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9

SUGARCANE TRASH AS FEEDSTOCK FOR SECOND GENERATION PROCESSES

Edgardo Olivares Gómez, Renata Torres Gomes de Souza, George Jackson de Moraes Rocha, Eduardo de Almeida and *Luís Augusto Barbosa Cortez*

INTRODUCTION

The stage of development reached by the sugarcane industry in Brazil, mainly focused in the production of ethanol, has increased attractiveness in surplus bagasse through more advanced agricultural and industrial technologies, as an integral or partial recovery of sugarcane agricultural residues – SAR, basically trash, or of some of its fractions (e.g. straw and green leaves).

This vision of agro-industry development is innovative in its implementation and it could increase the gains through an important increase in energy production, based on a thermo chemical process e.g. cogeneration in the electricity, or a biochemical process to produce ethanol, in addition to many direct or indirect by-products, without additional increases in the area of sugarcane plantation. This new concept known as "integral use" will improve current productivity of ethanol per hectare of sugarcane, increasing the overall production of renewable energy during the phase of ethanol production while reducing environmental impacts.

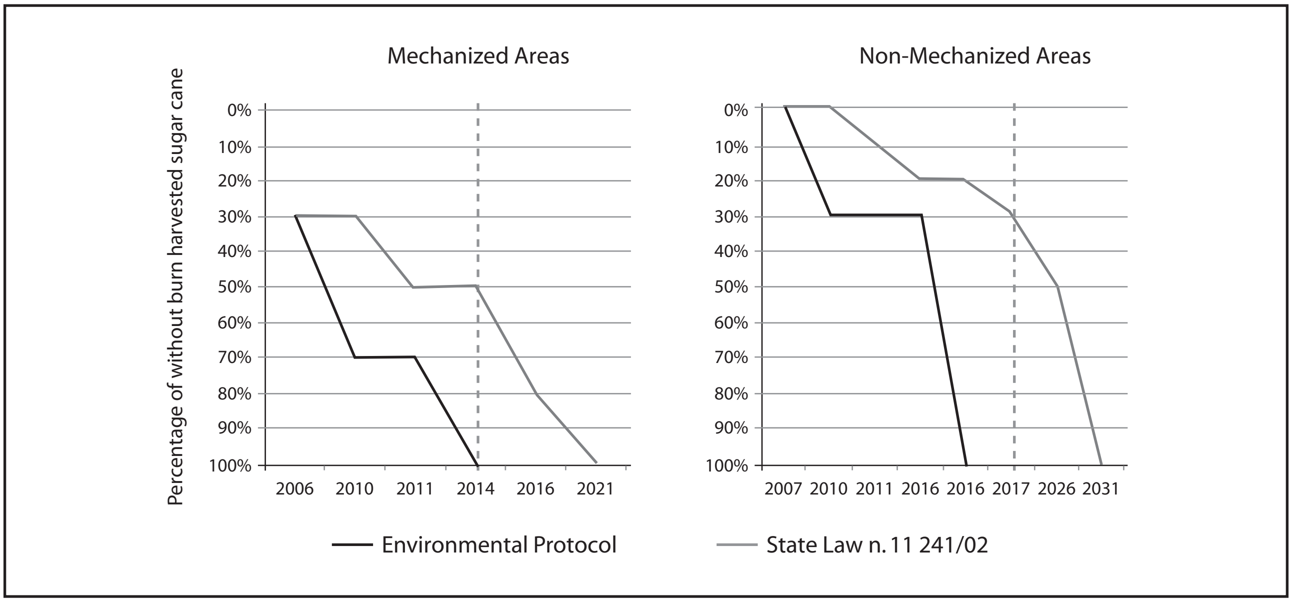
The lignocellulosic raw materials obtained as a result of the crop and the industrial processing of the sugarcane during the production of sugar and ethanol (bagasse and general residues – SAR) shows a high potential for energy production, can be obtained through conversion technologies based on biochemical routes (hydrolysis) and termochemical (combustion, pyrolysis and gasification).

By 2031 the whole sugarcane trash generated during harvesting in Brazil could be available for recovery and subsequently used. Methods of sugarcane crop and trash usage should be implemented by that time economically. At the time, cleaning systems, with recovery of straw should also be part of the industrial package of the sugar and ethanol mill. Sugarcane trash should become as important as bagasse, as a feedstock for the production of fuels and chemical products.

This chapter aims to contribute to recent thinking of how best to use sugarcane residues – SAR, based on the expectation of generation of large amounts of lignocellulosic biomass, which should be available in the next years; and partly due to law enforcement prohibiting cane burning in Brazil. This chapter assesses the technical and economical evaluation of some possible ways to utilize sugarcane residues. It discusses sugarcane residues and the main physiochemical and energy characteristics. It also considers the usage of these materials focused on the generation of energy through combustion. The base for such discussions are results obtained from research accomplished undertaken at universities, research centers and private sector primarily in the sugar and ethanol mills.

THE LAW OF SUGARCANE BURNING IN BRAZIL – TRASH HARVESTING AND RECOVERY

In Brazil, when sugar and alcohol began to be produced in a large scale producers found sugarcane burning as the easier solution to increase the yield by manual harvesting.



Note: Mechanized areas have slope less of than 12%.

Source: Adapted from UNICA, 2007.

FIGURE 1 Phasing out trash burning in the São Paulo State.

However, aware of the environmental damage caused by burning this situation is changing as a result of public pressure, and even through trade unions and other associations, sanctioning laws aimed to control or phase out burning.

At the federal level, sugarcane burning is regulated by Decree n. 2 661/98, which concerns mainly with phasing out burning in areas where harvesting can be done mechanically.

The São Paulo State Law n. 11 241/02 is more restrictive than federal laws, and aims to phase out burning both in manually mechanized harvested areas. The law aims at phasing out burning in non-mechanized and mechanized areas by 2021 and 2031, respectively. Within this context, the São Paulo State signed, in June 2007, a cooperation protocol between the State Government, the Department of Agriculture and Supply and the Union of Sugarcane Industry – UNICA. This was a major step toward for ending sugarcane burning, putting forward previously agreed deadlines set by state law (Figure 1).

It should be noted that this protocol has been signed by 155 mills located in the state, representing 90% of the sector in São Paulo, and over 24 sugarcane supplier's cooperatives (UNICA, 2009).

It is also worth noting that the São Paulo State is leader in this sector e.g. in 2007 produced approximately 60% of sugarcane planted in Brazil, compared to the second larger producer, Paraná State, with about 8% (IBGE, 2009). Other states, such as Goiás and Mato Grosso, there are also similar initiatives to phase out sugarcane burning (BNDES and CGEE, 2008).

Therefore, we can say that in a short period of time, there will be availability large amounts of sugarcane trash; there are two main options available, not necessarily exclusive: i) leave sugarcane trash in the field or ii) recover it as a raw material for of fuels or chemicals.

Sugarcane trash in the field

Regarding the effects of trash[1] left on the field, CALDEIRA (2002) pointed out the positive aspects to the soil, in terms of erosion control, moisture retention, improved biological, chemical

[1] Trash is material left in the field after harvesting; this is particularly the case with mechanical harvesting. Trash, consists of green and dry leaves, tops and fractions of stems, roots and soil particles attached to them (RIPOLI, 1991).

and physical properties arising from decomposition of crop residues on the soil surface.

On the other hand, FRANCO (2003) citing CALDEIRA (2002), emphasizes that leaving the trash in the field can cause problems such as delay in the budding due to the lower incidence of light, coupled with an decrease in soil temperature and humidity with consequent spread of disease, immobilization of nutrients, especially nitrogen, which can affect the yield; difficulties in operating machinery for implementation of cultural practices, operational problems, causing injuries and loss of stumps, and higher incidence of pests,a among other problems.

