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Environmental benefits of the integrated production of ethanol and biodiesel

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HIGHLIGHTS

- Integrated bioenergy systems can favor the sustainability of biofuels.
- We analyzed the integrated production of ethanol and biodiesel in Brazil.
- GHG emissions and fossil energy use in the ethanol life cycle would be reduced.
- Socio-economic and other environmental aspects must be analyzed in future works.

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ABSTRACT

The biorefinery of the future will be an integrated complex that makes a variety of products (e.g., biofuels, chemicals, power and protein) from a variety of feedstocks. The objective of this work was to evaluate the environmental benefits, compared to the traditional sugarcane ethanol system, of the integrated production of ethanol and biodiesel through a sugarcane–soybean biorefinery concept in Brazil. The environmental aspects considered here were the fossil energy use and the greenhouse gases (GHGs) emissions associated with ethanol production. In the Integrated System, soybean would be cultivated in part of the sugarcane reforming areas, which represents ~17% of the total sugarcane area. Sugarcane and soybean oil would be processed in a combined ethanol–biodiesel plant, which would use only bagasse as fuel. All the demand for utilities of the biodiesel plant would be provided by the distillery. The output products of the combined plant would comprise sugarcane ethanol, soybean biodiesel (which would be used as diesel (B5) substitute in the sugarcane cultivation), bioelectricity and glycerin. The results indicate that the Integrated System can reduce the fossil energy consumption from 75 to 37 kJ/MJ of ethanol, when compared to the traditional system. For GHG emissions, the value would drop from 22.5 to 19.7 g CO_2eq/MJ of ethanol. This analysis shows that the Integrated System is an important option to contribute to ethanol's life cycle independence from fossil resources. This is an attractive environmental aspect, but socio-economic (as well as other environmental) aspects should also be analyzed in order to assess the sustainability of such systems in a broader perspective.

1. Introduction

In a broad sense, a biorefinery can be seen as an integrated complex which is able to produce different products (fuels, chemicals, power and protein) from different biomass feedstocks, in a concept that could also optimize the commitment of land for bioenergy purposes. Today it is possible to say that the already established sugarcane mills in Brazil are important pacesetters of the future biorefineries, using sugarcane biomass for the production of ethanol, sugar, power and other products. But the potential for improvement is still enormous. In addition to the better use of the lignocellulosic material, the more efficient use of land aiming at the integration of bioenergy systems deserves attention as well. One example of such integration has been tested in commercial scale in Brazil, exploring the integrated production of ethanol and biodiesel [1].

The synergies from this integration are verified not only in the agricultural and industrial areas, but also in the administrative and commercial contexts [2]. In the agricultural sector, the oilseeds production in crop rotation with sugarcane is an already known practice that helps to break sugarcane diseases and pests cycles and contributes to the recovery of soil fertility. Additionally, the common use of agricultural and industrial infrastructure allows

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the split of costs, the optimized use of the industrial facilities and minimization of the investments, as well as the possibility of using biodiesel as fuel in machineries and trucks. In the administrative and commercial fields, the use of the same business structure and the diversification of products bring important strategic advantages, and the biodiesel commercialization can also take advantage from the experience gained in the ethanol market [1].

The objective of this study was to investigate the environmental benefits of this type of integration by assessing its impact on the fossil energy use and GHG emissions associated with ethanol production. A hypothetical production system was analyzed, assuming that soybean would be grown in the sugarcane reforming areas. The soybean oil would be the feedstock for the biodiesel production in a conversion plant adjacent to the sugarcane mill. The biodiesel produced would partially displace diesel fuel (B5) for sugarcane cultivation.

2. The liquid biofuels in Brazil

2.1. Ethanol

Ethanol has a long history in Brazil. The production started back in 1930s, when a 5% blend with gasoline was compulsory. But only during the 1970s, with the oil crises, the national ethanol program (Pro-álcool) was launched, and the production was boosted (Fig. 1) [3].

The technology to produce ethanol from cane's sugars is well-known and mature. In Brazil, it is based on the fermentation of either cane juice, molasses or a mixture of both. Most of the mills in Brazil are sugar mills with adjacent distilleries [5], but the number of autonomous distilleries has been increasing with the new greenfield projects.

