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SECOND GENERATION ETHANOL (E2G) AS AN ALTERNATIVE FOR PRODUCING FUEL DERIVED FROM SUGAR CANE: A BIBLIOGRAPHICAL REVIEW BETWEEN 2011 AND 2023

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Abstract: The cultivation of sugar cane is of great importance for the country, being one of the main commodities produced in Brazil, with a fundamental role in generating jobs, the trade balance and regional development. The sustainable potential of products originating from sugar cane is highly recognized and specifically one of these by-products has been highlighted in recent years, the so-called second-generation ethanol (E2G). Therefore, the general objective of this work is to analyze the academic bibliographical production regarding second generation ethanol (E2G) between the years 2011 and 2023. 26 articles were found, 21 in Portuguese and 5 in English, which speak directly on second generation ethanol and its production aspects. It was possible to ascertain that the country has potential for E2G production, mainly due to its already outstanding production, being a world leader in this regard. Furthermore, the possibility of increasing ethanol production without increasing the sugarcane planted area is a great attraction for agents in the production chain. However, there are obstacles to be overcome in order to establish the country as a large-scale producer of E2G, especially with regard to steps such as pre-processing of the raw material.
Keywords: Second generation ethanol; Sugar cane; Cellulosic ethanol.

INTRODUCTION

Brazil is one of the largest food producers and exporters in the world, placing the agribusiness sector as one of the main drivers of the country's economic growth in recent decades, so that it plays a prominent role in the country's economy, being responsible for a percentage significant increase in exports and food supply both internally and externally. In Brazil's agribusiness, some products such as soybeans, corn, beef, pork, chicken meat, sugar, cotton stand out, products that contribute to the positive balance of the country's trade balance (QUINTAM and ASSUNÇÃO, 2023).

More specifically, the sugarcane production chain has become important for agribusiness due to the record production and export of sugar, in addition to its contribution to the combustion of automobiles via ethanol and the generation of energy through burning of bagasse. Brazil is the largest producer and exporter of sugar in the world, with a representation of more than 30% and foreign exchange revenue of more than 8.7 billion dollars in 2020 (EMBRAPA, 2022).

Given the context presented regarding sugar cane, ethanol and E2G, the importance of searching for sustainable solutions for fuel production, moving away from dependence on fossil fuels as much as possible, thus contributing to the reduction of emissions of GHG, in addition to the scenario presented that shows Brazil as the largest producer of sugar cane in the world, the questions that guide this work arise: how research on E2G has been carried out in Brazil between the years 2011 and 2023 ? What are the objectives and final considerations of the selected articles? What are the points of convergence or divergence between research on the topic in question? What are the processes carried out to obtain second generation ethanol?

Given the questions presented, the general objective of this article is to analyze the academic bibliographical production regarding second generation ethanol (E2G) between the years 2011 and 2023. Specifically, it is intended to characterize the processes for obtaining second generation ethanol (E2G); Highlight the objectives of the selected articles, as well as their final considerations; Establish the points of convergence or divergence between the selected articles and verify the main bottlenecks in the production of second-generation ethanol.

SUGAR CANE CULTURE IN BRAZIL

Sugar cane was first described by Linneu, in 1753, calling it *Saccharum*. As it is a plant with a tropical climate, its geographic distribution range is between latitudes 35º North and 35º South, with Brazil being the largest producer, followed by India and China (RODRIGUES and ROSS, 2020).

The creation of the Sugar and Alcohol Institute (IAA) in 1933 was also an important milestone for the sugarcane production chain. The IAA was responsible for regulating and promoting the production, transport and trade of sugar cane and alcohol, suggesting to the Union and state governments all the measures that depended on them and were necessary, including production quotas, taxes and fees, fixing the purchase and sale price for the industry and the consumer (DIBRARQ, 2023).

Garofalo et al. (2020) point out that the development of fuel ethanol resulted from the oil crisis in the 1970s, in which countries dependent on oil exports needed to seek alternative energy sources, culminating in the creation of the National Alcohol Program (Proálcool) in 1975, promoting the expansion of sugar cane cultivation.

Proálcool was a large-scale replacement program for petroleum derivatives. Between 1975 and 2000, around 5.6 million vehicles powered by hydrated ethanol were produced in Brazil. Furthermore, Proálcool was responsible for replacing the volume of pure gasoline consumed by a fleet of more than 10 million vehicles with the addition of a percentage of anhydrous ethanol, avoiding carbon dioxide emissions of around 110 million tons (PISSINATO, 2014).

Within this period, three major crises in the sugar-energy sector were observed. The first with the failure of the 1986/87 harvest in the Center-South, due to the lack of rain, causing losses in ethanol production, together with the withdrawal of Proálcool stimuli.

The subsequent crises, between 2004 and 2008, and between 2015 and 2017, presented declines in production, linked to elements such as dependence on state action regarding gasoline price policy; low competitiveness of the price of ethanol in relation to gasoline; unpredictability of climate and bad weather and seasonality of production (GAROFALO et al., 2020).

The sugarcane harvest in the Center-South region ended 2022 on a high, with 541.57 million tons of raw material processed, an increase of 3.63% compared to the end of 2021 (TAGUCHI, 2023).

Figure 1 presents a comparison of production in thousand tons of sugar cane between the UFs of Brazil belonging to the Southeast, Center-West and Northeast regions.

