Biobutanol as an Alternative and Sustainable Fuel: A Literature Review

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We need investiments in cleaner, renewable and sustainable energy sources to meet global fuel demand. Biobutanol is produced by the biotechnological route, by the ABE fermentation process. Biobutanol as a biofuel has gasoline-like properties, and its energy efficiency is 25% higher than ethanol. The objective of this work was to conduct a literature review on the production of biobutanol and to collect data on the market of this biofuel to understand the challenges involved in the production of biobutanol. We did the systematic review using the inclusion method. We analyzed the biobutanol world scenario and its applicability in Brazil as a solvent in industries.
Keywords: Biofuel. Biobutanol. ABE Fermentation. n-Butanol. Literature Review.

Introduction

The growing environmental need is to turn to cleaner, renewable and sustainable energy sources to meet the ever-increasing demand for fuel. Renewable energy will be the world's fastest-growing energy source, expected to double from 2015 to 2030. [1] Biofuel, produced through a biological process, has drawn scientists' attention due to its environment-friendly feature [2].

Biobutanol is butanol production from natural or organic or biodegradable or renewable biomass [3]. Butanol is higher alcohol whose chemical formula is $C_4H_{10}O$ and which has four structural isomers: n-butanol, isobutanol, tert-butanol, and sec-butanol [4].

n-Butanol is a chemical compound that falls within the alcohol reagent family. Due to their increasing use as additives, solvents, and fuels, alcohols have found their position in the market. Biobutanol as a fuel derived from biomass feedstock produced using ABE fermentation turns out to be an extremely clean and sustainable fuel with a high energy density comparable to gasoline [3].

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Biobutanol is considered the gasoline of the future. It will be a good substitute for gasoline due to its physical properties such as high boiling point, economy, and safety [4, 5]. From the United States (USA) perspective, ASTM D7862 - 21 standard allows butanol intended to be blended with gasoline at 1% to 12.5% by volume for use as automotive spark-ignition engine fuel [6], while ASTM D787533 provides a method for determining the butanol and acetone content in butanol by gas chromatography technique, intended for blending with gasoline [4,7].

Brazil has a large availability of fermentable raw materials, especially sugarcane and corn, and well-established industrial facilities for alcoholic fermentation, so it has the potential to become a reference for the export of biobutanol [8].

Industrial initiatives in the n-butanol field are aimed at the biofuels market because of n-butanol's better properties compared to ethanol, as it has 25% more energy than ethanol, lower water miscibility, and less corrosive properties. Butanol can be blended with gasoline and diesel in higher proportions, it can replace gasoline use, while ethanol can only be used as an additive [5,9].

Therefore, the objective of this work was to conduct an integrative review of the production of biobutanol, collect data on the foreign and internal markets of this biofuel, and understand the challenges involved in the production of biobutanol.

Materials and Methods

The present work sought the literature review to show the main points related to the production of the biobutanol process and commercial prospection in the Brazilian scenario. The databases that provide scientific articles were consulted, such as SciELO, ScienceDirect, and Google Academic.

The search was for articles written between 2013 and 2021, preferably considering articles available in their full version. Inclusion and exclusion criteria were also used in which more than 60 articles were found throughout the research. We evaluated 10 sources, considering some themes: Renewable energies; Production of Biobutanol, and economic and market analysis. After the sources selection, according to the inclusion criteria, we divided the review into five phases (Figure 1), according to a previously established protocol [10].

Literature Review

Phase 1: Preparation of a Guide Question

In this phase, we defined the questions that will guide the research. For the elaboration of this work, we used the following questions:

1. What are the applications of Biobutanol?
2. Is there a possibility that biobutanol is a biofuel used in Brazil?
3. What is the market forecast for biobutanol by 2030?

Phase 2: Research or Sampling in Literature

In this step, the strings used to search the literature and the databases to be searched are defined. The data were obtained using the following platforms: SciELO, Google Scholar, and Science Direct. Figure 2 shows the steps followed for the literature survey.

Steps 1 and 2 were performed to obtain information regarding the amount of research conducted on biofuels and biobutanol specifically. In step 3, we were raised on the biobutanol production processes and their production prospects. Step 4, reflects the crossover between biobutanol production and its market prospects. At this phase, we applied the inclusion and exclusion criteria. The inclusion criteria were articles, dissertations, and technical reports published in English or Portuguese. The exclusion criteria were duplicate articles and non-eligibility for the proposed theme.

