

BIOBUTANOL AS AN ALTERNATIVE AND SUSTAINABLE FUEL: AN INTEGRATIVE REVIEW

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Abstract: It is necessary to invest in cleaner, renewable and sustainable energy sources to meet global fuel demand. Biobutanol is produced by biotechnological route, by ABE fermentation process. Biobutanol as biofuel has gasoline-like properties and its energy efficiency is 25% higher than ethanol. The objective of this work was to conduct an integrative review on the production of biobutanol, in order to collect data on the market of this biofuel in order to understand the challenges involved in the production of biobutanol. The systematic review was carried out using the inclusion method. It was possible to analyze the world scenario of biobutanol and evaluate that so far in Brazil its demand is of greater applicability as a solvent in industries.

Keywords: Biofuel; Biobutanol; ABE Fermentation; n-Butanol; Integrative Review

Resumo: É cada vez mais necessário investir em fontes de energias mais limpas, renováveis e sustentáveis para atender a demanda global de combustível. O biobutanol é produzido por rota biotecnológica, pelo processo de fermentação ABE. O biobutanol, como biocombustível, possui propriedades semelhantes às da gasolina e sua eficiência energética é 25% maior que a do etanol. O objetivo deste trabalho foi realizar uma revisão integrativa acerca da produção de biobutanol, com o intuito de levantar dados sobre o mercado deste biocombustível a fim de compreender os desafios envolvidos na sua produção. A revisão sistemática foi feita utilizando o método de inclusão e exclusão. O cenário mundial de biobutanol foi analisado e, constatou-se que, no Brasil, até o momento, a sua demanda é de maior aplicabilidade como solvente em indústrias.

Palavras-chave: Biocombustíveis; Biobutanol; Fermentação ABE; n-butanol; Revisão Integrada.

1. 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 biological process, has drawn great attention from the world due to its environment-friendly feature. ^[2]

Biobutanol refers to the butanol produced from the natural or organic or biodegradable or renewable biomass. ^[3] Butanol is a higher alcohol whose chemical formula is represented as $C_4H_{10}O$ 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]

Biobutanol is considered the gasoline of the future, and a good substitute for gasoline due to its physical properties such as high boiling point, economy and safety ^[4,5]. In 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 material, especially sugarcane and corn, and well-established industrial facilities for alcoholic fermentation, so it has great potential to become a reference for the export of biobutanol ^[8].

Most industrial initiatives in the field of n-butanol, however, 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 the use of gasoline, while ethanol can only be used as an additive ^[5,9].

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

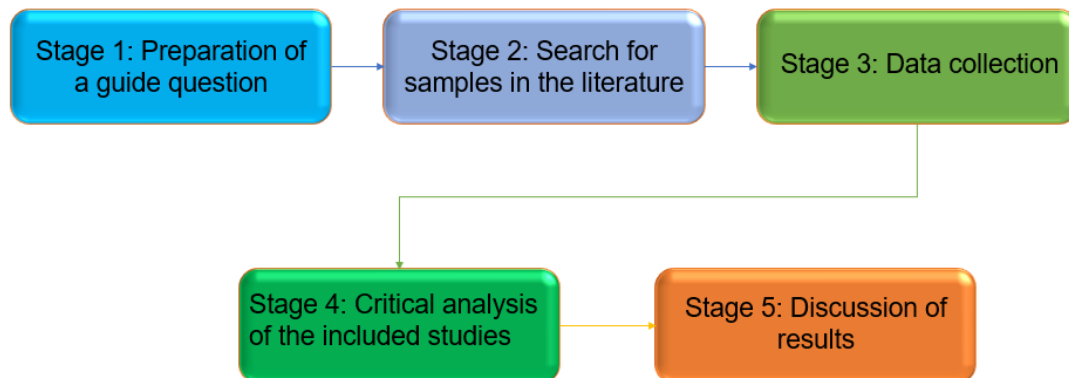
2. METHODOLOGY

The present work sought with the review integrativ, to show the main points related to the production process of biobutanol, commercial prospection in the Brazilian scenario. The main 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 its full version. Inclusion and exclusion criteria were also used in which more than 60 articles were found throughout the research. Throughout the research, 10 sources were evaluated, considering some themes: Renewable energies; Production of Biobutanol, economic and market analysis. After the selection of the sources, according to the inclusion criteria, the following steps.

This review was divided into four stages, as shown in Figure 1, according to a previously established protocol ^[10].

Figure 1: Stages of the integrative review that will be addressed at work.



Source: Authors (2021).