To minimize problems associated with sugarcane trash, studies have been carried out to assess the optimum amount of trash that should to left in the field. HASSUANI *et al*. (2005) recommended that about half of the trash be kept on the ground to reduce erosion, recycle nutrients and maintaining a minimum level of moisture in the soil. The documents on sustainability organized by CTC (2005) recommend the amounts of trash be between 7.5 and 9 t/ha to promote an efficient control of the most common herbs. Species that do not depend on light or change in soil temperature for germination are not controlled by trash. Following are recommendations concerning maintenance or removal of trash on the soil according HASSUANI *et al*. (2005). The trash should be removed in the following situations:

- In areas inhabited and/or near to roads due to the risk of accidental or criminals fires.
- In areas subject to risk of electrical storms (relief tops).
- Before preparing the soil, in areas suffering from soil pest infestation, requiring the complete removal of culture wastes.
- In areas of very wet winter, especially in soils with poor drainage that affect sprouting.

Trash may be removed after a technical-economic analysis in the following cases:

- In places with planted varieties whose sprouting failures are caused by trash cover.
- In areas with high infestation of pests favored by the trash in the absence of effective biological control.
- In places where the soil tillage cannot be used by the occurrence of uncontrolled plant infestation by trash or soil pests whose control depends on the soil movement.

The trash may be partially removed in the following cases:

- During or after sugarcane harvesting leaving the total amounts of trash (> 7.5 t/ha) evenly distributed aiming to produce the herbicide effect.
- In a region of approximately 60 cm above the rows of sugarcane varieties with low ability to sprout under the trash and subject to loss productivity.

The study organized by CTC (2005) concludes that trash removal can be an advantage or disadvantage depending on the agronomic conditions involved, and should be balanced, depending on specific situations and overall costs and benefits involved.

Trash recovery

Currently, the widespread use of technology for harvesting chopped cane may also allow trash recovery by two ways: recovering the trash in the field during the harvesting operation by harvester extractor, or full harvest recovering where the trash is processed by the harvester, with industrial stems and loaded later on trucks for subsequent transport to the mill (CORTEZ *et al*., 2008). Thus, in the short term the following trash recovering routes can be considered: in bulk, chopped bulk, densified and baling, and integrated harvesting.

In bulk

In traditional sugarcane harvesting, most trash is separated from the stalks by the harvester, through the pneumatic separation principle. The stalks and trash are thrown into a cleaning chamber in which there is an updraft generated by an axial flow extractor. With respect to the previously cited extractor, known as primary extractor, when programmed to operate in maximum rotation it separates most of trash and removing impurities from biomass, and then releasing them on the field. The trash and other impurities that are not removed, along with the stalks, are conducted to an elevator installed at the end the secondary extractor. In this extractor, the biomass undergoes a second process of separation and material that was not cleaned by secondary heavier extractor, is discharged into a transshipment located beside the harvester. The trash and other impurities that were separated by the secondary extractor are then laterally thrown out and left in the field. The secondary extractors are located at on top of discharge of the stalks, and then the separate impurities are released after the line where the transshipment is traveling.

It is possible to adjust the traditional sugarcane harvester with a duct that directs the separated material by a secondary extractor to a transshipment that would move alongside the transshipment of stalks and other materials not separated by the secondary extractor. Once reached processing location, the trash needs to be unloaded, cleaned, stored and forwarded to processing.

The main difficulties of this route is cost because raw trash density is about 60 kg/m^3, which leads to high transport costs even for short distances between crop and mill, unless cogeneration becomes economically more attractive.

Chopped in bulk trash

CORTEZ *et al.* (2008) state that when chopped in bulk the trash left on the soil undergoes a natural drying process and then it needs to be concentrated. After this step, the trash is recovered by a forage harvester that undergoes a process of chopping to size, approximately 10 mm in terms of average size particles. Then the chopper loads the trash in a transshipment to be transported by truck at a later stage to the processing units. Once it reaches processing unit, this material needs to be unloaded, cleaned, stored and forwarded for final processing.

This system has three major problems:

- The first refers to the technological level in the field, because this route leads to a drastic increase in trash contamination by mineral impurities due to the contact with the soil after harvesting which affect the raw trash quality, independent of the chosen technology for energy generation. In addition, agricultural machinery operations could cause serious soil compaction that may affect crop productivity.
- The second problem refers to technological level in the processing units because current trash equipment used for soil removing such as rotational and vibration sieves, is very inefficient in removing impurities, especially if trash has high moisture.
- The last difficulty refers to costs due to the low density of trash e.g. about 90 kg/m^3, that makes it economically unfeasible to transport trash to long distances, considering the low price for electricity from cogeneration.

Baling and condensing at low pressure

In order to mitigate the economic costs caused by low density trash in bulk, a route was tested in Santa Elisa Energy Company with a condensed cotton press system (LIMA, 2002).

In this mechanism, after receiving the chopped trash, the transshipment feeds the cotton press in the field. MICHELAZZO (2005) reported that the transshipment has a metering conveyor moved by a hydraulic motor to uniformly supply the press. Subsequently, the press operates in an intermittent consolidation process of low pressure in stationary units, where the own bale weight, due to its large size, ensures higher density. The bale is then transported by a special truck to the mill.

During the baling operation, the trash is recovered by the baler, at low pressure and mooring after, because the bales may become loose again. The bales are then released by the baler and left the field to be later loaded and transported to the processing unit. After transporting to processing unit, the condensed or baled raw material needs to be unloaded, unpackaged, cleaned and sent for processing.

Other the technological problems are very similar to those described in the case of chopped trash recovery in bulk: a large amount of mineral impurities is brought to the process unit, and thus it is important to solve these problems, as well as soil compaction.

Analyzing the technological difficulties facing the mill, the task of baling and compacting remains unfavorable when compared to recovery of chopped trash in bulk, because there is at least one further step that the mill needs to take, that is, uncompacting and loosing up the raw material. This is even more critical because bales are often kept together by strings, which can cause problems when processing the feedstock.

In mills that have tested this system, the bale is uncompacted with a knive chopper, which normally has high costs caused the need to change the knife and high energy consumption because its high horsepower; and also because limitations in losing up the bales to sizes that do not cause problems in traditional boiler feeders.

As far as economics go, this alternative has greater potential to enable transport to longer distances between cane fields and processing unit, as the bales density may reach up 200 kg/m^3. However, it is important to keep in mind baling or condensing operations are responsible for a significant cost in raw material.

Whole harvesting

In order to promote trash recovery during whole harvest, the harvester must operate with the prime and/or secondary extractors working partially (on and off). The prime extractor has a rotational speed control, unlike the secondary extractor that has only on-off control.

In this system the biomass unloaded at the mill feed table has the same components as sugarcane fully harvested under normal harvest conditions, such as stalk, leaves (green and dry), stumps, palm and mineral impurities. The only difference is when the extractors are off or working partially and thus the amount of trash in the mill will be higher and needs to be separated in the mill's receiving sector to avoid damaging extraction.

There are two well known industrial systems in Brazil able to perform the separation of sugarcane with light impurities (trash + soil) on an industrial scale (a feed table system, of approximately 450 tons of biomass per hour in a normal harvest). In both systems, most of the organic impurities such as palm and stumps are not separated otherwise a good proportion of stalks would be lost before reaching the extraction process.

The physical principle used is pneumatic separation inside a cleaning chamber and then depressurizing the separated material to be retained by channels/mats and transported for processing.

The difference between these systems is significant, caused by the air flow in the biomass: the first separation system is biomass counter-flow because the fans are located below the feed table taking advantage this structure; the second step is done by the separation of biomass curtain by air – flow as the fans are located below the drive shaft of the table. Both suppliers reported an average cleaning efficiency of about 70%.

To increase the removal efficiency a second air separation can be used between mats, or the adoption of mechanical cleaning by rotating brushes endowed with stalks to remove minerals and impurities adhered to cut sugarcane stalks.

SCHEMBRI *et al*. (2002) tested the efficiency of a cleaning system developed by SRI in Australia, which also uses the pneumatic separation as physical principle. The test results indicated that the cleaning efficiency of the system is affected by the mass flow of air applied to the biomass and the moisture content of the biomass when feeded.

