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Review

Sustainable production of liquid biofuels from renewable microalgae biomass

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ABSTRACT

Microalgae are important as feedstock in production of liquid biofuels such as biodiesel, bioethanol and bio-oil. Biodiesel and bioethanol can be produced from lipids and carbohydrates of microalgae biomass, respectively. Bio-oil and bio-char are prepared using thermochemical treatment of microalgae biomass or residual biomass after lipid extraction and/or saccharification of cellular carbohydrates. Recent advances in biorefinery present opportunities to develop sustainable and integrated productions of various liquid fuels from microalgae biomass in economical way within the next decades. This review examines the recent progress of microalgae-based liquid biofuel production with regard to characteristics and applicability of microalgae as feedstock.

Contents

Introduction

Biofuel production from biomass is a promising alternative to petroleum-based fuels [1]. Among available biomass sources, microalgae have been frequently considered and investigated as a third-generation biomass [2–5]. Microalgae are photoautotrophic microorganisms that use carbon dioxide, water and sunlight to grow. Microalgae have several distinct advantages over other biomass sources [6]. First, microalgae can be cultivated using carbon dioxide [7], thus providing greenhouse gas mitigation benefits. Second, microalgae have high growth rates of 1–3 doublings/day, which is at least five to ten times higher than those of plants. Third, microalgae can use growth nutrients such as nitrogen and phosphorus from waste streams. Additionally, microalgae can be cultivated from non-productive, non-arable lands such as deserts, coasts and offshore marine environments. Large-scale photobioreactors can also be used for microalgae cultivation [8–11]. Thus, large amounts of biomass can be obtained as non-food-based sustainable feedstock from cheap substrates.

Production of liquid fuels from microalgae requires many downstream processing steps (Fig. 1). Harvesting is the subsequent step right after cultivation of microalgae and potentially contributes up to 20–30% of the total production cost of microalgae biomass. Generally, after harvesting step such as centrifugation

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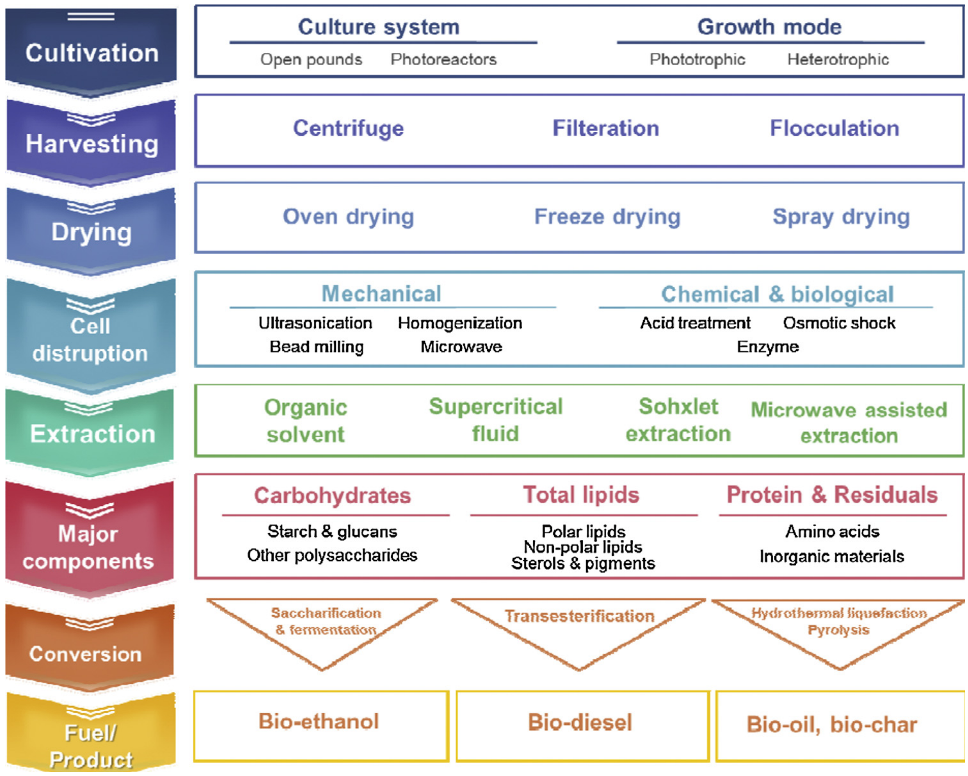

Fig. 1. Downstream processing of biomass harvesting, disruption, and integrated production of biofuels from the major components of microalgae.

