ARTICLE IN PRESS

Renewable and Sustainable Energy Reviews xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

# A review on bio-fuel production from microalgal biomass by using pyrolysis method

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ARTICLE INFO

*Keywords:*
Biomass
Microalgae
Thermochemical conversion
Pyrolysis
Bio-fuel

ABSTRACT

Due to the depletion of fossil fuels and their environmental issues, it is necessary to find energy resources which are renewable. Algal biomass becomes promising feedstock for bio-fuel production. They are considered as sustainable, renewable and effective biomass and bio-fuels obtained from them are more environment-friendly than fossil fuels. The aim of this work is to provide a state of the art review on pyrolysis of microalgae for generation of bio-fuels. Initially, some general aspects of biomass such as microalgae characteristics, different thermochemical processes and advantages of microalgae pyrolysis to produce bio-fuels are discussed. Then, different pyrolysis methods are explained and parameters affecting the process are addressed. Bio-fuels including gaseous, solid and liquid products have been characterized in a separate section. Finally, the technical challenges associated with microalgal pyrolysis commercialization are discussed in the last section of this article.

## 1. Introduction

### 1.1. Biomass and bio-fuel

In recent decades, increasingly vast research efforts are devoted for developing renewable energy resources due to fossil fuels resources reduction and environmental problems caused by them such as air and water pollution, acid rains and global warming. Of all the alternative renewable resources, biomass has been recognized as a promising candidate to meet the global demand [1–3]. Bio-fuels including gaseous, liquid and solid products could be acquired from different biomasses which could be categorized into 1st, 2nd, 3rd and 4th generations according to their origin [4]. Bio-fuels produced from food crops are considered as “first generation” bio-fuel. Feedstock for these fuels can be categorized into starch and sugar crops, and oil seeds [5]. Rice, wheat, maize, sugarcane, oil palm, soybean and barley are some of such feedstocks [4,6,7]. Although the first generation bio-fuels have been commercialized worldwide, its sustainability have been interrogated because of its destructive effects on the environment and ecosystem [4–7]. Moreover, this kind of bio-fuel cannot meet the world energy demand because of competition with materials which are used as animal feed and human food. Such problems have led to appearance of the second generation of bio-fuels [8].

Second generation bio-fuels are produced from waste and lignocellulosic feedstocks. Their main advantage over first generation feedstocks is to not having competition with food/feed supplies [4,8]. Moreover, they offer higher bio-fuel production yield and they require lower land for growing [4]. Despite of these advantages over the first generation of bio-fuels, they have some serious drawback of not being economically viable at large scales [9,10].

Third generation of bio-fuels does not have the disadvantages of previous generation of bio-fuels. They are derived from algal biomass and are the most promising alternative resource [11,12]. These new potential alternative feedstock can be used for large scale generation of bio-fuel without disrupting the environment. Therefore, they can overcome drawbacks associated with first and second bio-fuel generation [4,13]. Their bio-fuel production rate is much higher than the other types of bio-fuels due to their higher grow rate [12]. Moreover, they are able to grow in non-arable lands, and they have no overlap with food supply [12]. Production costs and cost efficiency of algal final products are high and low, respectively. Thus, in spite of mentioned positive aspects, algae have not been produced on a large commercial scale [14].

Genetically modified microorganisms such as microalgae, yeast, fungi and cyanobacteria are the fourth generation bio-fuels. $CO_2$ could be directly converted to fuel by these microorganisms [4]. Microalgae are microscopic cells or chains of cells which live in fresh or saline water and are able to convert carbon dioxide, water and sunlight into biomass through photosynthesis. The growth rate and oil content of microalgae are faster and higher than macroalgae. Besides, they have

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http://dx.doi.org/10.1016/j.rser.2017.10.033
Received 11 March 2017; Received in revised form 1 September 2017; Accepted 26 October 2017
1364-0321/ 

Please cite this article as: Azizi, K., Renewable and Sustainable Energy Reviews (2017), http://dx.doi.org/10.1016/j.rser.2017.10.033

