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ALGAL BIOFUEL: A STEP TO GREENER FUTURE

A research report on renewable energy (ALGAL BIOFUEL)

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ABSTRACT: The world is facing declining liquid fuel reserves at a time when energy demand is exploding. As supply dwindles and costs rise, nations will be forced to utilize alternative energy sources. Coal, both non-renewable and environmentally destructive, is the most likely near-term candidate for replacing oil as a primary energy source. In order to achieve a secure and stable energy supply that does not cause environmental damage, renewable energy sources must be explored and promising technologies should be developed. Biodiesel derived from green algae biomass has the potential for high volume, cost effective production. It can be carbon neutral and produced intensively on relatively small areas of marginal land. The quality of the fuel product is comparable to petroleum diesel and can be incorporated with minimal change into the existing fuel infrastructure. Innovative techniques, including the use of industrial and domestic waste as fertilizer, could be applied to further increase biodiesel productivity.

INTRODUCTION

The world is entering a period of declining non renewable energy resources, popularly known as ‘Peak Oil’, while energy demand is increasing. The world’s oil production is expected to decline in between one and ten decades (Crookes, 2006). As a result of this impending energy crisis, both governments and private industry are examining alternative sources of energy. Other non-renewable sources of energy exist, such as coal and uranium; however, these sources are limited and will also inevitably decline in availability. Coal is the likely immediate candidate for replacing oil as an energy supply. It is energy rich, can be converted to liquid fuel, and is still very abundant. It is particularly plentiful in the United States, China, and India. Our reliance on fossil fuels has caused carbon dioxide (CO2) enrichment of the atmosphere, and is the primary contributor to the generally-accepted phenomenon called global warming. Because using coal produces even greater CO2 emissions than oil, the depletion of oil will be unlikely to improve this pattern of CO2 enrichment. Thus, the need for renewable sources of portable, liquid fuel is starting to receive greater attention, and much of this attention has been focused on biomass-derived liquid fuels, or bio fuels Algae, especially microalgae are emerging to be the only source of renewable biodiesel that can fit on the global demand for transport fuels. Oil productivity of many microalgae greatly exceeds the oil productivity of the best producing oil crops. Algae are said to yield about 1,200-10,000 gallons of oil/acre, compared to 48 and 18 gallons/acre for soy and corn, respectively Above all, algae can be very efficient in absorbing carbon which is generated by fossil fuel power plants which makes it a carbon neutral bio fuel With this one can say that algae can produce a bio fuel which can be efficient enough while cleaning up other environmental problems This research paper examines the feasibility of biodiesel as a potential replacement for petroleum-based liquid fuels. In particular, the use algae as a source of biomass for fuel production is investigated, in terms of its productivity, practicality, and innovative potential to create a cost competitive, environmentally friendly, and renewable source of liquid fuel.

Background: Algae are unit or multi cellular, primarily aquatic, plant like organisms which require three basic components to grow: sunlight, CO2 and water. Like plants, algae also use photosynthesis as an important bio-chemical process to convert the energy of sunlight to chemical energy. Algae are known to the world in two forms: Microalgae and Microalgae. Being more important as bio fuel, microalgae are microscopic organisms that grow in salt or fresh water. These can be further divided in four groups, diatoms (Bacillariophyceae), the green algae (Chlorophyceae), the golden algae (Chrysophyceae), and blue-green algae (cyanobacteria). Microalgae have considerable lipid content which can even be very high under certain stress conditions. Microalgae are much efficient in converting solar energy into biomass. The

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major species of microalgae commercially utilized for the production of biofuel includes Isochrysis, Chaetoceros, Chlorella, Arthrospira (Spirulina) and Dunaliella

DIFFERENT BIOMASS PRODUCTION SYSTEMS FOR MICROALGAE

To produce biomass from microalgae is considered as pricier than that to grow crops. It requires temperature within 20 to 30°C. Growth medium must be a provider of inorganic elements that constitute the algal cell, including nitrogen, phosphorus, and iron Growth media are usually low-priced. Biomass of microalgae contains about 50% carbon by dry weight. Large-scale production of microalgae biomass requires continuous culture during daylight. In this method, fresh culture medium is fed at a constant rate and the same quantity of microalgae broth is withdrawn continuously considerably, two main methods are opted for the large-scale production of algal biomass- 1. Raceway ponds 2. Tubular photo bioreactors.