Costs of trash recovery and transportation

FRANCO (2003) citing RIPOLI *et al*. (2003), argues that what is intended with trash recovery studies is to obtain information on two key issues: which system has the lowest cost per ton and what is the percentage of soil impurities in the trash at the mill. However, the authors believe that the most important issue is the energy cost of the trash and which system has better energy efficiency. This may occur because, although the cost per ton of a particular recovery system can be lower, the overall energy cost may not present any advantage.

TABLE 1 Technical parameters of cutting, loading and transport.

Trash (Mg, dry basis)	Reference	Rote 1	Rote 2	Rote 3
Amount of trash in the canefield	180,697	180,697	180,697	180,697
Trash transported with cane	43,909	43,909	170,759	127,934
Trash left in the field after harvesting	136,788	136,788	9,938	52,764
Baled trash	–	114,902	–	–
Trash left in the field	136,788	21,886	9,938	52,764
Trash removed in the cleaning station	–	–	119,531	89,554
Total trash available at the mill	–	114,902	119,531	89,554

Source: Adapted from HASSUANI *et al*., 2005.

Based on these observations, the Sugarcane Technology Center (CTC) published (see HASSUANI *et al*., 2005) a balance sheet of trash recovery costs of three studies. The chosen routes were:

1. Green sugarcane harvesting (unburned cane) with connected harvester fans, leaving all trash on the field for later baling (Route 1) – (Reference Route).
2. Green sugarcane harvesting with disconnected harvester fans, and collecting all trash together with sugarcane, for later separation at the cleaning station (Route 2).
3. Green sugarcane harvesting with disconnected secondary harvester fans, collecting only part of trash together with sugarcane, for later separation at the cleaning station, and the rest left on the field (Route 3).

The results found in experiments carried out by the CTC are shown in Tables 1 and 2.

MICHELAZZO (2005) studied various ways of transporting trash whose results are shown in the chart (Figure 2).

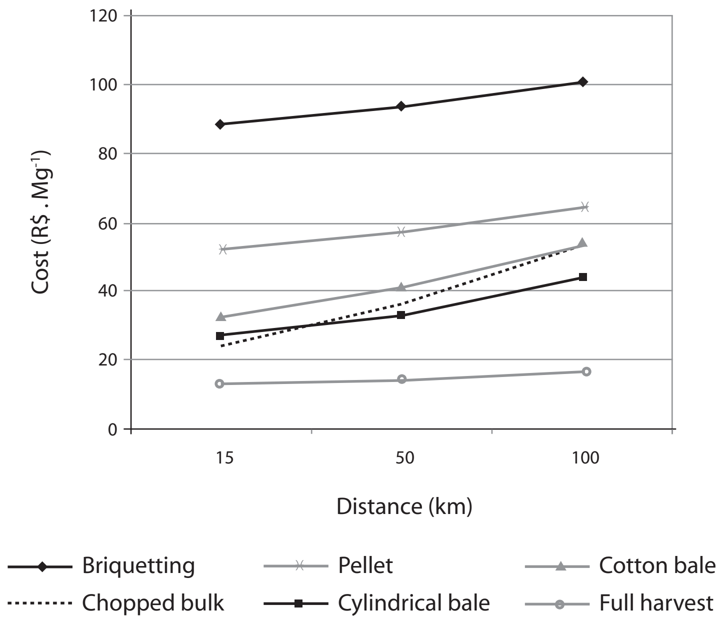
From Figure 2, MICHELAZZO (2005) concluded that transport distance has a major influence on the cost of trash recovery, as increases significantly with transport distance. He concluded that the type of system use should be based on the distance from where the trash will be collected.

TABLE 2 Trash total cost.

Items	Rote 1	Rote 2	Rote 3
Trash available in the cane field (Mg db/year)	180,697	180,697	180,697
Trash recovered (Mg db/year)	114,902	119,531	89,554
Recovery efficiency (%)	64	66	50
Cost of trash (U$$/Mg db)	18.49	31.12	13.7
Cost of trash (U$$/GJ)*	1.06	1.79	0.79

* HHV, dry basis.

Source: Adapted from HASSUANI *et al*., 2005.



Source: Adapted from MICHELAZZO, 2005.

FIGURE 2 Estimated costs of trash recovered in various systems, for distances of 15,5 and 100 km.

Various systems can be used, in accordance to the distance to be transported and the trash purpose.

If the trash is intended to generate energy, and production areas are located near the mills, a good option would to recover the trash with chopped or whole harvesting that has lower costs (MICHELAZZO, 2005). However, if the trash to be recovered is produced far from the mill and its purpose is to sell to third parties (i.e. as poultry litter or mulch) the baling systems would be more appropriate.

Trash impurities

The main impurities present in the sugarcane are soil particles, according to FRANCO (2003), citing BRAUNBECK and BIANCHI (1988) and SARRIERA (1997); the main factors influencing the presence of soil impurities are the methods used for loading and recovery e.g. type of harvester, soil type, sugarcane variety, level of exudation, number of sugarcane cuts, loading, to load the trucks, among others. FRANCO (2003) citing RIPOLI *et al*. (2003), points out that the attached soil in the remaining crop after harvesting is mainly due to the action of basal cutting discs and harvester ventilation systems, which lead to the accumulation of soil particles, making them one of the trash constituents given the nature of trash in the ground. Then, depending on the type of recovery used, the amount of soil can be minimized or increased. RIPOLI (2003) studied three trash recovery systems and found that 4.5% of soil was in the recovered trash in bulk, 1.39% occurred during whole harvesting and 0.63% in baled trash. Finally it is noted that in the literature no studies were found on "tolerable levels" of impurities caused by use of machinery that could be transported with the trash, to ensure this material does pose any problem in the distillery.

DEFINITIONS, CHEMICAL AND MORPHOLOGICAL CHARACTERIZATION OF SUGARCANE RESIDUES – SAR

Solid materials, specifically those obtained from agricultural or industrialized biomass, be it in its natural form or resulting from any process of physical or chemical nature, are composed by a large amount of particles which may have different shapes and sizes and have specific physical characteristics (CORTEZ *et al.*, 2008). Under these circumstances the material is found in polydisperse shape, i.e., it is formed by a mix of physically different particles.

In order to obtain an effective performance of any polydisperse solid material it is crucial to master the physiochemical and energetic characteristics of the particles of the material. On the other hand, it is also necessary to understand the aerodynamics (or fluidynamics) of the particles movement on the equipment, where solid particles of polydisperse biomass, in two-phase systems and others, are worked on. That leads to the calculation of the final speed of the mix of the particles, of some fractions of the mix, or even a single isolated particle, with the aim to know the aerodynamics conditions and the drag force phenomenon which might influence the expected results.

In this case, aspects of the physiochemical, energetic, and fluidynamics characterization of the stover fraction, or of a mixture of leaves and straw without differing any kind of particle present in the agricultural residues of the sugarcane, is questioned. The morphological characterization is monitored have consistently proven that, in some cases, positive correlations have been observed between the results of the physical-chemical analysis and the SEM analysis, demonstrating how important it is for these analytical techniques to be available in research centres and universities so that theoretical studies on this area are carried out in greater depth.

Sugarcane residues – SAR: green leaves, straw and trash

The approximate composition of the sugarcane *in natura* is the following:

- Stem and green leaves: 8%
- Sheath and dry leaves: 20%
- Clean Stalk: 72%

A generic definition for the Sugarcane Agricultural Residues (SAR) considers residues "vegetal residues" left on the field, in a smaller or larger amount after the harvest, and are composed of straw, green leaf, sheath, tops, stalk, including the presence of mechanical impurities, such as roots and soil. This mixture is known as sugarcane trash. Following are the definitions for each of the residues constituents.

Definitions

The definitions presented in this chapter are for the purpose of explaining the different components of sugarcane residues, specifically for analytical aims.

