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Review

Recycling and reuse of spent microalgal biomass for sustainable biofuels

Naim Rashid [a,b], Muhammad Saif Ur Rehman [a], Jong-In Han [a,*]

[a] Department of Civil and Environmental Engineering, Korea Advance Institute of Science and Technology (KAIST), 373-1, Guseong dong, Yuseng-gu, Daejon 305-701, Republic of Korea
[b] Department of Environmental Sciences, COMSATS Institute of Information Technology, Abbottabad 22060, Pakistan

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ABSTRACT

The use of microalgal biomass (MAB) for biofuel production has been recognized since long. Despite distinct advantages of algal biofuels, however, their sustainability and economic viability is still doubtful. Overall process cost and low energy recovery need to be significantly improved. The use of MAB, after extracting primary fuels in the form of hydrogen, methane, biodiesel and bioethanol, can be one promising route. This algal biomass, collectively termed as spent microalgal biomass (SMAB), contains even up to 70% of its initial energy level and also retains nutrients including proteins, carbohydrates, and lipids. Potential application routes include diet for animals and fish, the removal of heavy metals and dyes from wastewater, and the production of bioenergy (e.g., biofuels and electricity). Unlike whole algae biomass whose applications are relatively well documented, SMAB has been studied only to limited degree. Therefore, this work gives a brief overview of various ways of SMAB applications. An insight into current status, barriers and future prospects on SMAB research is provided. The feasibility of each application is evaluated on the basis of its energy recovery, economic viability, and future perspectives are provided.

Contents

1. Introduction

Microalgal biomass (MAB) is a promising feedstock for the production of biofuels [1]. All of its components, carbohydrates, lipids and proteins, can be converted into fuels such as biodiesel,

* Corresponding author. Tel.: +82 42 350 3629; fax: +82 42 350 3610.
E-mail address: jihan@kaist.ac.kr (J.-I. Han).

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bioethanol, bio-hydrogen and bio-methane, by means of different processes [1]. However, high processing cost and low energy recovery impair the commercialization of algal biofuels [2–4]. A proper exploitation of spent microalgal biomass (SMAB) can improve the overall economics of microalgal biofuels. In this review, SMAB means, microalgal biomass obtained after any of its primary use, for example, lipid extraction, hydrogen/methane, and bioethanol production [4,5,6]. SMAB accounts for 70% of the whole algal biomass (on dry basis) and thus, can be used for several applications [7]. MAB consists of three major components, lipids, carbohydrates and proteins, and these components vary significantly depending on microalgal species types, cultivation conditions, harvesting and lipid extraction methods. For example, Yang et al. reported that SMAB from *Scenedesmus* contains protein (32.4%), lipid (6.5%), carbohydrate (24.7%), ash (10%), and unknown materials (26.4%) [5]. Another report shows that *Chlorella vulgaris* contains, protein 51–58%, carbohydrates 12–17% and lipids 14–22%; *Chlamydomonas rheinhardii* have protein 18%, carbohydrates 17% and lipids 21%; *Spirulina platensis* contains, protein 46–63%, carbohydrates 8–14% and lipids 4–9%; *Dunaliella bioculata* have protein 49%, carbohydrates 4% and lipids 8%, and *Anabaena cylindrica* contains protein 43–56%, carbohydrates 25–30% and lipids 4–7% [8,9]. SMAB, especially lipid-extracted algae residues, contain high contents of carbohydrate and proteins, and thus, it can be used for the production of biogas [10]. Besides biofuels, SMAB can also be converted into other types of products. The high contents of nutrients make SMAB an alternate food supplement for livestock and a feed for microbes. Moreover, it can be used as biosorbent to remove heavy metals and dyes from industrial wastewaters.