Oil Content of Microalgae

microalgae	oil content (% dry weight)
Botryococcus braunii	25−75
Chlorella sp.	28−32
Crypthecodinium cohnii	20
Cylindrotheca sp.	16−37
Dunaliella primolecta	23
Isochrysis sp.	25−33
Monallanthus salina	>20
Nannochloris sp.	20−35
Nannochloropsis sp.	31−68
Neochloris oleoabundans	35−54
Nitzschia sp.	45−47
Phaeodactylum tricornutum	20−30
Schizochytrium sp.	50−77
Tetraselmis sueica	15−23

Raceway Pond method for algal biomass production

A raceway pond is made up of a closed loop recirculation

channel in which mixing and circulation are produced by paddlewheel. Flow is maintained around bends by baffles which are placed in the flow channel. Raceway channels are built by concrete or compacted earth which may be covered with white plastic. The culture is fed continuously during daylight in front of the paddlewheel where the flow begins. On the completion of the circulation loop, broth is harvested behind the paddlewheel which is operated all the time to prevent sedimentation .This method of culturing microalgae has being practiced since 1950s.Cooling can be achieved only by evaporation process in raceway ponds in which temperature fluctuates within a diurnal cycle and with seasonal change due to contamination with unwanted algae and microbes which feed on algae the productivity decreases. With this the biomass concentration remains low because raceways are poorly mixed and are not able to uphold an optically dark zone It is apparent that raceway ponds are less expensive than photo bioreactors, because they cost less to build and operate.

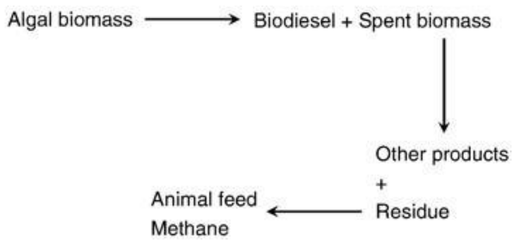


Fig. 1 . A simplified raceway pond

Photo bioreactors: the next option

Photo bioreactors allow essentially single- species culture of microalgae for extended durations which is generally not seen in the case of open raceway ponds. Various researchers have documented the successful production of large quantities of microalgae biomass using photo bioreactors in which there is an array of straight transparent tubes called solar collector usually made of plastic or glass. In these solar collector tubes, which generally have a diameter of 0.1 m or less, the sunlight is captured. It is necessary to limit the tube diameter because light should not penetrate too deeply in the dense culture broth which is essential for ensuring high biomass productivity in the photo bioreactor. Microalgal broth is distributed from a reservoir to the solar collector and back to the reservoir. Continuous culture operation is used, as explained above. In this whole procedure the main objective of the manufacturing solar collector is to maximize sunlight capture which is one of the most indispensible steps. To prevent the sedimentation of biomass in these tubes the highly turbulent flow is maintained which is produced using either a mechanical pump or a gentler airlift pump. Mechanical pumps can damage the biomass but are easy to design, install and operate. Airlift pumps have been used quite successfully.

This comparison is based on an annual production level of 100 t of biomass in both cases. If the losses to atmosphere are assumed as constant or unnoticed, then both production methods consume an identical amount of CO2.

Photo bioreactors yield much more oil per hectare as compared to raceway ponds and this is because the volumetric biomass productivity of photo bioreactors is more than 13-fold greater in comparison with raceway pond.

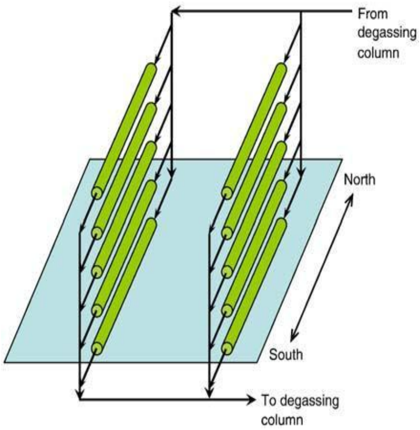


Fig. 2. A fence-like solar collector.

