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Bio-based liquid fuels as a source of renewable energy: A review

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ABSTRACT

Limited availability of fossil fuels and their associated environmental impact during combustion remains the primary basis for exploring alternative energy sources such as bio-based liquid fuels. Several feedstocks have been used to produce biofuels for different applications with their own pros and cons. For instance, production of bio-fuels using human food chain raw materials such as corn, soy, peanut, and sugarcane are receiving increased criticism due to the competing demands of the same sources for human consumption as food. However, the non-food biomass in the form of agricultural wastes, municipal wastes, waste vegetable oil, and microbial sources are abundantly available that can be utilized as feedstock for production of biofuels. Because of this reason, most biofuels have been produced using the feedstocks that do not affect the food chain. Thus, in this work, the feedstocks of different generation biofuels and their potential yield and associated greenhouse gas emissions, production technologies are critically surveyed. Moreover, the application of biofuels for different purposes are analyzed and compared with their corresponding conventional fuels. The survey also points out the recent issues and challenges of biofuels with their resolution. The future research directions are suggested to sustain biofuel production.

1. Introduction

The world demand for energy is increasing at a fast rate with the increasing trend of modernization and industrialization. Most of the developing countries import crude oil to meet their increasing energy demands. For this reason, a major portion of their hard earnings is spent on purchasing petroleum products. Awareness of the acute shortages of crude oil started during the worldwide fuel crisis in the 1970s. After that, significant attention was given to the improvement and utilization of alternative fuel sources. Besides this attention towards the energy crisis, today another important concern for us is the degradation of the environment due to emissions associated with fossil fuel combustion. Exhaust gases such as carbon monoxide (CO), Sulphur dioxide (SO_2), and nitrogen oxides (NO_X) are responsible for the greenhouse effect in the atmosphere, which in turn causes global warming. Hence, it is essential to develop alternative fuels with low emissions to mitigate the above mentioned energy related problems. Efficient sourcing of fuels from renewable sources is an option for meeting these challenges. Some of the renewable energy sources include hydropower, traditional biomass, solar, wind, and biofuels [1,2]. Biofuels derived from bio-resources (biomasses) can be ideal option to replace fossil fuels due to the fact that biofuels have cheap cost of materials to make them; they are renewable; and they are good for the environment given their net zero CO_2 emission [3,4]. A variety of fuels can be produced from plant biomass and fatty acids such as ethanol, methanol, butanol and biodiesel [5,6]. Compared to conventional fossil fuels, biofuels have several advantages like the source of biofuel is renewable [3,7,8], combustion of biofuels produce less toxic compound [7,8] and biofuels can reduce net carbon emissions up to a very low level [3,7–9]. Apart from these, biofuels have almost similar combustion properties like conventional fossil fuels. Diesel and gasoline can easily be replaced by biofuels with a little modification to the engines. Alcohol fuels like ethanol, methanol and butanol can replace gasoline and suitable to use in spark-ignition engines. On the other hand, biodiesels are suitable to use in compression ignition engines and has the potentiality to replace diesel fuel [10]. For example, gasoline-ethanol blends are widely used in Brazil [9,11,12]. Among all the renewable sources of energy, biofuels have the most market potentiality. For this reason, a remarkable number of developed and rapidly developing countries have emphasized on biofuel production to meet their energy demands. In the year of 2007, all the members of European Union set a target to fulfill 20% energy of their overall energy consumption from renewable sources by 2020. In addition, out of this 20% energy demand, 10% will be fulfilled by biofuels which will mainly be used in transportation sector [13]. In order to achieve this target perfectly, all the countries under European Union have taken several initiatives such as improving infrastructure

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for producing more biofuel, reducing taxes, allowing more percentages of biofuels to be blended with conventional fuels, etc. [8,14].

Numerous works were reported about bio-based liquid fuels in the literature focused on different scopes. For instance, different conversion technologies were reported namely: hydrothermal liquefaction of microalgae [15,16], biomass upgrading by torrefaction [17,18], and thermochemical biomass gasification for producing biofuels, biopower and chemicals [19]. A review on biodiesel composition, properties, and specifications was done by Hoekman et al. [20]. Zhang et al. [21] also made a review on pretreatment of lignocellulosic biomass for biofuels and biochemicals using organic solvents. Furthermore, several studies were carried out experimentally on performance and emission evaluation of a diesel engine using a biodiesel produced from different biomass sources and its blends with diesel fuel [22–24]. Review on production, performance and emissions from a diesel engine using biodiesel as alternate to conventional diesel fuel was done by Datta and Mandal in 2016 [25] and recently Tamilselvan et al. [26] made review on the performance, combustion and emission characteristics of biodiesel fueled diesel engines. However, there is no noticeable critical review on bio-based liquid fuels biomass that includes biomass feedstocks, production technologies and their extensive application and the associated emissions in one form.