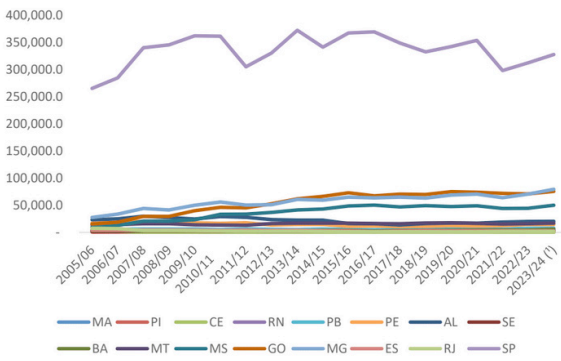

Figure 1: Production in one thousand hectares in states belonging to the South, Southeast and Central-West regions

Source: Conab (2023)

FIRST GENERATION (E1G) AND SECOND GENERATION (E2G) ETHANOL IN BRAZIL

Ethanol or ethyl alcohol is obtained by fermentation of sugar or synthesis in the laboratory. The common ethanol sold at gas stations is called hydrated ethyl alcohol, a mixture of approximately 96% ethanol and

water. Ethanol that is mixed with gasoline is called anhydrous ethanol, a type of ethanol that has at least 99.6% pure ethanol (MONTEIRO, ROSA and REIS, 2016).

The difference between anhydrous and hydrated ethanol is the fact that anhydrous ethanol is characterized by a minimum alcohol content of 99.3%, composed only of ethanol or ethyl alcohol. The hydrate is a hydroalcoholic mixture with a minimum alcohol content of 92.6% composed of ethyl alcohol or ethanol. It is used in the pharmaceutical, alcohol-chemical and beverage industries, vehicle fuel and cleaning products (NOVA CANA, 2017). Figure 3 illustrates the technological route for ethanol production.

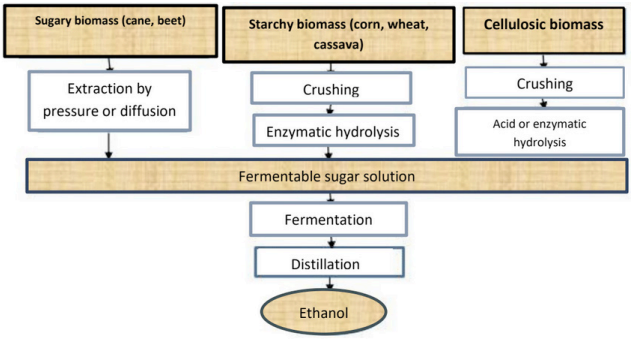

Figure 3 - Technological route for the production of ethanol from various raw materials.

Source: Marinho et al. (2020)

It is worth noting that the production of first-generation ethanol presents bagasse and sugar cane straw as waste, which can be used to generate electricity by burning waste. However, this waste can also be sent to the production of E2G, where the biomass undergoes pre-treatment (liquid or solid). It is important to emphasize that E1G and E2G only differ in the production process, as their chemical composition is the same (COSTA, 2014).

One of the main differences between conventional ethanol and E2G is the raw material. Instead of using sugarcane juice, made up of fermentable sugars, second generation ethanol technology allows the processing of sugarcane bagasse and straw, which are biomasses classified as lignocellulosic.

Brazil has competitive advantages in relation to other countries in terms of E2G production, due to its lower cost and easy availability of large quantities of raw material, even more so due to the possibility of using bagasse and sugarcane straw. de-sugar in these processes. This technology can be incorporated into the existing structure of production units, thus reducing installation and operation costs (PACHECO, 2011).

Currently, Brazil produces 25 billion liters of ethanol per year from sugar cane. Thinking about sustainability and reducing the exploitation of finite sources, biomass, which is also known as lignocellulosic material, is an excellent alternative as it is a material rich in carbon. Biomass, in general, is formed by hemicellulose (20-35%), lignin (10-25%) and cellulose (35-50%), which are sources of bioenergy. First generation biofuels are produced from saccharine and starchy raw materials, which are also used for human consumption. On the other hand, second generation waste is produced from industrial waste, agricultural waste and even urban waste produced in abundance (MORAIS et al., 2017).

It is worth highlighting the fact that two thirds of sugarcane are made up of lignocellulosic material, indicating great energy potential. Lignocellulosic material is made up of three types of polymers: cellulose, hemiocelluloses and lignin, which are in association by hydrogen bonds or covalent chemical bonds. There are several technological routes researched for the production of ethanol from lignocellulosic material. One of them consists primarily of a pre-treatment, which separates the hemiocellulose, the best pre-treatment being

the one that does not destroy the cellulose and lignin (PACHECO, 2011).

The main stages of E2G production consist of the pre-treatment of the lignocellulosic material, in which the component is prepared to be used as raw material for the enzymatic hydrolysis stage, which converts the biomass into available sugars. This conversion of pretreated lignocellulosic waste requires the synergistic action of several enzymes for the hydrolysis of cellulose and hemicellulose (ELEVAGRO, 2022).

Despite many advantages, E2G production is still approximately 30% more expensive than first generation production, due to the need to use many enzymes to degrade the sugars present in straw and bagasse. Although the price of enzymes has fallen by 78% in recent years, this portion represents the highest cost in production. However, it is important to highlight the strategic aspect of cellulosic ethanol and its ability to mitigate the impact that is being caused by the use of fossil fuels (DOS REIS, 2017).