3. INTEGRATIVE REVIEW

3.1 Stage 1: Preparation of a guide question

In this stage are defined the questions that will be guide the research that will be developed. For the elaboration of this work, the following questions were used:

- 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?

3.2. Stage 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 bibliographic survey.

Figure 2: Steps for bibliographic survey.



Source: Authors (2021).

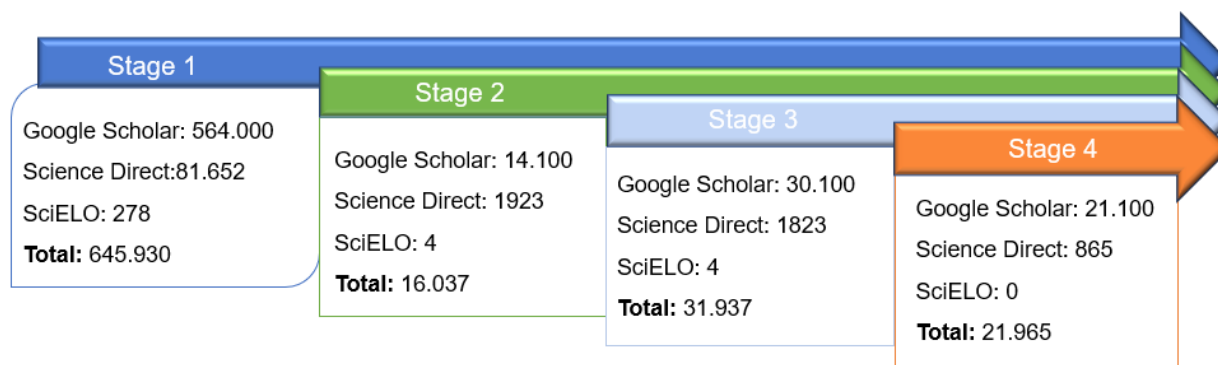
Stages 1 and 2 were performed in order to obtain information regarding the amount of research conducted on biofuels and biobutanol specifically. In step 3, we were raised on the biobutanol production processes and their production prospects. In step 4, it reflects the crossover between biobutanol production and its market prospects.

At this stage, the inclusion and exclusion criteria were applied, considering the exclusion criteria for duplicate articles and non-eligibility for the proposed theme. While the inclusion criteria were selected articles, dissertations and technical reports published in English or Portuguese.

3.3. Stage 3: Data Collection

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

Figure 3: Number of searches found at each stage.



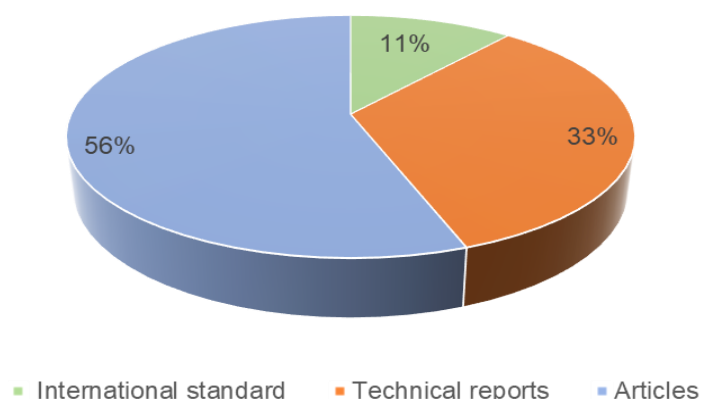
Source: Authors (2021).

Research on biofuels has great relevance in the market. A total of 60 articles addressing the theme of biobutanol were selected. 10 articles were evaluated, considering some themes: Renewable energies; Production of Biobutanol, economic and market analysis. Besides, 2 international standard and 6 technical reports without full access were consulted in order to understand the projection of the biobutanol market by 2030.

3.4. Step 4: Critical Analysis of Studies Included

In this stage it is performed after the application of the inclusion and exclusion criteria of papers in order to make a critical analysis of the selected bibliography. Figure 4 shows the quantity of the bibliographic survey corresponding to 67% of articles, 22% of technical reports and 11% of international standards.

Figure 4: Quantitative bibliography.



Source: Authors (2021).

The studies address the scope of the insertion of biofuels in the energy matrix as a relevant factor to combat global warming. The applications of biobutanol as solvent in the chemical, petrochemical and also biofuel industries. They specifically

present the production of n-butanol by biochemical route through ABE fermentation using clostridium bacteria as the main microorganism for the process.

