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USE OF SUGARCANE BIOMASS IN BRAZIL

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Abstract:
Recently, the use of biomass energy has been growing worldwide on an accelerated trajectory, with the prospect of staying among the main renewable energy sources for the coming decades, along with wind and solar energy. Brazil is the largest producer of sugarcane on the planet and the second-largest producer of ethanol. But in addition to sugar, first-generation ethanol, and vinasse (for ferti-irrigation), other by-products and process residues from the plants (such as bagasse, filter cake, vinasse, straw, and sugarcane tip) can be used for the production of thermal and electric energies and also second-generation ethanol and biogas fuels. In this context, this paper presents the current scenario of sugarcane biomass in Brazil, discussing issues involving the use of sugar-alcohol by-products for bioenergy and biofuel production. Furthermore, a study on the reuse of sugarcane bagasse fibers for the production of eco-composite material is also presented. Finally, the concepts of biomass energy are described from a bibliographic survey and the previous experiences of the authors.

Keywords: Bagasse; Organic residue; Biogas; Biofuel; Bioelectricity; Sustainability.

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INTRODUCTION

Human activities have increased greenhouse gases (GHGs) emissions, like carbon dioxide (CO2), from burning fossil fuels and deforestation, causing extreme weather and melting polar ice as some of the effects. However, renewable energy sources are known to be the least expensive options for increasing population access to electricity, reducing air pollution and CO2 emissions worldwide (Wessier, 2007; Palmer, 2014; Wizelius, 2015; Rao et al., 2017; Brasil, 2019). Sustainable Development Goal # 7, from the United Nations, that seeks to ensure access to affordable, reliable, sustainable, and modern energy for everyone and recommends a substantial growth in the share of green energy in the global energy matrix by 2050.

Biomass, wind, solar, tidal, geothermal, hydraulic, and nuclear are renewable forms of energy that cause little environmental impact and do not interfere with pollution at the global level (Sovacool and Watts, 2009). Biomass has been growing significantly in recent years in Brazil and worldwide, being considered a good alternative for the diversification of the energy matrix and consequent reduction of dependence on fossil sources, once it is possible to generate energy for electricity, heating, cooling, and transportation. Brazil is the largest producer of sugarcane on the planet, accounting for 45% of the world's sugar exports. It is also recognized as the second-largest producer of ethanol, a renewable fuel. In addition, sugarcane takes advantage of all the waste ranging from the generation of thermal energy, electricity, fertilizer, second-generation ethanol, and biogas.

In this context, this work provides an overview of the use of sugarcane biomass in Brazil as a source of clean and renewable energy, showing that biomass energy is a sustainable option because it is economically viable, socially fair, environmentally correct, and corroborates the achievement of the country's sustainable development goals.

Current Biomass Scenario In Brazil

Biomass is an indirect form of use of solar energy absorbed by plants, since it results from the conversion of sunlight into chemical energy (Gomes and Maia, 2012). Biomass can be defined as any organic matter that can be transformed into mechanical, thermal, or electrical power, and can be of forest origin (wood, mainly), animal (manure), agricultural (soybean, corn, rice, sugarcane, among others) and urban and industrial waste (solid or liquid). The derivatives obtained from these residues depend both on the raw material used (whose energy potential varies from type to type) and on the processing technology to bring the energy sources (Aneel, 2008; Okudoh et al., 2014; Souza et al., 2015). Thus, one of the main advantages of biomass, which has contributed to the emergence of a global trend, concerns the possibility of using agricultural residues precisely.

Forest energy biomass is defined as products and by-products of forest resources that basically include woody biomass, sustainably produced from cultivated forests or native forests, obtained by deforestation of native forest to open areas for agriculture, or even originated in activities that process or use wood for non-energy purposes, highlighting the pulp and paper industry, furniture industry, sawmills, etc. According to Demirbas (2009), agricultural energy biomass, on the other hand, refers to products and by-products from non-forest plantations, typically originating from annual harvests, whose crops are selected according to the properties of starch, cellulose, carbohydrates, and lipids contained in the matter, depending on the technological route for which it is intended. Agroenergetic crops mainly use specialized courses of biological and physical-chemical transformations, such as fermentation, hydrolysis, and esterification, used to produce liquid fuels, such as ethanol, biodiesel, and various vegetable oils. Bilandzija et al. (2018) explained that these crops include sugar cane, corn, wheat. Finally, the biomass contained in urban solid and liquid waste is found in garbage and sewage and has different origins. Urban waste is a heterogeneous mix of metals, plastics, glass, cellulosic and vegetable waste, and organic matter. The technological routes for its energy use are: direct combustion, gasification, by thermochemical route, after the separation of recyclable materials, and anaerobic digestion, in the production of biogas, by biological route (Ventorino et al., 2018).

