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Whether will the usage of microalgae as a biofuel feedstock affect their traditional applications?

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Abstract*—In response to energy crisis, global warming and global climate changes, microalgae, which have the competence to use water, sun-light and CO_2 to synthesize biomass through photosynthesis, have received a great deal of interest as a biofuel feedstock. Microalgae can provide the biomass feedstock for the flexible production of several different types of renewable and sustainable biofuels such as biodiesel, bioethanol, biogas, and biohydrogen among others via thermochemical and biochemical conversion processes. However, there are a lot of voiced concerns related to the impacts of microalgal biofuels production on the conventional applications, such as cosmetics, pharmaceuticals and nutritious feed. It is therefore questionable whether the microalgal biofuels production will affect the original functions. On the other hand, the microalgal biofuels also witness an obvious and serious dilemma, where it is found that there is no commercial production at a large scale for bulk application due to the overwhelming investments in capitals and operation. From a sustainability point of view, the authors of this paper explore the current challenges in algal applications, and map out the solutions to realizing the microalgal biofuels production without compromise of other traditional applications. Afterwards, four microalgal biorefinery options have been proposed, after which a net energy ratio assessment and cost-effectiveness assessment have been highlighted to testify their feasibilities. Finally, some crucial actions, including optimal culture technologies, considerate marketing strategies, successful integration of technologies in corporate and efficient government policies, have been suggested to help establish the microalgal biorefinery process in a prosperous manner.

***Keywords*—microalgae; biofuels; traditional application; microalgal biorefinery; challenge**

I. INTRODUCTION

Microalgae, which grow in aquatic environments, are the simple microscopic heterotrophic and/or autotrophic photosynthetic organisms, ranging from unicellular to multi-cellular forms. On contrast to aquatic plants, microalgae do not have real embryos, roots, stems and leaves. They have the competence to use water, sun-light, and CO_2 to synthesize biomass through photosynthesis.

Microalgae are not newly known microorganisms for human beings since they are widely used for decades as the feedstock for the traditional applications in cosmetics, pharmacy and nutrition sectors (Table I). The forms of microalgal products include tablets, capsules, liquids, pure molecules with high value like fatty acids, pigments and stable isotope biochemicals, and cosmetics found in face and skin care products, such as anti-aging cream, refreshing or regenerant care products, emollient and anti-irritant in peelers [1]. Many influenced global companies, such as Cyanotech, Seambiotic, Mera Pharma and FujiChemical, are operating at a relevant scale to produce microalgae for high value added applications in cosmetics, nutritious feed and pharmaceuticals. Another growing market is the application of microalgae in poultry aquaculture by the incorporation of a certain amount of microalgae into poultry rations for the commercial utilization in animal feed [2].

TABLE I. MICROALGAL STRAINS AND THEIR MAJOR MARKETABLE PRODUCTS [3]

Microalgal strain	Major products
Nannochloropsis oculata	Lipids, especially high-value poly-unsaturated fatty acids
Arthrospira sp.	Protein: fish farming, dietary or health food; Lipids, especially high-value fatty acids (linoleic acid and g-linolenic acid); Pigments (phycocyanin, carotenoids)
Chlorella vulgaris	Protein: dietary or health food, fish farming and feeding of cattle, pigs and poultry; Cosmetic purposes
Chlorella sp.	Protein: fish farming and feeding of cattle, pigs and poultry
Crypthecodinium cohnii	Lipids, especially high-value poly-unsaturated fatty acids
Haematococcus pluvialis	Pigments (astaxanthin)
Dunaliella salina	Pigments (b-carotene; bixin, zeaxanthin)
Botryococcus braunii	Hydrocarbons; Pigments (violaxanthin, lutein)

II. NEW APPLICATIONS

Confronting to energy crisis, global warming and global climate changes, biofuels have become the limelight of research on the renewable and alternative energy in an effort to search for sustainable development (Fig. 1). Microalgae, which convert CO_2, water and sunlight through photosynthesis to produce lipids, carbohydrates and proteins in large amounts, have come under increased research interest with regard to the production of biofuels [4–7]. Thus, people's attraction on microalgae has been increasingly diverted from its traditional functions to biofuels production.

