Renewable Energy 59 (2013) 49–52

Contents lists available at SciVerse ScienceDirect

Renewable Energy

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

Technical note

Plastic vs. fuel: Which use of the Brazilian ethanol can bring more environmental gains?

Rodrigo A.F. Alvarenga, Jo Dewulf*

Department of Sustainable Organic Chemistry and Technology (Research group EnVOC), Ghent University (Faculty of Bioscience Engineering), Coupure Links 653, 9000 Ghent, Belgium

ARTICLE INFO

Article history:
Received 23 November 2012
Accepted 20 March 2013
Available online

Keywords:
Ethanol
Ethylene
Fuel
Life cycle assessment

ABSTRACT

Ethanol from sugarcane is mainly used as fuel for cars in Brazil. However, the chemical industry is considering ethanol also as biotic feedstock for several plastics (e.g. polyethylene and polyvinyl chloride). Both uses are able to cause less environmental impacts than their fossil references if we look to certain specific environmental impact categories such as fossil energy consumption and greenhouse gas (GHG) emissions. However, which use would be able to bring the most environmental gains to society? In order to answer this question, we performed an attributional life cycle assessment of using 1 kg of hydrous ethanol as fuel for transportation and the same amount for monomer production (ethylene), and compared them with the common practice of today in Brazil. Using ethanol to produce ethylene (instead of fossil-based ethylene) would generate environmental gains in the order of 32.0 MJ of fossil energy and 1.87 kg CO_2eq, whereas the use of ethanol for transportation (instead of gasoline mixture, for flex-fuel cars) would generate environmental gains in the order of 27.2 MJ of fossil energy and 1.82 kg CO_2eq. Some uncertainties were quantified, for instance we could observe that when the ethanol-to-ethylene reaction yield was lower than 96%, the fuel route had better results for GHG emission savings.

1. Introduction

Ethanol can be produced from several types of biomass, but in Brazil it is mainly produced from sugarcane. The sugarcane-ethanol industry in Brazil has already shown good performance, reaching energy ratios of 9.3 [1], i.e., for every 1 MJ of fossil energy supplied, 9.3 MJ of bioenergy is provided. Ethanol (from sugarcane) is the source of biofuels in Brazil since the 1970's [2], either as stand-alone fuel (E100) or blended with gasoline (e.g. E25). In the last years it has also been (re)considered as an alternative for making renewable plastics, for instance to produce bioethylene for polyethylene (Braskem – http://www.chemicals-technology.com/projects/braskem-ethanol/), for polyvinyl chloride (Solvay S.A. – http://www.plasticstoday.com/articles/solvay-indupa-invests-sugar-cane-derived-ethylene-pvc), and for polyethylene terephthalate (The coca-cola company – http://www.thecoca-colacompany.com/citizenship/plantbottle.html). Ethanol has several other applications (e.g. pharmaceutical), but considering the established biofuel market in Brazil and the potential increase in the bio-based plastics market [3], these two uses are the most promising.

When hydrous ethanol (with 96° GL) is used as fuel for cars in Brazil (E100), it avoids the use of gasoline mixture, which includes typically 20–25% (in volume) of anhydrous ethanol (with 99.7° GL) (Brazilian law number 10.203, from 2001). At the same time, when hydrous ethanol is used to produce bio-based ethylene, fossil-based ethylene is avoided. In this sense, we may raise the question of which of these two uses for hydrous ethanol may bring more benefits to the environment? The objective of this study was to evaluate which of the two options for using hydrous ethanol (as fuel for cars or as monomer in the chemical industry) could bring more environmental gains to society. Since most of the studies that compared bio-based and fossil-based fuels/plastics have shown that the contributions are mainly in the decrease of greenhouse gases (GHG) emissions and fossil energy consumption [4–6], we focused on these two environmental impact categories.

2. Material and methods

We used attributional life cycle assessment (LCA) methodology, but unlike traditional LCA studies which assess two or more comparable products, we assessed the environmental impacts of two different possible uses for hydrous ethanol. Consequently, in order to have comparable results between these two possibilities, we subtracted from the results the value of the alternative products

* Corresponding author. Coupure Links 653, Blok B, 9000 Ghent, Belgium. Tel.: +32 9 264 59 49; fax: +32 16 9 264 62 43.
E-mail address: jo.dewulf@ugent.be (J. Dewulf).