Historically, Brazil stands out for having a high percentage of renewable sources in its energy matrix when compared to the rest of the world, reaching 46.1% share of renewables in 2019, due to the expansion of the sugar-alcohol sector and the strong penetration of other renewables, such as wind, bleach and biodiesel sources (Epe, 2020). With the drop in oil experienced at the beginning of 2020, the ethanol market went through difficulties, and, as a result, the mix of plants ended up pointing in the direction of sugar production as a compensatory measure. Even so, in 2021, biomass has a share of 8.7% (15.3 GW) in the Brazilian electricity matrix, as shown in Table 1. Bioelectricity generated in power generating plants (GHP) from biomass, together with small hydroelectric plants (SHP), is the fourth most important source of the Brazilian electricity matrix (Unica, 2021).

Table 1. Participation of biomass energy in the Brazilian electric matrix.

Source	Installed Capacity (MW)	Installed Capacity (%)
Hydroelectric	103,0 GW	58,3%
Wind	19,1 GW	10,8%
Biomass	**15,3 GW**	**8,7%**
Natural Gas	14,8 GW	8,4%
Petroleum	9 GW	5,1%
SHP[a]/GHP[b]	6,3 GW	3,6%
Coal	3,6 GW	2,0%
Solar Photovoltaic	3,3 GW	1,9%
Nuclear	2 GW	1,1%
Total	*176,4 GW*	*100%*

[a] SHP: Small Hydropower Plants; [b] GHP: Gas Hydropower Plants (Source: the authors, based on Aneel (2021) data.

As it is a clean and renewable energy, the use of biomass brings as great advantages its direct use through combustion in ovens and boilers, the generation of employment and sustainable local development, and a reduced cost compared to the use of fossil fuels (Andreae, 1991; Rípoli et al., 2000; Brasil, 2018).

Sugarcane Biomass

Virtually all biological organisms that can be harnessed as energy sources are called biomass. For example, among Brazil's most used raw materials are sugarcane and its by-products, such as bagasse, straw, sucrose, and vinasse, which contribute to the reduction of burning in sugarcane fields (Gomes and Maia, 2012). Sugarcane is a grassy-type plant, with a thick fibrous stem, which can grow up to 6 m in height, with high sugar content and low fiber content, having several varieties grown in Brazil. It is one of the world's main crops, grown in over 100 countries, and represents an important source of rural labor in these countries. However, around 80% of the planet's production is concentrated in around ten countries despite this worldwide diffusion.

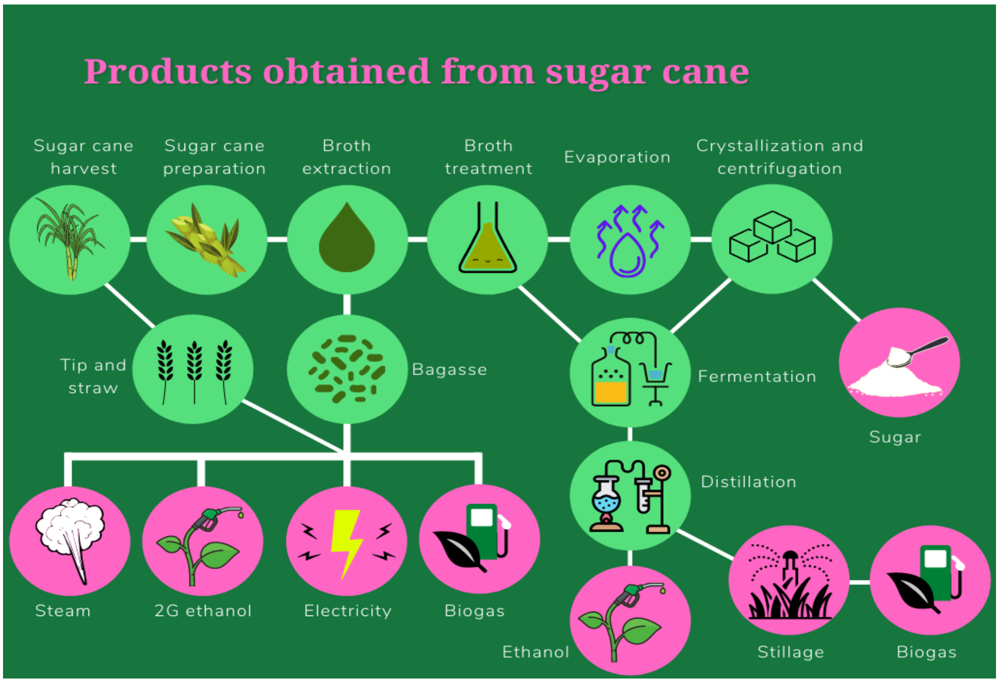
Brazil is one of the most traditional sugarcane producers in the world, producing more than 650 million tons per year, being also in a privileged position concerning other producing countries, as it has advanced knowledge of the production process of the crop and at the same time, from a technological point of view, the use of ethanol as an agro-energy alternative. As a result, it is estimated that by the year 2050, the annual production of sugarcane should reach around 1,050 million tons (Tolmasquim, 2016). Of the total sugarcane produced in Brazil, around 54% is destined to produce almost 30 billion liters of ethanol per year, while sugar absorbs around 46% of the current harvest, generating around 42 million tons of sugar. The Southeast is the main sugarcane-producing region in Brazil (especially São Paulo and Minas Gerais states), followed by the Midwest, South, Northeast, and North. The Northeast region of Brazil, despite being favored by the climate, is responsible for the production of about 51 million tons per year.

