Obtaining Ethylene from Second Generation Ethanol (2GE) from Sugarcane

Gabriel Moreira[1*], Matheus Quadros[2], Járcia Melo[3], Natanael Batista[4], Sayonara Santos[5], Wadson Brabosa[6] Willian de Santana[7]
[12457]SENAI CIMATEC, Petrochemical technician, Salvador, Bahia, Brazil
[3]SENAI CIMATEC, Methodological guidance, Salvador, Bahia, Brazil
[6]SENAI CIMATEC, Technical guidance, Salvador, Bahia, Brazil
[*]Corresponding author: SENAI CIMATEC, gabriel.pacheco@ba.estudante.senai.br

This study analyzes the technical and economic feasibility of ethylene production from second-generation ethanol (2GE) derived from sugarcane bagasse, considering ecological aspects such as CO_2 emissions and alternative sources to fossil raw materials, in addition to comparing it with conventional petrochemical routes. Through a systematic literature review, the processes for transforming sugarcane bagasse into second-generation ethanol (2GE)—which involve the steps of physical and chemical pretreatment, followed by enzymatic hydrolysis and fermentation—and its conversion to ethylene, through the substeps of catalytic dehydration, caustic washing, and purification, were examined.These two parts were evaluated and compared with the cracking of the main fossil raw materials used in petrochemical industries, such as naphtha, natural gas, and ethane. The results demonstrate that the second-generation ethanol (2GE) route consumes approximately 13% of the energy used in fossil-fuel vapor cracking processes (2–5 GJ/ton of ethylene) and sequesters approximately 3 tons of CO_2eq/ton of ethylene, contributing to the carbon neutrality of the process and significantly reducing its carbon footprint—although it currently has a relatively high cost (R$3,200/ton) due to being a relatively recent production process compared to the routes used in the previous comparisons.Future projections indicate a 25–50% cost reduction by 2030, facilitating the development of the cellulosic ethanol market and making the presented route a viable alternative, enabling its adoption on an industrial scale. The conclusion reached is that, despite the challenges of scale, "cellulosic ethylene" constitutes a viable and sustainable alternative for the first-generation petrochemical industry, aligning with green values, contributing to a better energy transition, and promoting a sustainable future.

Keywords: Sugarcane. Ethylene. 2GE, second generation ethanol. Conversion

1.INTRODUCTION

Petroleum plays a fundamental role as a global and industrial energy matrix, being one of the main raw materials for various resources on which society depends. This dependence demands high demand, which consequently harms the environment due to the non-renewable nature of oil and its derivatives.

Thus, ethylene is conventionally obtained from ethane, which is derived from naphtha, one of the main direct derivatives of petroleum. Despite being the main raw material in ethylene production, naphtha is still a fossil resource and, to a certain extent, polluting and harmful to the environment.

Concurrently, the desire for a favorable and cleaner future creates a great need for the creation and adaptation of green methods, which includes the replacement of fossil resources such as naphtha. For the production of thermoplastic resins, such as polyethylene (PE), polypropylene (PP), and polyvinyl chloride (PVC), ethylene (ethene) is the main input.

However, the biggest problem lies in the fact that it is obtained from a fossil source, naphtha in this case. Therefore, one of the alternative routes to obtain ethylene is through the dehydration of cellulosic ethanol, representing an alternative to naphtha and reusing a raw material that is generally used as combustion fuel: sugarcane bagasse.

This possibility is due to Brazil's global position as one of the world's largest agricultural powers, with agribusiness as one of its main economic activities, with an enormous production capacity for biomass, such as sugarcane itself, which is subsequently transformed by the sugar and ethanol industry, generating both first- and second-generation ethanol.

Given this context, some questions arise: How is second-generation ethanol produced? How does the process of converting ethanol to ethylene work? Is this route to ethylene production viable?

Therefore, the current work aims to present the process of converting second-generation ethanol (2GE) from sugarcane bagasse into ethylene, aiming to assist in the petrochemical industry's energy transition.

To this end, the following specific objectives will be addressed: to demonstrate the steps involved in producing cellulosic ethanol from sugarcane bagasse, to demonstrate the cellulosic ethanol dehydration process, to compare the production of fossil ethylene with that of ethylene from second-generation ethanol (2GE), and to analyze its technical and economic feasibility.