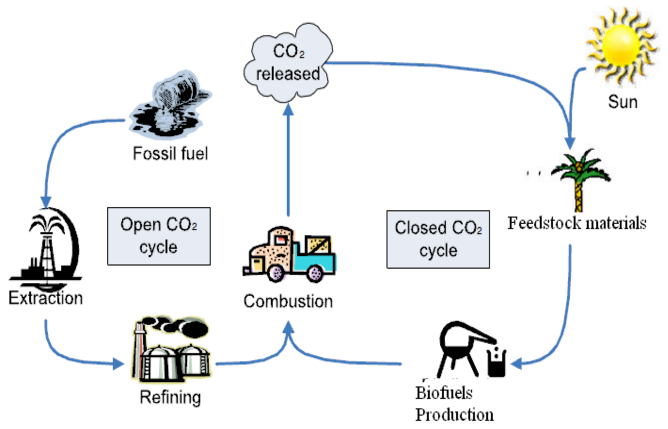

Fig. 1. CO_2 cycle for fossil fuel and biofuels. Modified from [8]

The advantages to produce biofuels from microalgae are many, such as high photosynthetic efficiency, high lipid content, noncompetition for farmlands and toleration to wastewaters for cultivation. Nevertheless, the real hallmark of microalgae is their versatile functions for the production of several different types of biofuels such as biodiesel, bioethanol, biogas and biohydrogen among others. The idea of biofuels production from microalgae is not new, but recently research on the microalgal bio-energy has grown exponentially with 717 papers in total published by November 2010 [9]. The number will continue to increase dramatically in the near future. Most of these studies have been focused on, for instance, culture methods and cultivation system engineering, genetic and metabolic engineering, efficient biomass harvest measures, biofuels conversion technologies, cost-effectiveness, and policy implications.

The integration of microalgae cultivation with wastewater treatment for nutrient removal and biofuels production is a most promising solution, since the microalgal biofuels applications appear to be strongly economically convenient only in conjunction with wastewater treatment. Using piggery wastewater to cultivate microalgae in photobioreactors, it is found that the system has high nutrient removal efficiency and enjoys the substantial productivities in biomass, lipid and biodiesel [10,11]. Except aquaculture wastewater, wastewaters from industry, municipality and agriculture can also become the suitable sources to provide nutrients for the growth of many microalgae species to mainly accumulate lipid, protein, starch and fat, which are the efficient ingredients for the biofuels conversion.

III. NEW CHALLENGES

Along with the development of microalgal biofuel technologies and the expansion of biofuel market size, concerns on its influences on microalgal conventional applications such as cosmetics and chemicals seem to become a controversial topic. Whether will the microalgal biofuels production cause the shrinkage or depression of conventional applications? Some people hold the opinion that microalgae-based biofuel production will compete with the other traditional microalgae usages and thus will give rise to the potential recession or shrinkage in the original industries, while others especially form developing countries find that it is difficult to adapt and accept microalgal biofuel in their daily life since microalgal fuel is a very new biofuel type to them [12]. To make it worse, some handful of people might be pessimistically afraid that algal biofuel production may cause the disappearance of its traditional utilization.

Nonetheless, the microalgal biofuels also witness an obvious and serious dilemma, where it is found that there is no commercial production on a large scale for bulk application due to the overwhelming investments in capitals and operation. For example, capital costs for microalgal biodiesel production can account for approximately 50% of the total costs, while harvest including drying has been claimed to contribute to 20–30% of the total biomass production costs [13]. In other words, this apparently promising approach is still in its infancy before its economics can be improved [11]. Inevitably, people might cautiously think about a question–Is it too luxurious to produce microalgae only for biofuels application?

IV. NEW SOLUTIONS

In an attempt to find out the solutions, the review of microalgal product market size and its value pyramid is necessary, as shown in Fig. 2. It can be seen that the market demand for microalgal biofuels is large, but their value is low. In contrast, the market value for traditional microalgal applications is high, despite of small market size. Thus, microalgal biofuel is one application, but co-production of high values from microalgae can also be considered.

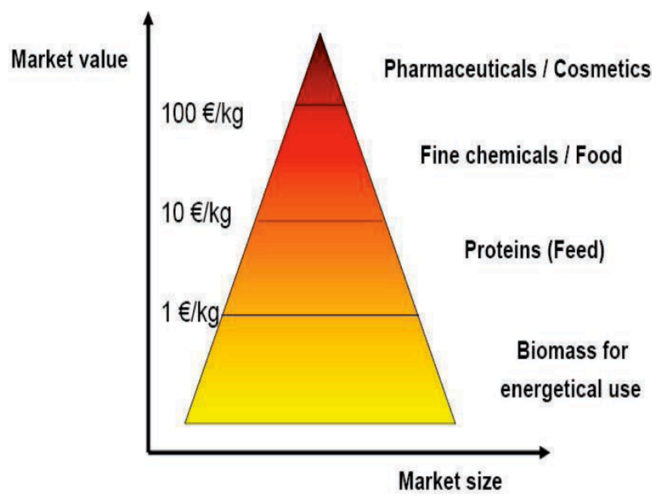

Fig. 2. Value pyramid for microalgae product markets [14]

