An overview on biodiesel fuel production from algae

Evelyn and Padil
Department of Chemical Engineering, University of Riau
Kampus Bina Widya Km 12,5 Simpang Panam Pekanbaru 28293
Tel. 0761-632732, email: evelyn_yusa@yahoo.com

Abstract

Biodiesel fuel has emerged as a viable substitute for petroleum diesel and as a component to mitigate greenhouse gas emission. Biodiesel is biodegradable, less CO_2 and NO_x emissions and can be obtained from renewable sources. The fuel can be made easily from either virgin or waste cooking oil such as palm, soybean, canola, rice bran, sunflower, corn oil, fish oil and chicken fat. Those feedstocks are still estimated compete with the food consumptions in the future. Presently, research is being done on algae as one of alternative feedstock which are particularly rich in oils (up to 60% of their mass) and whose yield per hectare is considerably higher than that of palm (7 to 31 times).

The objective of the paper gives a brief overview on biodiesel fuel production from algae to further undertake significant research. It also describes the common method of production which is base-catalyzed transesterification and some requirements of that are needed in order to achieve high-yield algal oil production. Algae require primarily three components to grow: sunlight, CO_2 water and Indonesia has appropriate geographical condition that could support the growth and production of algae, therefore it is expected to introduce algae as potential feedstock for biodiesel production. In practice however, while algal oil certainly appears promising, it should be pointed out that lots more aspects need to be analysed and further experimentations to be done before one can be sure of algal oil being a worthy substitute for petro-diesel.

Keyword: Biodiesel fuel, Algae

1. Introduction

Humanity's dependence on petroleum for transportation fuel comes at a high cost. Global production of petroleum has arguably already peaked, while demand will soar in the future as the huge populations will require more fuel as those economies continue to grow [4]. The environmental impact of fossil fuels is well known. It contributes to global warming by transferring previously sequestered carbon molecules into the atmosphere as carbon dioxide, a greenhouse gas. It also is a major source or air pollution through other combustion products found in exhaust. Finally, the nations that cannot supply their own petroleum needs are forced into an unfavorable balance of payments with petroleum exporters.

Biofuels offer a partial solution to many of these problems. It has been claimed that biofuels do not contribute to global warming. Like petroleum, exhaust from biofuels contains carbon dioxide. Since plants remove carbon dioxide from the atmosphere during photosynthesis, the net production of CO_2 is arguably zero. The levels of other pollutants are also generally lower with biofuels than with petroleum. The fuelstocks for biofuels are produced by domestic agriculture, which means that biofuel production occurs domestically as well.

Biodiesel is an attractive alternative to petroleum diesel. Production of biodiesel is easily done and requires low energy inputs. While it can be made from animal fat, the main fuelstock is vegetable oil, which can be obtained from an amazing variety plants. It has been well-reported that biodiesel obtained from canola and soybean, rapeseed, palm, sunflower oil as a diesel fuel substitute[8,14].

The main drawback of biodiesel is the availability of vegetable oil. There is not enough arable land to meet current domestic diesel consumption. It may be possible to produce enough oil by farming microbes, such as algae, whose oil yields per unit land area could be two orders of magnitude higher than with conventional oil crops [7]. In fact, algae are the highest yielding feedstock for biodiesel. Some types of algae can produce up to 60% of their body weight of natural oil, suitable for biodiesel [11]. The table below presents indicative oil yields from various oilseeds and algae.

Oilseeds and algae	Yield of Various Plant Oils Crop Oil in Liters per hectare
Castor	1413
Sunflower	952
Safflower	779
Palm	5950
Soy	446
Coconut	2689
Algae	***100000***

Source: http/www.oilgae.com

2. Algal Biological Concepts

Research in algal oil is not new. It has been produced and used for the cosmetic industry, primarily from macroalgae (larger sized algae) such as oarleaf seaweed etc. [1]. Biodiesel production using macroalgae species is also reported recently [7]. However, there are still only a few amount of research being done in the field of oil from microalgae (less than 2 mm in diameter) which best suited for biodiesel production. Microalgae has much more oil than macroalgae and it is much faster and easier to grow [10]. Microalgae can provide a number of potential fuel products. These include production of methane gas via biological or thermal gasification [11, 10], production of ethanol via fermentation [1], photobiologically produced biohydrogen [6, 7] and production of biodiesel [2, 11, 15].