Phase 3: Data Collection

In the third phase, the articles were resumed and organized according to the reference to the theme addressed. Figure 3 shows the number of publications found in the integrative review steps.

Research on biofuels has great relevance in the market. A total of 60 articles addressing the theme of biobutanol were selected. Ten articles were evaluated, considering some themes: Renewable

Figure 1. Literature review phases.

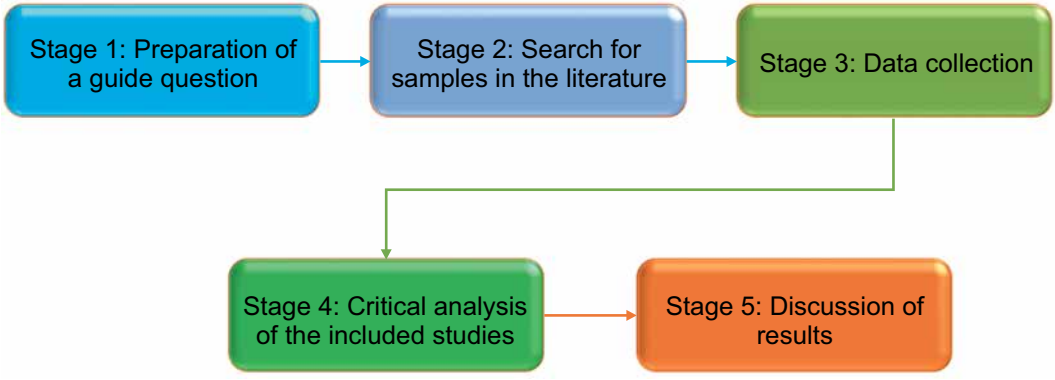
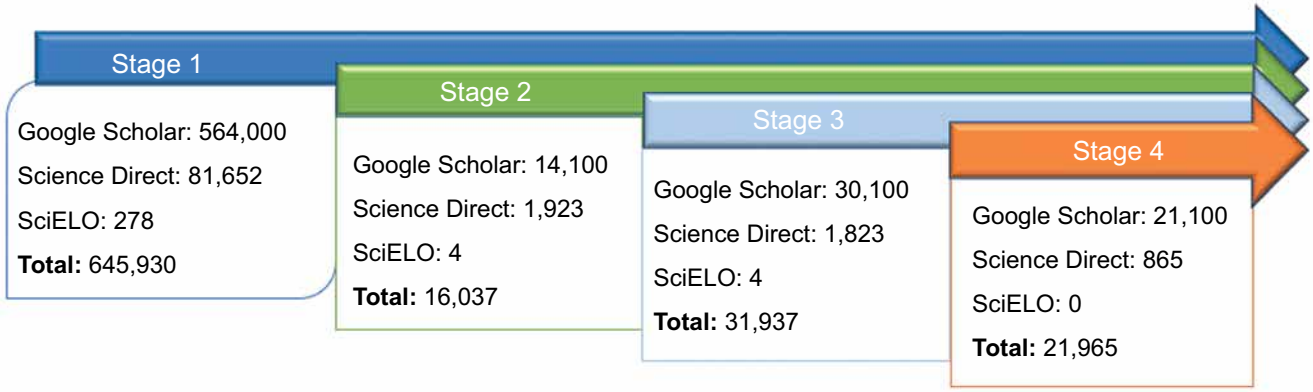


Figure 2. Steps for the literature survey.

Figure 3. Number of searches found at each phase.



energies; Production of Biobutanol, economic and market analysis. Besides, 2 international standards and 6 technical reports without full access were consulted to understand the projection of the biobutanol market by 2030.

Phase 4: Critical Analysis of Studies Included

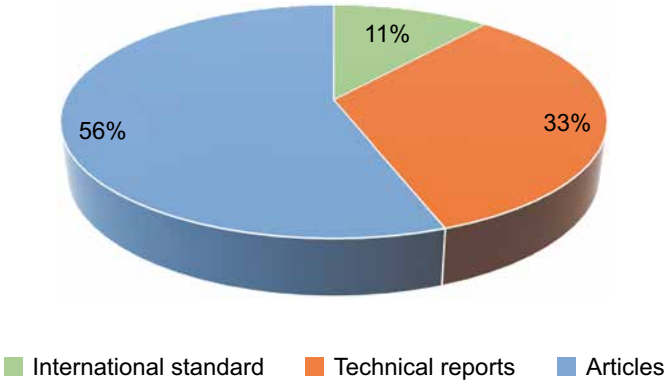
In this stage, we did a critical analysis of the selected literature after the inclusion and exclusion criteria of papers. Figure 4 shows the quantity of the literature survey corresponding to 67% of articles, 22% of technical reports, and 11% of international standards.

