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A Promising Oil Alternative: Algae Energy (An Integrated Approach)

Abstract

Biodiesel production from algae is a promising technique. Microalgae have the potential to produce 5,000-15,000 gallons of biodiesel (acre-year). However, there are challenges; these include high yield of algae biomass with high lipid content and the effective technique to harvest the grown algae, extract the algal oil and transesterify the oil to biodiesel. Biodiesel is created through a chemical reaction known as transesterification. By simplifying the reaction conditions and pretreatment operations, while examining the effects in terms of maximum fatty acid methyl esters (FAME) produced, it can be determined that a direct transesterification with chloroform solvent was more effective than the traditional extraction-transesterification method.

Keywords: Alternate fuels, biodiesel, green fuels.

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Introduction

With petroleum reserves dwindling, the search is on to replace gasoline with a cleaner, greener alternative. Though much eco-talk has centered on ethanol from corn and biodiesel from soybeans, the biofuel that looks more likely to replace petroleum on a large scale comes from a most unlikely place: pond scum.

Algae, like corn, soybeans, sugar cane and other crops, grows via photosynthesis (meaning it absorbs carbon dioxide) and can be processed into fuel oil .However, the slimy aquatic organisms yield 30 times more energy per acre than land crops such as soybeans, according to the U.S. Department of Energy. The reason: They have a simple cellular structure, a lipid-rich composition and a rapid reproduction rate. Many algae species also can grow in saltwater and other harsh conditions -- whereas soy and corn require land and fresh water that will be in short supply as the world's population balloons."If you replaced all the diesel in the U.S. with soy biodiesel, it would take half the land mass of the U.S. to grow those soybeans," says Matt Caspari, chief executive of Aurora Biofuels, a Berkeley, Calif.-based private firm that specializes in algae oil technology. On the other hand, the Energy Department estimates that if algae fuel replaced all the petroleum fuel in the United States, it would require 15,000 square miles, which is a few thousand miles larger than Maryland.

Another bonus: Because algae can be grown just about anywhere in an enclosed space, it's being tested at several power plants across the nation as a carbon absorber. Smokestack emissions can be diverted directly into the ponds, feeding the algae while keeping greenhouse gases out of the atmosphere. Although processing technology for algae fuel -- a.k.a. "oilgae" in some environmentalist circles -- is improving, it's still years away from reaching your local gas pump. "It's feasible; it's just a question of cost, because no large-scale facilities have been built yet," Caspari says. Boeing and Air New Zealand recently announced a joint project with a New Zealand company to develop an algae-based jet fuel, while Virgin Atlantic is looking into the technology as part of a bio fuels Initiative.

Materials & Methods

To produce algae biodiesel the process involves the following steps

1. Algae cultivation

Algae can produce up to 300 times more oil per acre than conventional crops, such as grapeseed, palms, soybeans, or jatropha. As Algae has a harvesting cycle of 1–10 days, it permits several harvests in a very short time frame, a differing strategy to yearly crops (Chisti 2007). Algae can also be grown on land that is not suitable for other established crops, for instance, arid land. land with excessively saline soil, and drought-stricken land. This minimizes the issue of taking away pieces of land This minimizes the issue of taking away pieces of land from the cultivation of food crops (Schenk et al. 2008). Algae can grow 20 to 30 times faster than food crops.

Photo bioreactors Most companies pursuing algae as a source of bio-fuels are pumping nutrient-laden water through plastic tubes (called "bioreactors") that are exposed to sunlight (and so called photo bioreactors or PBR). Running a PBR is more difficult than an open pond, and is more costly. Because algae strains with lower lipid content may grow as much as 30 times faster than those with high lipid content, the difficulties in efficient biodiesel production from algae lie in finding an algal strain with a combination of high lipid content and fast growth rate, that isn't too difficult to harvest; and a cost-effective cultivation system (i.e., type of photo bioreactor) that is best suited to that strain. There is also a need to provide concentrated CO_2 to increase the rate of production.