Still in relation to first and second generation ethanol, it is worth highlighting that there may be an integration between the production processes of both, in such a way that in Brazil the great difference in making second generation ethanol technology viable compared to other countries is, in addition to biomass at reduced costs, the fact of being able to integrate the new technology into an existing industrial park, resulting in a reduction in investments in equipment and also in the shared use of inputs. The first point of integration of the processes is the use of the sugar stream from the second-generation technology to dilute the molasses from the first-generation technology, with the resulting juice sent for fermentation. The second point of integration is related to the energy balance of both technologies. During biomass processing, lignin, which is one of its main components, is separated in solid form after the enzymatic hydrolysis step together with unconverted cellulose. This final material, called cellulignin, returns to burning in the boilers and allows the generation of more energy, so that the first- and second-generation processes are self-sufficient in energy (TOMÉ, 2014).

There is a tendency that in 2025, the production cost of cellulosic ethanol will be equal to that of the first generation and from 2030 onwards, second generation ethanol will be cheaper than the first, depending on the overcoming of agricultural, industrial and technological. The production cost of second-generation ethanol in 2014 was around R$1.50 per liter, while the production cost of first-generation ethanol was around R$1.15 per liter. Projections for 2025 show that the production cost of E2G could fall to R$0.75 per liter, reaching R$0.52 per liter in 2030 (AGENCY: FAPESP, 2017).

METHODOLOGY

In order to achieve the proposed objective of analyzing the academic bibliographical production regarding second generation ethanol (E2G) between the years 2011 and 2023, exploratory and descriptive research was used. Fernandes and Gomes (2003) highlight that exploratory research aims to provide greater familiarity with a given topic, whose main objective is to describe, analyze or verify the relationships between facts and phenomena. Furthermore, data collection is one of the instruments that enable the researcher to accurately describe the characteristics of a population or phenomenon.

Lima and Mioto (2007) and Sousa, Oliveira and Alves (2021) highlight that it is a methodological procedure that is offered to the researcher as a possibility in the search for solutions to their research problem.

Bibliographic research is mainly inserted in the academic environment, with the function of improving and updating knowledge, through scientific works already published.

Brito, Oliveira and Silva (2021) highlight that the sources of bibliographic research can be primary, secondary or tertiary. Primary ones are those that contain or disseminate original information or that present information already known. They present great technical and scientific production. They include books, periodicals and serial publications, event annals, technical reports, technical standards, theses, dissertations and patents.

In order to answer the guiding questions of this work and fulfill the objectives proposed previously, a search was carried out on the Google Scholar portal, publications in Portuguese and English, between 2011 and 2023, peer-reviewed, with the keywords "cane -sugar", "ethanol", "second generation", "E2G", "biofuel" and "sustainability". For articles in English, the keywords were added "*sugar cane*", "*second generation ethanol*" and "*bioethanol*" From the selected articles, an analysis of their content was carried out, by reading their title, summary, introduction, results and final considerations. Publications that are not directly talking about the so-called second-generation ethanol and its various aspects, which involve sustainability, production and use of second-generation ethanol, etc., were eliminated from the analysis.

Furthermore, only publications with free access were chosen, thus eliminating articles that presented some type of block for full access, which ended up happening with a considerable number of articles published in English.

By combining the terms highlighted previously, 26 articles were found, 21 in Portuguese and 5 in English, which discuss E2G and its aspects of production, research and development, production, environmental and economic aspects, among others. It is noteworthy that 2011 was the year chosen to delimit this research. According to Lorenzi and Andrade (2019), there has been a lot of discussion about E2G since 2011, when BNDES and the Studies and Projects Financier launched the BNDES – FINEP plan to support Innovation in the Sugar-Energy and Sugar-Chemical Sectors (Paiss) and some plants and research centers, such as GranBio, Raízen and Oderbrecht Agroindustrial, announced their research, development and commercial-scale production projects for the fuel, representing an important milestone for E2G in Brazil.

RESULTS AND DISCUSSIONS

INFORMATION ABOUT SELECTED ARTICLES

The selected articles that are somehow related to the central theme of this work (second generation ethanol) were grouped for analysis and their basic information is found in Table 2, such as title, authors, objectives, magazine in which it was published and year of publication of each of the articles selected for analysis.

Among the articles analyzed, the year 2017 stands out, presenting five of the selected articles, with 2019, with four articles and 2013, 2020 and 2023 being other notable years, with three publications in each of the years mentioned. It is also noteworthy that within the parameters used for analysis, no articles published in 2015 and 2016 were found. Figure 2 details the distribution by year of the selected articles.

