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A review on the production processes of renewable jet fuel

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ABSTRACT

The aviation sector contributes with 2% of the total anthropogenic CO_2 emissions, and predictions estimate that air traffic will double in the next 20 years, doubling fuel requirements and CO_2 emissions. The International Air Transport Association (IATA) has identified the development of renewable aviation fuel, known as biojet fuel, as the most promising strategy to reduce the environmental impact of the aviation sector. The renewable hydrocarbons that constitute biojet fuel are also known as synthetic paraffinic kerosene (SPK), and their properties are almost identical to those of jet fuel. SPK has also the advantage of containing very little sulfur, producing lower CO_2 emissions than jet fuel. The focus of this paper is to review the scientific and technological advances related to the existing pathways to produce biojet fuel, and to identify those that could lead to the future implementation of a sustainable production chain for renewable aviation fuel. The production process of biojet fuel is the key to satisfying both technical and economic goals required to obtain a more competitive biofuel, and allow the sustainable development of aviation sector.

1. Introduction

In recent decades, there has been a considerable increasing in the concentration of pollutants in the atmosphere, particularly greenhouse gases which are, to a great extent, responsible for climate change. The consequences of this phenomenon have been observed in recent years, and they include the accelerated melting of the polar ice caps, changes in weather patterns and even the extinction of animal species. Among the greenhouse gases, CO_2 is the main contributor to climate change [1].

According to the Intergovernmental Panel on Climate Change, annual CO_2 emissions increased by 80% between 1970 and 2004; this increment is explained in terms of the growth rate of CO_2 equivalent, which from 1995 to 2004 was more than double (0.92 $GtCO_2$-eq per year) than that of the previous period from 1970 to 1994 (0.43 $GtCO_2$-eq per year) [2]. CO_2 emissions arise mainly from power generation and transport, which together represented 64% of the total anthropogenic CO_2 emissions in 2009 [3]. This fact has driven the search for alternative energy generation and renewable fuels to reduce emissions into the atmosphere.

In particular, in 2014 the transport sector required 2627.02 million tons of oil equivalent, representing 27.9% of the total energy produced in the world [4]. In addition, it is estimated that energy consumption in this sector will increase between 80% and 130% in the next decades (2010–2050), therefore CO_2 emissions due to transportation will grow from 16% to 79% [4]. It is worth to mention that the increase in CO_2 emissions is smaller than the growth in fuel consumption due to increasing engine efficiency of vehicles. The large growth predicted for the transport sector is due to the doubling of international air traffic, along with the increasing by 50% of transportation of goods by road. Jet fuel and diesel will be the primary fuels required for the growth of the transport sector.

Therefore, the goals of reducing CO_2 emissions in the transport sector have become an important driver for the development of biofuels [5]. The International Energy Agency estimates that by 2050 biofuels will account for 27% of all fuels in the transport sector, particularly as a replacement of diesel and jet fuel [5,6]. Therefore, it is of great interest to develop efficient and sustainable processes to produce renewable diesel and renewable aviation fuel; this work focuses on the production processes of renewable aviation fuel, also known as biojet fuel.

Biojet fuel has recently started to attract interest, and it has been identified by the IATA as the most promising strategy to reduce CO_2 emissions in the aviation sector [7]. Additionally, it is expected that the use of biojet fuel in the aviation sector will allow, at least, partial fuel independence. Next, we will define fossil jet fuel in order to present biojet fuel.

Fossil jet fuel is composed of approximately 20% paraffins, 40% isoparaffins, 20% naphthenes and 20% aromatics [8]. This combination

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Table 1
Some properties of fossil and renewable jet fuel.

	Jet-A	Jet-A1	Biojet fuel from jatropha	Biojet fuel from camelina
Fuel type	Kerosene	Kerosene	Synthetic paraffinic kerosene	Synthetic paraffinic kerosene
Boiling range (°C)	170–300	170–300	172–243	188–263
Freezing temperature (°C)	−40	−47	−57	−63.5
Flash temperature (minimum 38 °C)	38	38	46.5	42.0
Density at 15 °C (kg/m^3)	775–840	775–840	751–840	751–840
Viscosity at −20 °C (maximum 8 mm^2/s)	8.0	8.0	3.66	3.33
Energetic content (MJ/kg)	43.28	43.28	44.3	44.0

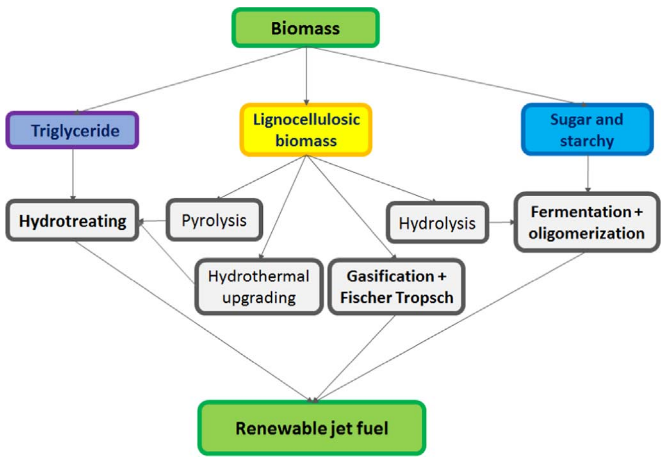

Fig. 1. Identified pathways for the production of biojet fuel.