Sugarcane is a plant made up of four main parts: roots, butchery (agricultural fruit), leaves, and flowers. Its composition consists mainly of fiber and juice, in which the juice is made up of water, soluble solids, or Brix (formed by sucrose, reducing sugars, and salts, the latter two being considered impure substances). Commercial sugarcane varieties are complex hybrids of several species, and the best-known species is *Saccharum officinarum*. It is estimated that for each ton of cane that is crushed, around 250 to 270 kg of bagasse are generated with humidity around 50%, with a lower calorific value of $2257 kcal.kg^{-1}$, so that one ton of cane contains the energy equivalent to 1.2 barrels of oil, with about 1/3 of this energy being chemically stored in the juice (sugars) and the rest in sugarcane biomass: approximately half in bagasse and half in straw (Gomes and Maia, 2012; Tolmasquim, 2016).

The amount of sugar contained in the cane is determined using the ATR index (total recovered sugar), which is a unit of measure widely used in the sugarcane industry, since the amount of ATR present in the cane will influence the remuneration and the number of products (sugar and ethanol) that can be obtained. Historically, sugarcane improvement programs prioritized increasing the sucrose content, developing regional varieties, adapted to specific environments (Novacana, 2016). Given this scenario of cellulosic ethanol development, efforts have been made to develop sugarcane varieties with higher fiber content at the expense of sugar content. Efforts in this direction are made using another species of cane, such as *Saccharum spontaneum*. The varieties developed from this species are called energy cane instead of sugar cane (Novacana, 2016).

Sugarcane biomass stands out for its quantity and economy, as its availability is due to the production of sugar and ethanol, products with huge domestic and international markets, especially in the case of sugar, which is a commodity (Tolmasquim, 2016; Longati et al., 2020). The offer of sugarcane biomass has a seasonality, due to the plant's maturation cycle, which restricts its availability to a certain period of the year. In the central-south region, the sugarcane harvest is carried out, approximately, between the months of March and October. In the north-northeast region, the harvest occurs approximately in the off-season period in the central-south region. This difference is explained by the climatic conditions of these two regions. The use of sugarcane for the production of sugar and ethanol gives Brazil, as well as other countries whose climatic conditions allow its cultivation, a huge competitive advantage over other world producers, who use corn to produce ethanol (such as the States United States) and sugar beet and ethanol (in the case of Europe), which are the two main competing crops. In Brazil, ethanol and sugar production plants are large industries, capable of processing up to 10 million tons of sugarcane, as in São Paulo.

In addition to the high productivity of sugar and ethanol per area, sugarcane provides a significant volume of biomass for the production of second-generation ethanol and use as fuel for the generation of steam and electricity, which makes sugar and ethanol plants energy self-sufficient and even exporters of energy (Novacana, 2016), as outlined in Figure 1.



