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Recent progress in microalgal biomass production coupled with wastewater treatment for biofuel generation

El-Sayed Salama[a], Mayur B. Kurade[a], Reda A.I. Abou-Shanab[b], Marwa M. El-Dalatony[a], Il-Seung Yang[a], Booki Min[c], Byong-Hun Jeon[a,*]

[a] Department of Earth Resources and Environmental Engineering, Hanyang University, Seoul 04763, South Korea
[b] Department of Environmental Biotechnology, City of Scientific Research and Technology Applications, New Borg El Arab, Alexandria 21934, Egypt
[c] Department of Environmental Science and Engineering, Kyung Hee University, 1 Seocheon-dong, Yongin-si, Gyeonggi-do 446-701, South Korea

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ABSTRACT

Microalgae are a potential source of sustainable biomass feedstock for biofuel generation, and can proliferate under versatile environmental conditions. Mass cultivation of microalgae is the most overpriced and technically challenging step in microalgal biofuel generation. Wastewater is an available source of the water plus nutrients necessary for algae cultivation. Microalgae provide a cost-effective and sustainable means of advanced (waste) water treatment with the simultaneous production of commercially valuable products. Microalgae show higher efficiency in nutrient removal than other microorganisms because the nutrients (ammonia, nitrate, phosphate, urea and trace elements) present in various wastewaters are essential for microalgal growth. Potential progress in the area of microalgal cultivation coupled with wastewater treatment in open and closed systems has led to an improvement in algal biomass production. However, significant efforts are still required for the development and optimization of a coupled system to simultaneously generate biomass and treat wastewater. In this review, the systematic description of the technologies required for the successful integration of wastewater treatment and cultivation of microalgae for biomass production toward biofuel generation was discussed. It deeply reviews the microalgae-mediated treatment of different wastewaters (including municipal, piggery/swine, industrial, and anaerobic wastewater), and highlight the wastewater characteristics suitable for microalgae cultivation. Various pretreatment methods (such as filtration, autoclaving, UV application, and dilution) needed for wastewater prior to its use for microalgae cultivation have been discussed. The selection of potential microalgae species that can grow in wastewater and generate a large amount of biomass has been considered. Discussion on microalgal cultivation systems (including raceways, photobioreactors, turf scrubbers, and hybrid systems) that use wastewater, evaluating the capital expenditures (CAPEX) and operational expenditures (OPEX) of each system was reported. In view of the limitations of recent studies, the future directions for integrated wastewater treatment and microalgae biomass production for industrial applications were suggested.

1. Introduction

The major problems that humanity faces in the 21st century are water quality issues and energy supply. Population of the world will need 70% of foodstuff, 50% of energy, 50% of water, and a 50–80% decrease in carbon dioxide (CO_2) releases to sustain political, social, and weather safety [1,2]. The pollution of surface water has become a key environmental challenge worldwide, in addition to the existing problem of water scarcity, because the contamination of large freshwater bodies makes the water unsuitable for human use [3]. This is a serious concern in developing countries, where human health is in danger as a consequence of the fast pollution of H_2O supplies by heavy metals, eutrophication, persistent organic pollutants, sewage, and acidification [4].

There is increasing interest in coupling biological waste treatments to bioenergy production [5]. One approach uses a microalgae-based

Abbreviations: CAPEX, Capital expenditures; OPEX, Operational expenditures; OP, Open pond; PBRs, Photobioreactors; POPs, Persistent organic pollutants; EOCs, Emerging organic contaminants; HRAPs, High-rate microalgal ponds; HRT, Hydraulic residence time; NADH, Nicotinamide adenine dinucleotide; ATP, Adenosine triphosphate; Glu, Glutamate; ADP, Adenosine diphosphate; PSUs, Photosynthesis structure units; BOD, Biological O_2 demand; COD, Chemical oxygen demand; AD, Anaerobic digestion; ATS, An algal turf scrubber; ANA, All Nippon Airways;; TAGs, Triglycerides; TFAs, Total fatty acids; USFAs, Unsaturated fatty acids; CMW, Concentration municipal wastewater; WWTP, Wastewater treatment plant; TKN, Total Kjeldahl nitrogen

* Corresponding author.
E-mail address: bhjeon@hanyang.ac.kr (B.-H. Jeon).

