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Technological, technical, economic, environmental, social, human health risk, toxicological and policy considerations of biodiesel production and use

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ABSTRACT

This paper overviews the technological, technical, economic, environmental, social, toxicological and human health risk considerations of biodiesel production and use. The future efforts in the technological domain should be directed towards low–cost and non–edible feedstocks, advanced technologies with reduced overall production costs and profitable production capacity. Process innovations that include new more active and stable catalysts, advanced reactors, continuous operation, lower energy inputs, better energy balance and lower GHG emissions and produce low or no wastes can lead to more efficient biodiesel production. Environmentally sustainable biodiesel production requires that sustainability standards cover direct and indirect impacts on the environment, i.e. soil, water and air. The combination of technological with economic, social and environmental issues will increase biodiesel benefits and may lead to integrated biorefineries capable of producing sustainable biodiesel and other valuable chemicals. Government policies will be the primary driving force for further increases in biodiesel production. Increased cooperation among governments and various stakeholders is needed to develop and apply corresponding sustainability criteria in a consistent way worldwide as soon as possible.

1. Introduction

Biomass-based diesel fuel can be produced by several technologies and processes, some of which are in commercial or pre-commercial production while others are still in the research and development phase. Different processes used to create biomass-based diesel include transesterification and hydroprocessing of lipids, cellulose pyrolysis, conversion via carboxylic acid and gasification, etc. Currently, the biodiesel is the predominant form of biomass-based diesel [1], which is mainly produced by transesterification of acylglycerols from natural resources most frequently with methanol or ethanol over a catalyst. After proper post–treatment, the resulting mixture containing methyl or ethyl esters is considered as biodiesel if fulfills the biodiesel quality standard. Biodiesel is commonly used for diesel engines after mixing up with mineral diesel, although the biodiesel itself can nowadays be employed without or with minimal engine modifications. Other recognized advantages of biodiesel are:

- Technical (ease usage, safety due to high flash point and favorable lubricity properties);
- Environmental (renewable, biodegradable, non–toxic, mitigated greenhouse gases – GHGs);
- Social, economical and political (national energy security, trade balance and development of rural regions); and
- Those regarding human health (reduced harmful exhaust gases).

However, overall biodiesel production commonly consumes non–renewable energy for machinery work in cultivation and processing of feedstock, oil extraction, biodiesel synthesis and purification, transportation of raw materials, inputs and distribution, as well as energy embedded in chemicals (fertilizers, agrochemicals and methanol), which must be taken into account when evaluating biodiesel as environmentally friendly alternative fuel.

As the popularity of biodiesel increases, many techno–economically and environmentally related studies on its production and use have been conducted in order to evaluate their not only economic potential

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but also overall environmental and social implications. These studies have examined one or more categories of these implications, but only a few of them present more comprehensive evaluations [2–5]. The main result is that the expansion of biodiesel production, although being of small capacity compared to total energy demand, may contribute to energy security and is significantly related to the current type and level of agricultural production. Also, the potential environmental and social impacts of its increased growth are well–recognized, such as reduced GHG emissions, negative impacts on land, water, air and biodiversity, promoted agricultural growth and rural economic development, etc. These impacts are generated at all stages of feedstock production and processing and biodiesel production, but the processes related to land–use change and intensification dominate [6]. The integrated production of biodiesel and ethanol combining soybean and sugarcane cultivation and processing can further improve the environmental aspects of biodiesel by reducing the GHG emissions and the fossil energy use in the ethanol production chain [7].

This paper provides a general overview of the technological, technical, economic, environmental, social, toxicological and human health risk considerations related to biodiesel production and use. First, important issues related to biodiesel technologies including feedstocks, production, purification, storage and application are shortly reviewed. An emphasis is given to the comparison of emerging with conventional biodiesel technologies and to the integrated biodiesel production in lipid biorefineries. Then, technical, socio–economic and environmental impacts of biodiesel are critically considered. The technical feasibility includes the consideration of the direct solar energy use in biodiesel production and the assessment of centralized biodiesel production and various extents of decentralization. The economic considerations include the assessment of the biodiesel production itself using different feedstocks and processes and the impact of crude glycerol on the biodiesel production. The environmental issues involve the contribution of biodiesel on sustainable development based on the assessment of GHG emissions, carbon stock change and environmental sustainability indicators. They also include the environmental impacts of biodiesel production and use. The connections of biodiesel with energy and food markets, the possibility to improve labor conditions and worker rights, the effects of biodiesel policy and the relations between social and economic impacts, as being among the most important socio–economic–political aspects of biodiesel are focused on. Environmental, economic and social impacts are also assessed through life cycle assessment (LCA), life cycle cost assessment (LCCA) and social life cycle assessment (sLCA) tools, respectively. Finally, the potential toxicological impacts and human health risks of biodiesel production and use are discussed.