[12], filtration [13] and flocculation [14], microalgae consist of 30% solid with 70% moisture content [15]. Drying or dewatering of microalgae biomass is generally used prior to various conversion steps. The energy required for dewatering is known to constitute up to 84.9% of total energy consumption [16]. Extraction of lipid is required for biodiesel production.

The main components of microalgae for liquid biofuel production are lipids, carbohydrates and others such as proteins. Various conversion methods including transesterification, fermentation, pyrolysis, liquefaction and anaerobic digestion are used for production of biodiesel, bioethanol, bio-oil and methane (Fig. 2). The lipid is extracted using organic solvent and then transesterified to biodiesel in the presence of base or acid catalysts. Bioethanol is produced from microalgae fermentation, while methane can be produced through anaerobic digestion. Thermochemical processes such as hydrothermal liquefaction and pyrolysis can be applied for bio-oil production. Currently, no liquid biofuel production from microalgae is commercially implemented because "liquid fuel production only" is not economically feasible. Thus, the whole components of microalgae biomass should be used to produce multiple products including various liquid biofuels for economically viable option [17]. In this review paper, recent progress on the production of liquid biofuels, including biodiesel, bioethanol and bio-oil, are addressed, and some concluding remarks are also discussed for a successful zero-waste microalgae biorefinery.

Biodiesel production

Biodiesel is a mixture of fatty acid methyl esters (FAMEs) produced by transesterification of triglycerides with alkyl acceptors such as methanol in the presence of a catalyst, usually NaOH, KOH or lipase. Since methanolysis of triglyceride is an equilibrium reaction, a high excess of methanol, generally six moles of methanol per mole of triglyceride, is applied [6]. At present, biodiesel is mainly produced from rapeseed and palm oils. Recently, microalgae are being considered as feedstock for biodiesel production [16,18,19]. The lipid content of some microalgae species such as *Botryococcus braunii* exceeds 80% of the dry weight [20]. *Chlorella* and *Dunaliella* are known to have lipid contents as great as 50% of the dry weight. Thus, considerable amounts of lipid for biodiesel production can be obtained from large-scale cultivation of microalgae. As indicated in some reports, the yield of microalgae lipid per hectare is around 58,700 l/ha, almost ten times greater than those from palm crops [21].

Biodiesel can be produced using a two-step method of oil extraction-transesterification or one-step transesterification (so called '*in site* or direct transesterification'). The common method for extracting oil from microalgae is a solvent extraction using hexane, ethanol, methanol and methanol–chloroform mixture (2:1 v/v) [22]. The extraction efficiency of microalgae oil using *n*-hexane is rather low, although it is widely used for oil extraction from seed crops [23]. Ultrasonic-assisted extraction, microwave-assisted extraction and supercritical fluid extraction can be an alternative to organic solvent extraction. After lipid extraction, alkali, acid catalysts and lipase are used for transesterification. One important thing is microalgae oil generally contains a certain amount of free fatty acid. Thus, an acid-catalyzed conversion can be an efficient method with high conversion, though its reaction rate is approximately 4000 times slower than base-catalyzed processes [24].

Recent advances in biodiesel production from microalgae are summarized in Table 1. In two-step transesterification, microalgae lipids were extracted using different solvents and extraction methods from various microalgae strains [25–32]. The extracted lipids were transesterified to FAMEs using H_2SO_4, HCl and lipase. An acid catalyst was used because microalgae biomass generally contains large amounts of free fatty acids that cause the formation of soaps in the presence of alkali catalysts [25]. Lam et al. [26]