Biofuel from Microalgae: Current Status, Opportunity and Challenge

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***Abstract*—Biofuel from microalgae is a renewable energy, which may be instead of the fossil fuel resources in the future with decreasing of the fossil fuel daily. Microalgae have received more attention in the recent decades. This review highlights the current status, opportunity and challenge for biofuel microalgae. This review divides in four parts. First overview is discussed the typical species product biofuel in the world and the main methods of exploring new strain. Second is discussing the mechanism and approach of transfer lipid in culture processing. More specifically, an overview is given on technology to promote the lipid content through the change of the nutrition and new reactor to capture more light. Finally the harvesting, extraction and refining technology of microalgae is reviewed in this paper which can supply an outlook to the current status, opportunity and challenge.**

Keywords-microalgae; biofuel; culture processing; biotechnology; extraction

I. INTRODUCTION

Fossil oil has become an important factor to promote economic growth and maintain standard of living. However fossil fuel resources are decreasing daily. Renewable fuels for alternative energy sources have been paid a great attention in recent years. Microalgae for biofuel are a renewable energy in the recent decades which may be instead of the fossil oil in the future. Although microalgae offers great potential for exploitation, including the production of biodiesel, the technology is still some way from commercial viability. Because the application for energy and bioresource production is still in its nascent stage and suffer from a trouble which is lack of application and cultivation.However their economic outlook is promising [1-4]. So many companies are carrying out the research on the commercialize algal fuel such as Algenol Biofuels co., Aquaflow co. and so on. In the future, fossil oil will be exhausted, while microalgae biofuel will likely be an important energy feedstock.

Microalgae offer great potential for exploitation because of the production of biofuel, the growth speed and the large scale culture technology. However, some problems of the process prevent it from commercial application. The problems including that (1) there is little established background knowledge. So in the future research, we should focus on the integration of biology and engineering including in the optimization of algal biomass production and the content of lipid within the microalgae cell [5]. (2) The technology is not suit to culture microalgae and extract for biofuel. So it is important to develop the new technology to adapt the typical species culture and the biofuel extraction cheaply. (3) The biofuel from different microalgae is also different from the fossil oil resource which is used nowadays. So we should focus on the characters of the lipid molecular and develop some new technologies or catalyze to modify the algal lipid to make a significant contribution to our transport energy needs.

With the global increasing use in the scale of biodiesel production, Opportunities and challenges have been raised. Two years ago, Stuart published a report to review the challenges and prospects of biodiesel algae. The concern for the growth of algae for biofuel was proposed. Here we highlight the important aspects of the biofuel which will reveal perspective. Four major areas of microalgae of biofuel are reviewed as the following:

(1) Typical species of mictoalgae for biofuel;
(2) Culture methods to promote the growth speed;
(3) Nutrition to improve the oil productivity;
(4) Harvesting, extraction and catalytic processing of biofuel cheap and quickly.

II. MICROALGAE FOR BIOFUEL AND PRODUCTION TECHNOLOGY

A. *Microalgae for Biofuel*

Chinese used Nostoc to survive during famine about 2000 years ago which is the first use of microalgae [6]. But microalgae biotechnology started to develop in the middle of the last century because of the numerous content of the valuable products in the microalgae cell such as biofuel, fatty acid, polysaccharides, protein, pigment and so on. So in the world, there are many programs surveying algae species in different areas for suitable strains.

Microalgae living in saline or fresh water environments are unicellular photosynthetic microorganisms. There are estimated 300 000 species with a much greater diversity than other land plants. Microalgae are very efficient solar energy converters and they can produce a great variety of metabolites. Many species exhibit rapid growth and high productivity, and can be induced to accumulate substantial quantities of lipids, often greater than 60% of their dry biomass. Therefore in recent decades, much current research work is focusing on several fast-growing microalgae species with the ability of accumulating substantial quantities of lipids. Especially phytoplankton increase in numbers rapidly to form algae blooms [7]. In recent time, the typical algae species for biofuel contain green algae, diatoms and so on.

