First-Generation (1G) and Second-Generation (2G) Ethanol: Differences and Importance for the Petrochemical Industry

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This paper investigated the differences between first-generation ethanol (E1G) and second-generation ethanol (E2G) in the context of the search for more sustainable energy alternatives in light of the depletion of fossil fuels. The research focused on a comparative analysis of production processes, environmental impacts, and petrochemical applications of both types of ethanol. The central question was: Is second-generation ethanol truly a more sustainable and strategic alternative for the petrochemical industry compared to first-generation ethanol? The hypothesis considered was that E2G represents a more efficient solution by using agricultural waste and reducing emissions. The objective was to assess the strategic potential of E2G in light of environmental challenges and E1G limitations. A qualitative, exploratory, and bibliographic research approach was adopted, using academic and institutional publications indexed between 2016 and 2025, available in databases such as SciELO, CAPES, and EPE. The data, analyzed through the theoretical framework of sustainability and energy transition, indicated that E2G contributes to the circular economy and has a lower environmental impact. It was concluded that, despite technical and economic challenges, second-generation ethanol offers significant sustainable advantages and can strategically complement E1G and strengthen the Brazilian energy matrix.

Keywords: E1G. E2G. Sustainability. Petrochemical industry. Biofuels.

In recent decades, the world has witnessed significant changes in how energy is consumed and produced. Growing concern for the environment, the progressive depletion of fossil fuels, and the social and economic impacts of climate change have highlighted the urgency for more sustainable energy alternatives.

Biofuels, especially ethanol, have stood out as sustainable alternatives to fossil fuels. It is within this context that interest has arisen in deepening the understanding of the role of biofuels, particularly ethanol, in the Brazilian and global energy transition. This article also aims to assess how E2G could impact the production chain of sustainable materials in the petrochemical industry, such as bioplastics and other eco-friendly petrochemical derivatives, which are expected to play an increasingly important role in economies with stricter environmental policies.

The central question that guides this research is: What are the main differences between first- and second-generation ethanol, and what are their contributions and limitations when applied as inputs in the petrochemical industry? The hypothesis guiding this investigation is that second-generation ethanol represents a more strategic and sustainable alternative, both environmentally and industrially.

THEORETICAL BACKGROUND

This article is based on bibliographic research, bringing contributions from renowned

scholars in the field of E1G and E2G production from sugarcane biomass residues. The studies analyzed discuss the effectiveness of the transesterification process of vegetable oils for biodiesel production, highlighting not only its energy efficiency but also its role in glycerin purification using alternative techniques that promote sustainability in the sector.

Souza and Lima (2019) mention that Brazil, favored by ideal climate conditions and extensive agricultural production, has established itself as a global leader in the production of first-generation ethanol (E1G), derived from sugarcane juice fermentation. On the other hand, second-generation ethanol (E2G), also known as cellulosic or green ethanol, is produced from agricultural and forest residues such as sugarcane bagasse and straw.

Thus, Brazil shows significant advantages in producing both E1G and E2G, mainly due to its status as the world's largest producer of sugarcane, a highly productive raw material available at low cost and on a large scale.

According to Brito and Pereira (2021), the concept of a circular economy has gained relevance in the biofuels debate. They argue that "the implementation of processes that maximize the use of waste is one of the main strategies to reduce pressure on natural resources and promote sustainability in the energy sector."

Between 2011 and 2015, the ethanol market in Brazil saw significant growth, with production increasing from 22.7 million m^3 to approximately 28.9 million m^3, driven by the expansion of flex-fuel vehicles, the greater share of renewable sources in the national energy matrix, and the competitiveness of sugarcane ethanol (SENNA, 2019).

METHODOLOGY

This article was developed through qualitative, exploratory research, based on a critical bibliographic review of scientific publications in Portuguese, published between 2016 and 2025. The purpose of this methodology was to understand, compare, and discuss the main characteristics, advantages, and challenges of first-generation ethanol (E1G) and second-generation ethanol (E2G), especially in the context of the petrochemical industry.

Works by authors who thoroughly explore biofuels and their industrial applications were selected. The main sources used included databases such as Google Scholar, SciELO (Scientific Electronic Library Online), the CAPES Portal of Journals, and the Brazilian Energy Research Company (EPE), based on the

most recent publications available up to 2025. Inclusion criteria considered publication currency, topic relevance, academic rigor, and a focus on the Brazilian context. Duplicate texts, non-scientific sources, or those that did not address direct comparisons between E1G and E2G were excluded from the analysis.