The four most important abundant source of microalgae are the diatoms (Bacillariophyceae), the green algae (Chlorophyceae), the golden algae (Chrysophyceae) and the blue-green algae (Cyanophyceae). The first two listed are the most prominent line for biodiesel derived microalgal oil [12,13,14,]. The United States Department of Energy (DOE) through the Aquatic Species Program (ASP) has been experimenting with algae for 18 years and also had identified around 300 strains of algae that are the most suitable for producing biodiesel [3]. These photosynthetic organisms are remarkable and efficient biological factories capable of taking a waste (zero-energy) form of carbon (CO_2) to combine energy from the sun and water, further converting it into a high density liquid form of energy (natural oil) hence biodiesel.

3. Biodiesel production

The processes of making biodiesel from algae is a process including the cultivation of algae strain in a bioreactor, the algae oil extraction, the evaporation of solvent, followed by the transesterification, settling, separation of biodiesel, washing and finally drying. The cultivation of algal strain can be done in an open ponds (raceway tracks) or lakes, or alternatively algae could be grown in closed structures called photobioreactors. Then extract the algae from its growth medium (using an appropriate separation process), and use the wet algae to extract the oil usually using expeller/press method or by using hexane solvent oil extraction or by using

supercritical fluid extraction [1]. The resulted oil is then evaporated using vacuum to release the solvent and it is further esterified by adding catalyst and alcohol.

3.1. Algae production concepts

Since algae need for their growth sunlight, carbon-di-oxide and water, they can be cultivated in open ponds & lakes, in which some source of waste CO_2 could be efficiently bubbled into the ponds and captured by the algae (Fig 1.). Algae utilize those sources to produce sugars by photosynthesis, which are then metabolised into fatty oils and protein.

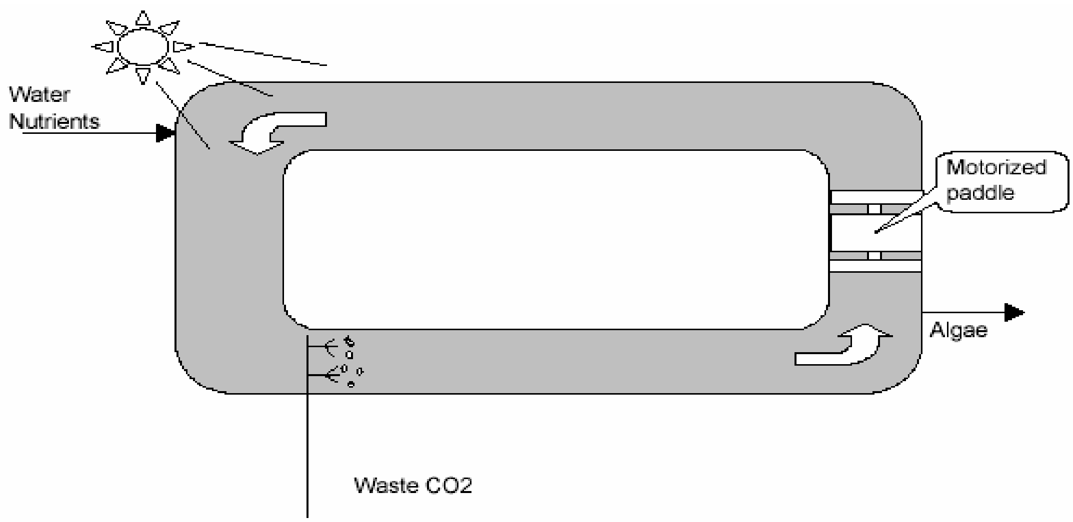

Figure 1. The open pond design for algae cultivation

The ponds are 'raceway' designs, in which the algae, water and nutrients circulate around a racetrack, with paddlewheels provide the flow the algae thus kept suspended in water, and are circulated back to the surface on a regular frequency. 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. These type of ponds has been extensively research on the production of biodiesel from algae that use waste CO_2 from coal power plants for the ASP because of their relative low cost [3].