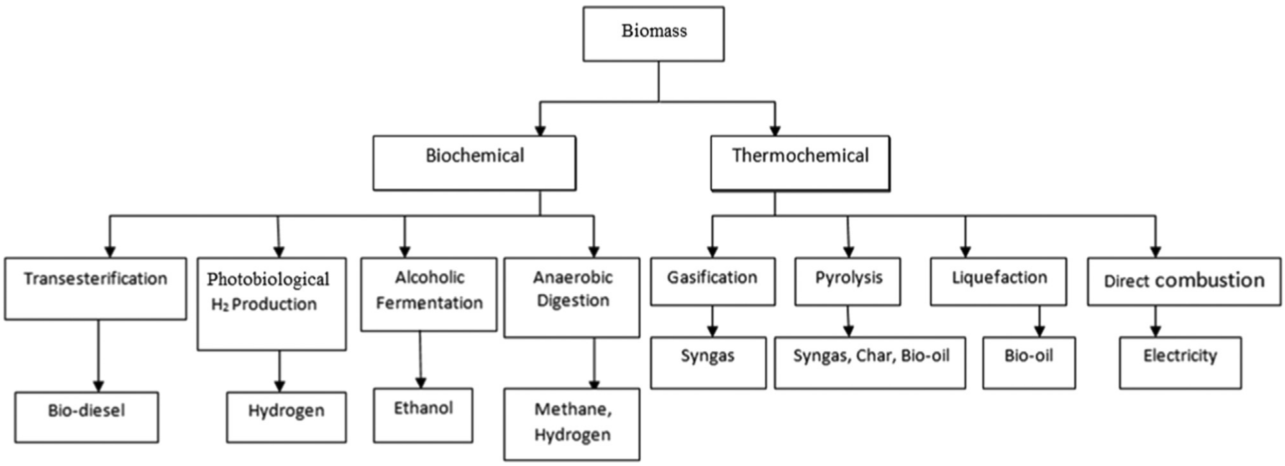


**Fig. 1.** Two main pathways for conversion of biomass to bio-fuel and derived products.

less complex structures than macroalgae [12]. Microalgae have numerous commercial applications. They can be used as a nutritional value to improve food, as animal feed, as a feedstock for different industries [2].

Different forms of bio-fuels can be obtained from microalgal biomass via two different pathways as shown in Fig. 1.

Microorganisms convert biomass into bio-fuels through biochemical process. As it is shown in Fig. 1., it could be categorized into anaerobic digestion, alcoholic fermentation, photobiological hydrogen production and transestrification. Biomass is heated and decomposed in the presence or absence of air or oxygen through thermochemical process. Solid, liquid and gas bio-fuels can be formed by using thermochemical processes in comparison with biochemical processes [15]. There is currently no preference between biochemical and thermochemical methods. But it is illustrated that conversion through thermochemical process is more favorable due to low conversion efficiency, lengthy reaction steps, and high production costs of biochemical conversion processes [15]. There are a lot of review papers on thermochemical conversion of microalgal biomass to bio-fuels. However, to our knowledge, a paper which has specifically reviewed microalgae pyrolysis has not been published yet. This paper aims to review the process for microalgal conversion using pyrolysis method. Commonly used types of pyrolysis process have been discussed and parameters affecting the conversion of microalgal biomass have been described. This study also focused on different types of bio-fuels produced form pyrolysis of microalgae.

### *1.2. Microalgae characterization*

It is important to use an appropriate feedstock to attain high bio-fuel yields of pyrolysis. Biomass ability in converting to high value of bio-fuel is investigated by determining the elemental analysis (carbon, hydrogen, oxygen, nitrogen and sulfur), biochemical composition, ash content, moisture content and higher heating value (HHV) of biomass [1]. Numerous studies about characterization of microalgae have been performed worldwide. The summarized data to describe the composition and properties of microalgae based on reference data from different investigations are described below. The elemental analysis, biochemical composition and physical properties of some microalgae are summarized and tabulated in Tables 1, 2.

Major components of microalgae are lipid, protein and carbohydrate. Different microalgae contain different amount of mentioned major component. As it was mentioned, elemental analysis, ash content, moisture content and HHV are determined to investigate conversion of microalgae to bio-oil.

Different formulas are presented to calculate the HHV of biomass fuel from elemental analysis. For instance, HHV of microalgae can be calculated according to the following equation [32]:

$$HHV = 0.3491\times C+1.1783\times H+0.1005\times S-0.1034\times O-0.0151\times N-0.0211\times A$$

where C, H, S, O, N and A are carbon, hydrogen, sulfur, oxygen, nitrogen and ash percentage of the material on the dry base respectively. As it can be concluded from the above equation, the more amounts of carbon and hydrogen that exists in the biomass will result the fuel with higher HHV.

Bio-diesel obtain from lipids accumulated in microalgae. Lipid, protein and carbohydrates could be converted to bio-oils. [2]. According to Biller and Ross [31] findings, biochemical composition of microalgae affects the bio-oil yield. Their results showed that bio-oil generation follows the trend lipids > proteins > carbohydrate. Large amounts of nitrogen heterocycles, pyrroles and indoles produce from protein; cyclic ketones and phenols produce from carbohydrates; fatty acids obtain from lipids [2,31].

### *1.3. Thermochemical conversion of microalgal biomass*

In thermochemical process, organic compounds of biomass are decomposed to bio-fuels at elevated temperature. This process provides a simpler route to generate bio-fuels, in comparison with chemical and biochemical processes [2]. For example, an extra purification step required to refine the biomass before chemical conversion process. On the other hand, biochemical conversion processes rely on biocatalysts, such as enzymes and microbial cells, in addition to heat and chemicals. Besides hand, in some cases, several days are required to complete the biochemical conversion reaction [2]. Thermochemical processes offer more profitable options since they rely on heat and/or physical catalysts and they can be applied to a variety of biomass feed stocks. In this process, usually there is no need to add chemicals and the reaction is accomplished in a short period of time. In this process, heat and chemical reaction act as two factors that affect products and energy formation [2]. Gasification, liquefaction, direct combustion and pyrolysis are the most common subcategories of thermochemical conversion [2,33].

#### *1.3.1. Gasification*

Conversion of organic or fossil based carbonaceous compounds into synthetic gases or syngas is named gasification. Conventional gasification and supercritical water gasification are two different routes to gasify microalgal biomass. The former process, materials react at high temperature (800- 1000 °C) without combustion with controlled amount of air, oxygen, argon, water or steam. Carbon monoxide,