and they may be lined with plastic materials (Yusuf Chisti, 2007). Contamination with unwanted algae and microorganisms that feed on algae may occur and this affects the productivity. Raceways are perceived to be less expensive than other culture methods, because they cost less to build and operate (Yusuf Chisti, 2007). Open culture systems (including raceway ponds) have been extensively used to culture algae in many developed countries including New Zealand as well as other developing countries like Japan and a host of others, though there are numerous ponds in African countries (e.g. Nigeria), very little are being used exclusively used as algae culture media.

Photobioreactors

Algae can be cultivated in either open systems like ponds or closed systems like photobioreactors. In a photobioreactor, the operator usually has full control of all growth requirements and the environment. As it is a closed system, all growth requirements such as carbon dioxide supply, water supply, optimal temperature, efficient exposure to light, culture density, pH levels, gas supply rate, mixing regime etc., can be introduced into the system and controlled according to the specification of the desired products (Oilgae, 2014).

This photobioreactor technology has been extensively used in developed countries like Germany, US, UK, they have also thrived well in some advanced developing countries like China and India. There are scanty reports in Egypt and South Africa about the use of photobioreactors on experimental scales.

A tubular photobioreactor consists of an array of straight transparent tubes that are usually made of plastic or glass. This tubular array, or the solar collector, is where the sunlight is captured (Fig. 1). The solar collector tubes are generally 0.1m or less in diameter. Tube diameter is limited because light does not penetrate too deeply in the dense culture broth that is necessary for ensuring a high biomass productivity of the photobioreactor.

Microalgal broth is circulated from a reservoir to the solar collector and back to the reservoir.

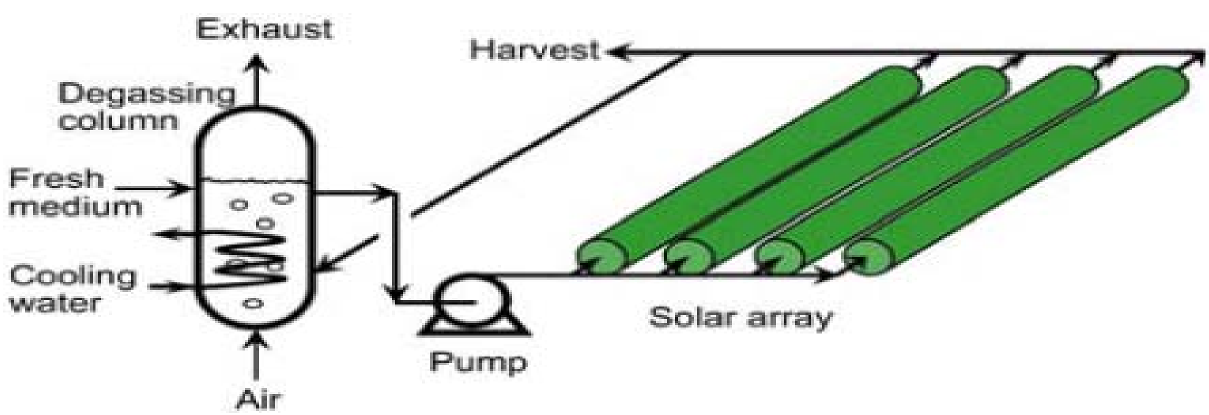

Figure 1: A diagrammatic representation of algae production using tubular photobioreactors (Source: Yusuf Chisti, 2007).

A solar receptor arranged parallel to each other are aligned to maximize the capture of sunlight (Fig. 1). The ground beneath the solar collector is often painted white, or covered with white sheets of plastic (Tredici, 1999), to increase albedo. A high albedo increases the total light received by the tubes (Yusuf Chisti, 2007). A turbulent flow is required in order for sedimentation of the biomass to occur as it is being produced and this can be made possible by providing a pump (Fig. 1). A standard photobioreactor is quite expensive but considering it enormous yields it is usually worth it in the long run

Table 1: Comparison of various variables involved in algae oil production cultured in photobioreactor facility and raceway ponds.

VARIABLE	PHOTOBIOREACTOR FACILITY	RACEWAY PONDS
Annual biomass production (kg)	100,000	100,000
Volumetric productivity ($kg/m^3/d$)	1.535	0.117
Areal productivity ($kg/m^2/d$)	0.048[a] 0.072[c]	0.035[b]
Biomass concentration in broth (kg/m^3)	4.00	0.14
Area needed (m^2)	5681	7828
Oil yield (m^3/ha)	136.9[d] 58.7[e]	99.4[d] 42.6[e]
Annual CO_2 consumption (kg)	183,333	183,333
Number of units	6	8

[a] Based on facility area.

