



Anaerobic digestion of vinasse from sugarcane ethanol production in Brazil: Challenges and perspectives



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ABSTRACT

The replacement of fossil fuels by biofuels has been extremely important worldwide to stimulate the growth of economies based on the sustainability through the use of renewable resources. Anaerobic digestion for biogas production is recognized as a clean technology that allies the suitability of wastes with energy generation, fulfilling the requirements for a sustainable alternative to provide the optimization of the biofuels production. This alternative is especially interesting for the sugarcane ethanol production in Brazil, in which the generation of vinasse, the main liquid waste, is very expressive. Nevertheless, the use of vinasse for anaerobic digestion has been finding some challenges to its establishment in the Brazilian sugarcane biorefineries. This paper reviews the actual context of anaerobic digestion within the sugarcane ethanol production in Brazil, presenting the main obstacles for its full application and the directions to promote it as well. Alternatives for biogas use are also presented and compared, highlighting the environmental and energy advantages of applying anaerobic digestion in the sugarcane biorefineries. This scenario is envisaged as a suitable way to achieve the future biorefineries model, based on the use and recovery of renewable resources with economic, social, and environmental benefits.

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1. Background

The growing need to expand the use of renewable energy sources in a sustainable manner has boosted the production of biofuels worldwide. Within this scenario, Brazil stands out due to its use of ethanol from sugarcane; the first-generation production process is already established on a large scale in the country, whereas the second-generation process is still in a developing stage. From an environmental perspective, the replacement of fossil fuels by ethanol would reduce greenhouse gas emissions. However, this biofuel production process generates large volumes of wastewater, especially vinasse (also termed stillage), which may constitute a serious environmental problem depending on its final destination. Another biorefinery liquid stream with considerable impact is the pentoses liquor obtained during the pretreatment of bagasse from the sugarcane used in the production of ethanol from lignocellulosic material (second-generation ethanol). Although several studies have examined the production of ethanol and other products from pentoses, this process stream should be given an appropriate destination to avoid environmental damage; however, these alternatives are not technologically feasible on a full scale. The same statement can be made for vinasse from second-generation ethanol production, which must also be treated and properly disposed.

Brazilian sugarcane ethanol production began to develop in the 1970s as a result of the oil crisis, which boosted the search for alternative fuels [1–3]. Since then, Brazil has been implementing biofuels policies to not only reduce the country's dependence on fossil fuels but also benefit from the many environmental, economic, and social advantages associated with the sustainable production and use of biofuels [4]. Nevertheless, although the disposition, treatment, and reuse of vinasse in the sugar and ethanol sectors has improved over the past 30 years, the current policies and regulations that provide guidelines are still inefficient and outdated. Prior to the 1970s, the discharge of vinasse in watercourses was identified as a serious environmental problem, increasing the pollution load of rivers and streams near the sugarcane plant area. In 1967, the Federal Government issued Decree-Law no. 303 prohibiting this action. In 1978, Ordinance no. 323 [5] was enacted for the same purpose, aiming to protect the ecological balance and environment in response to the increasing amount of distilleries promoted by the Brazilian Alcohol Program (Proálcool), which was created in 1975 to increase the production of alcohol for fuel purposes [2]. Thus, alternatives for vinasse disposal were sought; application in soil as a fertilizer for sugarcane crops (fertirrigation) was the most common practice until now. However, the criteria for vinasse application in soil were regulated only recently, by a statewide technical norm decreed in São Paulo State [6]. This regulation only forecast the impacts caused by vinasse on soil, water, and groundwater, prescribing vinasse application according to its potassium content but neglecting organic matter content and atmospheric impacts due to air emissions. Additionally, in some sugarcane processing plants, vinasse application in soil is carried out in a rather indiscriminate manner, intensifying the environmental impacts associated with this action, e.g., soil salinization [7], leaching of metals and sulphate [8–10], and groundwater contamination [11–14]. The release of malodours and attraction of insects are also commonly associated to this practice.

The situation is more complex in the case of the other liquid streams (second-generation vinasse and pentoses liquor), for which there are no environmental regulations thus far. This lack of regulation is understandable because the second-generation ethanol production process is still in a research phase; however, the destination of the wastewater generated in this process must be planned. Additionally, the composition of these liquid streams

prevents them from being used as fertilizers in sugarcane crops because their nutrient content (nitrogen, phosphorous, and potassium) is very low, unlike the vinasse from first-generation ethanol production. Thus, apart from its associated environmental impacts, fertirrigation is not suitable in this case, and an alternative disposal method of such liquid wastes must be pursued.

In this context, and considering the current available technologies for wastewater treatment, anaerobic digestion stands out as an interesting alternative to be applied to the liquid wastes of sugarcane biorefineries. Anaerobic digestion can reap environmental and energy advantages. From an environmental perspective, such technology reduces the organic matter content of those wastes while maintaining the inorganic nutrient content, which is particularly important in the case of vinasse generated in first-generation ethanol production. In this manner, the biodigested vinasse can still be used as fertilizer in the sugarcane crop while having a lower pollutant load. In the case of pentoses liquor and vinasse from second-generation ethanol production, a decrease of their pollutant load would facilitate their final disposal. Regarding energy aspects, the biogas generated from the anaerobic process would be an attractive alternative energy source due to the high heat of combustion of the methane present in the biogas. Although these advantages of applying the anaerobic digestion process to the liquid wastes of sugarcane biorefineries are well known, several challenges and obstacles remain for its full implementation, mainly associated to the insufficient understanding of the bioprocess applied to that specific wastes, the lack of appropriate legislation on fertirrigation practice as well as the non appreciation of biogas as an alternative fuel in Brazil. Thus, to overcome those barriers, the combined efforts from the government, scientific community and environmental agencies are indispensable.

This paper presents an overview of the actual stage of development of sugarcane ethanol production in Brazil as well as the main trends in this field, with a focus on the destination of the principal liquid waste, vinasse. This paper also identifies the barriers for the full application of anaerobic digestion in the treatment and use of effluents from sugarcane biorefineries and provides potential directions for overcoming these challenges. Based on the indicated paths, future prospects are outlined to highlight the importance and advantages of the application of this biotechnology in the biorefinery context.

2. Sugarcane biorefinery concept: Current status and trends

2.1. First-generation ethanol production

In Brazil, the technology applied to first-generation ethanol production from sugarcane is already consolidated, considering its experience of almost four decades in the development and production of this biofuel. Nevertheless, there are still many opportunities for investment in research, development, and innovation to enhance the production of first-generation ethanol from sugarcane, increasing the financial return and productivity of the overall conversion process [3,4,15,16].

First-generation ethanol is produced from sugarcane juice or molasses (or a mixture thereof) depending on the processing plant: in autonomous distilleries, ethanol is produced from sugarcane juice, whereas in annexed plants, a fraction of the sugarcane juice is diverted for sugar production, and the remaining fraction along with the molasses is used for ethanol production. According to CONAB [17], 63.5% and 30.5% of the sugarcane processing units in Brazil are annexed and autonomous plants, respectively, and the remaining units produce only sugar. The prevalence of annexed plants in the country is related to its flexibility to produce more ethanol or more sugar depending on the market demands, which

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