It is estimated that 10 to 15 liters of vinasse are generated for each liter of sucrose ethanol produced, a residue with an acidic pH and a high organic and nutrient load (Ventorino et al., 2018; Longati et al., 2020). Due to its composition, rich in potassium, nitrogen, phosphorus, and organic matter, the vinasse produced in Brazil is destined almost entirely for irrigation of areas cultivated with sugarcane, having high fertilizing power. Thus, it is the simplest and cheapest solution to dispose of such a voluminous amount of waste, without agreeing with current Brazilian legislation prohibiting its direct disposal in water sources. However, this use must be carried out with caution, as it can alter the characteristics of the soil, causing salinization and altering microbial respiration, or even favoring the contamination of groundwater and surface water. At harvest time, the tip and straw have about 50% moisture, which can be reduced to about 15% after a week or two in the field. The total amount of straw and tip produced, per ton of sugarcane processed, is about 155 kg (15% moisture), according to Tolmasquim (2016).

Bagasse, tip, and straw can be stored in an open courtyard. On the other hand, stillage, residual effluent from the distillery, cannot be stored, as the action of wild microorganisms leads to uncontrolled bio digestion, with loss of organic load and potential fugitive emission of methane. Thus, its use is restricted to the period of operation of the distillery.

Biomass From Sugarcane By-Products

Bagasse is defined as the fibrous residue of the cane resulting from the last milling or pressing process of the cane, consisting of fiber plus residual juice. Bagasse is made up of cellulose, hemicellulose, and lignin. Its participation has been growing nationally due to the strong ethanol and sugar industry established on national soil. According to Longati et al. (2020), the bagasse generated in the sugar and ethanol production process from sucrose (first-generation ethanol) can be reused for the production of second-generation ethanol (2G ethanol), for energy production (thermal and electric), and for production of biogas, as we will see below. This scenario can be expanded with the reuse of vinasse generated in ethanol production for biogas and electricity production; however, this potential is still little explored and demands the improvement of the vinasse bio digestion technology for its large-scale use.

Concerning bagasse, the sugar-energy sector has shown a very mature technical level of use in this biomass's learning curve in cogeneration and self-supply of electricity by plants. Despite this, the technological differences between the production units are notorious, showing great variation in efficiency and capacity. Concerning the use of straw, there is an increase in its use by the mills due to the suitability of the mills regarding the legislation prohibiting burning in sugarcane fields. For this reason, straw has been the subject of economic, agronomic, and environmental studies to identify its real availability in production environments and potential use as fuel biomass or raw material for obtaining second-generation ethanol (Trombeta and Caixeta Filho, 2017).

Sugarcane bagasse can be used to feed ruminants, where the residue undergoes some treatments, such as chemical (which helps in the animal's digestion process) and especially steam under pressure (which has greater nutritional value, promoting a gain in weight in cattle and greater potential for milk production in cows). Sugarcane bagasse can also be used in civil construction, in the cement used. In this case, when burned, the bagasse has its fibers transformed into ash, which has a high concentration of silica, which, when in contact with water and together with hydrated lime, it forms a binding compound that hardens. Thus, a cement with resistance similar to that produced in industries is produced. Land fertilizer is another destination for sugarcane bagasse, which avoids using inoculants or mineral fertilizers in the soil. This type of fertilizer involves millions of soil microorganisms, which use fresh organic matter (bagasse) as a source of energy and food.

Production Of 2g Ethanol from Sugarcane Bagasse And Straw

The development of energy cogeneration from biomass, driven by the Brazilian Incentive Program for Alternative Sources of Electric Energy (PROINFA), has placed the sugar-alcohol sector on a new level of importance. For this reason, today's mills are not just sugar and alcohol industries, but biorefineries, as sugarcane bagasse and straw have great potential as a renewable source of energy, not only in boilers for generating heat and electricity for the obtaining alcohol and sugar from sucrose, but also in the generation of surplus electricity that can be traded, in addition to the production of second-generation (2G) ethanol.

The 2G ethanol, or bioethanol, is produced from lignocellulose present in the plant-derived waste. The bagasse used as raw material in the production of 2G ethanol uses the process of acid or enzymatic hydrolysis, in which the cellulose and hemicellulose fractions are converted to hexoses and pentoses. After purification processes, the mixture obtained can be fermented to produce biofuel. The development of 2G ethanol production technologies has been important and necessary worldwide to minimize competition for land use for energy generation and food production, especially in places that do not have a favorable climate or territorial extension for cultivation. Added to this is the fact that ethanol is globally considered a clean and renewable source of energy and an alternative to supplying the scarcity and consequent rise in fossil fuel prices, contributing to the reduction of greenhouse gas emissions. Furthermore, despite emitting CO_2 during the production and burning of ethanol, sugarcane cultivation can capture CO_2 from the atmosphere to generate biomass, representing an environmental gain compared to gasoline.