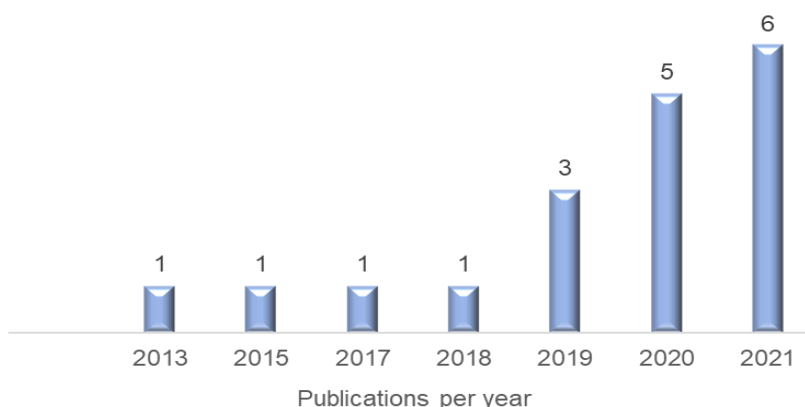
The solvent separation technologies obtained by ABE fermentation are presented in most articles as impact agents in the economy of biochemical processes, because the separation processes directly influence the production price of biobutanol.

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], but in Brazil, biobutanol as a biofuel, since there is a large investment in the ethanol production market and since cars are well adapted to this biofuel ^[4], at the moment, the largest market in Brazil for biobutanol to be used is as a solvent in the paint and varnish producers' industry.

3.5. Step 5: Discussion of results

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

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



Source: Authors (2021).

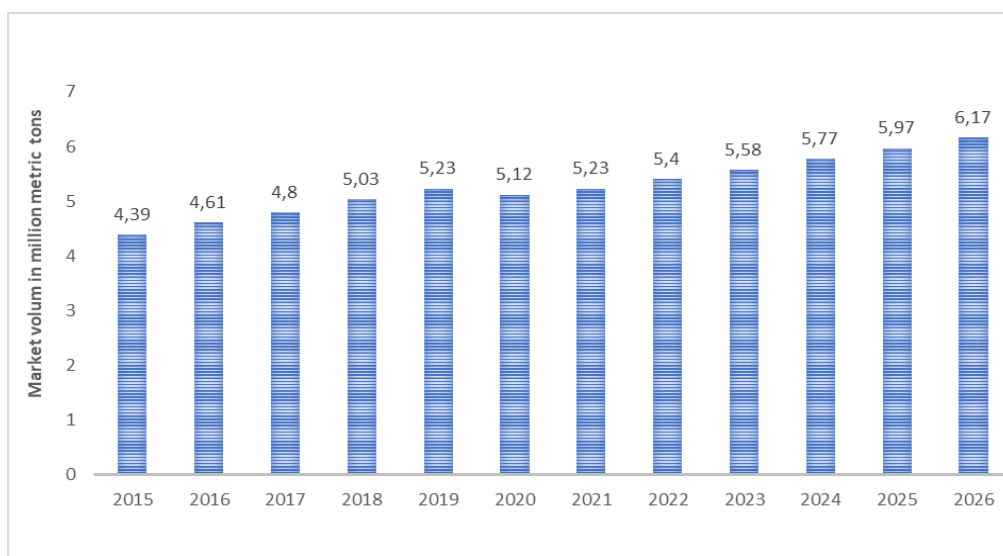
According to The Energy, Information Administration (EIA) the increase in world energy consumption would be around 56% in 2040 compared to 2010 ^[15, 16]. Shenbagamuthuraman (2021) showed that gasoline and other liquid fuels are the dominant energy sources for the transportation sector, although there is a slight decline in total transport energy consumption from 96% in 2012 to 88% in 2040. ^[17] Countries such as the US, China and Brazil have a goal of achieving 15-27% of biofuel mixture with conventional fuel by 2020-2022. ^[1]

Most industrial initiatives in the field of n-butanol, however, 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 the use of gasoline, while ethanol can only be used as an additive. ^[5,9]

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



Source: Statista (2020).

The biobutanol market is in an incipient and apparently 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] In Brazil, according to the Brazilian Chemical Industry Association (ABIQUM), Oxiteno and Elekeiroz are currently producing butanol isomers.

4. 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 totally open to the possibility of

inserting biobutanol as biofuels in its energy matrix, mainly in countries such as China and the U.S. 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 regulation, since this biofuel is currently can be considered an experimental fuel by the Brazilian National Agency of Petroleum, Natural Gas and Biofuels (ANP), because at present Brazil does not have technical standards to designate the use or 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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