Micro-algal Technology for Sustainable Energy Production: State of the Art

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Abstract: Biodiesel is a renewable fuel currently derived from vegetable oils and animal fats. One of the limiting factors for the growth of the biodiesel market is the availability and price of feedstock. Feedstock for biodiesel has to compete with the food crops for land and water. Hence, alternative feedstock's that are not also food crops need to be found. One such renewable energy sources are microalgae. Microalgae are capable of fixing CO_2 using sunlight to produce biofuel and other chemical compounds with numerous additional technological advantages. This present study highlights the concept of algal biofuel production using open raceway ponds and a closed photo bioreactor. This article addresses its current status and future prospects of biodiesel production from micro-algae.

Keywords: Biofuel; CO_2 fixation; Micro algae; Photosynthetic CO_2 Sequestration; Sunlight.

1. Introduction

Finding alternative energy resources is a pressing mission for many countries, especially for those countries lacking conventional fuel resources [1]. With the rapid development of modern industry, the demand for energy has increased substantially in recent years, and therefore, alternative energy sources are being explored. Biodiesel is currently produced from plant and animal oils. Biodiesel is a transportation fuel that has grown immensely in popularity over the past decade. With dwindling reserves of fossil fuels, it is now more important than ever to search for transportation fuels that can serve as alternatives to crude oil-based fuels such as gasoline and diesel. Common sources for biodiesel feedstock include soy, sunflower, safflower, canola, and oil palm. Lately there has been growing controversy about the use of potential food sources for the production of fuel. In attempt to address these concerns, researchers have turned their focus from popular feedstock's and are currently investigating the use of alternative, non-food related feedstock such as oil from algae. Micro algae are sunlight-driven cell factories that convert CO_2 to potential biofuels, foods, feeds and high-value bioactive compounds [2]. Micro algae can provide several different types of renewable biofuels [3].

The fact that microalgae grow in aqueous suspensions; allows for more efficient access to water, CO_2 and other nutrients which explains the potential for the production of more oil per unit area than other crops currently used. The growth of algae requires CO_2 as one of its main nutrients. There is an opportunity to sequester CO_2 by using flue gas emissions from industrial sources as the feed for algae cultivation [2]. The objective of the present paper is to summarize the current status and future prospects of Biodiesel production using microalgae.

2. Micro-algae: A multipurpose feedstock

Algae are more efficient at utilizing sunlight than terrestrial plants [4], consume harmful pollutants, have minimal resource requirements and do not compete with food or agriculture for precious resources [5]. Algae have higher growth rates than terrestrial plants, allowing a large quantity of biomass to be produced in a shorter time. Algae growth rates of 10 to 50 g m-2 d-1 (grams of algal mass per square meter per day) have been reported [6]. Compared to terrestrial plants such as corn and soy, algae have shorter harvest times because they can double their mass every 24 hours [2]. These short harvest times allow for much more efficient and rapid production of algae compared to corn or soy crops. The yields of different oil producing feedstock can be examined, as shown in Table 1.

Table 1. Amount of oil produced by various feedstock's' [7].

Feedstock	Liters/Hectare
Castor	1413
Sunflower	952
Palm	5950
Soya bean	446
Coconut	2689
Algae	100000

2.1 Resource requirements for algae growth

One of the most compelling advantages of using algae as a biofuel feedstock is that the resource requirements are less intensive compared to other crops and plants. Algae require only a few basic resources to grow successfully: CO_2, water, sunlight and nutrients. Sunlight is normally abundant throughout most of the year and utilized more efficiently than terrestrial crops. CO_2 can be obtained in high concentrations from power plants and industrial processes, or at ambient concentrations from the atmosphere. Algae will grow in most water sources with varying pH levels from fresh drinking water, saline or brackish aquifers to wastewater effluent [8]. Brackish, or moderately salty water, is abundant and provides a suitable environment and resource for algae to grow in. Algae, through the process of photosynthesis, are adept at sequestering CO_2 from the atmosphere [9]. There is potential to effectively reduce the amount of carbon dioxide and nitrogen oxides released into the atmosphere from many stationary emitters by feeding the carbon-rich flue gas to the algae [10]. Based on a theoretical ratio, algae are able to fix approximately 1.8 kg of CO_2 fixed for every 1 kg of algae biomass produced [2].

2.2 Oil Content and composition of algae

Algae can be oil-rich organisms; oil content, the percentage of oil per weight of dry biomass, typically ranges from 20 to 50% depending on the species [2]. This oil is composed of many different types of lipids that can be processed easily into biodiesel, jet fuel or other chemicals. Algae species and their typical oil contents are presented in Table 2.

Compared to terrestrial crops such as corn, soy or even palm plants, algae are far more oil-rich and offer a higher yield of oil per unit of land per year. The main components of algae are carbohydrates, proteins, and lipids [11]. Of particular interest are the lipids, which can be processed into valuable fuel products such as biodiesel (through transesterification), jet fuel, and even traditional gasoline and diesel products depending on the species. Lipids produced from algae contain saturated and polar lipids, which are suitable for use as a fuel feedstock and are contained in higher concentrations than other plants [12].