Title	Authors	Year of publication	Magazine in which it was published	Objectives
Second generation ethanol in Brazil: can it compete with electricity production?	Dias, M.O.S.; Cunha, M.P.; Jesus, C.D.F.; Rocha, G.J.M.; Pradella, J.G.C.; Rossell, C.E.V.; Maciel Filho, R.; Bonomi, A.	2011	*Bioresource Technology*	Present a preliminary technical and economic analysis regarding the integrated production of first- and second-generation ethanol from sugar cane in Brazil based on the evaluation of different technological scenarios.
Potential of sugarcane straw for ethanol production.	Santos, F.A.; Queiróz, J.H.; Colodette, J.L.; Fernandes, S.A.; Guimarães, V.M.; Rezende, S.T.	2012	New Chemistry	Carry out a review on the recalcitrant structure of sugarcane straw and its potential use in the production of cellulosic ethanol.
Second generation ethanol: study of lignocellulosic materials and applications of lignin.	Alves, J.M.B.; Macri, R.C.V.	2013	Science & Technology	Study lignocellulosic materials and efficient techniques for removing and producing cellulosic ethanol.
Sugarcane and fuel alcohol: history, sustainability and energy security.	Carvalho, L.C.; Bueno, R.C.O.F.; Carvalho, M.M.; Favoreto, A.L.; Godoy, A.F.	2013	Biosphere Encyclopedia	Collect information about the main historical facts of sugarcane cultivation and fuel ethanol production in Brazil.
Agro-industrial waste: potential for second-generation ethanol production in Brazil.	Nunes, R.M.; Guarda, E.A.; Serra, J.C.V.; Martins, A.A.	2013	Liberato Magazine	Analyze the potential of agricultural residues, used in Brazil, as a source of biomass, for the production of second-generation ethanol.
Pre-treatments in second generation ethanol production.	De Rossi, E.; Lindino, C.A.; Santos, K.G.; Baricatti, R.A.; Cremonez, P.A.; Antoneli, J; Nadaleti, W.C.	2014	Environmental Monographs Magazine - REMOA	Report the main pre-treatments used to expose cellulose and hemicellulose to hydrolysis (saccharification).
Development of a technological route for the production of second-generation cellulosic ethanol from sugarcane bagasse	Patrocínio, A.B.; Siqueira, E.M.G.R.; Soares, S.	2014	Bioenergy in review: dialogues	Evaluate the acid pre-treatment of sugarcane bagasse with a 2^3 factorial design with parameters time, temperature and solid/liquid ratio (bagasse/acid).
Study of the enzymatic hydrolysis of sugar cane straw for the production of second-generation ethanol.	Lucarini, A.C.; Delquiaro, A.C.T.; Vidoca, L.C.P.T.; Braz, R.; Martins, R.M.; Alves, T.P.	2017	*The Journal of Engineering and Exact Sciences*	Study the enzymatic hydrolysis of sugarcane straw to obtain fermentable sugars.
Technological exploration of the use of sugarcane bagasse for the production of second-generation ethanol.	Lopes, J.G.; Santos, K.C.; Costa, A.A.	2017	Prospecting Notebooks	Carry out technological monitoring of the process of obtaining second generation ethanol, based on patent documents and scientific publications.
Environmental innovation systems in developing countries: a discussion based on the development of second-generation ethanol in Brazil.	Ansanelli, S.; Senna, P.P.; Campos, D.A.C.; Silva, G.R.	2017	Research & Debate Magazine	Discuss the creation of environmental innovation systems in developing countries, through a case study of the development of second-generation ethanol in Brazil.
2nd generation ethanol: current production and prospects.	Morais, P.P.; Pascoal, P.V.; Rocha, E.S.; Martins, E.C.A.	2017	Bioenergy in review: dialogues	Verify the potential for using second-generation bioethanol.
Innovation in Biorefineries I. Production of second-generation ethanol from Elephant Grass (Pennisetum purpureum) and sugarcane bagasse (Saccharum officinarum).	Grasel, F.S.; Stiehl, A.C.; Bernardi, L.P.; Herpich, T.L.; Behrens, M.C.; Andrade, J.B.; Schultz, J.; Mangrich, A.S.	2017	Virtual Chemistry Magazine	Subject elephant grass and sugarcane bagasse to acid hydrolysis (to produce glucose) under atmospheric pressure. The aim is to treat the biomass to separate the cellulose from other components of the plant biomass.