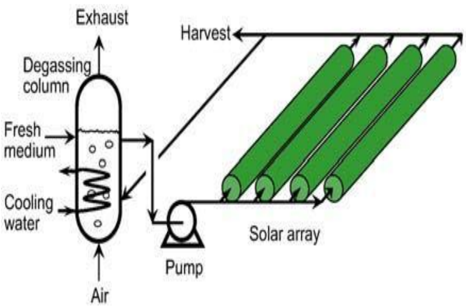


Fig.3. A tubular photo bioreactor with parallel run horizontal tubes

Comparison of photo bioreactor and raceway production method

Variable	Photobioreactor facility	Raceway ponds
Annual biomass production (kg)	100,000	100,000
Volumetric productivity ($kg\ m^{-3}\ d^{-1}$)	1.535	0.117
Areal productivity ($kg\ m^{-2}\ d^{-1}$)	0.048 [a] 0.072 [c]	0.035 [b]
Biomass concentration in broth ($kg\ m^{-3}$)	4.00	0.14
Dilution rate (d^{-1})	0.384	0.250
Area needed (m^2)	5681	7828
Oil yield ($m^3\ ha^{-1}$)	136.9 [d] 58.7 [e]	99.4 [d] 42.6 [e]
Annual CO_2 consumption (kg)	183,333	183,333
System geometry	132 parallel tubes/unit; 80 m long tubes; 0.06 m tube diameter	978 m^2/pond; 12 m wide, 82 m long, 0.30 m deep
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.

Extraction

After the growth of algae to their harvest concentration, separation and extraction of the microalgal biomass from the culture broth is required to use the oil, alcohol, or target product. Biomass can be separated from the broth by filtration, centrifugation, flocculation (colloidal separation), and other means.A significant task involved with the cultivation of microalgae is the difficulty in economically harvesting and extracting the target product (such as oil) from a dilute suspension.The next step in the process involves the separation of lipid oil from the rest of the algae biomass.One separation technique is by crushing with an oil press. Commercial manufacturers often use a combination of mechanical pressing and chemical solvents to extract algae oil. Two other methods, osmotic shock and ultrasonic extraction, cause the cell walls of cells in a solution to rupture and release the lipid contents into a solvent.

Biomass

After oil extraction from algae, the remaining biomass fraction can be used as a high protein feed for livestock.

This gives further value to the process and reduces waste.

(a) Biogas production from microalgae biomass

Biogas is produced from the anaerobic digestion of organic matter, consisting chiefly of 55.0– 65.0% methane (CH4), 30.0–45.0% carbon dioxide (CO2), traces of hydrogen sulphide (H2S) and water vapour [2]. The process of anaerobic digestion involves three chronological stages: hydrolysis, fermentation and methanogenesis. The anaerobic digestion process is optimized when one uses compounds with moisture content between 80.0% and 90.0%, and the use of microalgae biomass is highly appropriate. The biogas content obtained in the methane was 77.7%.

(b)Fermentation of microalgae biomass for ethanol production

Alcoholic fermentation is considered one of the most important processes of the glycolytic pathway and it consists in its anaerobic conversion to ethanol and CO2, in two steps. In the first step, pyruvate is decarboxylated by the enzyme pyruvate decarboxylase, releasing CO2 and forming acetaldehyde, which is then reduced to ethanol by the enzyme alcohol dehydrogenase. The fermentation can be represented by the equation [16].

C6H12O6 + 2ADP + 2Pi →2C2H5OH + 2CO2 + 2ATP + 2H2O

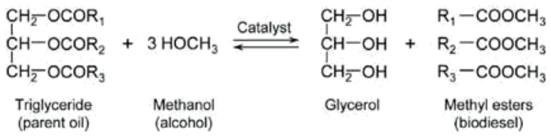
The principal reason and benefit of using ethanol as a fuel is that it reduces level of lead, sulfur, carbon monoxide and particulates; which are considered potential air pollutants. Additionally, there is the worldwide advantage of reducing CO2 emissions.

