Renewable and Sustainable Energy Reviews 40 (2014) 760–778

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Current status, issues and developments in microalgae derived biodiesel production

Naim Rashid [a,b,*], Muhammad Saif Ur Rehman [b,c], Madeha Sadiq [d], Tariq Mahmood [e], Jong-In Han [b]

[a] Department of Environmental Sciences, COMSATS Institute of Information Technology, Abbottabad, Pakistan
[b] Department of Civil and Environmental Engineering. Korea Advanced Institute of Science and Technology (KAIST), 373-1, Guseong dong, Yuseong-gu, Daejon 305-701, Republic of Korea
[c] Department of Chemical Engineering, COMSATS Institute of Information Technology, Lahore, Pakistan
[d] Department of Biotechnology and Microbiology, Lahore College for Women University, (LCWU), Lahore, Pakistan
[e] Department of Environmental Science, PMAS Arid Agriculture University, Murree Road, Shamsabad, Rawalpindi, Pakistan

A R T I C L E   I N F O

Article history:
Received 17 March 2014
Received in revised form
17 May 2014
Accepted 9 July 2014

Keywords:
Microalgae
Cultivation
Heterotrophic
Autotrophic
Harvesting
Lipids extraction
Biodiesel

A B S T R A C T

Excessive uses of fossil fuels and environmental degradation have forced the scientists to find alternative and clean sources of energy. Biofuels are considered as potential alternatives as they are green in nature and are sustainable energy sources. Biodiesel is one of the most commonly used biofuel due to its fuel characteristics. Several feedstocks can be used to produce biodiesel. However, in recent years, microalgae have emerged as potential biodiesel feedstocks. Microalgae offer advantages over conventional feedstocks. Microalgae have ability to fix atmospheric CO_2 and convert it into sugars, which are then converted into fuel after biochemical processing. Microalgae have high growth rate and accumulate lipids up to 70% in their cell body. They demand less water and nutrients for their growth as compared to terrestrial crops. Despite these advantages, the scale-up applications of microalgae biofuels have some technical limitations. In this study, we have reviewed the overall process of biofuels production from microalgae with a particular emphasis on biodiesel. Critical factors affecting the biodiesel production process including species isolation, species selection, cultivation, harvesting, and oil extraction are discussed. Current research, barriers and developments concerned to each step of biodiesel production process are summarized. New ideas are proposed to improve the growth rate, lipid contents and harvesting efficiency of microalgae. To assess the economic viability of microalgae oil, an economical analysis is presented. Future research trends are also discussed.

Contents

* Corresponding author. Tel.: +92 992 383591; fax: +92 992 383441.
E-mail address: naimkanwar@yahoo.com (N. Rashid).

http://dx.doi.org/10.1016/j.rser.2014.07.104
1364-0321/

1. Introduction

In this century, industrialization and imprudent use of natural resources have raised serious concerns over global environment [1–3]. Anthropogenic activities have increased the concentration of carbon dioxide (CO_2), a major green house gas, up to 390 ppm [4–8]. If this trend continues, CO_2 emission is expected to be considerably high in near future. Thus there is an urgent need to neutralize the effect of CO_2 in the atmosphere for sustainable economic growth and to maintain living standards. In this perspective, several techniques can be applied. One obvious technique is to reduce the energy consumption; however, increased population and human life style are the major obstacles to implement this. Storage of released CO_2 can be another solution [9,10]. Technical as well as economical barriers limit this application also. CO_2 mitigation through natural sinks is a long-known process. Photosynthesis is natural process in which plants use CO_2 as a carbon source and convert it into carbohydrates [11–13]. Carbohydrates can be converted into fuel, called biofuels, through chemical or biochemical processing. Currently, biofuels are being promoted to displace fossil fuels [14–16].

Biofuels have some advantages over traditional fuel sources [17]. They are sustainable and environmentally friendly. Biofuels are derived from natural resources, which are versatile in nature. Based on the feedstocks, biofuels are categorized as 1st generation, 2nd generation and 3rd generation biofuels. Biofuels derived from crop plant such as jatropha, almond, barley, camelina, coconut, copra, fish oil, groundnut, laurel, oat, poppy seed, okra seed, rice bran, sesame, sunflower, sorghum, wheat soybean, rapeseed, karanja are termed as 1st generation feedstocks [18,19]. Biofuels production from such feedstocks faces criticism due to food versus fuel dilemma. Animal fats and waste cooking materials are also used to produce biofuels, known as 2nd generation feedstocks. However, these feedstocks do not have stable supply to fulfill future energy needs. Alternatively, microorganisms, called 3rd generation feedstocks, can be used. A wide variety of microorganisms have been indentified which serve as sink for CO_2 and produce biofuels. They are used to produce methane, bio-hydrogen, biodiesel, and bio-ethanol by subjecting them to different biological conditions. Fig. 1 shows the processes of biodiesel production from various feedstocks.

As noted earlier, biodiesel production from 1st and 2nd generation feedstocks have some ethical and sustainability issues [20]. Recently, the most promising choice for biodiesel production is microalgae. Microalgae have advantages over other feedstocks. Microalgae have high photosynthetic efficiency than terrestrial crops. They grow 100 times faster than other plants. They can give biomass yield of 15–25 t/ha/acre, which is much higher than soybean (0.4 t/ha/year), rapeseed (0.68 t/ha/year), oil palm (3.62 t/ha/year) and jatropha (4.14 t/ha/year) [21–24]. Microalgae have ability to use atmospheric CO_2 as a carbon source. They can fix CO_2 at higher rate than other plants. Microalgae fix CO_2 and convert it into value added products such as vitamins, lipid, protein, bio-ethanol, and bio-hydrogen. Besides distinct advantages of microalgae there are some technical limitations in their scale-up applications [25]. For economical biofuels production from microalgae, we need to select such species of microalgae which have high growth rate, probably less than one day. Also, high lipid yield ($>70\%$) is desired. There is a tradeoff between growth rate and lipid yield. Species growing fast accumulate less lipids. On the other hand, contamination is a serious issue for outdoor microalgae cultivation. Harvesting, which pose 30% of total cost of biodiesel production from microalgae itself is a complex process. No universal technology has been introduced so far for economical microalgae harvesting. Lipid extraction is another necessary step of biodiesel production process. Thus it is worthy to investigate each step of biodiesel production process in detail. In this article, we have reviewed the critical parameters which influence the biodiesel production process. A detail discussion about each parameter is provided to identify the problems which incur in biodiesel production process. This information might be helpful to set future research goals for sustainable microalgae biofuels.

2. Rationale of biodiesel production from microalgae

Continuous increase in human population, living standards, and energy consumption has led to excessive use of fossil fuels. [5,26,27]. According to an estimate, the existing fossil fuel reserves will exhaust in next 60–80 years [1,12,28]. The depletion of fossil fuels would put enormous pressure on the global economy [27]. Thus finding renewable and sustainable sources of energy is one of the most challenging issues of this century [14,29,30]. Biofuels production is a promising choice to overcome these challenges [31]. The most common biofuels are: bio-ethanol, biodiesel, and bio-hydrogen. Among these, biodiesel is an attracting option because of its high energy density, low NO_x and SO_x emission after combustion, and its compatibility with existing vehicle engines without modification. Biodiesel is a mono-alkyl ester of fatty acids. It is produced by the reaction of triglycerides with alcohols. Biodiesel can be produced from edible sources, called 1st generation feedstocks [16,18]. High nutrients and water demand,