Review of second-generation bioethanol production from residual biomass	Robak, K.; Balcerek, M.	2018	*Food Technology and Biotechnology*	Provide an overview of second-generation bioethanol production.
Analysis of the influence of chemical and physical pre-treatment on the characterization of the cellulose and lignin fractions of different biomasses and their potential for second generation ethanol production.	Andrade, T.C.C.; Siqueira, L.N.; Souza, D.A.; Silva, F.V.; Guarda, P.M.; Guarda, E.A.	2018	Magazine on Agribusiness and Environment	Evaluate whether the application of physical and chemical pre-treatments is favorable for the enzymatic hydrolysis processes to generate fermentable sugars and the subsequent microbial fermentation process to obtain lignocellulosic ethanol.
Competition between second-generation ethanol and bioelectricity using residual biomass of sugarcane: effects of uncertainty on the production mix.	Carpio, L.G.T.; Souza, F.S.	2019	*Molecules*	Use the mean-variance methodology to determine the optimal allocation of residual sugarcane biomass between 2G ethanol and bioelectricity production, with the simultaneous objective of maximizing return and minimizing risk for investors in this sector.
Second generation ethanol in Brazil: policies and sociotechnical networks.	Lorenzi, B.R.; Andrade, T.H.N.	2019	Brazilian Journal of Social Sciences	Discuss the formation of the cellulosic ethanol (E2G) network in Brazil, identifying the main actors involved in its research, development and production.
Evaluation of yeast fermentation aiming at second generation ethanol production.	Silva, F.S.G.; Gomes, W.P.C.; Nascimento, D.D.	2019	Bioenergy in review: dialogues	Evaluate yeast fermentation in the presence of xylose, pentose present in 2G ethanol must.
Optimization of Pichia *membranifaciens fermentation* conditions for second generation ethanol production.	Ribeiro, N.N.; Freita, L.A.; Tralli, L.F.; Slva, A.F.; Freita, C.M.; Mendes, F.Q.; Teixeira, V.; Junior, C.N.S.; Mutton, M.J.R.	2019	New Chemistry	Define the best pH and temperature for *Pichia membranifaciens* LJ04 in synthetic musts with pentoses aiming for future use in hemicellulosic liquors.
Acid pre-treatment of sugarcane straw aiming at the production of second-generation ethanol.	Marinho, C.C.P.; Pereira, L.V.B.; Vasconcelos, S.M.; Carvalho-Gonçalves, L.C.T.	2020	Technology and Society Magazine	Carry out the optimization of the acid pre-treatment of sugarcane straw aiming at the production of second-generation ethanol.
Assessment of the collection of information on cellulose, hemicellulose and lignin contents in sugarcane bagasse biomass.	Borges, C.P.; Gigliolli, A.A.S.	2020	*Brazilian Journal of Development*	Carry out bibliographical research in specialized literature, to demonstrate the levels of cellulose, hemicellulose and lignin in sugarcane bagasse, creating subsidies to propose new studies to optimize the processes for obtaining ethanol (2G).
Chemical pre-treatment and characterization of sugarcane bagasse: a perspective for ethanol production from agro-industrial waste	Oliveira, R.M.M.; Nunes, M.T.A.S.; Sousa, R.M.S.	2020	*Brazilian Journal of Development*	Investigate the chemical pretreatment of sugarcane bagasse.
Review: yeasts used in the production of second-generation ethanol	Almeida, S.C.; Nascimento, D.D.	2021	Bioenergy in review: dialogues	Carry out a review of research involving the search for microorganisms capable of fermenting pentoses present in various lignocellulosic biomasses. Also address other genera of yeast known to have the ability to ferment pentoses.

Analysis of total, direct, indirect and spillover effects on the Brazilian economy through the increase in ethanol production via second generation ethanol: in the light of input-output analysis.	Ruiz, S.C.M.	2021	Journal of Regional Urban and Labor Economy	Analyze the effects generated on the Brazilian economy from the increase in ethanol production via second generation ethanol, via the application of the Input-Output Analysis (AIP) methodology.
Brazil and the world market in the development of technologies for the production of second-generation ethanol	Penalva Santos, D.C.L.; Correa, C.; Alves, Y, A.; Souza, C.G.; Boloy, R.A.M.	2023	*Alexandria Engineering Journal*	Investigate Brazil's participation in technological development using biomass to produce second generation ethanol.
Second-generation ethanol: concept, production and challenges.	Medeiros, P.V.C.; Theophilo, P.H.M.; Lopes, G.S.; Ribeiro, P.D.	2023	Eclectic Chemistry	Carry out a bibliographical review of the literature and scientific journals for the current discussion of concepts, production methodologies and challenges for the energy sector considering second generation ethanol.
Second generation ethanol (E2G) in relation to society and the media.	Távora, C.C.; Morgado, E.M.	2023	*Peer Review*	Study the role of the media in promoting information to society about innovations and development in the country, relating it to general knowledge about second generation ethanol (E2G).

Table 2: Basic information regarding the articles selected for analysis.

Source: Prepared by the author (2023)

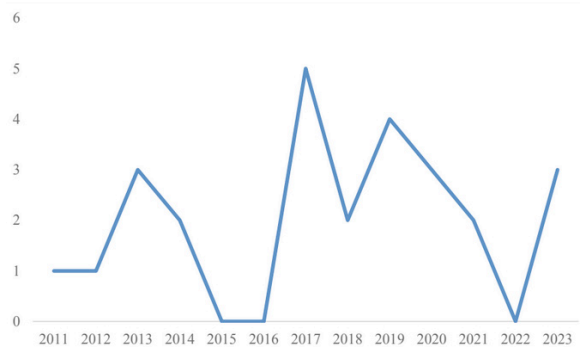

Figure 2: Number of articles published per year

Source: Prepared by the author (2023)

MAIN RESULTS, POINTS OF CONVERGENCE AND DIVERGENCE BETWEEN THE SELECTED ARTICLES

ARTICLES COVERING THE E2G PRE-PROCESSING STEP

Among the articles that highlight the pre-processing step, De Rossi et al. (2014) sought to report the main types of pretreatment used to expose cellulose and hemicellulose for hydrolysis. The authors conclude that the need for the development of appropriate yeasts to conduct the fermentation of hexoses, and the development of microorganisms that ferment pentoses in ethanol, is of paramount importance, in order to optimize the pre-treatments of cellulosic material with the aim of achieving improvement enzymatic conversion, resulting in less waste. Furthermore, it is noteworthy that the SSF process may present a greater production of furfural, an inhibitor of the development of the fungus responsible for fermentation.

Patrocínio, Siqueira and Soares (2014) sought to evaluate the acid pre-treatment of sugarcane bagasse with the parameters time, temperature and solid/liquid ratio, in order to determine which parameters are most significant and their interactions in relation to refers to reducing sugars (AR). The authors conclude that the physical-chemical conditions of the process are of paramount importance to avoid the formation of these phenolic compounds and according to the conditions, the more sugar generated in the pre-treatment, the less phenol is produced in the samples.