[b] Based on actual pond area.

[c] Based on projected area of photo-bioreactor tubes.

[d] Based on 70% by wt oil in biomass.

[e] Based on 30% by wt oil in biomass.

(Yusuf Chisti, 2007)

Algae Oils

Particular microalgae strains could have their oil contents in excess of about 80% of the total dry weight of the algae biomass. Even though agricultural oil crops, such as soybean and oil palm, have been extensively used produce biofuels, their yields (usually less than 5% of total biomass basis) cannot be compared to those of microalgae strains (Yusuf Chisti, 2007). A conceptual process for the production of biodiesel from microalgal is illustrated in Figure 2. The process begins with the production of the microalgal biomass which requires light, carbon dioxide, water and inorganic nutrients (Yusuf Chisti, 2007).

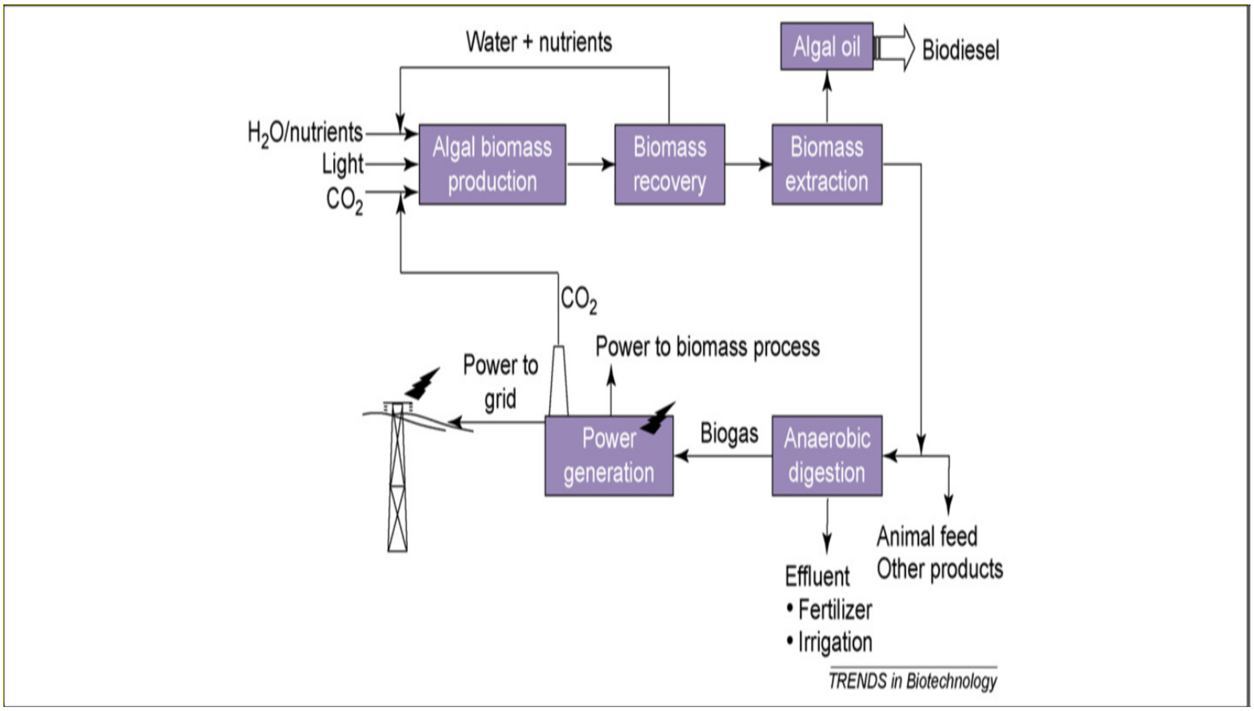

Figure 2: A conceptual process for producing microalgal oil and its various by-products

(Source: Yusuf Chisti, 2007).

The algal biomass produced in next stage is further processed to recover the biomass (Molina *et al*. 2003). The water and nutrients recovered at this stage can be recycled into the system again. The concentrated biomass is then dried and extraction process is carried out either by percolation using a solvent (benzene) or through “Soxhlet Extraction” to obtain the algal oil. This can then be further converted to biodiesel.

