Available online at www.elixirpublishers.com (Elixir International Journal)

Bio Technology

Elixir Bio Tech. 46 (2012) 8454-8457

ISSN: 2229-712X

Algal Biofuel: an alternative green energy

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ARTICLE INFO

Article history:

Received: 21 March 2012;

Received in revised form:

12 May 2012;

Accepted: 23 May 2012;

Keywords

Biofuel,

Microalgae,

Carbon dioxide,

Oil seed crops,

Alternative energy.

ABSTRACT

Biofuel, is committed to becoming a worldwide leader in the development and deployment of renewable energy resources. Biofuels have been one of the substances at the forefront of the discussion. A number of sources for the production of biofuels have been considered. The production of energy from renewable and waste materials is an attractive alternative to the conventional agricultural feed stocks. Algae mainly microalgae have recently gained a lot of attention as a new biomass source for the production of renewable energy. Microalgae can provide several different types of renewable biofuel including methane produced by anaerobic digestion of the algal biomass, biodiesel derived from microalgal oil and photobiologically produced biohydrogen. Algae have received global attention as a renewable resource of biodiesel and may play an important role as a component contributing to the economic growth of the northeastern (NE) region of India. Exploitation of algal diversity and its sustainable use as a feedstock for biodiesel through biotechnological interventions is the need of the hour to ensure future energy security. Many microalgae are exceedingly rich in oil which can be converted to biodiesel using existing technology. In dramatic contrast with the best oil-producing crops, microalgal biodiesel has the potential to be able to completely displace petroleum-derived transport fuels without adversely affecting supplies of food and other agricultural products.

Introduction

There are at least 30,000 known species of microalgae. Only a handful are currently of commercial significance. These are generally cultivated for extraction of high-value components such as pigments or proteins. A few species are used for feeding shellfish or other aquaculture purposes. However one of the key research tasks for commercialisation of algae for energy purposes is the production of Biofuel. Biofuels are fuels that are produced from living organisms or from metabolic by products. In order to be classified as a biofuel, the fuel must contain over 80 percent renewable materials.The first generation biofuels are derived from edible biomass, primarily corn and soybeans. The second generation biofuels are made from cellulosic biomass whose sources include wood residues like sawdust and other cellulosic sources like construction debris, agricultural residues like corn stalks and wheat straw, fast growing grasses and woody materials that are grown for the sole purpose of making biofuel. The third generation biofuel includes fuel produced from algae and cyanobacteria. Algae grown in ponds can be far more efficient than higher plants in capturing solar energy especially when grown in bioreactors. If algal production could be scaled up to industrial capacity, less than 6 million hectares would be needed worldwide to meet the current fuel demand. This consists of less than 0.4% of arable land which would be an achievable goal from global agriculture. In addition, many of the most efficient algal species are marine which means that no freshwater would be necessary in the culture phase. Biofuel produced from algae is an intriguing option. The potential of this option will need to be explored. All algae are primarily made up of proteins, carbohydrates, fats, and nucleic acids in varying proportions. While the percentages can vary with the type of algae, some types of algae are made up of up to 40% fatty acids based on their overall mass. It is this fatty acid that can be extracted and converted into biofuel .

There are a number of species of algae that are being studied for their suitability as crops for mass-oil production. Table 1 below gives a list of these species.

Table 1: Algae used for Oil Production

Neochloris oleoabundans	Class Chlorophyceae
Scenedesmus dimorphus	Class Chlorophyceae. Preferred species for oil production for biodiesel. Problem – produces thick sediment if not constantly agitated
Phaeodactylum tricornutum	Diatom
Pleurochrysis carterae	Class Haptophyta Unicellular coccolithophorid alga. Able to calcify subcellularly
Prymnesium parvum	Toxic algae
Tetraselmis chui,	Marine unicellular algae
Tetraslmis suecica	Marine unicellular algae
Isochrysis galbana	Microalgae
Nannochloropsis salina (Nannochloris oculata)	Microalgae
Botryococcus braunii	Can produce long chain hydrocarbons representing 86% of its dry weight
Dunaliella tertiolecta	Oil yield of about 37%. Fast growing