Diatoms and green algae are especially species for biotechnology which have the physiological potential to accunmulate high proportions of lipid. Green algae are considered by researchers because it can accumulate over 60% lipid in the cell wall although it grows very slowly[8]. However a large number of microalgae remain unknown to science, giving logical heed to explore this realm for potential application. Nowadays only 15 of the currently known microalgae specie are cutivated in some applied form for use in nutraceuticals, cosmetics, feed, or for wastewater treatment [9]. Furthermore, the estimated number of unknown species for all algae is projected to be two orders of magnitude greater than those currently known [10]. Therefore it is is very important to improve the oil productivity of the microalgae and to reduce the cost of algal biofuel. Oil productivity is the mass of oil produced per unit volume of the mictoalgae broth per day, depends on the algae growth rate and the oil content of the biomass. Microalgae with high oil productivities is desired for producing biodiesel [11]. Obtaining the new species with high oil productivity is an important way. Recently there are two methods to change or upgrade the microalgae species for high oil productivity.

First method is to explore the local species. Exploring the local species which is an adapted method to the prevailing regional abiotic, and also biotic factors is popular in recent study. Maybe it can offer a diverse base of organism naturally engineered to regions that have needs for waste treatment and bioresource production [12]. M. Odlare cultured an indigenous algae species in Mälaren and introduced some new species on microalgae.

Second method is genetic engineering. There are several papers to discuss the typical species of microalgae for biofuel[13-16]. Considering the enormous biodiversity of microalgae and recent developments in genetic engineering, genetic microalgae will likely have the greatest impact on the feasibility of micaroalgae biofuel. Increasing the content of the lipid compounds through the engineer microalgae is very tempting. Therefore the transformation system had to be developed from the techniques to introduce DNA into cell, suitable promoters, new selectable marker genes, and expression vector and codon usage [17]. Genetic engineering will only improve the production of the biofuel and compound in closed culture systems, which should complement and can't instead of the screening of new species. Different species of algae may be better suit for different types of fuel [18]. So exploring the typical microalgae species to meet the social need is the opportunity and chanllenge of the microalgae.

B. Culture Methods

Microalgae appear to be the only source of renewable biodiesel that is capable of meeting the global demand for transport fuels, but the culture is limited to background. The knowledge of the commercial growth of microalgae for high-value products can supply some help to understand the lipid metabolism and direct the culture of microalgae on a large scale. But there are not good methodologies of the energy inputs. So as a product of relatively low value to be produce on a very large scale, a different approach is necessary for algal-based biodiesel, and the major challenge is to ensure that it is not made at the expense of more energy than is obtained in the final fuel product. Nowadays, there are open ponds, photobioreactors and closed systems [19].

Open pond systems are shallow ponds in which algae are cultivated. Nutrients can be provided through runoff water from nearby land areas or by channeling the water from sewage/water treatment plants. Technical and biological limitations of these open systems have given rise to the development of enclosed photoreactors. A few open systems are presented for which particularly reliable results are available. Emphasis is then put on closed systems, which have been considered as capital intensive and are justified only when a fine chemistry is to be produced.

To cut the cost and achieve higher biomass productivity, many microalgae for biofuel were cultured under photoheterotrophic conditions because most of microalgae require light to photosynthesize for their fast growth. Photobioreactors are different types of tanks or closed systems in which algae are cultivated. Although photobioreactoes require a high capital investment, it can be able to produce biomass at a lower final price. And it can be concentrated microalgae broth to reduce the dewatering costs and time substantially [20-23]. 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. Tredici[30] has reviewed mass production about photobioreactors. Although there are many different designs of photobioreactor, but the tubular photobioreactor seems to be most satisfactory for producing algal biomass.

Closed systems are much more expensive than ponds. However, the closed systems require much less light and agricultural land to grow the algae. High oil species of microalgae cultured in growth optimized conditions of photobioreactors have the potential to yield 19,000–57,000l of microalgal oil per acre per year. The yield of oil from algae is over 200 times the yield from the best-performing plant/vegetable oils. Microalgae are photosynthetic microorganisms that convert sunlight, water and carbon dioxide to algal biomass [25]. On the one hand, typical bioreactors were invented for producing a much more contribution on the culture of the microalgae. Comparing two major types of large-scale microalgae culture systems, open ponds have a low productivity compared to photobioreactors[26]. An ideal biomass production system should use the freely available sunlight.

On the other hand, these algae need to have carbon dioxide (CO_2) in large quantities in the basins or bioreactors where they grow. In order to have a high yield and fast-growth, the basins and bioreactors need to be coupled with traditional thermal power centers producing electricity which produce CO_2. This carbon dioxide must be fed continually during daylight hours and available at little or no cost.