Table 2. Algae species and typical oil content [2].

Micro algae	**Oil content (% dry weight)**
Botryococcus braunii	25-75
Chlorella sp	28-32
Crpthecodinium cohnii	20
Cylindrotheca sp	16-37
Dunalielia primolecta	23
Isochryais sp	25-33
Monallanthus salina	>20
Nannochloris sp	20-35
Nannochloropsis sp	31-68
Neochloris oleoabundans	35-54
Nitzschina sp	45-47
Schiochytrium sp	50-77
Tetraseknus sueica	15-23

2.3 Algae for Carbon Sequestration

Energy from biomass via CO_2 sequestration using microalgae is potentially an important method of mitigating greenhouse gas emissions. Biological Sequestration is a concept based on capturing the total (process + combustion) CO_2 emitted from a thermal power plant via growing micro algae which are used to produce bio-fuel, and its residue can be burned as solid biomass, as well. However, contrary to what is often stated, CO_2 capture by algal cultures is not a CO_2 sequestration or greenhouse gas abatement process. That can only come from converting the algal biomass to biofuels and their use in replacing fossil fuels. As a mitigation strategy, Microalgae offer the advantage of allowing the continued use of the well-established fossil fuel power generation infrastructure. The main steps in this process for a standard fossil-fuel power plant are shown in Fig.1.

Based on literature reviews, one can determine that approximately 40 ha of algae ponds are required to fix the carbon emitted from one MW of power generated from a coal plant at 50% capture efficiency [13]. The carbon used to create lipids in the algae is still released into the atmosphere upon combustion of the fuel, but the overall amount of carbon has been used twice: once for energy production in a power plant and second to grow algae for producing bio-fuels. An ideal methodology for photosynthetic sequestration of anthropogenic CO_2 has the following characteristics: (1) a high rate of CO_2 uptake and mineralization of CO_2, (2) results in permanently sequestered carbon, (3) produces revenue from the sale of high value products, and (4) use of concentrated, anthropogenic CO_2 before it enters the atmosphere.

3. Commercial Scale Cultivation of Microalgae

Algae are typically found growing in ponds, waterways, or other wetlands which receive sunlight and CO_2. Growth depends on many factors and can be optimized for temperature, sunlight utilization, pH control, fluid mechanics and more [13-14]. Man-made production of algae tends to mimic the natural environments to achieve optimal growth conditions. Algae production systems can be organized into two distinct categories: open ponds and closed photo bioreactors. Open ponds are simple expanses of water recessed into the ground with some mechanism to deliver CO_2 and nutrients with paddle wheels to circulate the algal broth. Closed photo bioreactors are a broad category referring to systems that are enclosed and which allow more precise control over growth conditions and resource management. Table 3 presents a short comparison of open pond systems and closed photo bioreactors.

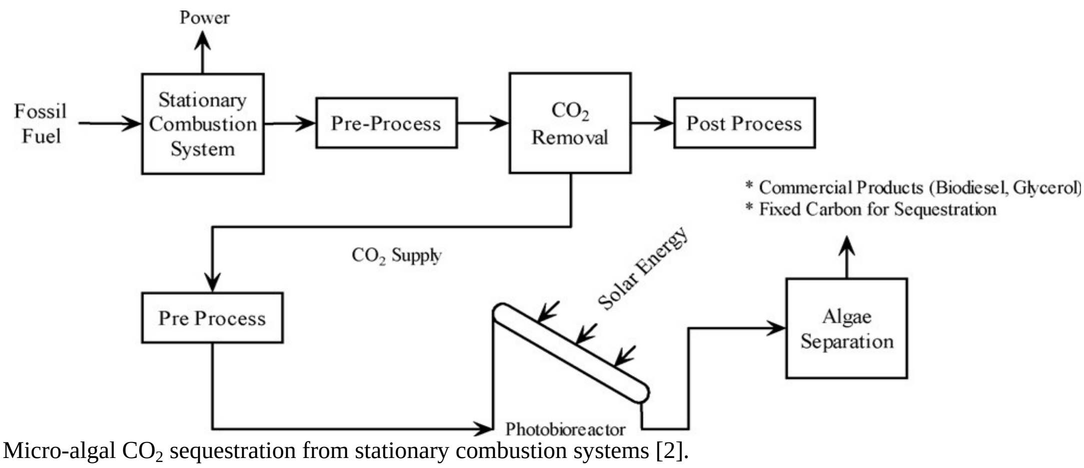
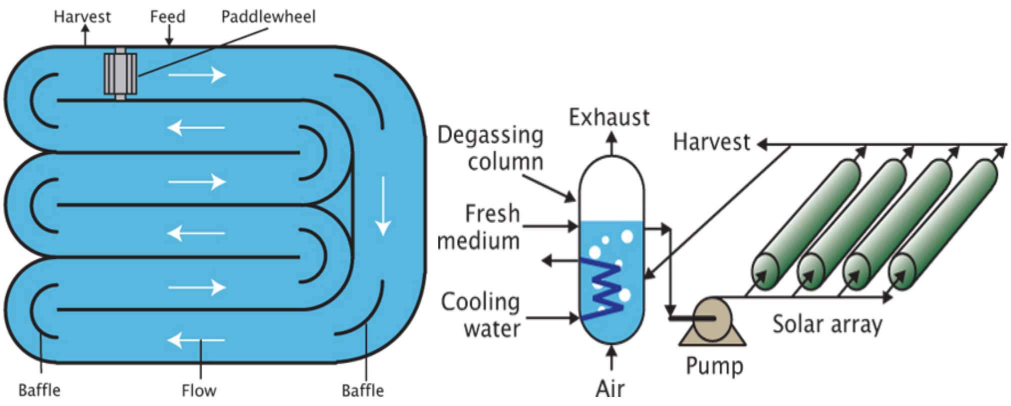