Sugarcane straw

Sugarcane straw refers to the dry leaves and sheaths removed from stems or stalks during the cleaning process to help the plant grow healthier. Figure 3 illustrates the constituent parts of "raw sugarcane".

Sugarcane green leaves

They refer to the green leaves located at the top of the plant, varying from 30 to 35 leaves on each tip.

Sugarcane trash

It refers to the material collected from the ground after mechanical harvesting, where a

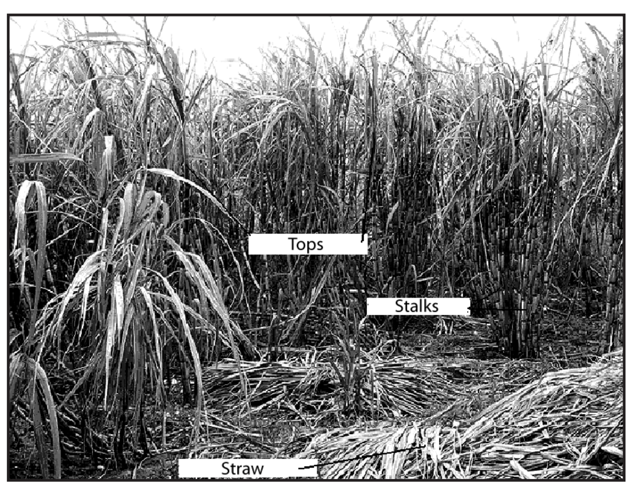


FIGURE 3 Constituent parts of the raw sugarcane at the crop.

greater concentration of a mixture of leaves and tops of sugarcane can be found. A large amount of lignocellulosic residues are left on the ground during mechanical harvesting. These residues, composed of a varied number of residual components after harvest is known as trash – basically green and dry leaves, sheath and leaves' tip, including physical impurities.

Chemical and morphological composition of sugarcane

Sugarcane straw comprises sheath and dry leaves – they have a particularly different structure from the green leaves found on the tops.

Chemical composition of the sugarcane straw

The chemical composition of sugarcane straw differs from the green leaves, trash and bagasse, mainly because the concentrations of lignin and ashes. Table 3 shows the chemical composition of the sugarcane straw.

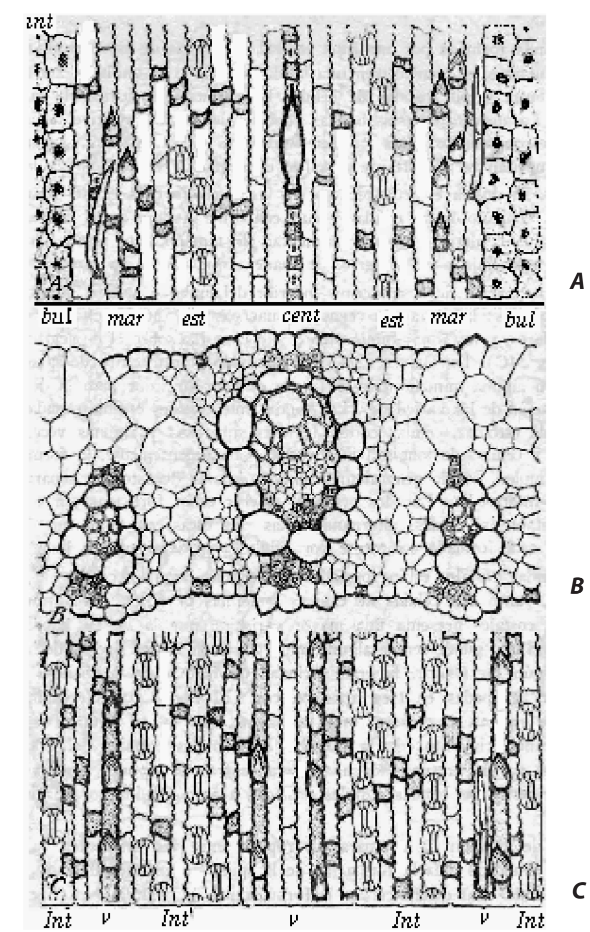
The amount of silica contained in the straw is two or three times as much as the amount found in the green leaves, causing a greater hardening and mechanical resistance in these parts of the plant. Consequently, the amount of lignin is approximately 60% smaller than those found in the green leaves. The most likely hypothesis is that the plant does not need to metabolize a lot of lignin in the straw to perform this function, since silica does the "cementing" job in its stead.

TABLE 3 Chemical composition of the sugarcane straw (sheath + dry leaves).

Constituents	% in mass
Cellulose	44.5 ± 0.5
Polyoses	30.4 ± 0.3
Total lignin	12.3 ± 0.2
Ash	7.5 ± 0.3
Extractives (Cycle-Hexane/Ethanol 2;1)	3.7 ± 0.1
Total	98.4 ± 0.3

Morphologic composition of the sugarcane straw

In terms of morphology, both the straw and the green leaves are very similar. The only difference relates to the amount of silica contained mostly in the bullate endings of the superior epidermis of the limbo or layer (or the leaf itself). Figure 4 shows a Scanning Electron Microscopy – SEM image which considers three different sections of the same sugarcane leaf (leaf in its generic meaning)



A, view of the surface of the limbo superior epidermis: ***bul,*** bullate cells; ***mar***, marginal zone with sílios of the cells and short nails; ***est***, stomate; ***cent***, central zone.

B, limbo transversal section; different kinds of epidermic cells more or less close together in category, viewed from the surface.

C, view of the inferior epidermis surface; ***Int,*** epidermic tissue which covers the intercostal region; ***v***, epidermic tissue which covers the leaf veins.

Source: DILLEWIJN, 1951.

FIGURE 4 Different sections of a sugarcane leaf.

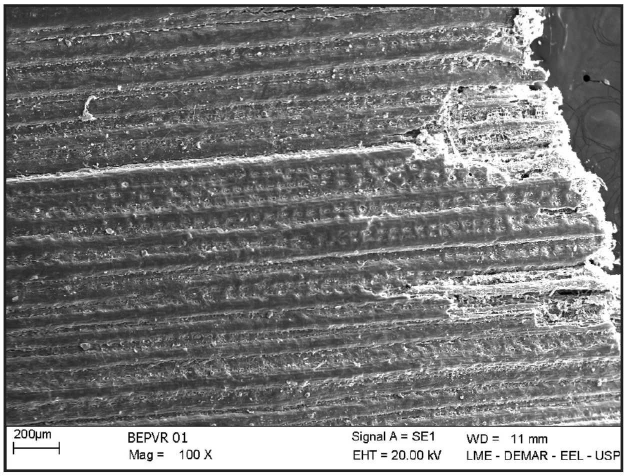


FIGURE 5 Inferior epidermis of the sugarcane leaf: image amplified 100 times, showing, at the top right-hand corner of the sample, an inner region of the leaf which was damaged during sampling, as well as the leaf veins and the stomata of the limbo.

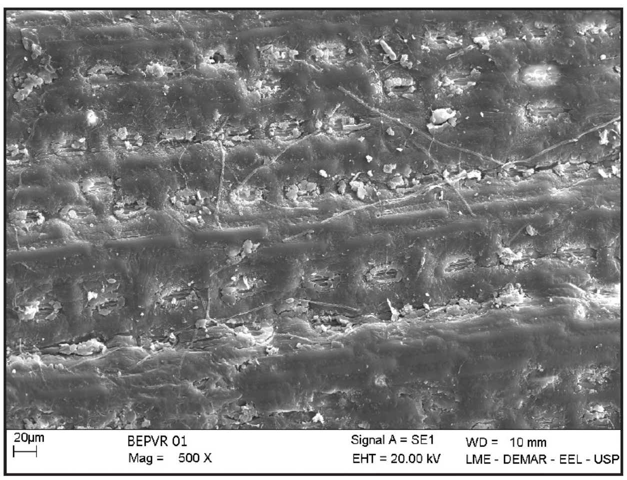


FIGURE 6 Image amplified 500 times: the inferior epidermis of the sugarcane leaf in which the leaf veins and the stomata stand out.