The studies address the scope of the insertion of biofuels in the energy matrix as a relevant factor to combat global warming. We focused on the applications of biobutanol as a solvent in the chemical, petrochemical, and biofuel industries. They specifically present the production of n-butanol by the biochemical route through ABE fermentation using clostridium bacteria as the main microorganism for the process.

The solvent separation technologies obtained by ABE fermentation are presented in most articles as impact agents in the economy of biochemical processes because the separation processes directly influence the production price of biobutanol.

The prospect of biobutanol by 2030 was optimistic according to the technical reports prepared between 2019 and 2021[1,11,12]. It also points out that countries such as China, India, and the United States have great interest in investing in biobutanol as fuel due [11], mainly the ability of biobutanol to be mixed and have squealing gasoline properties and have greater efficiency than ethanol. In the United States, the mixture of biobutanol in gasoline is regulated by ASTM D7862 [6] and ASTM D7875 [7]. The Brazilian market is promising for biofuels since the second largest consumer in the domestic energy matrix is the transportation sector, responsible for 31.2% of domestic energy consumption in 2020 (BEN, 2020) [13,14]. In Brazil, biobutanol is a biofuel since there is an investment in the ethanol production market adapting cars to this biofuel

Figure 4. Quantitative literature articles.



[4]. At this moment, the largest market in Brazil for biobutanol to be used is as a solvent in the paint and varnish producers' industry.

Discussion

In the phase 5, the interpretation and synthesis of the information obtained from the results of the research on the theme of biobutanol are made. The research covered the bibliography from 2011 to 2021. it is possible to observe in Figure 5 the distribution of material used in this work per year.

According to The Energy, Information Administration (EIA), the increase in world energy consumption would be around 56% in 2040 compared to 2010 [15, 16]. Shenbagamuthuraman (2021) showed that gasoline and other liquid fuels are the dominant energy sources for the transportation sector, although there is a slight decline in total transport energy consumption from 96% in 2012 to 88% in 2040. [17] US, China, and Brazil should achieve 15-27% of biofuel mixture with conventional fuel by 2020-2022 [1]. The biobutanol market is expected to register a CAGR (Compound Annual Growth Rate) of over 7%, during the forecast period. The major factors driving the market studied are carbon emission reduction and gaining prominence as a foundation for chemical manufacturing. [11] In 2020, the worldwide n-butanol market volume was more than 5.1 million metric tons. The market volume of this organic compound is forecast to grow to around 6.2 million metric tons worldwide by the year 2026 [18]. In Figure 6, we can analyze the n-butanol market by 2026.

Figure 5. Distribution of publications on the theme of research by year.