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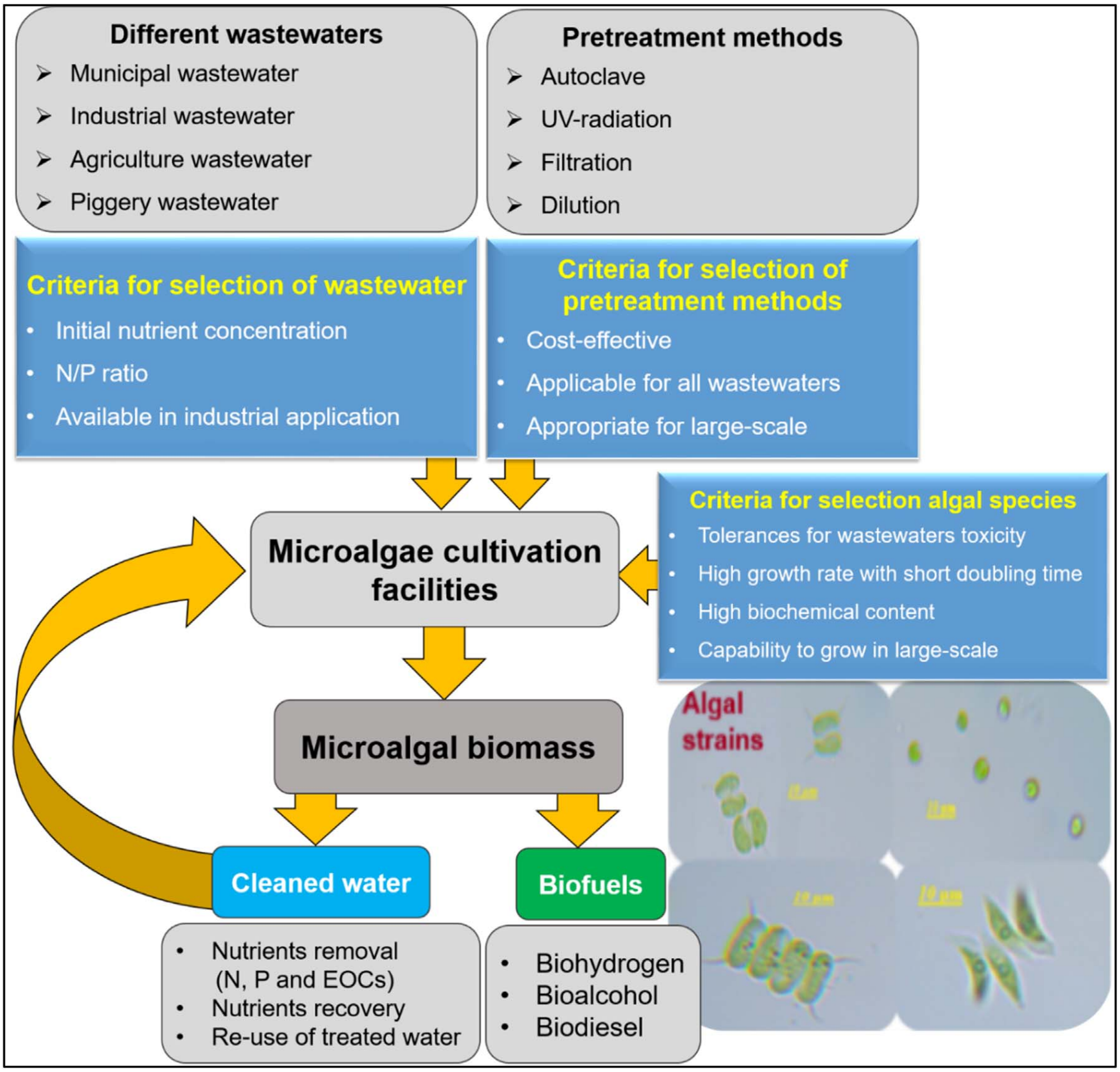

Fig. 1. Schematic presentation of simulations on wastewater treatment with microalgal biomass cultivation for biofuel generation.

method to treat wastewater and then uses the harvested algal biomass to generate biofuels [6]. Phytoplankton including microalgae are survive in the earth eco-systems, demonstrating a diversity of species present in a broad spectra of freshwater, brackish water, seawater, and even wastewater [7]. Microalgae have exceptional importance because of their primitiveness of structure and metabolic activities variation as higher plants. They have attracted substantial attention owing to their capability to take up organic/inorganic nutrients from (waste)water and produce biomass which can be further used for biofuel generation [8,9]. A schematic presentation of microalgae-mediated wastewater treatment with simultaneous biomass production for biofuel generation is shown in Fig. 1. Appropriately selecting the wastewater, robust microalgal species, and pretreatment method is critical to using advanced wastewater treatment with microalgae cultivation to produce biomass and lipids for microalgae-based biofuel.

1.1. History of wastewater treatment using microalgae

The history of the viable use of microalgae spans around seventy-five years with the application of various species, including *Chlorella* sp. and *Dunaliella* sp., in wastewater treatment to achieve subsequent biomass production [10]. Some of the developed nations, including the USA, Australia, Mexico, and Taiwan, have focused their research activities toward efficient cultivation of microalgae and simultaneous wastewater treatment [11]. Palmer [12] listed microalgae (60 genera and 80 species) in the order of their tolerance for organic pollutants as stated by 165 authors. Chlorophytes represent one of the main phyla of algae, with a vast display of strains and a widespread geographical distribution. *Chlorella* sp., *Scenedesmus* sp., and *Chlamydomonas* sp. have been used in many studies and found to be effective in removing N and P from various wastewaters with a variety of initial concentrations [13]. Their ability to eliminate the heavy metals and toxic organic compounds and eliminate secondary pollution problems has also been reported [14].

2. Advantages of using wastewater as a culture medium for cultivation of microalgae

Wastewater is a low-cost and freely available excellent medium for various microalgal growth [15]. It contains macro- and micro-nutrients that support the growth of microalgae [16]. Nitrate, ammonia, phosphate, urea, and trace minerals are the major nutrients existent in wastewater [17]. Carbon (C), nitrogen (N), and phosphorus (P) are the three nutrients of the most apprehension when evaluating a wastewater source for enhancement of microalgal growth [18]. Their molar ratio in the water/growth medium should be adequate to the stoichiometric ratio of microalgal biomass to prevent growth limitations. The N to P ratio is supposed to match the Redfield ratio (16:1) which is not a

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