Production of biofuel from microalgae

Algae have proved itself as one of the most efficient resources when it comes to renewable raw material for biofuels. The vegetable oil from algae can be harvested directly (by the etherification process) or it can be refined into a variety of bio fuels, which include renewable diesel and jet fuel. The extracted carbohydrates from algae can be fermented to make additional bio fuels, including ethanol and butanol, as well as other products such as plastics and biochemical's. Microalgae biomass can be used for pyrolysis oil or combined heat and power generation. Renewable diesels derived from microalgae and jet fuels can directly replace petroleum fuels without modification of engines. Algae can be considered a biomass resource which is without carbon footprint. Even if there are different technologies described in greater detail, this is considered as the principal energy process for aquatic biomass. Due to their rich photosynthetic activity and efficacy to generate lipids, a biodiesel feedstock, microalgae have engrossed the attention of various researchers. Microalgae do not generally contain lipids and are being considered for the natural sugars and other carbohydrates they contain, which can be fermented to produce either biogas or alcohol-based fuels.

Trans-etherification: a process to convert oil to biodiesel

Biodiesel is a bio fuel consisting of monoalkyl esters that are derived from organic oils, plant or animal, through the process of tranesterification The biodiesel transesterification reaction is very simple:



This is an equilibrium reaction where an organic oil, or triglyceride, can be processed into biodiesel, usually in the presence of a catalyst, and alkali such as potassium hydroxide The excess methanol is later recovered and reused. At 60 ˚C, the reaction can complete in 90 minutes. The process of making biodiesel occurs as follows: A) the triglycerides, methanol, and catalyst are placed in a controlled reaction chamber to undergo transesterification, B) the initial product is placed in a separator to remove the glycerine by-product, C) the excess methanol is recovered from the methyl esters through evaporation, and D), the final biodiesel is rinsed with water, pH neutralized, and dried Adopting biodiesel has a number of advantages. Firstly, because the fuel is derived from biomass, it does not contribute to atmospheric CO2 emissions. Second, biodiesel emissions are, on the whole, lower than petroleum diesel. Substituting biodiesel for petroleum diesel results in substantial reductions of soot, sulphur, unburned hydrocarbon, and polycyclic aromatic hydrocarbon emissions. Third, because biodiesel has twice the viscosity of petroleum diesel, its lubrication properties can actually improve engine life Fourth, biodiesel has low toxicity and is biodegradable Fifth, like petroleum diesel, biodiesel has a more complete combustion than gasoline, giving a cleaner burn .

Hydrogen Fuel

In addition to the algae-derived biofuels already mentioned, various petroleum-like products and end products can be generated from microalgae. An additional biofuel, for example, comes from the microalga Chlamydomonas reinhardtii, which has been demonstrated to grow in the laboratory to produce hydrogen.

While in a sulfur deprivation stage, Chlamydomonas reinhardtii stops producing oxygen and switches to the production of hydro gen.Hydrogen can be used to produce heat, electricity, or power (via fuel cells) for transportation.

Bio sequestration of CO2 by algae

One important term should be mentioned here which is referred to as Bio sequestration of CO2 by algae in which CO2 can be sequestered or immobilized through filtering or other mechanical/chemical processes and subjected for long-term storage to avoid release into the atmosphere .

The idea of establishing a coal- fired power plant along with an algal farm provides an excellent approach to GHG mitigation of the CO2 from coal combustion into a useable liquid fuel.

Algae's lead

Various reasons explain why algae have proved itself as a more efficient, environmentally sound, and sustainable bio fuel. These reasons are:

1) Algae are having very high photon conversion efficiency;

2) Algae can manufacture and accumulate large quantities of carbohydrate biomass for bio ethanol production even from inexpensive raw materials;

3) Algae are capable enough to bear and utilize considerably higher levels of CO2;

4) Algae are having such a vast group comprising several thousand diverse species which makes them enable to get chosen as per the desired species according to the working environment;

5) Algae are skilled of producing high yields of stored material; and 6) Algal cells can be harvested within a short span of time as compared to other feedstock's.