Residues that remains from the oil extraction can be used as animal feed and, possibly, as a source of small amounts of other high-value microalgal products (Gavrilescu and Chisti, 2005). Algal biomass residue could also undergo anaerobic digestion by certain anaerobic bacteria to produce biogas. The carbon dioxide (CO_2) given off from the combustion of biogas can be reintroduced into the process for culture of fresh microalgae biomass.

Typically, the yield of biogas varies from 0.15 to 0.65kg of dry biomass (Wulf, 2005). The total content of lipids in microalgae vary from about 1-85% of the dry weight (Rodolfi *et al*., 2009) with values higher than 40% typically achieved under nutrient starvation.

Algae for Biofuels

Algae fuel or algal biofuel is an alternative to fossil fuel that uses algae as its source of natural deposits (Scott *et al*., 2010). Unlike fossil fuel, algae fuel and other biofuels only release CO_2 recently removed from the atmosphere via photosynthesis as more algae grows. Impending energy crisis and the food crisis have ignited interest in algaculture (farming of algae) for producing biodiesel and other biofuels using lands unsuitable for agriculture so as not to compete with food crops. Algal fuels have notable advantageous characteristics in that they can be grown with minimal impact on fresh water resources (Yang *et al*., 2010), can be produced using saline and wastewater, they are biodegradable and relatively harmless to the environment if spilled (Demirbas, 2009; 2011).

Bioenergy Conversion of Algae

Biomass from microalgae and macroalgae can be converted into solid, liquid or gaseous energy carriers but there are some major differences in the chemical and physical chemical composition of algae as well as their physical composition which make them more or less suitable for a given conversion technology (Oilgae, 2014).

In general the most important issues to remember when evaluating bioenergy conversion technologies for algae are their high content of inorganics (more than 30% can be found), a low level of fermentable sugars, high protein and sulphur content and a potentially very high content of oils. The glycerine has many uses, such as in the manufacture of food, in the production of pharmaceuticals as well as a feedstock for biogas (Oilgae, 2014).

Algae Biodiesel

The term biodiesel covers diesel type oil made from vegetable oils. In plants oils are found as triglycerides, where three fatty acids of different chain lengths are coupled to a glycerol molecule by ester bonds. By splitting the triglycerides into their components via a transesterification reaction the single fatty acids can be separated for use as fuel in diesel engines (Oilgae, 2014).

Algae ethanol

Carbohydrates, Protein and Lipids are the three main components of an algae biomass. With Lipids extracted, the residue is obviously the Carbohydrates and Proteins. These Carbohydrates can be converted into either simple or complex sugars, depending on the strain, thereby serving as a feedstock for ethanol (Oilgae, 2014).

These sugars can be converted into ethanol through fermentation, which could either yield biodiesel or ethanol. The process of fermentation of algae carbohydrates to produces these products also releases carbondioxide (CO_2), which can be used to grow more algae in a closed loop system.

Sargassum, Glacilaria, Prymnesium paryum and Euglena gracilis are some strains of algae which can be used for the production of algae (Oilgae, 2014).

Biogas

The mixture of gases produced by the breakdown of organic matter in the absence of oxygen is referred to as Biogas. They can be produced from readily available raw materials such as recyclable wastes.

Biogas is produced by fermentation of biodegradable materials such as manure, sewage, municipal waste, green waste, plant materials and algae; or by anaerobic digestion through anaerobic bacteria (NNFCC, 2011). It is primarily methane (CH_4) and carbondioxide (CO_2) and may have small amounts of hydrogen sulphide (H_2S) as well as moisture.

The gases methane (CH_4), hydrogen (H_2), and carbon monoxide (CO) is usually combusted with oxygen and this energy release allows biogas to be used as a fuel; it can be used for major heating purpose like cooking and can also be used in a gas engines (Clark Energy, 2011).

Biogas can also be compressed and used to power vehicles. For instance in developed countries, biogas is estimated to potentially replace about 17% of fuels for vehicles (Dave Andrews, 2008). Biogas can be cleaned and upgraded to natural gas standards when it becomes bio-methane.

Algae Harvesting and Strains

The basic concept of algal oil production is to use relatively small (in total area) photobioreactors to produce a modest amount of "inoculum" culture (about 1-2 % of the total biomass produced) to seed much larger, totaling several hundred hectares, open ponds. The biomass would need to be concentrated by an initial factor of at least about thirty-fold, requiring very low-cost harvesting processes, such as "bioflocculation", a spontaneous flocculation-sedimentation of the algal cells, using no, or at most very little, flocculation chemicals. Such low-cost harvesting processes must be developed and demonstrated for each algal species and even strain. At present there are no low-cost harvesting technologies available. The algal strains to be cultivated would be selected based on many criteria, of which oil content (Table 2), productivity, and harvest ability would be primary, but also resistance to contamination, tolerance of high oxygen levels and temperature extremes, and adaptation to the local water chemistry and other local conditions experienced by the algal cells in the growth ponds. Figure 3 shows microalgal biomass being recovered from the culture broth by filtration (Oilgae, 2014).

