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Algae based biorefinery—How to make sense?

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ABSTRACT

The interest in algae based biofuels and chemicals has increased over the past few years because of their potential to reduce the dependence on petroleum-based fuels and chemicals. Algae is touted to be the most suitable and sustainable feedstock for producing green energy as the whole process is carbon—neutral in nature and can also be utilized for environment cleaning applications. This review article mainly focuses on how algae can be used as an efficient and economically viable biorefinery feedstock. An effective biorefinery using algae can only be constructed through its integration with other industries. To make sense of the algal biorefinery concept, there is a need to establish a proper connection between the various input and output streams of the products, as well as the services to be provided by the participating industries. Also highlighted in this article, is the entire spectrum of energy and non energy products that can be obtained using algal biomass as the raw material.

Contents

1. Introduction

The first generation of bioenergy strategies involved biofuel production based on sugar, starch, vegetable or animal oils using conventional technology [1], but these methods have been globally

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criticized because they competitively consume food resources [2]. To circumvent this problem, the second generation of bioenergy uses non-edible or waste vegetable oils and agricultural wastes such as lumber, straw and leaves; however, the availability of these was less [3]. Also, terrestrial bioenergy production systems are now facing issues related to indirect emission and carbon debt from land clearance and hence are becoming a sustainability hurdle for further expansion [4–7]. Therefore, a more sustainable feedstock had to be evolved to overcome these limitations.

Microalgae have been recognized as an alternative, so-called third generation feedstock not only because they remove carbon dioxide from the atmosphere, but also because they contain a much higher lipid content per biomass (Table 1) than other plants [9–11]. Marine microalgae species growing in seawater can also reduce fresh water consumption [12]. In addition, it can be grown with wastewater which indicates a high environmental sustainability of this feedstock [13].

Environmental factors, such as temperature, salinity, illumination, pH-value, mineral content, CO_2 supply, population density, growth phase and physiological status can greatly modify the chemical composition of algal biomass. Under conditions of high light intensity and nitrogen limitation, the flow of carbon fixed in photosynthesis is diverted from the path of protein synthesis to that leading to lipid and/or carbohydrate synthesis [14]. A detailed physicochemical characterization of the microalgae is essential, as it will allow determining which algae are best suited for different applications and purposes [15].

Table 1
Typical oil yields from the various biomasses [8].

S.N.	Crop	Oil yield (l/ha)
1	Rubber seed	80–120
2	Corn	172
3	Soybean	446
4	Safflower	779
5	Chinese tallow	907
6	Camelina	915
7	Sunflower	952
8	Peanut	1,059
9	Canola	1,190
10	Rapeseed	1,190
11	Castor	1,413
12	Jatropha	1,892
13	Karanj	2,590
14	Coconut	2,689
15	Oil palm	5,950
16	Microalgae (30% oil by wt)	58,700
17	Microalgae (70% oil by wt.)	136,900

Table 2
General composition of different algae (% of dry matter) [24,28].

Alga	Protein	Carbohydrates	Lipids
Anabaena cylindrica	43–56	25–30	4–7
Aphanizomenon flos-aquae	62	23	3
Chlamydomonas rheinhardii	48	17	21
Cholrella pyrenoidosa	57	26	2
Cholrella vulgaris	51–58	12–17	14–22
Dunaliella salina	57	32	6
Dunaliella bioculata	49	4	8
Euglena gracilis	39–61	14–18	14–20
Porphyridium cruentum	28–39	40–57	9–14
Scenedesmus obliquus	50–56	10–17	12–14
Scenedesmus quadricauda	47	–	1.9
Scenedesmus dimorphus	8–18	21–52	16–40
Spirogyra sp.	6–20	33–64	11–21
Arthrospira maxima	60–71	13–16	6–7
Spirulina platensis	46–63	8–14	4–9
Spirulina maxima	60–71	13–16	6–7
Synechococcus sp.	63	15	11
Chlorella vulgaris	51–58	12–17	14–22
Prymnesium parvum	28–45	25–33	22–38
Tetraselmis maculate	52	15	3
Porphyridium cruentum	8–39	40–57	9–14

Hence, the use of microalgae as feedstock for the production of biofuels offers many opportunities if challenges in large-scale cultivation, harvesting and conversion to useful fuels can be overcome [16]. Generally, centrifugation, flocculation and membrane filtration techniques have been proposed to concentrate algae from their growth medium. Among the various harvesting techniques, membrane filtrations offer several advantages because they do not require additive or coagulants and are able to function at moderate temperature and pressure and reduce the formation of undesired products, which further simplifies the subsequent purification of specific metabolite and the use of the residual biomass [17].

To find the appropriate application of algal lipid at industrial level, the fatty acid profile analysis is an important task. Recently, there has been an increased interest in the development of alternative methods that improve fatty acid profile analysis. These methods involve mainly three criteria: (1) direct trans-methylation of lipids, (2) elimination of the need for preliminary extraction steps, and (3) using a single-step derivatization procedure for generating fatty acid methyl esters (FAMEs) to denature the protein fraction [18].

Microalgae have the potential for co-production of valuable products like carbohydrates, lipids, and proteins, starch, cellulose and polyunsaturated FAs (PUFAs), pigments, antioxidants, pharmaceuticals, fertilizer, energy crops [19–21], natural colorants and also as biomass that can be used as animal feed after oil extraction. The most widely used biofuel is bioethanol, which is produced from sugar-based (sugar beets, sugarcane) and starch based (corn, wheat, barley, etc.) feed stocks [22], while technology leading to conversion of lignocellulosic materials (bagasse, corn stover, rice straw, switch grass, and so on) into ethanol is still under development [12].

Microalgae are currently being used to commercially produce carotenoids, for example, *Haematococcus pluvialis* for astaxanthin and *Dunaliella salina* for β-carotene. Several reports have stated that the unusual cell membrane of *Dunaliella* allows its cells to maintain high concentrations of intracellular glycerol without leakage to the external medium under normal conditions despite the sharp concentration gradient across the membrane [23]. This microalga is able to withstand temperatures over 50 °C for more than 8 h and produces pigments including astaxanthin, lutein, canthaxanthin after the cells are stressed for a period of time. *Chlorella* is widely produced and marketed as a health food supplement in many countries, including China, Japan, Europe and the US, with an estimated total production around 2000 t/year [15]. Nutritionally important fatty acids like eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) are commercially obtained from various marine fishes and microalgae [24]. Microalgae are a potential source of bio-active compounds with pharmaceutical, biomedical and nutraceutical prospects [25]. Therefore, microalgae could play important role in producing biofuels and bio-based chemicals based on both their natural components and refined (or fermented) products [26].

Fundamental principles of biochemistry show that the maximum theoretical energy conversion of the full sunlight spectrum into organic matter lies around 10%. So the yields of the products have a stoichiometric and thermodynamic constraint on them. The yields with outdoor cultures is one third to one tenth of the theoretical yield and therefore to make the whole process more profitable, the real challenge is to improve the efficiency of the photosynthetic system [27].

The biorefinery concept has been identified as the most promising way for the creation of a biomass-based industry. If the goal of biorefineries is to transform biomass into biofuels and high value-added products, the existing and emerging technologies for these