Other system design are possible. The Japanese, French and German government have invested significant R&D dollars on novel closed bioreactor design called photobioreactors (Fig 2.) for algae production [13]. The main advantage of such a closed systems is that they are not as subject to contamination with whatever organism (bacteria, protozoa or another species of algae) happens to be carried in the wind. Contamination is a serious problem for monospecific cultures of micro-algae and sterilization is mostly applied to handle this problem. The Japanese have developed a photobioreactor which is optical fiber-based reactor systems that could dramatically reduced the amount of surface area required for algae production. While breakthroughs in these types of systems may well occur, their costs are, for now, prohibitive especially for production of fuel.

Figure 2. The photobioreactor systems

3.2. Algae oil extraction

There are three well-known methods to extract the oil from oilseeds, and these methods should apply equally well for algae too:

1. Expeller/Press
2. Hexane solvent oil extraction
3. Supercritical Fluid extraction

Expeller/Press

Expression/Expeller press-When algae is dried it retains its oil content, which then can be "pressed" out with an oil press. Many commercial manufacturers of vegetable oil use a combination of mechanical pressing and chemical solvents in extracting oil. While more efficient processes are emerging, a simple process is to use a press to extract a large percentage (70-75%) of the oils out of algae.

Hexane Solvent Method

Algal oil can be extracted using chemicals. Benzene and ether have been used, but a popular chemical for solvent extraction is hexane, which is relatively inexpensive [(1)]. The downside to using solvents for oil extraction are the inherent dangers involved in working with the chemicals. Benzene is classified as a carcinogen. Chemical solvents also present the problem of being an explosion hazard.

Hexane solvent extraction can be used in isolation or it can be used along with the oil press/expeller method. After the oil has been extracted using an expeller, the remaining pulp can be mixed with cyclo-hexane to extract the remaining oil content. The oil dissolves in the cyclohexane, and the pulp is filtered out from the solution. The oil and cyclohexane are separated by means of distillation. These two stages (cold press & hexane solvent) together will be able to derived more than 95% of the total oil present in the algae.

Supercritical Fluid Extraction

This can extract almost 100% of the oils all by itself. This method however needs special equipment for containment and pressure In the supercritical fluid/CO_2 extraction, CO_2 is liquefied under pressure and heated to the point that it has the properties of both a liquid and gas. This liquefied fluid then acts as the solvent in extracting the oil.

There are other less well-known extraction methods such as enzymatic extraction, osmotic shock and ultrasonic-assisted extraction.

3.3. Transesterification

This is a common later stage of biodiesel fuel production. The bulk of natural oil made by oilseed crops and algae biomass is in the form of three long chain triacylglycerols (TAGS) attached to a glycerol backbone. Algal oil, as well as vegetable oils, are all highly viscous, with viscosities ranging 10–20 times those of no. 2 Diesel fuel. By a process called transesterification (reacting these TAG's with simple alcohols), it can create an alkyl ester [4], known as biodiesel (Fig 3.).

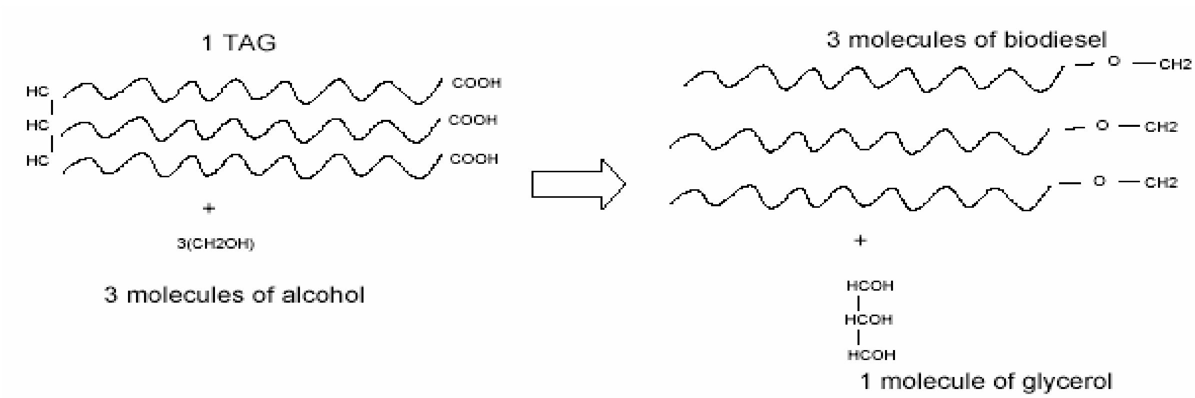

Figure 3. The transesterification process

It is a simple chemical reaction requiring only four steps and two chemicals.