After harvesting, further concentration and oil extraction is required, for which various processes are proposed, including cell breakage and solvent extraction, possibly using a three phase centrifugation.

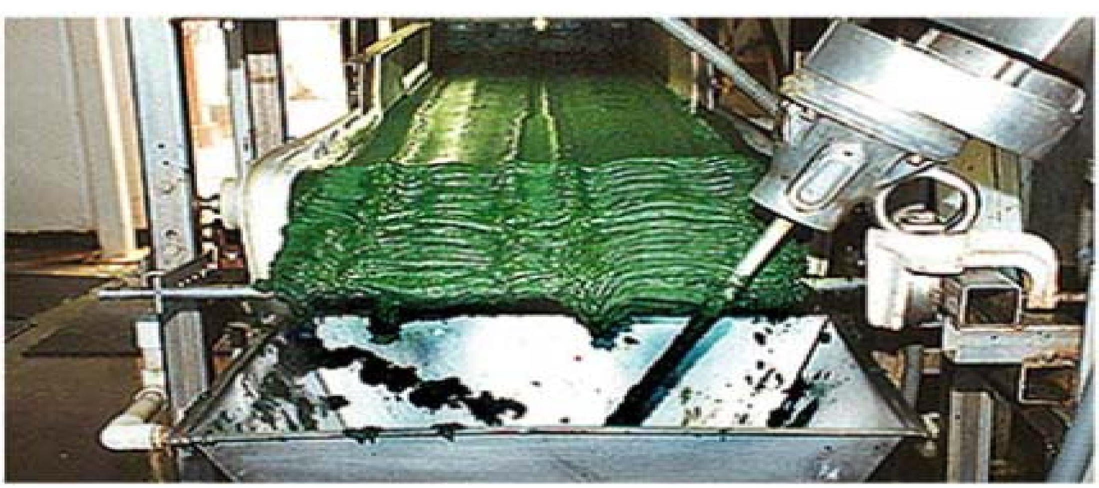

Figure 3: Microalgal biomass recovered from the culture broth by filtration

(Source: Oilgae, 2014)

Hundreds of species of microalgae are being experimented with, such as *Chlorella sp.* which is easy to culture and easy to harvest but does not contain very high oil content. *Schizochytrium sp.*, which is very high in oil yield, is not that easy to culture (Table 2). With the correct species in place and the right conditions the species can produce oil at near-theoretical limits

Table 2: Oil content of some microalgae

MICROALGA	OIL CONTENT (% DRY WT)
Botryococcus braunii	25–75
Chlorella sp.	28–32
Cylindrotheca sp.	16–37
Isochrysis sp.	25–33
Nannochloropsis sp.	31–68
Schizochytrium sp.	50–77

Modified from Yusuf Chisti (2007).

Biodiesel Production

Parent oil used in making biodiesel consists of triglycerides in which three fatty acid molecules are esterified with a molecule of glycerol. In making biodiesel, triglycerides are reacted with methanol in a reaction known as trans-esterification or alcoholysis. Trans-esterification produces methyl esters of fatty acids that are biodiesel, and glycerol (Figure 4).

The reaction occurs stepwise: triglycerides are first converted to di-glycerides, then to mono-glycerides and finally to glycerol.

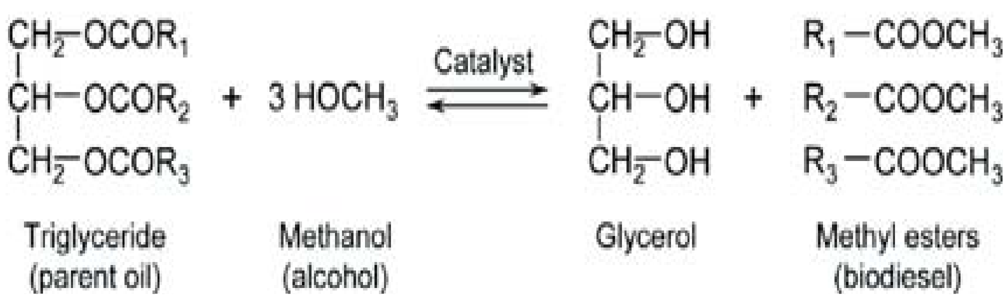

Figure 4: Transesterification of oil to biodiesel (R d1–3 are hydrocarbon groups).

