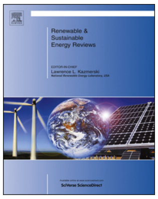
Renewable and Sustainable Energy Reviews 43 (2015) 961–972

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser



Biogas production from algal biomass: A review

M.E. Montingelli [a,*], S. Tedesco [a], A.G. Olabi [b]

[a] School of Mechanical and Manufacturing Engineering, Dublin City University, Glasnevin, Dublin 9, Ireland
[b] School of Engineering, University of the West of Scotland, Paisley, PA1 2BE, Scotland, UK

ARTICLE INFO

Article history:
Received 9 December 2013
Received in revised form
12 August 2014
Accepted 8 November 2014

Keywords:
Macroalgae
Microalgae
Anaerobic digestion
Methane
Biogas
Pretreatment

ABSTRACT

The objective of this work is to provide a comprehensive study on algal biomass as feedstock for biogas production. Algae-derived biofuels are seen as one of the most promising solutions to mitigate climate change and as alternative to fast depleting of fossil fuels and oil reserves. Microalgae and macroalgae underwent an intense academic and industrial research, thanks to their capability to overcome the drawbacks related to the first and second generations of biomass resources. Major advantages of algae are: no competition with food crops for arable land, high growth rates, low fractions of lignin which reduces the need for energy-intensive pretreatment and compatibility with biorefinery approach implementation. However, some disadvantages such as the presence of high water content, seasonal chemical composition and the occurrence of inhibitory phenomena during anaerobic digestion, make algal biofuels not yet economically feasible although they are more environment friendly than fossil fuels.

Contents

1. Introduction

The first generation biofuels are made from edible feedstock like corn, soybean, sugarcane, and rapeseed. The use of these resources for energy production was blamed for a rise of food prices. Second generation of biofuels from waste and dedicated lignocellulosic feedstocks have advantages over those of first generation. The major benefits are higher stock yields and lower land requirements in terms of quality and quantity. The main problem associated with lignocellulose conversion to biofuels is its strong resistance to degradation. Thus, second generation biofuels still lack of economic viability at large scale. Third generation biofuels feedstock is represented by micro- and macro- algae, which present further advantages over the previous two. This marine biomass shows the prospect of high yields requiring no use of arable land [1–3]. It has

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* Corresponding author. Tel.: +353 1 700 7564.
E-mail addresses: maria.montingelli3@mail.dcu.ie (M.E. Montingelli), silvia.tedesco3@mail.dcu.ie (S. Tedesco), Abdul.olabi@uws.ac.uk (A.G. Olabi).

http://dx.doi.org/10.1016/j.rser.2014.11.052
1364-0321/

been proven that macroalgae can reach 2–20 times the production potential of conventional terrestrial energy crops [4], while microalgae commonly double their biomass within 24 h [1]. In addition, a negligible or low amount of lignin makes them less resistant to degradation than lignocellulosic feedstocks, and avoids the need for energy-intensive pretreatments before fermentation [5].

Furthermore, estimates indicate that the energy potential of marine biomass is more than 100 EJ per year, higher than the land-based biomass accounting only for 22 EJ [6]. In terms of carbon capture during photosynthesis, macroalgal primary productivity rates are approximately 1600 g $Cm^{-2}\,y^{-1}$, comparing favorably to a global net primary productivity of crop land of 470 g $Cm^{-2}\,y^{-1}$ [7]. Approximately half of the dry weight of the microalgal biomass is carbon [1], which is typically derived from carbon dioxide absorption. Therefore, producing 100 t of algal biomass fixes roughly 183 t of carbon dioxide from the atmosphere. It has been proposed that microalgal biomass production can potentially make use of some of the carbon dioxide that is released by power plants when burning fossil fuels [1,8].

Macroalgae can be converted to biofuels by various processes including thermal processes and fermentation. The most direct route to obtaining biofuel from macroalgae is via anaerobic digestion (AD) to biogas [7]. On the other hand, microalgal biomass has been mainly investigated as substrate for biodiesel production. Thus, the literature available on the subject results to be poor. However, it is emerging a re-interest for AD of microalgae due to the algal biomass compatibility with integrated production of other fuels and co-products within biorefineries [9,10]. In addition, according to [10], regardless of species and operating conditions, the proportion of methane in the produced biogas is around 70%. This reveals that a good quality of conversion of the microalgal organic matter into methane is achievable.

The production of biogas through AD offers significant advantages over other forms of bioenergy production. It has been evaluated as one of the most energy-efficient and environmentally beneficial technology for bioenergy production [11]. Biogas generation can drastically reduce greenhouse gases compared to fossil fuels by utilization of locally available resources. The digestate represents an improved soil conditioner which can substitute mineral fertilizer [12].