Andrade et al. (2018) address physical and

chemical pre-treatments and the potential for second-generation ethanol production. The work used biomass from sugar cane, elephant grass and wood sawdust to evaluate cellulose and lignin contents before and after being subjected to the aforementioned pre-treatments. The results showed that sugar cane presented better results in relation to cellulose content, with greater availability after pre-treatment, different from the other biomasses used in the study, as the biomasses of elephant grass and wood sawdust presented lower cellulose contents after pretreatment.

Marinho et al. (2020) highlighted in their study the acid pre-treatment of sugarcane straw aimed at producing second-generation ethanol. The authors concluded that the optimization of different factors (H2SO4 concentration, time and temperature) in the pre-treatment of sugarcane straw proved to be an important tool for obtaining better conditions for greater release of reducing sugars and greater solubilization of macromolecular components of biomass.

Oliveira, Nunes and Sousa (2020) addressed the chemical pre-treatment and characterization of sugarcane bagasse for ethanol production from agro-industrial waste. Chemical analyzes showed that the internal part of the sugarcane stalk had a considerable hemicellulose content (approximately 46.88% of its composition). Among the pre-treatments carried out, the basic one showed significant removal of lignin and maintained a higher concentration of hemicellulose with a considerable degree of purity, favoring the following stages of hydrolysis and fermentation of sugars, leading to a better yield of ethanol production, so that the method was able to reduce the lignin content by 84.59% and solubilize cellulose in 91.36% of the bagasse *in natura*.

ARTICLES THAT ADDRESS THE FERMENTATION STAGE IN E2G PRODUCTION

Among the articles that address fermentation as the central theme, Silva, Gomes and Nascimento (2019) highlight fermentation by yeast aiming at the production of second-generation ethanol, particularly observing fermentation by yeast in the presence of xylose, pentose present in must. second generation ethanol. The results showed that the presence of xylose in the fermentation must affected the yield of ethanol production, so that the higher its concentration, the lower the presence of alcohol.

Ribeiro et al. (2019) sought to define the best pH and temperature for *Pichia membranifaciens* LJ04 in synthetic musts with pentoses, aiming to optimize fermentation conditions for the production of second-generation ethanol. The results showed that the ideal conditions for pentose fermentation by *Pichia membranifaciens* were at 32ºC and with pH varying between 4.0 and 4.5. Under ideal conditions, it was found that there was greater consumption of xylose, greater production of ethanol, low production of secondary compounds and high levels of cell viability during the fermentation process.

Almeida and Nascimento (2021) highlighted the yeasts used in the production of second-generation ethanol. The authors state that the search for microorganisms that naturally ferment pentoses opens new paths and different alternatives in order to achieve efficient productivity of 2G ethanol, so that research for microorganisms that ferment lignocellulosic biomass into ethanol more effectively and that present viability of industrial-scale production must continue, helping to achieve the introduction of E2G in the market.

Considering the articles that highlight fermentation, the presence of xylose in the

fermentation must stands out, having a direct relationship with ethanol production (the greater its presence, the greater the ethanol production), in agreement with the study that showed conditions Ideal for pentose fermentation by *Pichia membranifaciens* were at 32ºC and with pH varying between 4.0 and 4.5.

ARTICLES THAT ADDRESS THE STUDY OF LIGNOCELLULOSIC MATERIALS IN THE PRODUCTION OF E2G

Among the articles that address the study of lignocellulosic materials, Alves and Macri (2013) sought to study lignocellulosic materials and efficient techniques for removing and producing cellulosic ethanol. The authors report that lignin presents itself as a major impediment to the successful attack on cellulose, however lignin is seen as a source of energy and raw material for other products.

Borges and Gigliolli (2020) carried out a bibliographical survey in order to demonstrate the levels of cellulose, hemicellulose and lignin in sugarcane bagasse. The authors concluded that the standardization of sugarcane plants, through genetic improvement, may offer bagasse with better levels for the production of second-generation ethanol. Bagasse with lower lignin content offers less resistance to the action of yeasts that carry out the alcoholic fermentation of sugars. The authors reiterate that knowing the levels of lignin, cellulose and hemicellulose is extremely important for choosing appropriate pre-treatments, as this phase is a bottleneck for the production of second-generation ethanol in Brazil, being considered the most expensive stages and challenging aspects of the production process.

ARTICLES THAT ADDRESS ENZYMATIC HYDROLYSIS IN THE PRODUCTION OF E2G

The study of enzymatic hydrolysis of sugarcane straw was addressed by Lucarini et al. (2020). The objective was to study the enzymatic hydrolysis of sugarcane straw to obtain fermentable sugars, using both purified enzymes and commercial enzymes. When comparing the results of the tested enzymes, T. *Reesei* cellulase and Cellic CTec2 commercial cellulase, the enzyme that presented the most satisfactory results was commercial cellulase, with better conditions of use at 45ºC, pH 5.5 and 150 rpm of agitation. With these conditions, the yield obtained in enzymatic hydrolysis was 23.8% conversion of biomass cellulose into glucose.

Grasel et al. (2017) studied the production of E2G from elephant grass and sugarcane bagasse, in order to subject them to acid hydrolysis (to produce glucose) under atmospheric pressure. The results showed that it was possible to hydrolyze the biomasses of elephant grass and sugarcane bagasse in an acidic medium at atmospheric pressure, in addition to obtaining sugars that were fermented generating E2G.

