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Economic and GHG emissions analyses for sugarcane ethanol in Brazil: Looking forward

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ABSTRACT

There have been many efforts to improve sugarcane cultivation and conversion technologies in the ethanol industry. In this study, an economic assessment and greenhouse gas (GHG) emissions analysis are performed on ethanol produced conventionally from sugarcane sugar and on an emerging process where the sugarcane bagasse is additionally used to produce ethanol. The combined conventional plus lignocellulosic ethanol pathway is found to be less economically favorable than the conventional ethanol pathway unless a series of technical challenges associated with cost reductions in lignocellulosic ethanol production are overcome, reaching a production cost at 0.31 $/L. This is expected to be achieved in a prospective 2020 scenario. GHG emissions savings against gasoline for both the conventional ethanol and the conventional plus lignocellulosic ethanol pathways are confirmed and found to increase with technological developments projected to occur over time. However, the absolute numbers are highly sensitive to the way of claiming credits from surplus electricity co-generated in the mill. These are 86%, 110% and 150% for the conventional ethanol in the 2020 scenario when the surplus electricity is assumed to replace the average electricity, the 'combined-sources' based electricity and the marginal electricity, respectively. For the conventional plus lignocellulosic ethanol pathway, they are 80%, 85% and 95% respectively in the 2020 scenario. Finally, a series of sensitivity analyses found the comparison in the GHG emissions between the two production pathways is not sensitive to changes in the sugarcane yield or the emissions factor for the enzymes used in the lignocellulosic ethanol process. However, the plant size is an influential factor on both the ethanol production cost (a lowest MESP of 0.26 $/L at the scale of 4 MM tonne cane/yr) and the GHG emission factors, partially because of the important role that transport of feedstock biomass (sugarcane and trash) plays in both elements.

Contents

Abbreviations: 1G, 1st generation; 2G, 2nd generation; AD, anaerobic digestion; BAU, business-as-usual; CHP, combined heat and power; COD, chemical oxygen demand; DAP, Diammonium phosphate; EF, emission factor; FAO, Food and Agriculture Organization of the United Nations; FAPRI, Food and Agricultural Policy Research Institute; FFV, flexible-fuel vehicle; FPU, filter paper unit; GHG, greenhouse gas; GREET, The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model; H_2SO_4, sulphuric acid; H_3PO_4, phosphoric acid; IPCC, intergovernmental panel on climate change; ISBL, inside battery limits (of the plant); K_2O, potassium oxide; KCL, potassium chloride; LCA, life cycle assessment; LHV, lower heating value; MESP, minimum ethanol selling price; NREL, National Renewable Energy Laboratory; OPT, optimistic; P_2O_5, phosphorus pentoxide; R&D, research and development; UNICA, Brazilian Sugarcane Industry Association; WWT, wastewater treatment

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1. Introduction

Due to growing concerns over energy and climate security, ethanol produced from renewable sources is seen as an important alternative to fossil fuels [1]. As one of the worlds' largest ethanol producers, Brazil has used sugarcane as feedstock to produce over 27 billion litres of ethanol in 2011 [2], most of which was destined for use as a fuel. Brazil ethanol production has been commercialized for over 30 years and is entirely based on the fermentation of simple sugars extracted from harvested sugarcane stem either in autonomous distilleries or in annexed plants co-located with sugar mills that co-produce ethanol and crystalline sugar [3]. This type of conventional ethanol produced from sugarcane sugar juice is often referred to as 1st generation (1G) ethanol, and has the lowest production cost worldwide compared to other sugar or starch-derived ethanol [4]. Currently the biofuel industry in Brazil is expected to expand to meet the increasing domestic and global market demand either by increasing the capacity of the 1G ethanol industry or by introducing lignocellulosic ethanol (referred to here as 2nd generation (2G) ethanol) which is produced from lignocellulosic biomass such as wood, straw or sugarcane bagasse and/or trash [5].

Efforts by academic researchers and industry are also focused on improving sugarcane yields, seeking out new feedstocks and enhancing technologies in the ethanol production process etc [6]. Sugarcane bagasse refers to a lignocellulosic residue from sugarcane crushing, which used to be regarded as a waste product, but is now used to generate process heat and electricity [6]. Bagasse is also becoming an attractive biomass feedstock to produce 2G ethanol which is expected to deliver improved environmental benefits compared to 1G ethanol such as reduced GHG emissions and better energy ratio. However, the cost and GHG emissions of 2G ethanol still remains higher than those of 1G ethanol, though substantial efforts to achieve technological breakthroughs have been made [4,7,8].

With regards to technological improvements, focus areas for the future are: (1) achieving higher sugarcane yields due to better genetics and cultivation practices, lower fertilizer application rates and increased levels of mechanized harvesting to avoid field burning [9]; (2) aiming for higher 2G ethanol yields by optimizing pretreatment and enzyme stages of the process [10,11] (3) improving the energy balance in ethanol production by optimizing process design and increasing solid to liquid ratios in reactions [12]; and (4) enhancing boiler efficiency in the bagasse combined heat and power (CHP) sector which could benefit both 1G and 2G ethanol [13,14].

Several studies have been done on sugarcane ethanol regarding its techno-economic and environmental performance: Macedo et al. conducted a scenario study of life cycle GHG emissions analysis on 1G sugarcane ethanol including improvements in the agricultural sector [9]. Dias et al. performed techno-economic analysis on sugarcane ethanol with particular focus on the effects of optimizing simulation processes and improving boiler efficiency [7,13,15]. Albarelli et al. compared the economics of 2G with 1G ethanol by modeling a specific supercritical water pretreatment technology on sugarcane bagasse [16]. A recent techno-economic study on sugarcane ethanol by Macrelli et al. considered technology improvement in the ethanol production sector and scenarios of using trash as feedstock, but without taking into account the option of using pentose (C5 sugar) as a source for ethanol production [4].

However, none of these studies incorporate improvements in both the agricultural and ethanol production sectors of sugarcane ethanol production. Nor do they consider linking the economic and environmental scenarios in assessing potential technological improvements to the process. These issues are the main aims for this study, which will: (1) analyze the full supply chain for conventional 1G sugarcane ethanol production and (2) investigate the current economic feasibility via minimum ethanol selling price (with 2010 as reference year and USD as reference currency, without taking into consideration fluctuations in exchange rate) and GHG emissions performance of emerging 1G+2G sugarcane ethanol pathways and then project the prospects for these into the near- (2015 scenario) and mid-term (2020 scenario).

In addition to the above aims, there is also considerable public interest [17] in the economic and environmental effects of increasing the size of sugarcane plant capacity (from current dominant 2 million tonne [18] to a larger capacity of 4 million tonne or more, and/or cluster integrated plants representative of more advanced players and will likely to be the way forward [19]), including