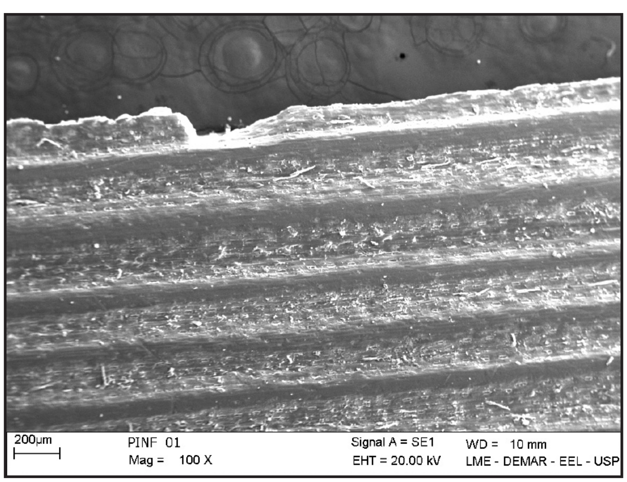


FIGURE 7 The sugarcane inferior epidermis: amplification of 100 times, standing out the most prominent veins.

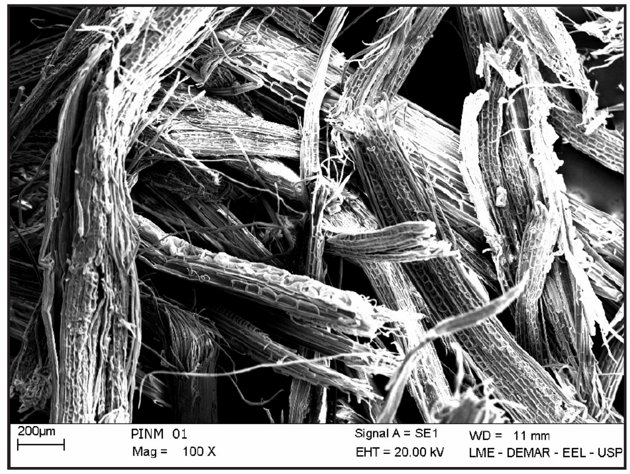


FIGURE 8 Micrographics of ground sugarcane leaves: panoramic picture amplified 100 times.

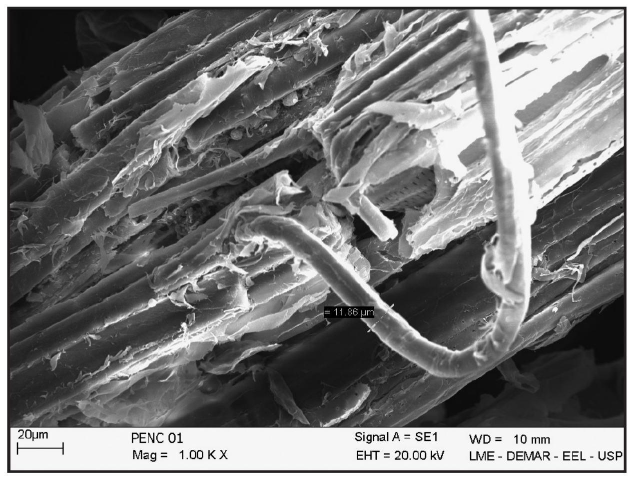


FIGURE 9 Micrographics of ground leaf: image amplified 1,000 times, standing out a cylindrical fiber with an approximate diameter of 12 micrometers.

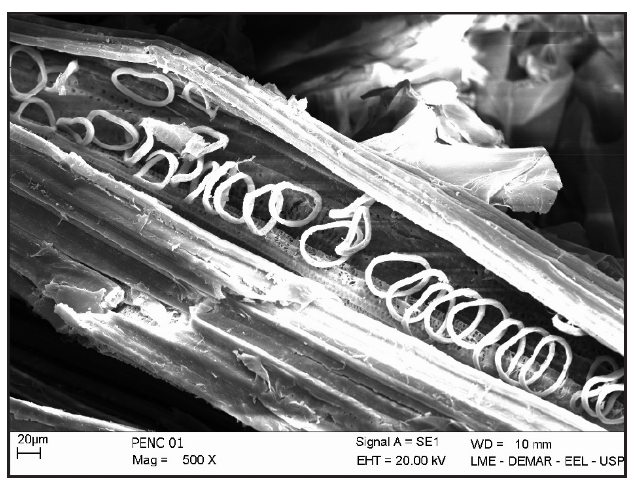


FIGURE 10 Photo micrographics of an inner part of sugarcane leaves: the elements of ring shaped vases contained in the interior of a pierced tube. Image amplified 500 times.

The photo micrographics of SEM (Scanning Electron Microscopy) presented in the following Figures – from 5 to 10, were obtained in a LEO equipment type 440, with Oxford detector, operating with a 20 Kv electrons beam, 2.82 A electrical current and I probe of 950 pA. The samples were recoated with 20 nm of gold and a Coating System BAL-TEC MED 020 metalizer and were kept in dessecator until moments before the analysis.

Chemical and morphological composition of sugarcane green leaves

The sugarcane green leaves found in their endings present a very different structure from that found in the straw.

Chemical composition of sugarcane green leaves

The chemical composition of sugarcane green leaves is shown in Table 4.

The results obtained from green leaves are very similar to those found in sugarcane bagasse as reported in literature (ROCHA, 2000; ROCHA 2005; ICIDCA, 1999), apart from the cellulose concentration in this material that presents numbers a little smaller than those found in the bagasse.

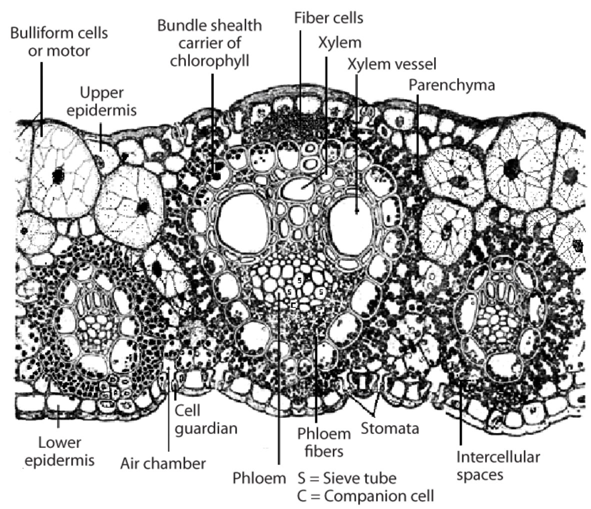
Morphological composition of the sugarcane green leaves

When it comes to morphology, green leaves are similar to dry leaves, which are compounded by layer and sheath. The green leaves are generally located in the knots, thus forming two rows in opposite sides which can be found approximately at the same level. They consist of two parts: limbo or layer (the leaf itself) and sheath, and are separated by one articulation ("dewlap", neck, leaf triangle). A completely developed green leaf is more than 1 (one) meter high. Figure 11 illustrates the transversal section of the limbo or layer of a sugarcane leaf.

Figure 12 and 13 show Scanning Electron Microscopy pictures of sugarcane green leaves with details of morphological aspects.

TABLE 4 Chemical composition of the sugarcane green leaves.

Constituents	% in mass
Cellulose	40.5 ± 0.8
Polyoses	30.8 ± 0.8
Total lignin	22.8 ± 0.2
Ash	2.1 ± 0.2
Extractives (Cycle-Hexane/Ethanol 2;1)	2.5 ± 0.1
Total	98.4 ± 0.4



Source: DILLEWIJN, 1951.

FIGURE 11 Transversal section of the leaf limbo or layer, showing a big vascular beam surrounded by two smaller ones.