Microalgae contain abundant lipids, carbohydrates or starch, cellulose, proteins, fats and a variety of inorganic and complex organic molecules. Some of the ingredients can be converted into biofuels, while others can be extracted and produced into different valuable byproducts or co-products, such as cosmetics, pharmaceuticals and nutritious feed. Thus, the combination of microalgal biofuels production with the conventional applications is a bright solution to prospering the microalgal biorefinery industry in a sustainable manner (Fig. 3). For example, Nilles [15] reports that more than 400,000 tons of glycerol, which is an expensive versatile chemical with over 1500 known commercial applications [14], can be co-produced when extracting 1 billion gallons of biodiesel. Moreover, poly-unsaturated fatty acids (PUFAs) are a potential co-product of microalgal biodiesel production. Microalgal PUFAs, which are rich in omega-3 fatty acids, are a vegetable alternative to e.g. fish oils. The PUFAs would be extracted prior to oil esterification, as these fatty acids are not the most efficient ingredients for esterification [14]. The conversion of co-products with higher value will have an important role to play in the improvement of the cost-effectiveness of microalgal biofuels production. After high values production from microalgae, biodiesel, ethanol and/or biogas can be optionally produced in a continuous manner on the basis of microalgal compositions [6].

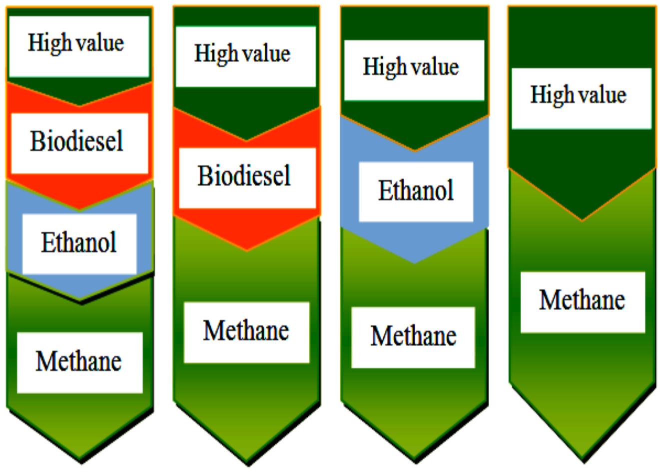

Fig. 3. Biorefinery option concepts for microalgal biofuels and conventional products

Thus, it can be expected that the microalgal biofuels production will not cause the shrinkage or stagnation of conventional applications, but accelerate their development. This is because the production of microalgal biofuels is not commercial at all until now and the cost gap between microalgal biofuels and fossil fuels still needs to be shortened or even closed. The development of microalgal biofuels still requires the support of its traditional applications from the economic point of view. Likewise, from the sustainability perspective, the success of conventional microalgal industry requires the reasonable disposal of the leftovers after high values are produced, and biofuels production is the solution. Thus, the integration of microalgal biofuels production with the original applications will become a win-win solution or strategy in near future.

V. NEXT ACTIONS

In order to prosper the integration of microalgal biofuels production with the original applications, there are several main practices required to be conducted with priority.

First, cultivation technologies should be developed on the basis of the desired end product. A suitable design of culture conditions such as stress levels and light control can induce and activate the accumulation of some targeted constituents like lipids, proteins, pigments, nutraceuticals and other commercially significant materials. In addition, genetic and metabolic engineering can also help improve the targeted ingredients.

Second, new markets for high values should be explored. The demand of biofuels in market far exceeds the accessibility of these kinds of feedstock. In contrast, the proposed microalgae biorefinery options might spur the production of high-value products, which might cause market saturation. However, nowadays people attach more and more importance to a high quality life. Meanwhile, as the economy grows more and more people can afford the costs of cosmetics, pharmaceuticals and nutritious feed from microalgae. Thus, the market for microalgal high values will be growing.

Third, traditional microalgal industry and biofuel corporate should be integrated. High-value products extraction can commercialize the microalgal biofuels, while microalgal biofuels production can sustain high-value products by using the post-extracts. So that, an incorporated microalgae company can produce a quota of high values and biofuels according to the market demand or size.

Last but not least, policy should be beneficial to microalgal biofuels development. Policies towards the greenhouse gas emissions and taxes can affect the microalgal biofuels practices. Government funding can help commercialize new technologies for the production of high values and biofuels, thus fulfilling a key political objective by creating jobs and reducing the reliance on fuel imports.

VI. CONCLUSIONS

Analyzing the current challenges and mapping out the biorefinery options for microalgae industry development, it can be found that the usage of microalgae as biofuel feedstock will not affect but accelerate the traditional applications. Optimal culture technologies, considerate marketing, successful integration of technologies in corporate and efficient government policies can help contribute to the prosperity of microalgal biorefinery.

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