2.THEORETICAL BASIS

This work presents the contributions of theorists in the areas of second-generation ethanol production from sugarcane and the production of ethylene through various methods, including ethanol conversion.

The main authors cited are Melo (2020), Balat (2011), and Menezes (2021). Thus, through the synthesis of information acquired from these sources, it is demonstrated how the conversion of second-generation ethanol (2GE) to ethanol becomes possible.

According to Melo and Balat, lignocellulosic materials are those composed primarily of cellulose, hemicellulose, and lignin. From this, the sub-steps for understanding the second-generation ethanol production process from lignocellulose present several stages, such as pretreatment, which consists of drying to remove as much water from the biomass as possible.

The biomass then undergoes several grinding steps to increase surface area, standardize particle size, and improve the efficiency of subsequent steps.

Next, in the hydrolysis stage, which occurs due to enzymatic action in an aqueous medium, the cellulose and hemicellulose molecules are converted into glucose, which then proceeds to the fermentation stage, generating second-generation ethanol. Due to its high caloric potential, the remaining lignin is generally used as fuel for energy generation or sold.

Concurrently, according to Menezes's work, the conversion of ethanol to ethylene can occur in several ways, the most common being through dehydration and subsequent caustic treatment. As shown in Figure 3, ethanol initially undergoes two stages.

The first is the conversion of hydrated ethanol into ethylene, which also generates oxygenated compounds and light and heavy hydrocarbons. After this, the stream undergoes a caustic treatment, which acts as a "wash," removing the oxygenated compounds. Finally, the ethylene is purified, separating it from other hydrocarbon fractions, as figure 1 shows.

The scheme shown in the figure 2 demonstrates more clearly the main reaction of the process of converting ethanol into ethene, which basically consists of removing the hydroxyl from ethanol, thus generating ethene and water.

If, during the conversion process, ethylene comes into contact with water, the reaction described above follows in reverse, generating ethanol. Therefore, due to this factor, water removal plays a fundamental role.

Figure 1. Ethanol to Ethylene Conversion Scheme.

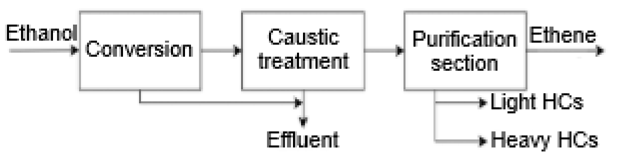
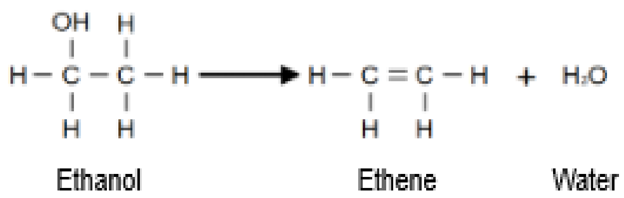


Figure 2. Representation of the ethanol dehydration reaction.



3.METHODOLOGY

This study involved a literature review using a qualitative methodology with an exploratory approach according to Lakatos and Marconi (2003), it was conducted between February 2025 and May 2025, utilising scientific libraries such as SciELO and Google Scholar, following four keywords for selection criteria: Ethanol, Sugarcane, 2GE and ethylene.

Yielding a total of 19 results which received a critical analysis on its contents, these were then grouped into the following main subtopics: chemistry and industrial processes (35%), which primarily addressed second-generation ethanol (2GE) production and the conversion of ethanol to ethylene; and agricultural sciences (25%), which evaluated energy efficiency and sugarcane harvesting.

The economic feasibility of the process was also analyzed, accounting for 25% of the research, to compare the costs involved between conventional and bagasse-based production.

Finally, the remaining 15% was an analysis based on environmental sciences to understand the environmental benefits and harms of this method compared to conventional ethylene production.

4.RESULTS AND DISCUSSION

Sugarcane bagasse, despite being a residue of the sugar, ethanol, food, and other industries, can be reused, primarily as fuel in boilers or as fertilizer. Furthermore, bagasse can be used in the production of second-generation ethanol.