13. Commercial Interests.

Worldwide commercial applications of algae are vast and many products have been developed. However, the current focus of industrial expansion has shifted from food-related products to fuel as market forces emphasize the search for renewable fuels. Commercial interests have created industries with a wide range of products using many forms of microalgae. One industry, Cyanotech Corporation based in Kona, HI, for example, uses Chlorella sp. for nutrition and health products.87 Spirulina (Arthrospira) is another algae often produced for human nutrition due to its high protein content, health benefits, and overall nutritional value.

Solazyme employs a hetero- trophic method to produce a lipid byproduct that is converted into biodiesel. Solazyme was the first algae manufacturer to be approved for algae jet fuel production by ASTM.89,90 Solazyme had a commercial plant by 2010. In 2009, it sold 20000 gallons (at a cost of $8.5 million for 20000 gallons or $425/gallon) of algae fuel to the U.S. Navy. Cellana (formerly HR BioPetroleum, Inc., (HRBP)) was founded in Hawaii in 2004 to produce feedstocks for biofuels, personal care products, nutritional oils, renewable chemicals, and aquaculture and livestock feed.

The cost of producing a kilogram of microalgal biomass is estimated to be approximately $2.95 for PBR and $3.80 for PRP.55,96 If the production scale is increased to an annual biomass capacity of 10000 tons, the biomass per kilogram production cost decreases to approximately $0.47 for PBR and $0.60 for PRP. With a conservative assumption of 30% oil extraction efficiency by weight of biomass, the cost of a liter of extracted oil would be $1.40 for PBR ($5.30/gal) and $1.81 for PRP ($6.85/gal).7,55,96 The conversion to algae-derived biodiesel, assuming a standard 66% efficiency, would yield a cost of $8.03/gal for PBR and $10.38/gal for PRP.

Risk Association

Depending on the algae organism and the process used, the constituents of the algae biomass and process stream can vary. The contents could also have potential human health risks such as those from infection (bacteria, mold, yeast, and GMOs) and exposure to allergens, toxins, carcinogens (endotoxins, mycotoxins, proteins, and organic and inorganic chemicals), antibiotics (used to prevent unwanted biological growth), enzymes (used to hydrolyze cellulose), chemicals (process additives), and acidic and caustic materials (used to hydrolyze cellulose).

Freshwater algae, marine algae, and cyan bacteria all produce toxins. These toxins can induce dermatitis, neuro-logical disruptions, and hepatotoxicity or liver failure. Anthropogenic factors such as point and nonpoint source discharges into waterways can cause increased nutrient levels in marine and limnic environments triggering algae blooms and negatively impacting biodiversity with increased toxins and decreased dissolved oxygen levels Commonly referred to as fish kills, the effects can be widespread and environmentally detrimental.

CONCLUSION

Microalgae-based carbon sequestration technologies are not only efficient in covering the cost of carbon sequestration but also manufacture environment-friendly biodiesel. Algae have achieved a renewed interest as an alternative and renewable source of energy in the current period of towering oil prices, diminishing world oil reserves, and the environmental deterioration associated with fossil fuel consumption and green house gases emission. Algae derived biofuels have minute impact on the world‘s food supply as compared to conventional biofuel producing crops. Microalgal biodiesel presents an excellent example of technically viable and carbon–neutral renewable alternatives. Conversion of algal biomass into biofuel can perform better developmental activities along with climate co-benefits. Utilization of the bio-refinery concept in raceway ponds engineering can further lower the production cost. It is the only renewable biofuel that can effectively and completely replace petroleum derived liquid fuels from the market. If the microalgae based bio-refinery concept can be adapted to a developing country like ours, it could become a greatly distributed source of fuel oil and may help to make us self-sufficient and make our economy positively accelerated. In the present scenario, algal biomass is a key link between energy, local environment and climate change and further research are necessary to unlock full potential of algae.