Figure 2 shows the scheme for obtaining 2G ethanol from sugarcane bagasse. After using sugarcane juice in the first generation, the bagasse, the tip, and the straw are used in the hydrolysis process, as these by-products still contain sugars to produce ethanol. In addition, these residues contain cellulose, lignin, and hemicellulose. Initially, the by-products are treated to be used as raw material in enzymatic hydrolysis. Thus, residues that can affect the production process and reduce production yields are separated, ensuring a better quality of the final product.

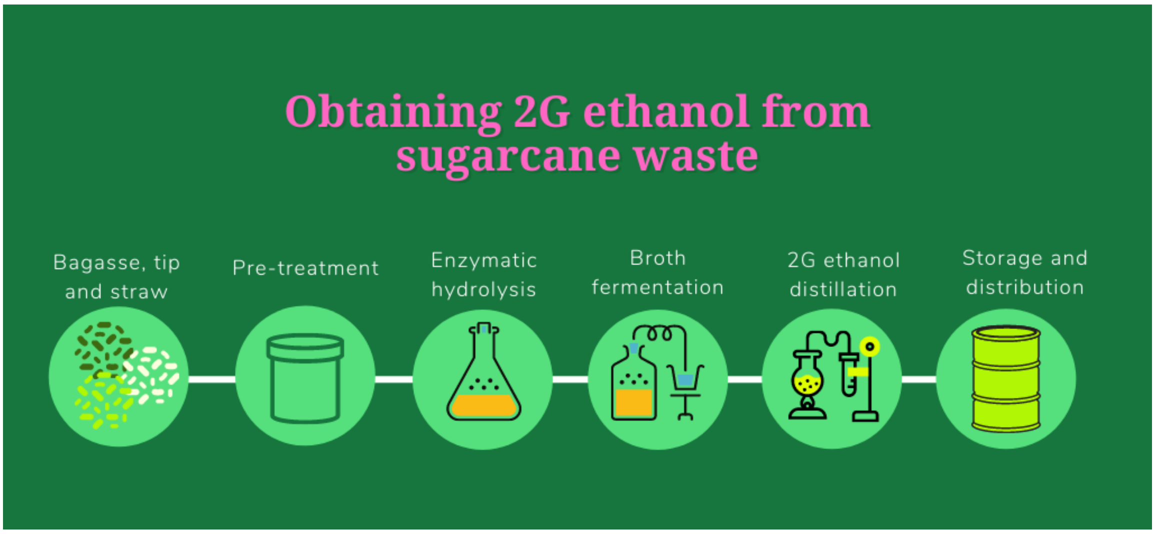


Figure 2. Stages of the process for obtaining 2G ethanol from sugarcane residues. Source: the authors.

In enzymatic hydrolysis, specific enzymes break down cellulose and hemicellulose molecules, converting them to sugars such as glucose. Lignin gives fiber resistance and protects cellulose from the action of microorganisms, but it has great inhibition of the fermentation process and does not contain sugars, which is why it is discarded. Furthermore, enzymes can only be used once in the hydrolysis process. They are soluble in water and, thus, end up being discarded, making the production route more expensive. In addition, the temperature of this stage of the process is low, around 40ºC to 50ºC (Propeq, 2020). The action of enzymes on the pre-treated waste in the hydrolysis step results in a liquid that is taken to traditional fermentation by yeasts that transform, in different tanks, the two types of sugars into ethanol. Yeasts such as Saccharomyces cerevisiae are used, due to the desirable and efficient characteristics they have for an industrial fermentation of sugars. At the end of fermentation, the distillation for physical separation of 2G ethanol is followed by heating the fermented homogeneous mixture. Finally, the 2G ethanol is ready to be stored and distributed to the consumer market.

Production Of Heat and Electricity from Sugarcane Bagasse and Straw

The process of burning bagasse in the plant's own boilers is called the cogeneration cycle, which is the combined generation of heat and electricity, with useful use of both forms of energy. According to Tolmasquim (2016), cogeneration is used to generate steam and bioelectricity consumed in the sugarcane industry's sugar and ethanol production processes. The steam mechanically drives the mills and choppers to process sugarcane stalks and in the sugar and ethanol manufacturing processes. In modern plants, the mills and choppers are electrified, which reduces the demand for steam and allows it to be directed to electric generation in specific turbines, thus making the plant energy self-sustainable and, in some cases, there is more energy for electricity sales. Sugarcane bagasse is the main biomass used for electricity generation in Brazil.