Figure 1. Micro-algal CO_2 sequestration from stationary combustion systems [2].

Table 3. Advantages and disadvantages of open and closed systems.

Parameter	**Open Raceway pond**	**Closed photo bioreactor**
Scale	Large & Pilot Scale	Laboratory Scale
Cost	Cheaper to construct.	More expensive
Usage	Commercial	Not commercial
Typical cost of biodiesel	2.0-2.5 USD/L	5-6 USD/L
Light utilization	Poor	Very high
$C0_2$ losses to atmosphere	High	Almost none
Typical Biomass Yield (g/m^2-day)	10-60	60-100
Area requirement	Large	Small



Open Pond System *Closed photo bioreactors*

Figure 2. Algae Cultivation Methods [15-16].

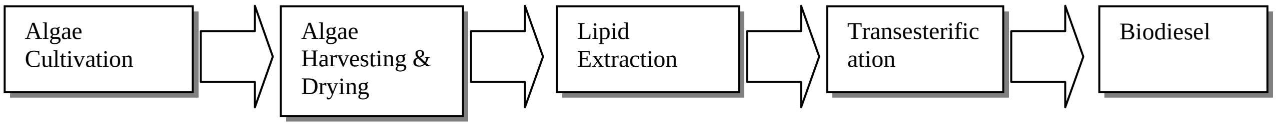


Figure 3. Algae growth and harvesting process [17].

4. Algae Harvesting and Oil extraction

Production of oil from algae is a straightforward process consisting of growing the algae by providing necessary inputs for photosynthesis, harvesting, de-watering and oil extraction. Energy in the form of photons is absorbed by the algae cells, which convert the inorganic compounds of CO_2 and water into sugars and oxygen. The sugars are eventually converted into complex carbohydrates, starches, proteins and lipids within the algae cells. In order to extract the valuable lipids a series of steps must be undertaken to isolate the algae cells and oil. A diagram of the overall growth and harvesting process is presented in Fig. 3. The traditional process begins by separating the algae biomass from the water broth in the dewatering stage using either centrifuges, filtration or flocculation techniques. Centrifuges collect biomass by spinning the algae-water broth so that water is flung away from the algae cells. Flocculation involves precipitating algae cells out of solution so that they can be concentrated and removed easily. Once the algae cells have been collected the oil must be removed from the cells. The oil can then be processed into biodiesel, jet fuel, ethanol, synthetic fuels or other chemicals.

5. Algal Bio-fuel: Future prospects

Large Scale Cultivation of algae for biodiesel production is still in the Research & Development phase. Currently it is too expensive to be commercialized. The long term potential of this technology can be improved by the following approaches.

- Cost saving growth technologies of oil-rich algae should be identified and developed.
- Integrated bio-refineries can be used to produce biodiesel, animal feed, biogas and electrical power thereby reducing the cost of production.
- Enhancing algal biology by genetic modification and metabolic engineering has the greatest impact on improving the economics of microalgae biodiesel.
- Area Efficient Techniques to capture CO_2 from Industrial power plants need to be identified.
- Recycling of Nutrients from Municipal sewage and Industrial waste waters are required to reduce the demand of fertilizers to grow algae.
- Economics of Microalgae production can be improved by additional revenues from waste water treatment and Greenhouse gas abatement.

6. Conclusion and Perspectives

In the endeavor to reduce dependence on fossil fuels and cut carbon emissions to achieve a clean environment, humble algae appear to be taking a lead over the more-talked-about biodiesel source jatropha. Tropical developing countries have the potential for mass cultivation of algae throughout the year as there is not much variation in climatic conditions. Despite having tremendous potential, many challenges inhibit the production of large amounts of algae in an economic and sustainable manner. If algae are to be produced in quantities sufficient for displacing billions of gallons of petroleum fuels, efficient methods for growing algae in ponds or photo bioreactors are needed to minimize resource, operation and maintenance costs. The harvesting, dewatering and oil extraction steps of the production process will need to become more efficient. The technology for processing algal biomass should be standardized, simplified and economized. Moreover it is essential to strengthen the competitiveness of Asian countries in Microalgal biofuel production through mutual cooperation.

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