ARTICLES THAT ADDRESS THE POTENTIAL OF E2G PRODUCTION THROUGH SUGARCANE WASTE

Dias et al. (2011) address second generation ethanol in Brazil from the perspective of the possibility of it competing with bioelectricity production. The authors highlight that there is controversy regarding the production of second-generation ethanol and possible competition with the production of first-generation ethanol. However, in Brazil, residues from the production of first-generation ethanol from sugar cane (bagasse and sugarcane straw) are used as raw material for the production of so-called E2G. The

analysis carried out by the authors shows the importance of using and integrating the use of sugar cane, including its biomass, being able to compete with other forms of obtaining energy.

The potential of sugarcane straw in ethanol production was highlighted by Silva et al. (2012). The authors showed that several forms of pre-treatment are being studied (as can be evidenced by the articles selected in this work that address the topic of pre-treatment), each with its intrinsic advantages and disadvantages. The authors indicate an increase in sugarcane production to meet the demand for ethanol through the introduction of new sugarcane cultivars and the full use of sugarcane, straw and bagasse.

The potential for second-generation ethanol production through agricultural waste is addressed by Nunes et al. (2013). The authors highlight that among the residues studied, sugarcane straw has a cellulose content of approximately 39%, sugarcane bagasse has levels close to 43%, followed by wheat straw with 35%, rice straw with 38% and banana pseudostem with 46%. Sugarcane residues showed a cellulose to ethanol conversion rate close to 89%, followed by rice straw with 80%. The other residues presented levels close to 60%.

The authors also consider that in Brazil there are several alternative ways of producing second generation ethanol. It is also noteworthy that lignocellulosic materials occupy a prominent place, mainly in relation to factors involving their abundance and renewable nature.

ARTICLES THAT COVER THE HISTORY OF SUGAR CANE AND ETHANOL PRODUCTION

Carvalho et al. (2013) carried out a history of sugarcane and fuel ethanol. Regarding second generation ethanol, the authors highlight that the use of raw material classifies it as second-generation fuels, that is, a range of raw materials can be used, representing a new alternative for the energy use of biomass, presenting environmental and economic advantages. Regarding second-generation ethanol, it presents itself as a promising source of sustainable and efficient fuel. Finally, in order for the technology for the production of this fuel to advance, it is necessary to integrate research groups from different areas, such as: physiology, ecology, biochemistry, genetics, physics, etc., in order to make Brazil self-sustainable in production, jointly integrating sustainability and technological development in the country.

ARTICLES THAT ADDRESS TOPICS INVOLVING THE ENVIRONMENT, ECONOMICS AND ENVIRONMENTAL POLICY

With regard to environmental innovation, Ansanelli et al. (2017) address the development of second-generation ethanol in Brazil, highlighting the fact that environmental innovations constitute an important path to reducing the technological gap in developing countries. It was verified that environmental innovations can result from interactions between different actors from different origins with a specific environmental objective, with the government as a facilitating agent. However, for developing countries, the authors report that such countries have low research and development rates, lack of governance and transparency conditions, etc.

The development of E2G in Brazil allows us to unite aspects of environmental

innovation with elements of innovation systems in developing countries, so that E2G is characterized by an environmental process innovation.

Carpio and Souza (2019) sought to determine the optimal allocation of residual sugarcane biomass between 2G ethanol productions, with the objective of maximizing return and consequently minimizing risks for investors operating in the sugarcane sector. of sugar. The model presented by the authors considers the risks and uncertainties inherent to the sugar and alcohol industry, mainly caused by price fluctuations in different markets.

Regarding economic issues, Ruiz (2021) analyzes the effects generated in the Brazilian economy from the production of ethanol via second generation ethanol, using the Input-Product Analysis (AIP) methodology, aiming to carry out an analysis of the impacts economic benefits with the implementation of the 2030 target for second generation ethanol established by the Nationally Determined Contribution (NDC) in the United Nations Framework Convention on Climate Change (UNFCCC), with the commitment to reduce GHG emissions by 2025 in 37% and in 2030, 43%, taking 2005 as a reference.

Lorenzi and Andrade (2019) analyze the political issues and socio-technical networks of E2G in Brazil, based on the discussion of the formation of the cellulosic ethanol network in Brazil, through the identification of the main actors involved in its research, development and production, in addition to the technologies used and in development, potential, divergences and controversies, through bibliographical research on the subject. As a result, the authors mapped the E2G network in Brazil, finding that the second-generation ethanol production network in Brazil involves several sectors, namely: part of the sugar-energy sector, equipment suppliers, government research funding institutions, such as BNDES, technology and genetic improvement companies, etc.). The authors highlight that the first impressions regarding E2G in Brazil were hasty, with too many promises too soon. However, current expectations indicate that E2G could become a paradigm in the sugar-energy sector in 2030 if most of the bottlenecks in its production are resolved.

The large-scale production of E2G still represents a challenge of utmost importance for those involved in research to make it economically viable, as the effects of scale production will be spilled over to all agents in the production chain, including suppliers of direct inputs. for manufacturing, as discussed previously. Finally, factors that interfere with pre-treatment, in addition to the difficulties in producing enzymes in an economically viable way, in addition to the efficient fermentation of sugars resulting from hydrolysis, constitute one of the main bottlenecks in achieving an industrial scale of production, as seen previously.