Traditionally, the configuration of the steam cycle adopted in the sugar and ethanol mill was that with backpressure turbines, and no surplus of bioelectricity was generated for commercialization. Improvements in this configuration allowed the generation of surplus bioelectricity. However, the plant remained limited to operating only during the harvest, when there was a demand for steam. Subsequently, introducing the condensing turbine in the steam cycle and allowing greater efficiency in an electrical generation made it possible to generate off-season (Tolmasquim, 2016). The high productivity achieved by sugarcane farming has made available an enormous amount of organic matter in the form of bagasse in sugarcane mills and distilleries, interconnected to the main electrical systems, which serve large consumption centers in the South and Southeast regions (Rípoli et al., 2000). Thus, the generation of bioelectricity surpluses, mostly from sugarcane bagasse, and its sale in the regulated and free markets are a reality on the national scene.

The participation of straw and sugarcane tips in electricity generation tends to be even more significant over time, since fires to facilitate manual harvesting have been inhibited (as they cause atmospheric pollution) through legislation and established agreements between public authorities and private initiatives to replace burning with the mechanization of harvesting. Thus, with mechanized harvesting, straw can also be used as fuel for cogeneration, increasing the amount of sugarcane biomass and generating surplus bioelectricity. In addition to being clean and renewable, bioelectricity is generated close to electricity-consuming centers and is complementary to hydroelectric generation. For example, the potential for electricity production from sugarcane bagasse and straw is estimated at an average of 20.2 GW by 2023 (Unica, 2020).

From January to July 2020, bioelectricity production in general for the grid reached 14,284 GWh, representing a 7% growth compared to the same period in 2019. This volume includes the generation of electricity for the grid by different types of biomass, and sugarcane biomass represented 11,339 GWh (or 79% of the amount of energy generated by biomass to the grid in the aforementioned period). Of the 366 sugar and ethanol mills in operation in 2019, 220 traded electricity (60% of the total plants) (Unica, 2020).

Biogas Production from Sugarcane Vinasse

Most of the vinasse, coming from the distillation process when producing ethanol, is used directly for ferti-irrigation. Since the 1970s, the energetic use of vinasse through anaerobic digestion for biogas production has been used in some distilleries to produce biomethane for vehicle fuel and generate electricity (Ventorino et al., 2018). However, several of these projects were discontinued, and the anaerobic bio digestion of vinasse did not become a common practice. It is important to note that the bio digestion of vinasse does not remove its fertilizing power; it only converts a percentage (60-80%) of the organic load into biogas, so that the resulting effluent can still be used in ferti-irrigation (Tolmasquim, 2016). Biogas is a clean source of electricity generation and can also be transformed into biomethane, similar to natural gas and a renewable substitute for diesel oil derived from petroleum. In addition, biogas can be produced from vinasse, straw, and filter cake in a sugar-alcohol plant, residues from the industrial process (Longati et al., 2020).

Until 2019, the biogas production sector in Brazil had 524 power plants in operation, producing 1.3 billion m^3, but the production potential is 84.6 billion Nm^3/year, and the sugar-energy sector can generate the corresponding to 41.4 billion Nm^3/year and the agribusiness sector to 37.4 billion Nm^3/year (Unica, 2020). Biogas production is considered viable even for smaller sugar and ethanol plants (with crushing starting at 1 million tons of sugarcane per harvest). It is estimated that investments in a biogas plant in a plant that processes 1 million tons of sugarcane are between R$15 million and R$20 million. On a national level, biogas production should be boosted in the coming years by the reforms being discussed in the sector and by the strengthening of the *RenovaBio* Program. It will be precisely the sugar-energy sector that should boost the potential of this market in Brazil, due to the quality of its waste, greater investment capacity, and experience within the energy sector. The sugar and ethanol sector should create local structuring gas pipelines for transporting biogas from the production plants to the consumer market. Differently from what happens in the distribution of natural gas, which is highly concentrated on the coast due to the proximity of exploration of the oil basins, biogas from the sugar-energy sector will have a greater concentration and distribution in the interior of the country, contributing even more to economic and social development cities located in these areas.

Production Of Eco-Composite Material from Sugarcane Bagasse

Nowadays, the use of raw materials and the destination of their residues have caused a lot of concern to the world, as many of these materials and their respective disposals have caused serious environmental impacts as many of them are derived from fossil sources and take a long time to suffer degradation. In this sense, there is a need to minimize these effects practically, so that people, from a growing ecological awareness as consumers, can reduce the consumption of products from non-renewable and non-biodegradable sources. Since the 1970s, fibers and fabrics have been used in the reinforcement of polymers, giving rise to polymeric matrix composites, and are currently considered excellent engineering materials, being used in various segments, such as: aeronautics, wind, marine, electric, oil, and gas, sports, etc. By definition, a composite material is a macroscopic combination of two or more distinct materials having a recognizable interface between them. This mixture intends to obtain a material with superior and unique properties concerning the individual properties of its constituents.