Many algae are exceedingly rich in oil (Sheehan et al., 1998), which can be converted to biodiesel using existing technology. Algae contain lipids and fatty acids as membrane components, storage products, metabolites and sources of energy. Most of the Algae contain between 2% and 40% of lipids/oils by weight. Biodiesel derived from oil crops is a potential renewable and alternative to petroleum fuels. Algal biomass contains three main components: carbohydrates, protein and lipids/natural oil. Because the bulk of the natural oil made by microalgae is in the form of triacylglycerides (TAGs) which is the right kind of oil for producing biodiesel, microalgae is the exclusive focus in the algae-to-biofuel arena (Danielo 2005).

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Microalgae grow very quickly compared to terrestrial crops. They commonly double every 24 h. During the peak growth phase, some microalgae can double every 3.5 h (Chisti 2007).

Microalgae, like higher plants, produce storage lipids in the form of triacyglycerols (TAGs) which can be used to synthesize fatty acid methyl esters (a substitute for fossil-derived diesel fuel). Microalgae represent a very attractive alternative compared to terrestrial oleaginous species because their productivity is much higher and it does not compete for land suitable for agricultural irrigation or consumption by humans or animals, providing therefore food security. Algal fuel is an alternative to fossil fuel and uses algae as its source of natural deposits. Several companies and government agencies are funding efforts to reduce capital and operating costs and make algal fuel production commercially viable. The production of biofuels from algae does not reduce atmospheric carbon dioxide (CO_2), because any CO_2 taken out of the atmosphere by the algae is returned when the biofuels are burned. They do however potentially reduce the introduction of new CO_2 by displacing fossil hydrocarbon fuels. Biodiesel (monoalkyl esters) is one of such alternative fuel, which is obtained by the transesterification of triglyceride oil with monohydric alcohols. It has been well-reported that biodiesel obtained from canola and soybean, palm, sunflower oil, algal oil as a diesel fuel substitute(Lang *et al*, 2002; Spolaore *et al*, 2006). Biodiesel is a nontoxic and biodegradable alternative fuel that is obtained from renewable sources. Biodiesel is defined as the mono-alkyl esters of fatty acids derived from vegetable oils or animal fats. In simpler terms, biodiesel is the product you get when a vegetable oil or animal fat is chemically reacted with methyl or ethyl alcohols to produce a new compound that is known as a fatty acid methyl or ethyl esters. Algae have received global attention as a renewable resource of biodiesel and may play an important role as a component contributing to the economic growth of the northeastern (NE) region of India.

Algae are of great interest in the production of biofuels due to the fact that a number of species of freshwater and marine algae contain large amounts of high quality polyunsaturated fatty acids which can be produced for aquaculture operations. Algae can grow heterotrophically on cheap organic substrates, without light, and under well-controlled cultivation conditions. Several strategies are important when determining ways to increase the use of algae for commercial production of polyunsaturated fatty acids in the near future. These include continued selection and screening of oleaginous species, improvement of strains using genetic engineering, optimization of the culture conditions, and the development of efficient cultivation systems. It is also important to determine whether the polyunsaturated fatty acids are located within the membrane lipids, or in the cytosol (Guschina & Harwood 2005). Algae can produce a large number of different types of lipids which include but are not limited to, neutral lipids, polar lipids, were esters, sterols, and hydrocarbons, as well as prenyl derivatives such as tocopherols, carotenoids, terpenes, quinones, and phytylated pyrrole derivatives like chlorophylls (Hu *et al*., 2008). When algae are grown under optimal conditions, they synthesize fatty acids principally for esterification into glycerol based membrane lipids which make up about 5-20% of their dry cell weight (DCW). Fatty acids include medium (C10-14), long chain (C16-18) and very long chain (>C20) fatty acid derivatives. The major components of the membrane glycerolipids are different kinds of fatty acids that are polyunsaturated and are derived through aerobic desaturation and chain elongation from the precursor fatty acids palmitic and oleic acids (Hu *et al*., 2008). When there are unfavorable environmental or stress conditions for growth, many algae change their lipid biosynthetic pathways toward the formation and accumulation of neutral lipids (20-50% DCW), mainly in the form of triacylglycerol (TAG). TAGs, unlike the glycerolipids found in membranes, do not perform a structural role but instead serve mainly as a storage form of carbon and energy. There is evidence that suggests that in algae, the TAG biosynthesis pathway may play a more active role in the stress response, in addition to functioning as carbon and energy storage under environmental stress conditions. After being synthesized, TAGS are deposited in densely packed lipid bodies that are located in the cytoplasm of algal cells (Hu *et al*., 2008).