ARTICLES COVERING PRODUCTION AND PROSPECTS FOR E2G

Regarding production and perspectives regarding E2G, Morais et al. (2017) highlight the potential of E2G as a sustainable biofuel, capable of reducing the release of greenhouse gases on the planet, that is, making it beneficial for the environment. However, the authors warn that investments and studies are needed with universities, research entities and large companies, in order to improve the production process, aiming to reduce production costs, making E2G economically viable and guaranteeing sufficient production for the current energy demand.

Still on the production of E2G, Lopes, Santos and Costa (2017) add that research on

the production of E2G is a study of great interest on the part of agents in the production chain, mainly due to the possibility of increasing production without increasing planted area. As a result, the authors' objective revolved around carrying out technological monitoring of the process of obtaining second generation ethanol. The results showed that from the search for patent families it was possible to verify important aspects about the initiatives regarding research and development in the sector, highlighting the fact that Brazil has been standing out in the world scenario of second-class ethanol production. generation, presenting patenting trends linked to aspects related to fuel production.

Robak and Balcerek (2018) carried out a review of the production of second-generation ethanol, due to the great need for alternatives to petroleum-derived fuels. The authors highlight that the shift in the transport sector from using petroleum derivatives as fuel to a more sustainable, renewable and environmentally friendly energy, such as second-generation ethanol.

From a more current perspective, Medeiros et al. (2023) highlight the concept, production and challenges of second-generation ethanol. The authors carried out a bibliographical review of the literature on the subject, in order to highlight concepts, production methodologies and challenges for the sector. The authors add that the pre-processing stage requires more expensive methodologies, but even so, the use of biomass becomes an excellent alternative. However, even with the possibility of expanding production to other countries, the authors highlight that Brazil will continue to be the largest country producing 2G ethanol, due to its great potential for producing biomass from sugar cane.

Penalva Santos et al. (2023) investigated Brazil's participation in the development of technologies that use biomass for the production of second-generation ethanol. The research was carried out using technological information contained in patent documents applied around the world. Innovations were protected from 2006 onwards and reached their peak in 2015, while in 2017 they began to suffer a relative decline, impacted by the reduction in public investments, mainly in the United States. It is also noteworthy that China has emerged as the main promoter of technological innovation for the production of E2G, despite the USA and Brazil being the largest producers. On the other hand, despite two commercial-scale factories being installed in Brazil, few innovations were protected by the Brazilian patent office, highlighting the general lack of culture for technological development. Furthermore, Brazilian patents are almost all formed by public teaching and research institutions.

In agreement with previously highlighted articles, publications that deal with the production and perspectives of E2G production, the need for investment and support for universities and researchers is highlighted, with the aim of reducing production costs and making it viable from the point of view of its production scale, in order to make E2G economically viable, also contributing to the supply of global energy demand.

ARTICLES THAT ADDRESS THE RELATIONSHIP BETWEEN SOCIETY AND THE MEDIA WITH E2G

Addressing the relationship between E2G and society and the media, Távora and Morgado (2023) highlight that the study shows that the interviewees are aware of the difference between ethanol and gasoline, however there is a lack of knowledge regarding first- and second-class ethanol. generation, in addition to the lack of knowledge about Brazil's capacity to produce E2G. The lack

of information regarding E2G highlights the lack of the media's role in building knowledge for society. The authors highlight that the media is an essential space for promoting teaching-learning to society, especially in relation to subjects that aim to contribute to society and the environment, with television and the internet being the main means of communication used by society.

FINAL CONSIDERATIONS

The present work analyzed publications that dealt with topics involving second generation ethanol in Brazil, between 2011 and 2023, thus fulfilling the determined general objective. Firstly, the great importance that the entire sugarcane complex has for Brazil is highlighted, mainly in relation to the production of sugar and ethanol from sugarcane, which is one of the main sources of exports for the country. Within this context, second generation ethanol appears as a highlight and has great potential, as it is made from residues left over from the manufacturing process of first-generation ethanol and sugar, resulting in a product with low environmental impact, contributing to lower greenhouse gas emissions, which is one of the main reasons for its recent prominence.

Through the articles selected for analysis, it was possible to ascertain that the country has great potential for the production of E2G, mainly due to its already outstanding production, being a world leader in this regard. The possibility of using first-generation industrial ethanol plants is also a prominent factor, as it contributes to reducing initial investments to start the production process.

Environmental issues are also highlighted, showing that the possibility of large-scale production of second-generation ethanol from sugar cane could contribute to the reduction of greenhouse gas emissions into the atmosphere, in order to favor the environmental sustainability thinking in the long term.

Economically, issues were highlighted that are linked to a possible increase in ethanol production using the same area planted with sugar cane, contributing directly to the local, regional and entire country's economy, generating a possible contribution to the Brazilian trade balance.

The importance of investments by both government and industry companies in research groups from different areas is detected, covering all stages of second-generation ethanol production, highlighting the incentive for research in the pre-production phase. treatment, hydrolysis and fermentation, with the aim of Brazil becoming a power in the production of second-generation ethanol, becoming self-sustainable and a major global supplier.

It is suggested for future research to review the literature on certain stages of second-generation ethanol production, such as, for example, pre-treatment, which presented several bottlenecks to be overcome. The specific study of this and other stages will map the studies, research and investments being carried out aiming at the evolution of the sector.

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