Thus, the aim of this paper is to critically review the different types of biofuels based on their feed stocks, their applications and production processes as well as the effects of biofuels on the performance and emissions of diesel engines. Moreover, this report focuses on the recent issues and challenges of biofuels. The last objective of the current wok is to present different research results in order to provide an easy comparison among them. The paper consists of nine sections, where Section 2 presents the different types of biofuels, Sections 3 and 4 present the various production processes and applications of biofuels, respectively. The effects of biofuels on performance and emissions of diesel engines are presented in Sections 5 and 6, respectively. Section 7 briefly discusses issues and challenges related to biofuels. Section 8 recommends the opportunities of future research to improve the production of biofuel and overcome the challenges. Finally, the review concludes with Section 9.

2. Types of biofuels

Biofuels are broadly classified into three generations. Each generation of biofuels contains a number of different fuels. The classification in terms of fuel generation is based on the source from which the fuel is derived. The structure of the biofuel does not change with the change of generation. It is source of biofuel which changes with changing the generations [9]. Fig. 1 shows the different types of liquid biofuels. In this section, different types of liquid biofuels and their feed stocks will be discussed in brief.

2.1. First generation biofuels

The first generation biofuels are those types of biofuels which are generally produced directly from food crops such as starch, sugar, animal fats and vegetable oil [27]. A relatively simple process is followed to generate first generation biofuels. The feed stocks used to generate these types of biofuels are not green or sustainable. This is the basic difference between first and second generation biofuels [28]. Most common feed stocks which are used to generate first generation biofuels are corn, wheat, sugarcane and soybeans.

Corn is the largest source for the production of first generation biofuels especially ethanol [29,30]. Around the world, United States (US) cultivates highest amount of corn crops every year. In the year of 2012, US uses more than 40% corn crops from its total amount of corn to produce ethanol. The US government set a target to produce 15 billion gallons of ethanol in a year from corn crops [31]. Corn has several advantages as a feedstock to produce biofuel. The conversion process of ethanol from corn crops is relatively simple and all the parts of the corn including stock, cob, etc. can be used to produce ethanol. Moreover, it has potential to reduce the dependency on gasoline and the land use costs for corn production is also very low [32,33]. On the other hand, it has some severe drawbacks. The price for fertilizer and pesticides for the cultivation of corn crops is very high and use of these contaminates the soil and water. If it is used in the production of biofuel, it will hamper the food chain because it is one of the main foods being used in many countries. Ultimately, it will increase the food price all over the world. The production rate of corn and the energy produced from it is very low [33,34]. Because of these drawbacks, corn cannot be a stable feed stock for biofuel production.

Sugarcane is the second largest source for the production of first generation biofuels especially ethanol [35–37]. Around the world, Brazil cultivates the highest amount of sugarcane every year and Brazil produces the highest amount of alcohol fuel after US. Every year 5 billion of ethanol biofuel is produced in Brazil. After the oil embargo in 1970, the government of Brazil took an auspicious position to produce ethanol from sugarcane and made a policy to use minimum 22% ethanol in gasoline fuel. However, 100% ethanol can be purchased in Brazil as well [38]. A simple process is followed to convert sugarcane into ethanol. At first, sugarcane provides starch which is then converted to ethanol through fermentation process [39]. Like corn, sugarcane has some pros and cons. The ethanol produced from sugarcane is higher than the ethanol produced from corn. The carbon dioxide emission from sugarcane biofuel is 90% lower than gasoline fuel if the land use remains unchanged [32,33]. On the other hand, sugarcane can only be cultivated effectively in some specific regions in the world and it is one of the main foods for the people of South and Central America [34,40]. Like corn sugarcane cannot also be a stable feed stock for biodiesel production because of having some serious drawbacks.

The third major feed stock for the production of first generation biofuels is soybean [41,42]. It is grown almost everywhere in the world especially in North America, South America and Asia. The US and Brazil are the two countries who produce most of the soybeans in the world which are 32% and 28% of the total production of soybeans, respectively. Unlike corn and sugarcane, soybean is used to produce biodiesel. The major advantage of soybean is that it is available in many regions in the world [32,33]. However, drawbacks of soybeans are many. The price is very high and the energy produced from it is very low compared to corn and sugarcane which is 70 gallons per acre [43]. Because of having these drawbacks, soybean has become the worst feed stock for the production of first generation biofuels.

Another feed stock for the production of first generation biofuel mainly biodiesel is vegetable oil [44,45]. It is referred to as first generation biofuel when it is used directly as virgin. However, when it loses its eligibility for cooking then it is used as a feed stock for the production of second generation biofuel. The advantages of vegetable oil as first generation feed stock is its worldwide availability, easy conversion to biofuel and possible to directly use it in diesel engines with little modifications [46]. The main drawback of vegetable oil is that when it is used directly in diesel engine incomplete combustion occurs which may damage the engine by carbon deposition [47].

Wheat, peanuts, rapeseed, sugar beets are also noteworthy feed stocks for the production of first generation biofuels [48,49]. However, like main feed stocks these relatively lower used feed stocks have some drawbacks. The production of biofuels from these feed stocks affects the food chain and increases the carbon emissions. Table 1 shows different crop resources that can be utilized for ethanol production and their comparative production potential.

2.2. Second generation biofuels

Second generation biofuels are referred to as advanced biofuels. The basic difference between first generation biofuel and second generation biofuel is the feed stocks. Normally second generation biofuels are not