The analysis was conducted through reflective reading and categorization of content into the following areas: physicochemical and production characteristics of E1G and E2G, their industrial applications, environmental aspects, and the advantages and disadvantages compared to fossil fuels. This approach made it possible to observe both technological advances in the biofuels sector and the ongoing challenges for second-generation ethanol to become a viable and sustainable large-scale alternative.

This enabled a critical assessment of the hypothesis proposed in the introduction, based on various databases such as SciELO, CAPES, EPE, and Google Scholar, and publications consulted up to the year 2025.

RESULTS AND DISCUSSION

To understand the technological and innovation intensity of Second-Generation Ethanol (2G) compared to First-Generation Ethanol (1G), it is important to examine the 1G production cycle, which constitutes one of the processes for obtaining ethanol (anhydrous and hydrated). The process begins with the Agricultural Phase, which includes the planting, cultivation, and harvesting of sugarcane, used as feedstock for the subsequent production stages.

Currently, there are two ways to harvest sugarcane—mechanically or manually—which, along with the presence or absence of the practice of burning sugarcane in the field, are the main factors determining the level of impurities in the plant material. Upon arrival at the plant, sugarcane can be classified according to the percentage of impurities present in the plant material, with “clean cane” (impurity concentration < 0.6%) considered the most suitable for ethanol production due to its low impurity content (ALBARELLI, 2013; REIN, 2007).

When the cane arrives at the plant, the First-Generation Industrial Phase begins, with the initial steps consisting of cleaning, extraction, and physical treatment of the sugarcane. Its average composition is as follows: water (70%–76% of cane mass), fibers (11%–16%), and other

solids (10%–16%). This variation is due to the type of cultivation used during the Agricultural Phase (mechanical or manual harvesting, burning practices, climatic conditions, and cane variety) (ALBARELLI, 2013; COSTA, 2014).

After cleaning—which can be performed dry or with water—the sugarcane is chopped and sent to the milling stage, where the juice is extracted for use in sugar and ethanol production.

In addition to process efficiency and low cost, first-generation ethanol production has the advantage of using a mature technology well-established in Brazil's sugar-energy sector, which increases the biofuel's competitiveness in both domestic and international markets (CARPIO, 2021). In contrast, second-generation ethanol (2G) represents a significant technological breakthrough for the energy sector.

The choice of sugarcane as raw material is strategic due to the abundance of farmland, favorable climatic conditions, and consolidated technical expertise in its cultivation and processing. An important point in this process is the use of sugarcane bagasse—a by-product generated after juice extraction—which is used as an energy source in the plants themselves, fueling boilers and generators. This creates a sustainable and economically viable production cycle, reducing operational costs and resource waste (ZART et al., 2020).

As highlighted by Ruiz (2020), 2G ethanol is produced from sugarcane lignocellulosic residues such as bagasse, straw, and leaves, which were previously underused or discarded. The process involves more sophisticated technologies and additional steps compared to 1G ethanol. Initially, the lignocellulosic biomass undergoes a pretreatment stage, which is crucial for breaking the rigid structure of the cell wall, exposing cellulose and hemicellulose polymers for the subsequent steps.

FINAL CONSIDERATIONS

Given the growing demand for renewable energy sources and the urgent need to reduce the environmental impacts caused by the excessive use of fossil fuels, ethanol stands out as a relevant alternative from both energy and industrial perspectives. The critical analysis of the characteristics, advantages, and limitations of first-generation (1G) and second-generation (2G) ethanol reveals distinct yet complementary paths for diversifying the energy matrix and strengthening a more sustainable petrochemical industry.

First-generation ethanol remains an easy-to-produce fuel, with well-established

technologies and competitive costs. However, its dependence on food-based raw materials and large cultivated areas raises concerns about its long-term sustainability.

In contrast, second-generation ethanol, which uses agricultural and forestry residues, represents a significant advance by increasing energy productivity without requiring the expansion of agricultural land. Although 2G production processes are more complex and demand greater technological investment, their environmental and industrial potential is promising.

Based on the hypothesis that second-generation ethanol may represent a more sustainable alternative to environmental challenges and fossil resource scarcity, the results discussed here indicate that its large-scale adoption will depend directly on research incentives, technological innovation, and public policies that enable its competitiveness against already-established biofuels. Such innovation investments should be accompanied by policy reforms encouraging the use of residues as a primary energy source.

The petrochemical industry, by incorporating renewable inputs such as ethanol—whether first or second generation—significantly contributes to the energy transition and the development of less polluting solutions, reaffirming the sector's role in building a more sustainable future.

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