C. Nutrition to Improve the Oil Productivity

In addictive, increasing the microalgae biomass productivity is the key way for microalgal biodiesel production and industrialization. Generally, microalgae use additive carbon source and light as the energy source for metabolic activity. They can also adapt to different energy conditions in different environment, exhibiting four different types of metabolic patterns, photoautotrophy, heterotrophy, photoheterotrophy, and mixotrophy[34]. ZhaoSheng Li[28] cultured the Chlorella mintissima UTEX2341 under photohererotrophy condition. With the carbon, nitrogen and phosphorus concentration of 26.37, 2.61 and 0.03 g L^{-1} d^{-1} respectively, a maximum biomass productivity of 1.78 g L^{-1} d^{-1} was obtained, which was 59 times more than that cultured under autotrophic condition. The lipid productivity reached to 0.29 g L^{-1} d^{-1}, which was 11.9 times higher than the highest value reported by Oh et. al. [29].

For microalgae that are able to survive heterotrophically, exogenous carbon sources offer prefabricated chemical energy, which the cells often store as lipid droplets [30-31]. Carbon concentration and source changes are the most important factor of effecting the biomass and lipid production of microalgae [32]. Nitrogen and Phosphorous is the second critical nutrient influencing lipid production and microalgae growth [33]. Therefore, it is essential to study the optimal carbon, nitrogen and phosphorus conditions of micoalgae culture medium to achieve higher biomass productivity. There are a large quantity of organic carbon and nitrogen in wastewater which could assist with the heterotrophic or photoheterotrophic metabolism [42]. Some studies used wastewater to cultivate microalgae and obtained good results either in the removal of nutrients in wastewater or in microalgae production [35-36]. Therefore it is very important to find out the appropriate microalgae species and the optimal nutrition and light conditions to adapt to the variable wastewaters which would benefit both microalgae growth and lipid productivity and also wastewater treatment.

Heterotrophically cultivated Chlorella protothecoides has been shown to accumulate as much as 55% of its dry weight as oil, compared to only 14% in cells grown photoautotrophically[37]. Another natural mechanism through which microalgae can alter lipid metabolism is the stress response owing to a lack of bioavailable nitrogen. Although nitrogen deficiency appears to inhibit the cell cycle and the production of almost all cellular components, the rate of lipid synthesis remains higher, which leads to the accumulation of oil in starved cells. Interestingly, nitrogen deprivation also promotes the accumulation of the antioxidant pigment astaxanthin in the green alga Haematococcus pluvialis. Despite the fact that specific fluxes in metabolic pathways caused by heterotrophic growth and nitrogen starvation have not been elucidated, these two conditions are important for understanding the mechanisms of regulating fatty acid biosynthesis in green algae.

D. Technology of Harvesting, Extraction and Refining of the Microalgae Biofuel

Advances in methods of harvesting the microalgae from the water, extraction of the oil from the microalgae cell and modifitation of the oil will improve the prospects of biofuel. Because the microalgae is unicellular microorganisms, harvesting is difficult and costs contribute 20%-30% of the total cost of algal cultivation. The biodiesel from algal oil in itself is not significantly different from biodiesel produced from vegetable oils [38].

The catalytic process of liquid fuel productions from microalgae is still at the very early stage of development compared to that using other biomass derived from feedstock. Future work should focus on a large number of microalgae having high oil contents. Other oil rich micro-algae containing glycerol or glyceryl lipids need to be investigated. Therefore, different species microalgae crude oil needs different refining technology and conventional catalysts of upgrading and refining. Improving the liquid fuel productions and the productions of hydrogen fuels from the algae lipids should be given attention in the future research because hydrogen would be needed to refine at the place of harvesting.

III. CONCLUSIONS

As fossil oil costs rise and supplies dwindle, biofuel become more attractive to both investors and government. Although biodiesel has great potential, the high cost and limited supply of renewable oils prevent it from becoming a serious competitor for petroleum fuels. New and innovative techniques for cultivation should be invented, miaroalgae may allow biodiesel production to achieve the price and scale of production needed to compete with, or even instead of petroleum. Microalgae with high yield, high density biomass is ideal for intensive agriculture. So genetic engineering, development of low cost harvesting processes, improvement on photobioreactor, and integration of coproduction of microfuel products are other alternatives in reducing algal oil production cost. Therefore developing the research on microalgae is the choice and challenge to us.

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