Chemical and morphological composition of sugarcane trash

The trash, which is the biomass residues which stays on the field after the sugarcane harvesting, consist basically of green leaves, dry leaves, sheath, tops, stalk fractions and physical mineral impurities. It is estimated that the amount of trash remaining on the ground after raw sugarcane harvesting without recovering depends on the variety of the sugarcane, representing between 10% and 30% of the stalks. The moisture content of tops varies between 60% to 65% and that of dried leaves

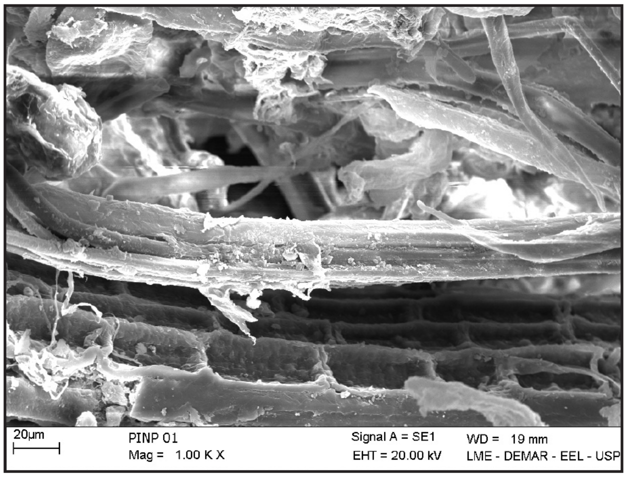


FIGURE 12 Ground green leaf microscopy: image amplified 1,000 times, showing underneath the epidermic tissue which covers the leaf veins.

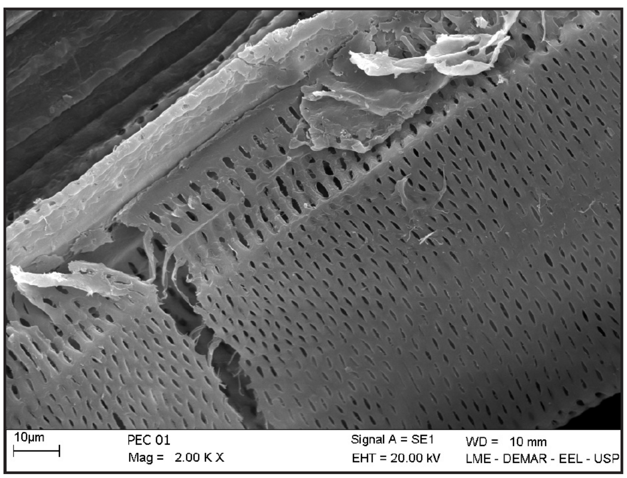


FIGURE 13 Microscopy images of a xylem vase amplified 2,000 times.

(normally let to dry on the fields) is 15%, both in wet basis.

Chemical composition of sugarcane trash

The chemical composition of the trash is shown in Table 5. It is worth noting that the material was washed prior to analysis, to remove all impurities.

The results presented in Table 5 are very similar to those found for the green leaves as shown in Table 4, proving that, in the mix of fractions of sugarcane biomass residues – SAR, the tops have

TABLE 5 Chemical composition of sugarcane trash.

Constituents	% in mass
Cellulose	40.1 ± 0.4
Polyoses	30.7 ± 0.2
Total lignin	22.9 ± 0.2
Ash	2.2 ± 0.2
Extracteds (Cycle-Hexane/Ethanol 2;1)	3 ± 0.3
Total	98.9 ± 0.3

significantly smaller concentrations than those found in the green leaves, and the tops have almost the same chemical composition.

Morphological composition of sugarcane trash

The Scanning Electron Microscopy analysis showed that the material contains a mix of elements, both in the stem and in the leaf, being very heterogeneous. Figure 14 and 15 show microscopic images of trash samples.

PHYSIOCHEMICAL AND ENERGY CHARACTERIZATION OF SUGARCANE STRAW

The physiochemical and energy properties presented in this chapter for SAR (particularly sugarcane straw) such as elementary and immediate chemical composition as well as High Heating Value, have already been published in the literature by different authors (OLIVARES *et al.*, 2008; PELÁEZ, 2007; HASSUANI *et al.*, 2005; LINERO and LAMÔNICA, 2005). Among these stand out those properties which are important in the calculations and thermal balances and thermodynamic system materials, thermal exchange surfaces, as well as in the modeling and simulation of the processes involving biomass conversion, among other processes.

The basic physical composition of the sugarcane straw considers the lignocellulosic fibers an inorganic material, mainly ash and land incorporate

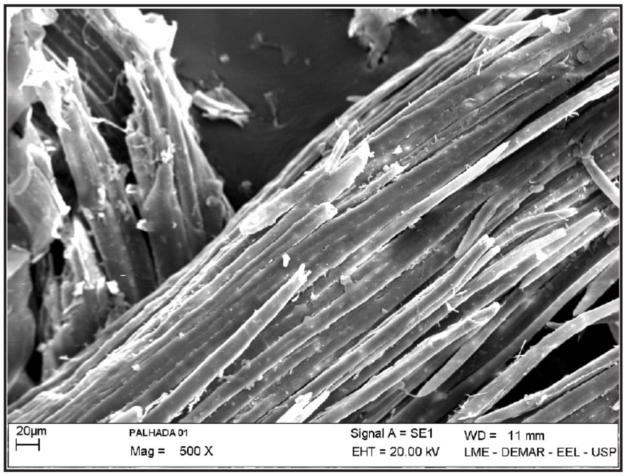


FIGURE 14 Scanning electronic microscopy of sugarcane trash: the fibers are very similar to those of the bagasse.

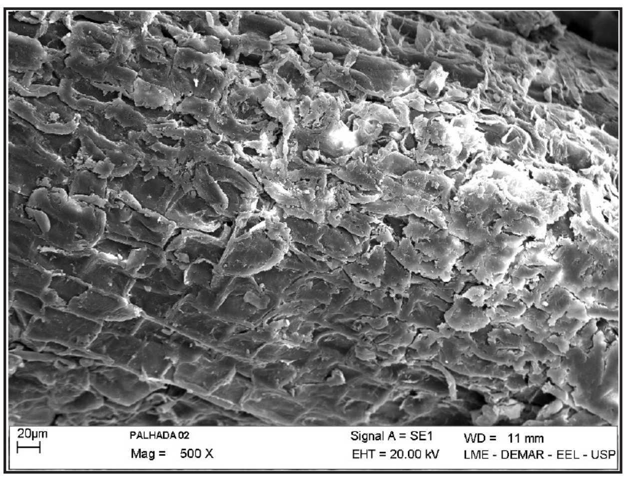


FIGURE 15 Scanning electronic microscopy showing a great number of parenchyma cells in an image amplified 500 times.

to the sugarcane during the crop process, as well as water. That is, the composition of straw ashes is largely variable depending on the criteria and agronomic practices such as the sugarcane age, the soil type, types and amounts of fertilizers used, as well as if it is influenced by other technical criteria related to the crop and cleaning procedures of the sugarcane in the dry cleaning systems which are being implemented at the mills in Brazil.

The vegetable cell of the sugarcane straw presents the same basic chemical components of the sugarcane bagasse or even wood. However, their physical-mechanics, geometric, thermal, fluid dynamics and energetic properties are different. The proportion of these properties and characteristics is important in the analysis and calculation of the project parameters and also in the operation of the hydrolysis processes, combustion, pyrolysis and gasification, influencing in variables such as processes energetic efficiency, velocity and temperature of reaction, yield, residence time etc.

When we mention the use of the sugarcane trash based on biomass obtained by dry cleaning systems, those where the sugarcane collides mechanically and it is fractioned in a pneumatic way system known as the sugarcane dry cleaning (CELLA, 2009), separating the heaviest stem from the lightest fractions, constituted by the dry leaves or straw and the leaves (still green or wet), so we can consider that the useful biomass to produce energy as being constituted just by these lighter fractions. It is this type of material that we will be calling straw, for the effects of its physiochemical and energy characterization, as well as the effects of its usage in conversion systems, unless we make some specification to identify the use of one or another lighter fraction.