According to Montes (2017), second-generation ethanol was produced to increase its production efficiency per cultivated hectare. Furthermore, cellulosic ethanol constitutes a sustainable alternative compared to other fuels.

The figure 3 exposes all the productive process of 2GE. Starting with bagasse undergoing a physical pretreatment stage, beginning with the drying process, which reduces water activity in the cells, thus preventing premature degradation and oxidation of the material.

Next, grinding is performed to break down the crystalline structure of the lignocellulose, reducing particle size and increasing the contact area. Finally, the final stage of pretreatment is chemical treatment, where the hemicellulose is solubilized in an acidic medium, which will later contribute to the digestion of the cellulose.

After pretreatment, enzymatic hydrolysis is performed, which, through favorable pH and temperatures, breaks down the cellulose. The entire supernatant content is separated and sent for fermentation, where fungi and bacteria produce starchy ethanol.

As shown in figure 4, fermentation occurs in two main reactions. The first involves the breakdown of the glucose molecule in a medium containing pyruvic acid, where decarboxylation occurs through a catalytic enzyme. In the second reaction, the enzyme alcohol dehydrogenase reduces acetaldehyde into ethanol.

With 2GE production complete, the next proposed step is to convert ethanol into ethene. To achieve this, ethanol undergoes catalytic dehydration, an endothermic process that removes the hydroxyl group from ethanol. This process is divided into three main stages: conversion of ethanol to ethene, caustic treatment, and ethene purification.

The exposed flowchart on the figure 5 illustrates the process components involved in converting hydrated ethanol to ethylene and subsequent caustic treatment.

Beginning with the conversion stage, the process occurs in the gas phase in a series of fixed-bed or fluidized reactors, in which the hydrated ethanol is pre-vaporized and introduced at an initial temperature of approximately 300°C into a catalytic environment. These conditions ensure complete vaporization of the ethanol and improve its contact efficiency with the catalyst surface.

The load then passes through a quench tower, which reduces the formation of heavier hydrocarbons that may form, condenses any water present, and sends the overhead stream to caustic treatment.

This step consists of a “wash” with an aqueous solution of caustic soda (NaOH) or caustic potash (KOH), removing impurities such as: organic acids, sulfur or chlorinated compounds that may be present in the ethanol and water that has not been removed in the quench tower.

After caustic washing, the stream, now composed of ethylene and heavier hydrocarbons, passes through dryers to remove any remaining water, as figure 6 shows.

The stream is then directed to the separation process, carried out through a distillation tower. The bottom stream contains heavy hydrocarbons, which are used as fuel, and the top stream contains ethylene and light hydrocarbons.

These hydrocarbons pass through a series of heat exchangers and are sent to a cooling section, which condenses the ethylene. The stream then passes through the rectifier tower, vaporizing the remaining light hydrocarbons and transporting the purified and ready-to-use ethylene to its intended destination.

Finally, the methods for obtaining ethylene must be compared. Considering naphtha as the raw material for the common process, the energy and raw material costs are approximately R$13,275 per ton of ethylene, which ends up being much more expensive than production from sugarcane bagasse, which has an average cost of R$3,300 per ton of ethylene.

With this, the FAPESP Agency (2017) concluded that by 2030, second-generation ethanol could reach R$0.50/L, being cheaper than regular ethanol, thus increasing its demand, which will not be a problem since sugarcane bagasse is generated in excess.

In addition, second-generation ethanol (2GE) brings the benefit of reducing atmospheric emissions, which consequently generates carbon credits for companies that follow this method, due to the absorption of CO2 by sugarcane during planting.