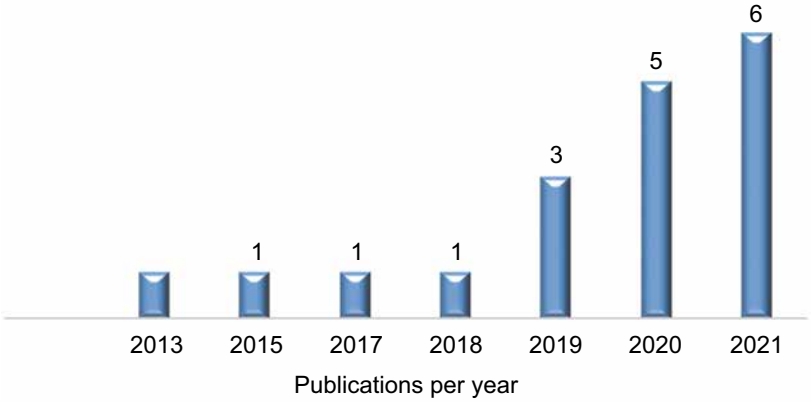
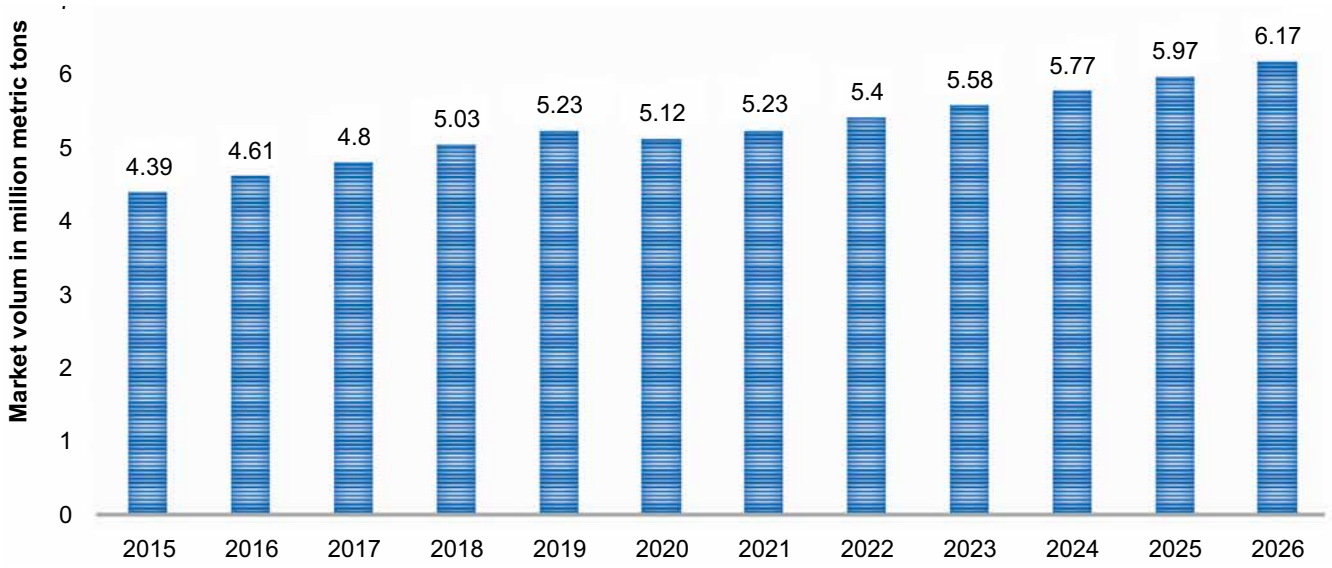


Figure 6. Global n-butanol market volume from 2015 to 2020, with a forecast from 2021 to 2026 (million metric tons).



The biobutanol market is in an incipient and consolidated phase. The main biobutanol producing industries are Cathay Industrial Biotech, Gevo inc, Butamax Advanced Biofuels, and Cobalt Technologies [11]. Cobalt Technologies has developed several technological innovations to produce biobutanol to reduce production costs by 30% to 60% and radically reduce the impact of carbon compared to petroleum-derived butanol, which finds applications in various chemicals and fuels, including 1-butylene, butadiene, lubricating oil, and poly-alpha-olefins. [12] Brazil, according to the Brazilian Chemical Industry Association (ABIQUIM), Oxiteno and Elekeiroz are currently producing butanol isomers.

Conclusion

In this work, 60 more articles related to the theme were collected using the databases of the Academic, Science Direct, and SciELO. Six technical reports and 2 international standards were considered to complement the information. This review demonstrated that biobutanol holds a promise as a renewable biofuel, given its ability to be a substitute for fossil fuels and its property of being blended with gasoline and diesel. In addition, the world market is open to the possibility of inserting biobutanol as biofuels in its energy matrix, mainly in countries such as China and the US. For Brazil, biobutanol may be a great possibility for insertion as a biofuel due to the large supply of raw material from sugarcane close to the areas where the plants will be implemented. However, to date, greater use of n-butanol is as a solvent applied in the production of paints and coatings. In addition, another obstacle to the inclusion of biobutanol as biofuel in the energy matrix is the regulatory agencies, since this biofuel is an experimental fuel by the Brazilian National Agency of Petroleum, Natural Gas, and Biofuels (ANP). At present, Brazil does not have technical standards to designate the use of a mixture of this biofuel with gasoline or diesel. It was also possible to highlight the scarcity of publications about the biobutanol market in Brazil, although the country has great potential to be a producer of this biofuel.

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