1. Mix methanol and sodium hydroxide creates sodium methoxide
2. Mix sodium methoxide into algae oil
3. Allow to settle for about 8 hours
4. Drain glycerin and filter biodiesel to 5 microns.

The alcohol used in this reaction can be either methanol or ethanol, normally done with ethanol, the catalyst is sodium hydroxide, and the oil is any fat or vegetable oil. The outputs are 86% Methyl Esters or biodiesel, 9% Glycerin which can be used to make soap and other products, 1% fertilizer, and 4% alcohol which can be recycled back through the process [16].

4. Conclusion

Theoretically, in general biodiesel produced from algae appears to be the only feasible solution today for replacing petro-diesel completely. No other feedstock has the oil yield high enough for it to be in a position to produce such large volumes of oil. In addition, algae technology can be quite simple since algae only need sunlight, carbon-di-oxide and water for their growth. In practice, however, need more research to make the process economically viable.

References

1. "Algae Oil Yield", http/www.oilgae.com, 11/05/2008.
2. Banerjee, A. et al. 2002. "A Renewable Source of Hydrocarbons and Other Chemicals". *Crit. Rev. Biotechnol*., 22: 245-279.
3. Benemann, J. and Oswald, P.I. 1996. "Systems and Economic Analysis of Microalgae Ponds for Conversion of CO_2 to Biomass". Department of Energy Pittsburgh Energy Technology Center.
4. Campbell, C.J. 1997. "The Coming Oil Crisis". Essex, England: Multi-Science Publishing Company and Petroconsultants, S.A.
5. Fedorov, A.S. et al. 2005. "Continuous H_2 Photoproduction by Clamydomonas reinhardtii Using a Novel Twostage, Sulfate-Limited Chemostat System". *Appl., Biochem.Biotechnol*. Adv., 23: 403-12.
6. Gavrilesu, M. and Chisti, Y. 2005. "Biotechnology a Sustainable Alternative for Chemical Industry", *Biotechnol. Adv*., 23: 71-99.
7. Hossain, S. et al 2008. "Biodiesel Fuel Production from Algae as Renewable Energy". *American Journal of Biochemistry and Biotechnology*. 4 (3):250-254.
8. Lang, X., A.K. Dalai, N.N. Bakhshi, M.J. Reaney and P.B. Hertz, 2002. Preparation and characterization of biodiesels from various Bio-Oils. Bioresour. Technol., 80: 53-62.
9. Markley, K. 1961. *Chapter 9: Esters and Esterification, in Fatty Acids: Their Chemistry, Properties, Production and Uses Part 2*, 2nd Edition (Markley, K.; ed.). Interscience Publications, New York.
10. Pahl, Greg 2005. *Biodiesel: growing a new energy economy*. White River Junction, VT: Chelsea Green Publishing Co.
11. Roessler, P.G. et al. 1994. "Genetic Engineering Approaches for Enhance production of Biodiesel Fuel from Microalgae". ACP Symp Ser. 566: 255-270.
12. Shay, E.G. in Hossain, S. et al (1993). "Diesel Fuel from Vegetable Oils: Status and Opportunities". *Biomass Bioenergy*, 4: 227-242.
13. Sheehan, J. et al. 1998. *A look Back at the U.S. Department of Energy's Aquatic Species Program: Biodiesel from Algae*. National Renewable Energy Laboratory (NREL), Colorado.
14. Spolaore, P. et al. 2006. "Commercial Applications of Microalgae". *J.Biosci.Bioeng*., 101: 87-96.
15. Thomas, F.R. 2006. "Algae for Liquid Fuel Production Oakhaven Permaculture Center". Retrieved on 2006-12-18. *Permaculture Activist*, 59: 1-2.
16. Tickel, J. 2003. *From the fryer to the Fuel Tank the Complete Guide to Using Vegetable Oils as an Alternative Fuel.* Tickel Energy Consultants.