2. Biodiesel technologies: feedstocks, production, storage and application

2.1. Feedstocks for biodiesel production

Depending on the type of feedstock, biodiesel can fall into all three well–known categories of biofuels: first, second or third generation. Nevertheless, it is important to notice that the structure of the biodiesel itself is the same independently of the category while the feedstock from which it is derived varies.

The first generation biodiesel refers to the biodiesel derived from edible vegetable oils and animal fats. Edible vegetable oils are provided by food crops that compete for scarce arable land, water and fertilizers. Depending on the climate and soil conditions, various edible vegetable oils are used for biodiesel production, but the main are soybean oil in the United States, rapeseed oil in Canada, sunflower oil in Europe, palm oil in Southeast Asia or coconut oil in the Philippines [8]. Among them are also safflower, corn, rice, barley, sorghum, wheat, canola and peanut oils [9]. Despite their relatively high prices as food crops, edible vegetable oils are still major feedstocks for the production of biodiesel (more than 95%) [10–12]. The main advantages of vegetable oils are the wide availability and the relative easiness of their conversion to biodiesel while their disadvantages are the threat of the food chain, the increase of carbon emissions when planted outside traditional agricultural settings and the intense growth requirements. Also, the use of edible oils in the production of biodiesel is restricted by their usage in the human diet and food industry, as well as the high price of biodiesel production [10–12]. Furthermore, even if the whole amount of available edible oils is used for the production of biodiesel, the gained amount of biofuel will not satisfy current diesel requirements [13]. Besides vegetable oils, various animal fats are also considered as favorable feedstocks for conversion into biodiesel [9] because they provide an economic advantage [14].

Second generation biodiesel separates from first generation one by the fact that feedstocks used in their production are generally non–edible crops or have already fulfilled their food purpose such as waste oily streams from the oil refinery, used cooking oils (UCOs) and waste animal fats (WAFs) like pork lard, beef tallow, poultry fat and fish oil. Use of these less expensive feedstocks primarily contributes to the reduction of the biodiesel production costs. For instance, market values of UCOs and non–edible oils like jatropha in 2012 were estimated 331 US $/ton and between 350 and 500 US $/ton, respectively [15]. Moreover, the use of these oily and fatty raw materials eliminates the need of their disposal, helping to the improvement of their overall environmental impact.

Second generation crops are grown on marginal land that cannot be used for arable crops that do not require a great deal of water or fertilizer to grow, making their plantation much cheaper than that of the edible oil crops [11]. Azam et al. [16] recommended 26 crops containing oil in their kernels or seeds more than 30% as potential raw materials for biodiesel production. A summary of the oil content of selected oilseed crops can be found elsewhere [8]. Among these crops, the most important are seed crops producing oils that are unsuitable for human use because of the presence of toxic compounds. An important disadvantage of most non–edible oils is a high amount of free fatty acids (FFAs), which enhances the cost of biodiesel production [12]. Moreover, some of these oilseed crops like jatropha and cammelina do not fulfill all required preconditions to be considered as full second generation crops, resulting in the waned interest for them in recent years.

Waste oily by–products from edible oil refinery including soapstocks, oil sediments, acid oils, spent bleaching earth and deodorizer distillate can also be used as raw materials for biodiesel production [17,18]. Due to the growth of world population, the consumption of refined edible oils will also increase, resulting in an increase of the amounts of these by–products. This use will add value to them and increase the efficiency to edible oil refineries [19]. World's generation of soapstock, acid oils and deodorizer distillate in 2011 is estimated to be 0.78–1.45, 0.39–0.72, 2.8–3.7 and 0.18–0.24 million tons per year [18].

All waste oily and fatty resources are used as a biofuel for more than a century, but they are also considered as favorable feedstocks for biodiesel production [18]. UCOs contain vegetable oils and/or animal fats used for preparing various foods at elevated temperature and their use as a feedstock for biodiesel production has no direct conflict with food availability and land usage. Based on their FFA content, UCOs are categorized into two groups. Yellow grease (< 15% FFAs) is a low–cost feedstock for biodiesel production [20] while brown (trap) grease (> 15% FFAs and water) are much less suitable for biodiesel production [21]. However, being highly impure and containing FFAs at high levels, UCOs must usually be filtered, purified and pre–esterified before used for biodiesel production. Another problem related to UCOs is collecting despite they are widely distributed in restaurants, homes and food processing facilities.

WAFs or rendered animal fats are also regarded as the second generation biodiesel feedstocks [9,22]. Because of their limited avail-