Closed loop system Another obstacle preventing widespread mass production of algae for biofuel production has been the equipment and structures needed to begin growing algae in large quantities. Maximum use of existing agriculture processes and hardware is the goal. In a closed system (not exposed to open air) there is not the problem of contamination by other organisms blown in by the air. The problem for a closed system is finding a cheap source of sterile CO_2. Several experimenters have found the CO_2 from a smokestack works well for growing algae

Open pond

Open pond systems for the most part have been given up for the cultivation of algae with high-oil content. Many believe that a major flaw of the Aquatic Species Program was the decision to focus their efforts exclusively on open-ponds; this makes the entire effort dependent upon the hardiness of the strain chosen, requiring it to be unnecessarily resilient in order to withstand wide swings in temperature and pH, and competition from invasive algae and bacteria. Open systems using a monoculture are also vulnerable to viral infection. The energy that a high-oil strain invests into the production of oil is energy that is not invested into the production of proteins or carbohydrates, usually resulting in the species being less hardy, or having a slower growth rate. Algal species with a lower oil content, not having to divert their energies away from growth, have an easier time in the harsher conditions of an open system.

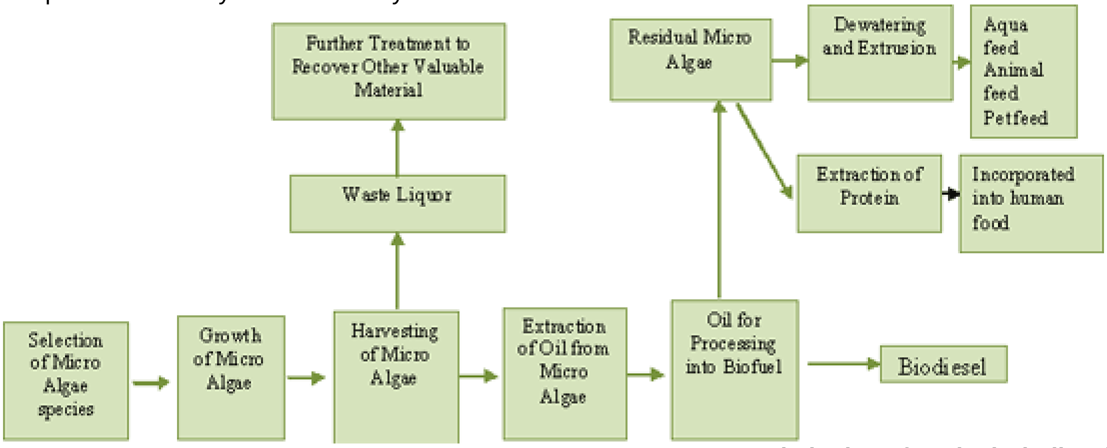
Biodiesel Production from Microalgal Biomass

Producing biodiesel from the microalgal biomass involves a number of steps. While the technology is the same as biodiesel production from terrestrial crops, there are some additional stages that must be considered. Regardless of the cultivation method of the algae, the cells must be dried before reaction. Once the oils have been extracted, then they are reacted with methanol and a catalyst, and the process for the creation of biodiesel is the same as when using vegetable oil. If direct methanolysis (transesterification using methanol prior to extraction) is performed, then filtering and washing steps are required to remove the destroyed algal tissue from the biodiesel.