The pretreatment commonly used for sugarcane straw, which is used for the production of energy or animal feed, is mainly based on the reduction of its size, may has several levels of reduction intensity depending on the specific application for what it is treated. Second Generation Technologies – SGT, seeking to add value to these materials through its mechanical or pneumatic classification, those that would allow to obtain a highly pure material and with adequate physiochemical composition for their subsequent biochemical or thermochemical conversion, are being developed.

It's normal to characterize the products or fuels obtained from biomass based on the properties which determine a specific usage. Usually the biomass used in the process to produce energy is mainly characterized according to their physiochemical and energy properties. However, the importance of more specific studies is emphasized with regard to a better characterization of these materials, which allows to identify important variables of physiochemical, biochemical and thermochemical processes.

Among the main physiochemical and energy properties of the combustible material, or lignocellulosic materials, used for energy production are the elementary analysis, immediate analysis and the high heating value. The elementary analysis supplies the fractions in mass of the atomic elements representatives of the analyzed material; they are carbon, oxygen, hydrogen and nitrogen. Other items analyzed are chlorine, sulfur and ashes. Commonly, have been used ASTM E775, E777 and E778 norms specific for wood. The immediate analysis supplies the fractions of moisture mass, volatile, ashes and fixed carbon (for difference check). In this case, has been used ASTM E870, and E872 norms specific for wood too. The high heating value – HHV of any organic material it is the maximum amount of heat produced during its combustion in perfect conditions for its burning in relation to 1 kg of solid or liquid fuel, or 1 m^3 of gaseous fuel. The difference among the HHV and the LHV is the fact of considering or not the strong condensation of the water steam present in the combustion gases.

The test standardized methods of ASTM – American Standard are the ones that are commonly used in the great majority of analyses for

TABLE 6 Approximate analysis, high heating value and low heating value of sugarcane straw samples from several authors.

Components, % d.b.*	GABRA *et al.* (2001)	PELÁEZ SAMANIEGO (2007)	LINERO and LAMÔNICA (2005)**
C	44.2	41.58	46.2
H	5.4	5.8	6.2
N	0.6	0.45	0.5
O	38.7	n.d.	43
S	0.1	0.08	0.1
Cl	0.3	n.d.	0.1

Note: n.d. – not determined.
* The sum is not necessary equal to 100% because are to missing some components.
** Analysis realized by Centro de Tecnologia Canavieira – CTC – Brazil.

TABLE 7 Elemental analysis of sugarcane straw samples from several authors.

Proprierty, % d.b.	GÓMEZ *et al.* (1999)	HASSUANI *et al.* (2005)*	LINERO e LAMÔNICA (2005)**	PELÁEZ SAMANIEGO (2007)
Moisture	9.72	10.05	29.4	9.92
Ash	7.66	8.15	3.9	11.7
Volatiles	71.34	76.23	83.3	81.55
Fixed carbon	20.99	15.62	12.8	6.9
HHV, MJ/kg	n.d.	16.98	17.4	17.74
LHV, MJ/kg	n.d.	n.d.	15.6	16.51

Note: n.d. – not determined.
d.b. – dry basis.
HHV is the high heating value.
LHV is the low heating value.
* Analysis realized by TPS company (Sweden) from Brazilian sugarcane samples.
** Analysis realized by Centro de Tecnologia Canavieira – CTC – Brazil.

different types of biomass. Correlation methods are obtained, in some cases, developed correlating energy parameters like High Heating Value – HHV, with compositional data such as content of ashes, of volatile material, content of carbon, of hydrogen, of oxygen, and moisture.

Tables 6 and 7 show data of immediate analysis, low and high heating value and elementary analysis of sugarcane straw samples.

Table 8 shows data which make it possible to do a preliminary evaluation of energetic potential of sugarcane biomass residues – SAR, based on a comparison with equivalent petroleum (adapted from ICIDCA, 1999).

In relation to the physiochemical characteristics of sugarcane biomass residues in Table 9, it can be observed that cane residues have a content of ashes between 2 and 4 times larger than sugarcane bagasse, although its moisture content is smaller and it presents a larger relationship between the content of volatile and fixed carbon components. These parameters are, without any doubt, essential in the evaluation of the combustion process of these biomass feedstocks.

As can be observed in literature, large amount ot data by different authors on physiochemical and energy properties related to sugarcane residues – SAR. However, there are, in some cases, significant differences among the quantitative values of these properties, what sustains the hypothesis that it is still necessary to study the norms being applied for analytical determination of these properties in the case of lignocellulosic products of sugarcane.

POTENTIAL TECHNOLOGINAL APPLICATIONS FOR SUGARCANE STRAW

The energy conversion of biomass can be accomplished through different processes. Among the more studied and economically attractive so far are: direct combustion, hydrolysis, pyrolysis and gasification.

Considering each one of the processes previously mentioned, it is important to mention that, due to the technological route chosen to accomplish the conversion of straw into energy, that is, the biochemical route or the termochemical route,

TABLE 8 Assessment criteria of sugarcane straw energetic potential.

Comparation criteria	Sugarcane straw (10% of moisture content, w.b.)	Equivalent oil*
HHV, MJ/kg	17	40
Boilers and furnaces thermal efficiency	75-85	85-90
Fuel needs (in mass) for generation of the same thermal energy quantity	2.85	1

* Equivalent oil is a reference term used to its energetic comparation in relation to others fuels. Its HHV is considered to be 40MJ/kg approximately.

Source: Adapted from ICIDCA, 1999.

TABLE 9 Physical and chemical properties, experimental calculations of sugarcane straw and bagasse.

Sugarcane biomass	Physical and chemical properties, % w/w (dry basis)				
	Moisture	Ash	Volatiles	Fixed carbon	HHV, kCal/kg
Straw (in the same way that those after harvest crop)	36.34	9.22	81.83	8.95	4,774
Sugarcane bagasse	47.98	2.56	83.48	13.96	4,902.3

Source: AGUILAR *et al.,* 1989.

a simple and strong system for the pretreatment of the straw will be necessary. For instance, the hydrolysis process to obtain the ethanol will be more sensitive to the sugarcane straw pretreatment than the combustion process, pyrolysis and gasification. Although it is inevitable a physical pretreatment stage in all cases. It is also very important to remember that in the specific case of lignocellulosic material pretreatment, the operational costs involved are significantly high and different, depending on the technology.

Although there is not, as yet, sufficient fundamental and technological information on the handling processes, transport and possible stockpiling of SAR, there has been significant progress in this sense, mainly due to the emergence of potential technological markets in the following application routes:

1. *Combustion in boilers:* boilers are used with furnaces equipped with burning systems in the form of grills and/or partially in suspension. It is commonly used with cane residues in mixtures with sugarcane bagasse, or conventional fuel of these industrial units. Parallel, it is already possible to discuss today some technologies that allow to fraction and, therefore, select residue samples, systems that would allow also to introduce drying in an economical way in sugarcane mills in Brazil (ROCA, 1988; ROCA *et al*., 1995).
2. *Briquetting and torrefaction:* the compacting and briquetting process, although already very known and tested with several types of agricultural and industrial residues, in the case of sugarcane agricultural residues – SAR, has not reached satisfactory techno-financial solutions yet, at least not published, probably due to technician-financial problems related to the preparation of this material. Straw and green leaves, besides the crop processes, handling and pretreatment are still being developed, they can have considerable influence on the briquetting tests results, above all for the levels of inorganic material present in the same ones which are significantly variable, that will bring technical problems to the process. In the case of the pre-pyrolysis or torrefaction process, although they are already known and widely studied, above all in Europe and United States (BHATTACHARYA, 1990 and FELFLI, 2003), they are not widely diffused mainly in applications where it is used with residues of biomass from agricultural processes. In both cases, they are still looking for viable techno-economical solutions to overcome barriers related to the morphologic characteristics of these residues, such as moisture and ash content, as well as their wide concentration of polydisperse particles according to size and form of these particles and their low apparent density.
3. *Pyrolysis:* studies have been accomplished inside and out of Brazil with sugarcane residues physically pretreated, with the purpose to obtain bio-oil and charcoal fines, and later some chemical fractions (BEZZON, 1998; ZANZI, 2001; OLIVARES, 2002; MESA-PÉREZ, 2004; PELÁEZ, 2007). The main applications in terms of properties and composition for use of sugarcane residues pretreated in pyrolysis processes are the control of its particle size composition, moisture content, and ash and inorganic materials content in general; factors which make this material to have a low standardization and a high dispersion degree, above all physiochemical.
4. *Gasification:* in the case of the gasification some studies have already been carried out inside and outside Brazil too, using sugarcane residues – SAR, as raw material (OLIVARES, 1996; ZANZI, 2001; HASSUANI *et al*., 2005). In Brazil, experimental studies in gasification pilot units with reactors of fixed and fluidized-bed, have also been carried out. The largest and most important project developed outside Brazil with sugarcane residues, was developed in partnership between the companies Centro de Tecnologia Canavieira – CTC, and the