0960-1481/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.renene.2013.03.029

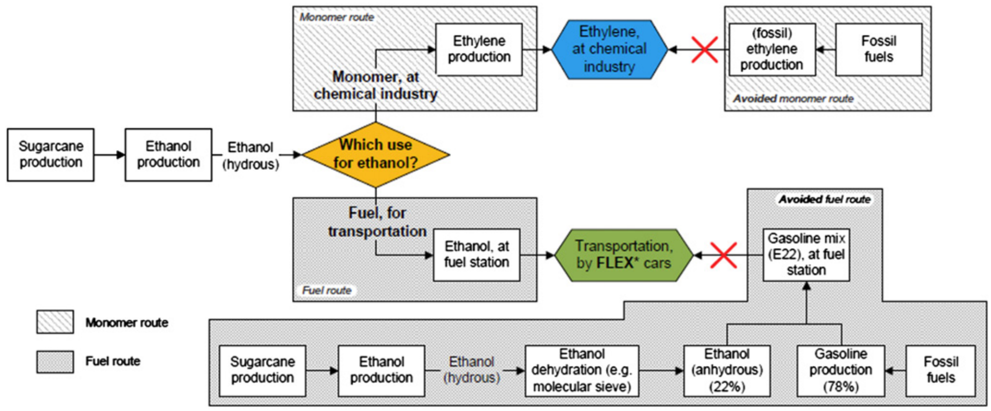

Fig. 1. Simplified flowchart of the two possible uses for hydrous ethanol considered in this study.

that ought to be used in Brazil (Fig. 1), i.e., the fossil-based ethylene and the gasoline mixture E22 (petrol with addition of anhydrous ethanol). The functional unit chosen was 1 kg of ethanol.

The sugarcane and ethanol production processes and supply chain were considered the same for both routes, based on data from Cavalett et al. [6]. According to them, 1000 kg of sugarcane (which requires approximately 120 m^2·year of land use) can produce 69.3 kg of hydrous ethanol. At the ethanol production process, electricity is co-produced, and in order to avoid allocation [7], we performed a *system expansion* with the Brazilian electric grid, based on data from the ecoinvent database [8].

In the monomer route, the ethylene production process was based on data from the CPM LCA Database [9], where a reaction yield of 100% is assumed. In this sense, for the functional unit of 1 kg of ethanol, 0.588 kg of bioethylene would be produced, which was used as the reference flow for the monomer route. The bio-ethylene produced may be used for different purposes (e.g. polyethylene), but we stopped our analysis at the monomer since the bio-based ethylene monomer has the same technical qualities of the fossil-based. For the fossil-based ethylene avoided we used the process 'Ethylene, average, at plant/RER', from the ecoinvent database [8].

In the fuel route, we considered that ethanol would be used in a flex-fuel car (Palio fire 1.0), with average fuel consumption of 10 L/100 km (for hydrous ethanol – E100) or 7.04 L/100 km (for gasoline with 22% of anhydrous ethanol – E22). Therefore, for our functional unit of 1 kg of ethanol, the reference flow at the fuel route was 12.7 km. The gasoline mixture (E22) avoided was modeled using the process 'Petrol, low-sulfur, at refinery/RER', from ecoinvent database [8] and the anhydrous ethanol production from Cavalett et al. [6]. The atmospheric emissions from the combustion of the fuels (at the use phase) were based on vehicle emission reports from *Companhia de Tecnologia de Saneamento Ambiental* (CETESB), the environmental agency from the state of Sao Paulo (Brazil) [10].

For the life cycle impact assessment stage, we used the fossil category of the method *Cumulative Energy Demand* [11], to calculate the fossil energy demand of each product; and the method IPCC 2007 (100 years) [12], to evaluate the GHG emissions. For the latter, we also considered carbon dioxide absorption and biogenic emissions.

This study is sensitive to several sources of uncertainties; two of them were quantified and are presented together with the results. First, while the reaction yield of ethylene produced from hydrous ethanol in the CPM LCA Database [9] was 100%, Alvarenga et al. [5] mentioned a reaction yield of approximately 90% (which would produce 0.53 kg of ethylene per kg of ethanol, instead of 0.588 kg). The second source was regarding the blend of anhydrous ethanol in the Brazilian gasoline mixture. According to Federal law (Brazilian law no 10.203, from 2001), 22% of anhydrous ethanol should be blended to the gasoline mixture (E22), however this value changed throughout the years, for political and economical reasons, varying from 20% (E20) to 25% (E25).

3. Results and discussion

3.1. Environmental profiles

In Table 1 we present the GHG emission and fossil energy consumption for the production of the bio-based products and the

Table 1
GHG emissions and fossil energy consumption throughout the life cycle of the different products (values are per kilogram of product).[a]

Life cycle phase	Product		GHG emissions ($kg\ CO_2eq/kg$)	Fossil energy consumption (MJ_{fossil}/kg)
Production phase (*cradle-to-gate*)	Hydrous ethanol	Bio-based (E100)	−1.55	2.00
	Gasoline mixture	E20 (20% bio-based)	0.17	44.10
		E22 (22% bio-based)	0.13	43.10
		E25 (25% bio-based)	0.06	41.50
	Ethylene	Bio-based (with reaction yield of 100%)	−1.78	10.79
		Bio-based (with reaction yield of 90%)	−1.62	12.00
		Fossil-based	1.40	65.20
Use phase	Hydrous ethanol	Bio-based (E100)	1.76	–
	Gasoline mixture	E20 (20% bio-based), E22 (22% bio-based), E25 (25% bio-based)	2.86	–

[a] Positive values mean GHG emission and fossil energy consumption, while negative values for the GHG emissions mean that the absorption of CO_2 is higher than the overall emissions of GHG.