Traditionally, the oils are extracted from the dry algal biomass through a number of ways. The least expensive extraction is simply through cold pressing. Up to 70% of the oil contained within the algae can be extracted this way. The use of organic solvents can increase this extraction level to 99%, but there is an increased cost in processing to achieve this . Using direct transesterification allows for a single step process that extracts and the algal oils and reacts them with methanol to result in biodiesel. Most extraction methods are based on a method developed by Bligh and Dyer in 1959 . There are a number of modifications to this method .However, algal tissue is much different from animal tissue, for which the Bligh and Dyer method was developed. Research has reported that the lipid in algae is more difficult to extract with these methods .Some direct transesterification reactions involve a mix of solvent, alcohol, and catalyst. The solvent works to extract the lipid as the alcohol and catalyst convert it into methyl esters. Others use heat combined with methanol and catalyst to remove and transform the fatty acids . These processes use less solvent than the extraction process followed by transesterification process .This is an important factor to consider since most organic solvents are toxic and must be recovered. Lewis (2000) found that direct transesterification greatly increased the total amount of fatty acids extracted. Another group found that direct transesterification led to a higher recovery of medium chain and long chain fatty acids in human milk and adipose tissue . Whichever way the oil is extracted (or directly reacted), it undergoes a transesterification reaction to produce the fatty acid methyl esters.After transesterification, the biodiesel is separated from the rest of the reactants. Glycerol must be removed with multiple washings with water .If direct transesterification was used, there will be particulate matter from the algal biomass in the mix, and it has to be removed via filtration. The biodiesel can be used as fuel after washing. There is still the matter of the algal meal though. This algal meal can be used in a variety of ways. Since it contains a large portion of N, P, and proteins, it is an ideal animal feed product or fertilizer .It could also be the feedstock for anaerobic fermentation to obtain biogas (Chisti 2007). Following this, or in place of it, the biomass could undergo pyrolysis to produce bio-oil (Chisti 2007). There is also the biorefinery concept, where other high value chemical compounds could be extracted .Some suggest that small-scale biodiesel production plants should be made accessible to small producers so that an integrated production of biofuels, electricity production, and feed for livestock could be obtained.

A Detailed Process of Biodiesel from Algae

The biodiesel is created by harvesting the algae and separating the plant components from the oil first and then through a process called trans esterification the oils FFA's (or free fatty acids) are neutralized and the glycerin in the oil is removed leaving an alchol ester. In algae oil transesterification sodium ethanolate is used as a catalyst and reacted with the algae oil. This results in the creation of biodiesel, glycerol and sodium ethanolate. The products are then mixed with ether and salt water and mixed well. This separates the products into layers and the layer of ether and biodiesel is separated from the rest. The biodiesel is then separated from the ether by use of a vaporizer and a high vacuum. The ether vaporizes before the biodiesel leaving the biodiesel ready for use.



Although algal biodiesel and petro diesel are similar, there are a few significant differences between their properties.

DISCUSSION

Comparison of Biodiesel from Microalgal Oil and Diesel Fuel

Properties	Biodiesel from Microalgal Oil	Diesel Fuel
Density Kg l-1	0.864	0.838
Viscosity Pa s	5.2×10-4 (40 ºC)	1.9 - 4.1 ×10-4 (40 ºC)
Flash point ºC	65-115*	75
Solidifying point ºC	-12	-50 – 10
Cold filter plugging point ºC	-11	-3.0 (- 6.7 max)
Acid value mg KOH g-1	0.374	0.5 max
Heating value MJ kg-1	41	40 – 45
HC ratio	1.18	1.18

*: Based on data from multiple source

Oil yields based on crop type (adapted from Chisti, 2007).

Crop	Oil yield (gallons/acre)
Corn	18
Soybeans	48
Canola	127
Jatropha	202
Coconut	287
Oil Palm	636
Microalgae	6283-14641

Current Limitations for Algal Biodiesel Production

The three major limitations that currently prevent algal biodiesel from being economically feasible (Sheehan et al 1998). These limitations are contamination with unwanted species, low oil yields, and the overly expensive harvesting step to recover the algal biomass from the growth medium. Such problems can be overcome through the use of photobioreactors or heterotrophic growth, but, in the words of Dr. Benemann, using such costly technology to produce a fuel is "totally absurd." As such, there is still plenty of room for new developments to reduce contamination, increase the lipid yields though metabolic or genetic engineering or growth type, and reduce the harvesting cost by increasing the biomass yield or utilizing a less expensive cultivation procedure. This effort will help to achieve these goals through the design and optimization of a low-moisture attached microalgal culture system.

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