The lipids from algae may include polar lipids, wax esters, sterols and hydrocarbons, as well as prenyl derivatives such as tocopherols, carotenoids, teepees, quinines and phytylated pyrrole derivativs such as the chlorophylls. The major membrane lipids are the glycosylglycerides(e.g. monogalactosyldiacylglycerol, digalactosyldiacylglycerol and sulfoquinovosyldiacylglycerol), which are enriched in the chloroplast, together with significant amounts of phosphoglycerides (e.g. phosphatidylethanolamine, PE and phosphatidylglycerol, PG), which mainly reside in the plasma membrane and many endoplasmic membrane systems. (Guckert and Cooksey 1990, Harwood 1998, Pohl and Zurheide 1979)

The idea of using microalgae as a source of fuel is not new (Nagle and Lemke,1999; Sawayama et al., 1995) but it is now being taken seriously because of the escalating price of petroleum and more significantly, the emerging concern about global warming that is associated with burning fossil fuels. (Gavrilescu and Chisti 2005) since algae is a renewable resource and it fixes CO_2 in the atmosphere through photosynthesis(Fig.1). Shay(1993) reported that algae were one of the best sources of biodiesel. In fact algae are the highest yielding feedstock for biodiesel. It can produce up to 250 times the amount of oil per acre as soybeans. In fact, producing biodiesel from algae may be only the way to produce enough automotive fuel to replace current gasoline usage. Algae produce 7 to 31 time greater oil than palm oil (Table.2&3). It is very simple to extract oil from algae.

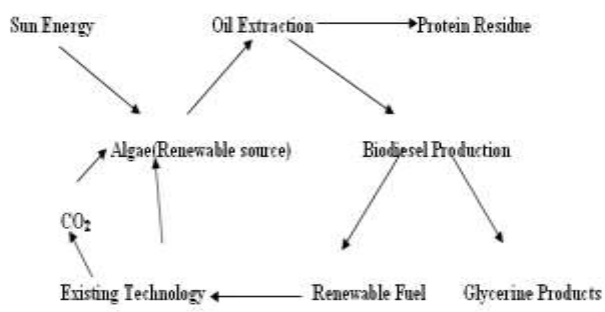

Fig 1: Schematic representation of Oil extraction from algae.

Cultivation Of Algae

The process of producing algae is really quite simple. Algae are grown in either open-pond or closed-pond systems. Once the algae have been harvested, the lipids (oils) are extracted from the walls of the algae cells. Microalgae cultivation using sunlight energy can be carried out in open or covered ponds or closed photobioreactors, based on tubular, flat plate or other designs. Closed systems are much more expensive than ponds, and present significant operating challenges (overheating, fouling), and due to gas exchange limitations, among others, cannot be scaled-up much beyond about a hundred square meters for an individual growth unit.

For large-scale biofuels production, which would require systems of hundreds of hectares in scale, this would mean require deploying tens of thousands such repeating units, at great capital and operating cost. Open ponds, specifically mixed raceway ponds are much cheaper to build and operate, can be scaled up to several hectares for individual ponds and are the method of choice for commercial microalgae production.

Advantages of Biodiesel from Algae Oil

One of the newest and most innovative forms of alternative fuels in development today is algae based biofuel. Algae are one of the fastest growing and most adaptive organisms on the planet and researchers are developing ways of using algae to capture CO_2 from the atmosphere and to output fuels that can meet our energy needs. Producing biodiesel from algae has been touted as the most efficient way to make biodiesel fuel (Table.4). The main advantages of deriving biodiesel from algae oil include:

- rapid growth rates,
- a high per-acre yield (7 to 31 times greater than the next best crop – palm oil),
- certain species of algae can be harvested daily,
- algae biofuel contains no sulphur,
- algae biofuel is non-toxic,
- algae biofuel is highly bio-degradable, and
- algae consume carbon dioxide as they grow, so they could be used to capture CO_2 from power stations and other industrial plant that would otherwise go into the atmosphere.