Figure 3. 2GE production process flowchart

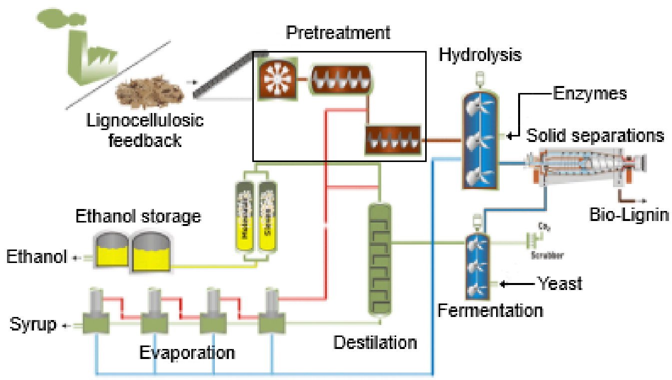


Figure 4. Representation of fermentation

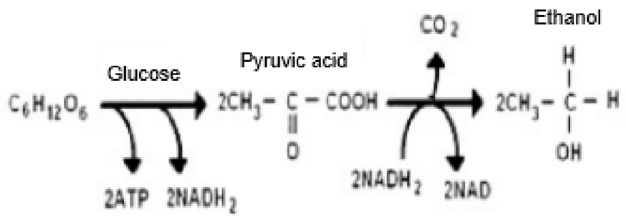


Figure 5. Ethanol Dehydration Flowchart

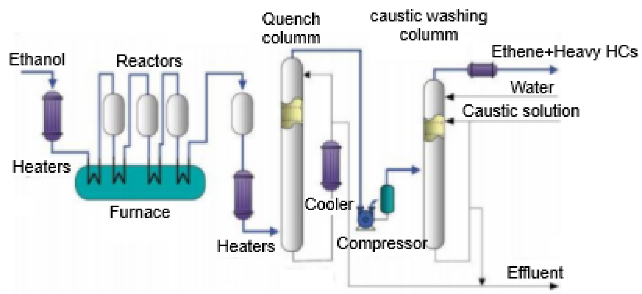
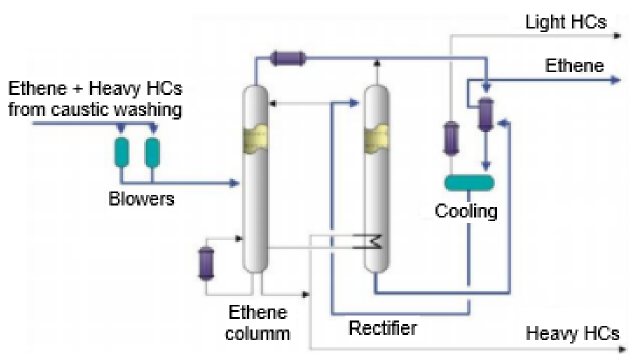


Figure 6. Ethylene purification section



5.CONCLUSION

This study explored the feasibility of using second-generation ethanol (2GE) derived from sugarcane as a raw material for ethylene production through catalytic dehydration. The objectives were met, the main one being to study the feasibility of obtaining ethylene from cellulosic ethanol derived from sugarcane bagasse. Furthermore, specific objectives were also met throughout the study.

In this context, it was demonstrated that ethylene production from second-generation ethanol (2GE) derived from sugarcane bagasse offers significant advantages over conventional petrochemical methods, both from an environmental and technical perspective.

The comparative analysis showed that the 2GE-based process consumes 30% less energy (2–3 GJ/ton) and sequesters 3.09 tons of CO_2 equivalent per ton of ethylene produced, constituting an alternative aligned with the principles of the circular economy and energy transition.

Despite the current high cost (R$3,200/ton of ethylene), projections indicate reductions of 25–40% by 2030, driven by technological advancements and increased production scale.

Additionally, the use of bagasse—a low-cost residue (R$25–400/ton)—adds value to the sugarcane chain, in addition to resulting in higher yields per hectare of sugarcane planted by utilizing bagasse in its production, reducing dependence on fossil fuels. Challenges such as the need for logistical adaptations and infrastructure investments were identified, especially considering that the technology is not fully established. However, the long-term benefits justify overcoming them. The second-generation ethanol (2GE) route not only meets industrial demands but also contributes to achieving environmental goals, such as carbon neutrality.

In summary, cellulosic ethylene represents a viable and sustainable solution for the petrochemical industry, combining operational efficiency, emissions reduction, and scalability potential.

Therefore, given the relevance of the data described above, it can be stated that they represent a significant contribution to research related to replacing the use of fossil fuels with the adoption of renewable and sustainable raw materials, highlighting an alternative form of ethylene production. Thus, having an alternative to fossil fuels shapes the vision of a more efficient and sustainable future.

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