Currently, there is a strong trend towards using natural fibers to reinforce polymeric materials, giving rise to the so-called eco-composites, as an attempt to reuse agricultural and industrial waste to manufacture various products, such as furniture, floors, and floors, coatings. Cars, acoustic insulating panels, toys, vases, etc. The use of vegetable fibers in the reinforcement of composites is not recent, and the first patents date back to the 1970s. The vegetable fibers most used as reinforcement material in polymer composites are sisal, coconut, jute, and banana fibers, in addition to fibers of wood, bagasse, and bamboo. Inorganic fibers such as fiberglass or mica are very expensive compared to fiber from wood and other vegetables. In most cases, the replacement of fiberglass by natural fibers is desired due to a series of advantages: they are renewable resources and are available in large quantities; are biodegradable; have a much lower abrasive nature; are recyclable; are low cost; stimulate rural employment; consume little energy in their production and may also exhibit natural microbiological resistance.

Among the limitations of natural fibers, the following can be mentioned: marked variability in mechanical properties; low dimensional stability; high sensitivity to environmental effects such as temperature and humidity variations; they are significantly influenced by soil function, harvest time, post-harvest processing, and relative location in the plant body; they withstand low processing temperatures, that is, they do not tolerate more than 200°C during consolidation within the matrix of a composite. In 2010, a study was initiated by the Production & Sustainability research group, from the Federal Institute of Pernambuco (IFPE), led by Prof. Juliana Lucena, using natural fibers in the reinforcement of composite materials, to produce ecological materials from plant residues from the municipalities of Ipojuca-PE and Cabo de Santo Agostinho-PE, such as sugarcane bagasse from the region's mills, green coconut, discarded as garbage on many beaches near the campus and also sawdust from various local logging companies, as shown in Figure 3.

Figure 3. Fibers from wood, green coconut, and sugarcane bagasse, respectively, were used in research with eco-composite material by the IFPE research group. Source: Lucena and Silva (2011).

In this study conducted at IFPE, the thermoplastic resin was used as polymer matrix as well as a curing agent (methyl-ethyl-ketone peroxide, MEKP), as a catalyst, following the procedure outlined in the flowchart in Figure 4, for the treatment of bagasse fiber and subsequent lamination of samples of eco-composite.

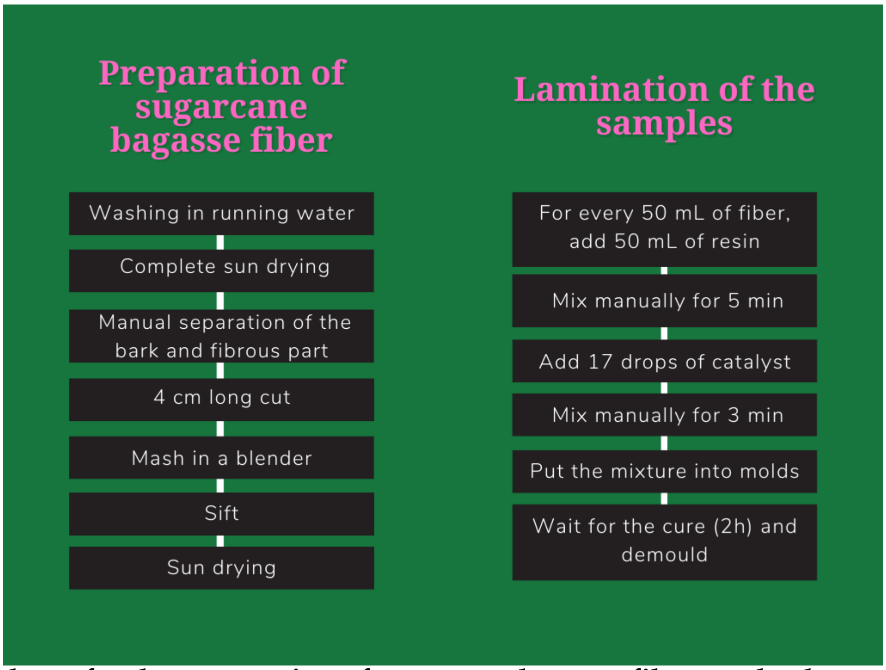


Figure 4. Flowcharts for the preparation of sugarcane bagasse fibers and subsequent manual lamination of the eco-composite samples studied at IFPE in Brazil. Source: Lucena and Silva (2011).