Trans-esterification requires 3mols of alcohol for each mole of triglyceride to produce 1mol of glycerol and 3mols of methyl esters (Fig. 4). Industrial processes use 6mol of methanol for each mole of triglyceride (Fukuda *et al*., 2001). Yield of methyl esters exceeds 98% on weight basis (Fukuda *et al*., 2001).

Transesterification is catalyzed by acids, alkalis (Meher *et al*., 2006) and lipase enzymes (Sharma *et al*., 2001). Alkali-catalyzed transesterification is about 4000 times faster than the acid catalyzed reaction (Fukuda *et al*., 2001). Alkali-catalyzed transesterification is carried out at approximately 60°C under atmospheric pressure; as methanol boils off at 65°C at atmospheric pressure. A higher temperature can be used in combination with higher pressure, but this is expensive.

The various advantages of producing microalgae for energy production include; Algae do not compete with agriculture, they have high per acre yield, they contain no sulphur therefore there is no risk of SO_2 emissions, they are nontoxic and highly biodegradable, they do not require soil for growth, they use as little as 8cm of water per year, they can adapt anywhere even at great distances from water.

Industrial emissions of CO_2 from power plants, refineries, and other stationary emitters can be productively consumed by micro algae in engineered plants and used to manufacture valuable products, thus making the whole process carbon neutral.

Economics of Biodiesel Production

Recovery of oil from microalgal biomass and conversion of oil to biodiesel are not affected by whether the biomass is produced in raceways or photobioreactors. Hence, the cost of producing the biomass is the only relevant factor for a comparative assessment of photobioreactors and raceways for producing Microalgal biodiesel. For the facilities detailed in Table 1, the estimated cost of producing a kilogram of microalgal biomass is $2.95 (N442.5) and $3.80 (N570) for photobioreactors and raceways, respectively (Yusuf Chisti, 2007). If the annual biomass production capacity is increased to 10,000 tonnes, the cost of production per kilogram reduces to roughly $0.47 (N70.5) and $0.60 (N90) for photobioreactors and raceways, respectively, because of economy of scale. Assuming that the biomass contains 30% oil by weight, the cost of biomass for providing a liter of oil would be about $1.40 (N210) and $1.81 (N271.5) for photobioreactors and raceways, respectively (Yusuf Chisti, 2007). Oil recovered from the lower-cost biomass produced in photobioreactors is estimated to cost $2.80/L (N420/L). Biodiesel from palm oil costs roughly $0.66/L (N99/L) or 35% more than petro-diesel. This suggests that the process of converting palm oil to biodiesel adds about $0.14/L (N21/L) to the price of oil. For palm oil sourced biodiesel to be competitive with petro-diesel, the price of palm oil should not exceed $0.48/L (N72/L).

Microalgal oils can potentially completely replace petroleum as a source of hydrocarbon feedstock for the petrochemical industry. For this to happen, microalgal oil will need to be sourced at a price that is roughly related to the price of crude oil. For example, if the prevailing price of crude oil is $60/barrel (N9000/barrel), then microalgal oil should not cost more than about $0.41/L (N61.5/L), if it is to substitute for crude oil. If the price of crude oil rises to $80/barrel (N12000/L) as sometimes predicted, then microalgal oil costing $0.55/L (N82.5/L) is likely to economically substitute for crude petroleum.

CONCLUSION

Overdependence on fossil fuels makes it imperative for countries to start looking at possible alternatives for fuels. Although this has begun in some developed, asides notable African countries like Egypt and South Africa, very little has been achieved in developing countries.

Algal biodiesel is technically feasible. Producing low-cost microalga biodiesel requires primarily improvements to algae biology through genetic and metabolic engineering.

Biodiesel has great potential; however, the high cost and limited supply of organic oils prevent it from becoming a serious competitor for petroleum fuels. As petroleum fuel costs rise and supplies dwindle, alternative fuels will become more attractive to both investors and consumers.

Photobioreactors still remain a better means of culturing algae when compared to others methods (such as raceway ponds), although a detailed economic analysis of production costs and yields is very necessary if algae biofuels would compete with fossil fuels.

Governments bodies who intend to go back to agriculture (for example in Nigeria), should invest in algaeculture and “oilgae” as individual investors/farmers might not be able to undertake such projects on economic and large scale basis. Schools should also encourage research in these fields.

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