Table 2. Comparison of some sources of biodiesel

Crop	Oil yield (L/ha)	Land area needed (M ha)	% of existing cropping area
Corn	172	1540	846
Soybean	446	594	326
Canola	1190	223	122
Jatropha	1892	140	77
Coconut	2689	99	54
Oil palm	5950	45	24
Microalgae	136,900	2	1.1

Making biodiesel from algae has huge implications for the future of biodiesel

- With such an efficient biodiesel crop, biodiesel from algae can offset many of the biodiesel problems inherent in other, less productive bio diesel oils.
- Less land is needed, which means less land is taken away from food production, averting the global starvation that contemporary oilseed biodiesel crops are contributing to.
- Similarly, much less land need ever be cleared of forest to grow it.
- Unlike conventional biodiesel crops, the land used for algae biodiesel production does not need to be good agricultural land.
- Unlike conventional crops, the farming inputs are relatively low.
- The algae can be fed on waste. In Permaculture systems it could conceivably be produced as a byproduct of duck or fish production waste waters, or perhaps even using sewerage effluent

Table 3. Oil content of some microalgae (Chisti, 2007, Gouveia & Oliveira, 2009)

Microalga	Oil content (% dry weight)
Botryococcus braunii	25-80
Chlorella protothecoides	23-30
Chlorella vulgaris	14-40
Crypthecodinium cohnii	20
Cylindrotheca sp.	16-37
Dunaliella salina	14-20
Neochloris oleoabundans	35-65
Nitzschia sp.	45-47
Phaeodactylum tricornutum	20-30
Schizochytrium sp.	50-77
Spirulina maxima	4-9
Tetraselmis suecia	15-23

Table 4: Comparison of properties of microalgal oil, conventional diesel fuel (Xu *et al*., 2006)

Properties	Biodiesel from microalgae oil	Diesel Oil
Density (kg L-1)	0.864	0.838
Viscosity (mm-2 s-1, cSt at 40°C	5.2	1.9-4.1
Flash point (°C)	115	75
Solidifying point (°C)	-12	-50 to 10
Cold filter plugging point (°C)	-11	-3.0 (max -6.7)
Acid value (mg KOH g-1)	0.374	Max 0.5
Heating value (MJ kg-1)	41	40-45
H/C ratio	1.81	1.81

Conclusion

In order to be a viable alternative energy source, a biofuel from algae should provide a net energy gain, have environmental benefits, be economically competitive and be producible in large quantities without reducing food supplies. Algae are an economical choice for biodiesel production, because of its availability and low cost. Biodiesel from microalgae seems to be the only renewable biofuel that has the potential to completely displace petroleum-derived transport fuels without adversely affecting supply of food and other crop products. Renewable biofuels are needed to displace petroleum derived transport fuels, which contribute to global warming and are of limited availability. Biodiesel is potential renewable fuels that have attracted the most attention. Biodiesel from microalgae seems to be the only renewable biofuel that has the potential to completely displace petroleum-derived transport fuels without adversely affecting supply of food and other crop products. It can also use seawater as a medium when marine microalgal species are utilized which mitigates the problem of freshwater shortages. In addition, there is much potential for cost savings when the production of novel products for use in medicine, food, and cosmetics are coupled with the production of biofuels (Li et al., 2008). Increases in atmospheric CO_2 concentrations and rapid declines in global oil reserves have made it imperative that we move more rapidly towards the development of carbonneutral, cost-effective, renewable substitutes for fossil energy sources (Schenk, 2008). Biodiesel produced from the mass cultivation of microalgae potentially offers a highly attractive and ecologically-friendly biofuel, but after almost half a century of research the full promise of algae as a feedstock for biofuel production has remained largely unfulfilled.

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