As the structure and nature of the fiber-matrix interface play an important role in the mechanical and physical properties of composite materials (because it is through this interface that the charge is transferred from the matrix to the fiber), it is important to ensure the proper proportion of fiber/resin in the composite. If there is an excess of fiber, the composite will be dry, losing properties; if there is an excess of resin, the composite does not lose mechanical properties because there is little reinforcement material. Thus, the maximum fiber contents obtained experimentally in this research are shown in Table 1, for each type of fiber studied.

Table 2. The fiber content concerning mass obtained for the eco-composite samples laminated at IFPE.

Fiber type	Fiber mass fraction (%) in the composite
Wood sawdust	19.8%
Green coconut	6.0%

Sugarcane bagasse	10.0%

Source: Lucena and Silva (2011).

One of the biggest problems in using sugarcane bagasse as reinforcement in composites is the low adhesion between fibers and polymer matrix, which makes the positive effect in improving the mechanical properties of the composite less effective. To guarantee the quality of the manufactured products, it is very important to ensure that the fibers are free from moisture and dirt. Sieving is also a fundamental step in manufacturing eco-composites because it guarantees greater uniformity of the fibers used. The amount of catalyst is also important to control as an excess catalyst will overheat the product during curing and can form bubbles inside the material. On the other hand, too little catalyst may not be enough to cure the resin or may increase the product's curing time by several days.

Fiber treatment involves a series of important steps that determine the final quality of the composite obtained. In addition to choosing the type of fiber to manufacture an ecological composite, other parameters must be considered: fiber size, mass fraction used, amount of curing agent, curing and post-curing time, and temperature. Thus, the fiber treatment step must be carefully carried out, with adequate control of these parameters, use of adequate equipment, and technique, which will interfere with the final result of obtaining the samples. The great contribution that this work developed at IFPE managed to achieve was with the issue of recycling these vegetable residues that are being underused by society, which can replace the use of non-renewable raw materials, thus contributing to the environment both in consumption and in the final destination of waste. With this study, it was possible to understand the vegetable fibers better and obtain a specific method for treating the studied fibers and the lamination of the composite. Future work may be conducted to understand these composites' mechanical properties better, aiming at structural applications.

CONCLUSIONS

This work showed that the use of sugarcane biomass in Brazil reflects the historical importance of the sugar-alcohol industry for the country's economy and, in recent years, it has stood out in the bioelectricity and biofuels segment, bringing several regional and national benefits by contributing to the sustainable development of remote and agricultural regions, where a large part of the mills is concentrated. The sugar-energy sector has been standing out as the supplier of raw material with the greatest energy balance for ethanol production and the by-products generated in sugarcane processing. Such by-products, mostly discarded until a few decades ago, have become potential inputs for the cogeneration of electricity and for the production of 2G ethanol, through the hydrolysis of bagasse (after the crushing of sugarcane, being the largest residue of the Brazilian agroindustry) and straw (left in the field during mechanized harvesting). Furthermore, the various uses of bagasse, straw, tip, and vinasse allow the mills to be considered self-sustainable biorefineries, since all the energy they demand comes exclusively from sugarcane, with possibilities to sell the surplus electricity produced.

Bioelectricity offered by the sugar-energy sector represents a strategic generation for Brazil, as it is equivalent to 5% of annual energy consumption and is a clean source that avoids the emission of $CO2$, a non-intermittent generation that generates security for the country's energy system. In addition, the generation of bioelectricity from sugarcane manages to save the use of water in hydroelectric reservoirs during the dry and critical period for the Brazilian electricity sector, due to its greater predictability and availability.

Despite all the advances in sugarcane biomass experimented on in Brazil, there is still an opportunity for a wide use of bagasse and other by-products by the sugar-energy sector. Therefore, investments in research for the development of new technologies and improvement of those already developed for the production of biofuels and bioelectricity, as well as better planning and sustainable use of energy from biomass, should be prioritized in the country, given the advantages for society, economy and the environment offered by sugarcane biomass. The study with eco-composite materials from sugarcane bagasse fibers reinforced the possibility of recycling underused vegetable waste to replace the use of non-renewable raw materials, contributing to sustainable development both in consumption and in the final destination of waste.

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