gives fossil jet fuel its physical properties, showed in Table 1, as freezing point (−47 °C) and energy content (43.28 MJ/kg) [9,10]. Biojet fuel consists of renewable hydrocarbons in the boiling range of fossil jet fuel; in other words, it has a similar composition to fossil jet fuel, and it can contain aromatic compounds depending on the production process used. If aromatic compounds are not present, the emitted particles from burning biojet fuel are lower than those generated with fossil jet fuel [11]. However, the lack of aromatic compounds can cause wear in certain types of engines [12], and they are required to swell o-rings and seals in engines. Therefore, using biojet fuel in mixtures of 50% volume with fossil fuels has been established as a standard [13]. However, aromatic compounds can be added to biojet fuel, and in this case it is technically feasible to use it at 100% in aircraft engines [14]. Biojet fuel, also known as synthetic paraffinic kerosene (SPK), is constituted by renewable hydrocarbons which properties are almost identical, or in some cases superior [15], to those of fossil jet fuel, as can also be seen in Table 1. The combustion of SPKs produces lower CO_2 emissions than fossil jet fuel [11]; also, they have the advantage of containing very little sulfur. Therefore, biojet fuel has been identified by the IATA as the most viable alternative for the replacement of fossil fuels in aviation [16,17].

Recently, two review papers have addressed the status of aviation fuel. In 2013, Liu et al. [12] wrote a review concerning the production of fossil jet fuel. In their work, a section was included where the commercially available processes for biojet fuel production were briefly described; however, in this section only two scientific references were included. On the other hand, Wang et al. [18] gave a review of the different pathways to produce biojet fuel; in their work, information about flow diagrams of different pathways were presented. Nevertheless, a compilation of all the scientific works related to the production of biojet fuel as well as the technological advances (patents) is still missing.

Therefore, the focus of this paper is to perform a review of the scientific and technological advances related to the biojet fuel production processes, identifying the future pathways that could lead to the implementation of a sustainable supply chain for renewable aviation fuel. The production process of biojet fuel is the key to satisfying both technical and economic goals required to obtain a more competitive biofuel.

The paper is organized as follows. First, the identified pathways to produce biojet fuel are presented, giving a brief description of the process involved in each one of them. Then, the scientific and technological advances reported in each pathway are described. Later, some insights into future efforts that could lead to the implementation of a sustainable supply chain for renewable aviation fuel are addressed. Finally, the up-to-date compilation of the demonstration flights where biojet fuel was used, along with industrial scale projects associated with biojet fuel are mentioned.

2. Pathways to produce biojet fuel

Synthetic paraffinic kerosene (SPK) can be produced from coal, natural gas or biomass [12]. However, biomass is the only renewable alternative; therefore, production processes where coal and natural gas are used as raw materials are not included in this review. In general, the biojet fuel production processes transform the biomass through different processing routes; the biomasses that can be used to produce biojet fuel include triglycerides, lignocellulosic biomass, sugar and starchy feedstock, as it is shown in Fig. 1. Depending on the renewable raw material, the following pathways are identified: hydroprocessing of triglyceride feedstock, thermochemical processing of biomass, and alcohol to jet [19]. From these pathways, the hydroprocessing of triglyceride and the thermochemical conversion of biomass by gasification and Fischer-Tropsch are the only ones certified by ASTM for the production of biojet fuel for commercial use.

These pathways offer different advantages and disadvantages. In general, those pathways with expensive feedstock, as materials containing triglycerides, requires low cost processing. On the other hand, low cost raw materials, as lignocellulosic biomass, require many stages of processing, which increases the cost. Therefore, the selection of the best production process must obey to the availability of the raw materials; since the raw materials costs and its transportation will affect the supply chain, which plays an important role in the viability of the production process of biojet fuel [20]. Next, a brief description of each pathway along with the scientific and technological advances reported in the literature are presented.

3. Hydroprocessing pathway

The hydroprocessing pathway consists on the chemical conversion of triglyceride feedstock through hydrodeoxygenation, hydroisomerizing and hydrocracking to produce biojet fuel [21]. Fig. 2 shows the block diagram of hydroprocessing pathway, where the main sections of the process can be observed. In the reactive section the triglyceride feedstock is first converted to lineal long chain hydrocarbons, with hydrogen and a solid catalyst at high pressure and temperature; for this, deoxygenation and decarbonylation reactions are performed, generating water, carbon monoxide and carbon dioxide as byproducts. The lineal long chain hydrocarbons generated in the first reactor enter