In the last 30 years a progressive technology evolution has been verified in both agricultural and industrial areas, leading to important cost reductions [6]. Today sugarcane ethanol is cost-competitive with fossil fuels, without any need for subsides, and further improvement is foreseen in the near future [7]. In terms of environmental performance, at the present conditions, for each fossil energy unit that is required in the ethanol production chain, around 9 units of renewable energy are produced. With respect to GHG emissions, ethanol is able to mitigate about 80% of the emissions when compared to gasoline [8,9]. Despite these positive environmental aspects, it is important to emphasize the high consumption of fossil fuel in sugarcane cultivation and transport. Souza et al. [10] indicate that diesel is responsible for almost half of the total fossil energy input in ethanol's life cycle and estimate that the replacement of diesel by palm biodiesel would increase the energy balance in 73%, while reducing the life cycle GHG emissions in 23%.

2.2. Biodiesel

The first references to the use of vegetable oils as fuel in Brazil date from the 1920s. In 1980, the Resolution No. 7, from the Conselho Nacional de Energia (CNE), established the national program for the production of vegetable oils for energy purposes (Proóleo). Among other objectives, the Program intended to replace diesel by vegetable oils in a blending of up to 30% by volume, encourage technological research to promote the production of vegetable oils in different regions of the country and pursue the complete replacement of diesel by vegetable oils. Also in the early 1980s, the department of industrial technology of the ministry of trade and industry (STI/MIC) developed and launched the national program for alternative renewable energy of vegetable origins, with some lines of action related to vegetable oil fuel, which led to the OVEG Program. Because of the subsequent fall in oil prices, these early initiatives of the government were unsuccessful [11,12].

Given such history and considering the strong European biodiesel program, the federal government launched in December 2004 the national program of biodiesel production and use (PNPB). By the law 11,097 of January 13, 2005, the Brazilian government established the mandatory addition of a minimum percentage of biodiesel to diesel oil sold to the consumers nationwide. Since January 1st 2010, all diesel fuel sold in Brazil contains 5% of biodiesel [13].

Soybean is the main feedstock used for biodiesel production in Brazil, followed by tallow (Fig. 2). Brazil is currently among the largest producers and consumers of biodiesel in the world, with an annual production of 2.4 billion liters (Fig. 3). In the end of 2011, there were 64 biodiesel plants authorized by ANP (the national agency of petroleum, natural gas and biofuels) to operate in the country, which corresponds to a total authorized capacity of approximately 17.8 $\times$ 10^3 m^3/day. Out of these 64 plants, 60 have authorization to commercialize the biodiesel produced, representing about 17.2 $\times$ 10^3 m^3/day [14]. The biodiesel plants are spread over practically all Brazilian states, with many of them located in areas with relevant sugarcane production.

Along with the incentives for biodiesel production, ANP establishes restrictions for experimental use and specific use of biodiesel. The monthly consumption of biodiesel (B100 and its blends

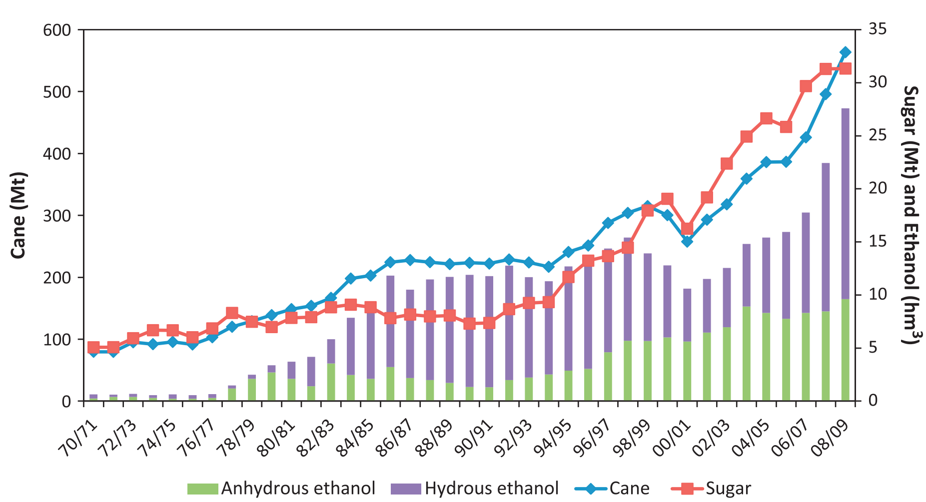

Fig. 1. Historical trends in the production of sugarcane, sugar, anhydrous and hydrous ethanol in Brazil (based on [4]).