Compared to other fossil fuels, methane produces fewer atmospheric pollutants and generates less carbon dioxide per unit energy. As methane is comparatively a clean fuel, the trend is toward its increased use for appliances, vehicles, industrial applications, and power generation [6]. Reijnders and Huijbregts reported that methane presents the higher heating value when compared to the most common transport fuels, such as biodiesel, bioethanol and biomethanol [13]. However, hydrogen which holds the highest heating value (LHV equals 120 MJ kg^{-1}) is not well developed commercially for production and use, and is more difficult to produce from biomass [6].

Biogas production from algal biomass needs to overcome certain feedstock-related obstacles. As algae have much higher water content when compared to terrestrial energy crops, they are more suitable for wet AD processes [14]. On the other hand, the main disadvantages associated with such elevate moisture content are the use of limited organic loading rates (OLR) of the digesters as well as short term storage of biomass [4,15,16]. Another crucial parameter is their wide variation in nutrients content, which is related to several environmental factors. Most of them vary according to season, and the changes under ecological conditions can stimulate or inhibit the biosynthesis of such nutrients [17]. For this reason, many studies concluded that the seasonal variation of their composition restricts the use of marine biomass as feedstock for biofuels [15,17–20]. Also, the unbalanced nutrients in algal biomass (e.g. low Carbon/Nitrogen ratio) were regarded as an important barrier in the AD process [21].

During AD, some process-related obstacles can also develop. Inhibitory phenomena can result from the accumulation of volatile fatty acids (VFAs) [22,23], ammonia (NH_4^+ and NH_3) [24], and production of sulfide (H_2S) [25]. Besides, as the hydrolysis is considered the main limiting step of AD, a pretreatment is needed in order to improve the methane yields [26]. In general, the pretreatment step is required to be both effective and economically feasible in terms of overall process [4,15,16,27–29]. In fact, the high pretreatments cost has been identified as one of the key barriers for commercialization of lignocellulosic biofuels [30].

This review aims to provide an overview of the major obstacles related to the exploitation of both microalgae and macroalgae biomass as feedstock for methane production through AD, gathering the main solutions reported in the literature. Biochemical composition of algal biomass, operational process-related parameters and occurrence of inhibitory phenomena are dealt with in this review.

2. Macro and microalgae production

Algal biomass can be cultured or acquired from natural, eutrophicated and degraded water bodies [31]. In 2010, the world production of seaweeds was estimated at 19 million tonnes, where *Laminaria japonica* was the most cultivated at 6.8 million tonnes [32]. The current uses of seaweeds are predominantly in the food, feed, chemicals, cosmetics and pharmaceutical sectors in Asian countries such as China, the Philippines, North and South Korea, Japan and Indonesia [33]. When the only outcome product is energy, the cultivation of algal biomass is unlikely to be economically viable [4,34], and thus many studies have been carried out in order to make it feasible. The main solution seems to exploit the bioremediation capacity of this kind of biomass [35–37]. Nowadays the eutrophication, with excessive amount of N, P, CO_2 and insufficient amount of dissolved O_2, is becoming a serious problem in coastal seawater environment [37–39]. Seaweeds can be used as nutrients remover. Therefore, there is a great potential to remove large amount of C, N, and P nutrients with extensive seaweed cultivation [37,40]. Seaweeds produced from these cultivations can then be used for high-value products [41] or as feedstock for bioenergy conversion processes.

Furthermore, there is potential for macroalgal cultivation in offshore renewable energy facilities, such as wind farms [42]. Sharing the infrastructure with an offshore enterprise can be beneficial from planning, design and operation perspectives [43]. Nevertheless, conflicts and operations incompatibilities may arise, and be addressed by ensuring prior suitability of the offshore site for seaweed cultivation [44].

In many countries, an excessive natural growth of macroalgae has been observed as result of the progressive eutrophication of coastal water [45,46]. The drift and consequent degradation of this resource is considered a pollution problem, which can be addressed through the exploitation of this kind of biomass as feedstock for AD [47,48]. Another option is represented by the collection of storm cast weed from beaches, which is more developed in countries such as the UK and Ireland [44]. Hughes et al. [44] consider this as the most readily available feedstock for the generation of biofuel on a small, localized scale. However, it is underlined that the biomass of beach-cast would unlikely be sufficient for larger scale exploitation of this resource for bioenergy purposes [44]. Besides, it must be considered that this source of biomass does not guarantee a constant and homogeneous feedstock supply as it depends on variable climatic conditions [31].

In the case of microalgae, the two most common systems used for cultivation are raceway ponds and photobioreactors. The former are made of a shallow closed loop recirculation channel, in which mixing and circulation are produced by a paddlewheel,