SMAB requires pretreatment step before its further utilization. Pretreatment which converts the macromolecules (carbohydrates, proteins) into small molecules, is a rate limiting step [5,11] However, the choice of pretreatment technique depends on the composition of SMAB and target products [7]. SMAB with lower contents of carbohydrates and proteins, require less energy intensive pretreatment than protein-rich SMAB. Protein-rich SMAB results in low biogas yield during subsequent fermentation process, due to excessive ammonia and low C/N value [12]. Alternatively, low protein SMAB can be mixed with a high carbon content waste material such as paper waste. This addition of extra carbon source maintains C/N value, and thus, results in high biogas yield. Alternate ways of protein rich SMAB are to use them as animal feed, or heavy metals and dye removal through biosorption. Both of these applications do not require pretreatment, and thus, pose no economic burden. SMAB is also associated with some disadvantages, for example, SMAB obtained after the production of hydrogen produce limited amount of methane as a secondary product due to low energy contents after its first use [5,8]. This particular SMAB can be used to remove heavy metals and dyes from wastewaters [13,14]. Similarly, lipid-extracted SMAB can serve as feedstock to produce methane but not the hydrogen. The applications of SMAB depends on its entire life cycle from upstream (algal species, cultivation, harvesting, lipid extraction) to downstream processing (pretreatment, fermentation) [2,15].

This is a baseline study that reviews the application of SMAB as a feedstock for bioenergy and bioprocesses. To the best of our knowledge, this is the first study that highlights the recycling and reuse of MAB. In this review, the term 'primary' fuels and/or products refer to those which are obtained from the whole algae biomass, whereas 'secondary' products represent those recovered from SMAB.

2. SWOT analysis

A tool, SWOT (strength, weaknesses, opportunities, threats) analysis, is used to identify the applications of SMAB (Table 1). This analysis can help to understand the feasibility of SMAB for commercial applications. SWOT analysis shows that pretreatment is one of the major controlling factors in the applications of SMAB. It is essential to reduce the pretreatment cost through systematic optimization process. No market exists for SMAB so far and their prices are also not known. Bryant et al. have used hedonic pricing method model to determine its cost. They calculated the cost of post-extracted alga reside as $100 per ton [16]. Nevertheless, vast applications of SMAB, lack of technical expertise, uncertain future roadmap and limited knowledge are the major drawbacks. Intensive and systematic research is required to set clear future guidelines for the commercialization of SMAB-based technologies.

Table 1
SWOT (strength, weaknesses, opportunities and threats) analysis for SMAB.

Strength	**Weaknesses**
-Rich in carbohydrates and proteins	-Pretreatment is complicated, since it depends upon upstream processing
-Can be used for multiple purpose	-Pretreatment is specie dependent
-Environmental friendly disposal	-Very least studied
-Pretreatment is easier than cellulosic biomass	-Routes of SMAB use are not optimized for high energy recovery
-Can reduce the biofuel cost due to high energy recovery	-Uncertainty exists due to lack of information
-Can be applied at large scale	-Cost is unknown
Opportunities	**Threats**
-Application in multiple directions is possible	-Diverse and complicated nature of pretreatment
-No surface modification required for biosorption	-Uncertain future roadmap
-Can be integrated with primary production process	-Numerous studies are not available
-Abundantly available	
-Easy anaerobic digestion	

3. SMAB uses and their controlling factors

SMAB can be used to produce various products such as:

- Hydrogen
- Ethanol
- Methane
- Bio-oil
- Plastics
- Fertilizers
- Animal feed
- Nutrients
- Electricity
- Sorbents

Fig. 1 shows the routes of SMAB.

The use of SMAB is controlled by several factors. The use of SMAB depends largely upon upstream processing (e.g., cultivation, harvesting and lipid extraction methods) and primary products (hydrogen, methane, ethanol, and lipids). Microalgal cultivation

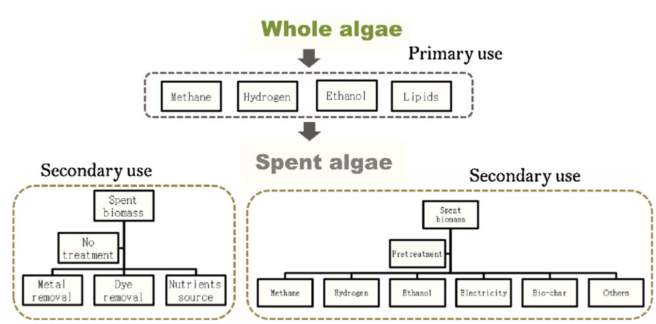

Fig. 1. Various routes and uses of microalgal biomass.