Swedish company TPS – Termiska Processes. The project showed the technical viability of making gasification of sugarcane residues – SAR.

5. *Enzymatic hydrolysis:* this technology being studied today in Brazil using surplus of sugarcane bagasse at sugarcane mills; other sugarcane biomass residues (i.e. tops and leaves), not used yet, could duplicate ethanol production in this country per hectare of harvested sugarcane. Despite current difficulties with this technology, significant progress has already been made. Some projections and published studies indicate that economical viability of this process could be attain within the 5 to 10 years, based on criteria such as availability and cost of biomass, its pretreatment and enzyme cost.

For any of these processes, concerning application of SAR, two issues deserve particular attention: firstly, many tests are still needed to achieve long duration in demonstrative units, aiming at sequenced technical viability and technology consolidation. Secondly, it is necessary to make reliable estimates on the costs of the economical viability of these processes.

Combustion of sugarcane straw

Two are the main aspects related to recovery and energy use of cane residues in conversion systems. The first refers to costs for harvesting, handling, and transport of cane residues to pretreatment locations, which should usually be located close to final consumption location. The second aspect is the pretreatment cost of cane residues for its efficient use in energy generation.

In relation to combustion of cane residues in boilers, three aspects deserve specific attention. The first relates to the amount and heterogenity of the material, that is, with wide granulometry, sizes and forms of the particles, and low density when in bulk, in the current systems of bagasse feeding to boilers; this is because traditional dosers of bagasse boilers at sugarcane mills in Brazil cannot operate only with sugarcane residues. Secondly are problems of maintenance of the thermal load of the boiler for long operational periods – to maintain the thermal load of the boiler requires to maintain the supply of steam by the boiler with the required quality and parameters control; and thirdly, it is necessary more reliable studies in different mixtures, to substitute bagasse technically and economically by other sugarcane residues.

In order to guarantee an optimum combustion reaction of solid and liquids fuels it is necessary to establish an appropriate size of their particles. In this case, the adequate size of the fuel particles allows an economic handling of this mixture in the combustion reaction. Besides when dealing with solid fuels its adequate size allows economic handling of this material through mechanical and pneumatic systems. Based on these considerations two variables are important, the amount of specific energy consumed in the fuel pretreatment, and the medium size of the resulting particles.

The possibilities to use the sugarcane straw in the boilers of sugar and ethanol mills have being appraised recently in the industrial and agricultural sector (straw usage). Mixtures of sugarcane bagasse and straw are fed into the boilers and burned in systems with combined ways of combustion as grill and suspension of a fraction of the mass or of the total number of the particles. The main criterion for applications of sugarcane residues is the fact that the use of such residues will make possible to produce larger amounts of surpluses of sugarcane bagasse that can be used in generating electricity and/or ethanol (of second generation). After preliminary tests at industrial scale, many mills moved to the systemization phase. In this phase, it was necessary to develop reception systems and pretreatment of sugarcane residues to be used in boilers with appropriate size of particles for combustion.

Some proposed systems for sugarcane residues pretreatment in mills involve: leveling equipment for the standardization of straw mattress height, to avoid stagnation points, underdoses or overdoses of residues volume, and knife mills in 2 consecutive stages to reach the project granulometry. This system facilitates the manipulation of material and guarantees a high efficiency in the boilers.

In relation to experiences carried out on combustion of sugarcane residues in boilers of sugar and ethanol mills (ICIDCA, 1999), it can be said that this combustion has an energy quality comparable to the sugarcane bagasse, traditionally used at the plant, whenever it is correctly prepared for its combustion e.g. with moisture control and right size particle composition.

In Cuba, where the sugarcane bagasse is largely used as industrial input and raw material for the cellulose and paper production, they have been studying several technological alternatives to make possible the use of sugarcane straw as a direct substitute for sugarcane bagasse, for the production of energy in the sugarcane sector, mainly boards, bagasse fiber boards, cellulose and paper; chemical products such as furfural, hidroximetilfurfural – HMF, among others.

Any technology improvement on the conversion of the sugarcane straw into energy, in larger or smaller scale, for physical preparation is always should be encouraged. In this process, two physical properties are generally controlled: the size of the particles and their moisture.

The downsizing preparation of the straw is usually made by using a grinding system based on different operation systems, generally with systems of knives and hammers working independently or combined. The control of the size of the material is made through sieves installed in the own mills, or using transport systems and pneumathic classification.

Some experiments with sugarcane straw burning in boilers showed that samples of sugarcane straw, pretreated in different ways from the crop to the pretreatment itself, showed different physiochemical characteristics. For instance, when centers of sugarcane cleaning are used for sugarcane harvested mechanically (Cuban model), with areas for temporary stockpiling of straw, the moisture content can be reduced considerably in some cases, up to 25% (b.u.). If we use the route of transport of sugarcane picked mechanically to stations of dry cleaning in sugarcane mills (model currently being implanted in Brazil), and where the material is not stocked, but driven directly for the boilers as soon as it is separated, its moisture (wet basis) may be superior to 25% or 30%.

Tests with sugarcane straw in boilers for steam generation were carried out in Cuba in the 1980s, using sugarcane straw and bagasse mixed with straw in proportions that varied from 10% to 43% of the mass (ICINAZ, 1990). Some of the main results of these tests which have already been published are summarized in Table 10. Table 11 represents the main physical and energy properties of sugarcane straw used in these tests. A boiler which burns in fasten layers on the top of the grill was used with a capacity of 20 ton/h and pressure of 17 bar, in other words, probably one of the oldest boilers in the sugarcane industry. The obtained efficiencies operating with sugarcane straw and bagasse mixed with straw varied between 65% and 75%, being the largest values reached when

TABLE 10 Boilers operation parameters fueled several sugarcane biomass solid fuels.

Operation parameters	Sugarcane bagasse	Sugarcane straw	Mixtures (average values of 10% to 43% in mass)
Flame temperature, ºC	981	1,080	1,009
Exit furnace gases temperature, ºC	879	872	979
Exit boiler gases temperature, ºC	264	250	277
Steam boiler rate, ton/h	19.43	18.57	19.31
Fuel rate, ton/h	9.06	4.88	6.49
Air excess	1.99	2.18	1.72

TABLE 11 Several physical and energetic properties of sugarcane straw of the tests.

Sugarcane straw properties	Average values
Particles characteristics dimension, mm	11.64
Ash content, %	8 ± 2
Moisture content, %	25 ± 5
HHV, kCal/kg	2,884
Bulk density, kg/m^3	40

it was operated with mixtures containing a larger amount of bagasse.

As to the previous results there appear to be few details of operation parameters to generated steam (pressure and temperature of the steam); secondly, little is known of the long time results, related to the problems e.g. damages the thermal exchange surfaces, that is, "fouling" and "slagging" problems; thirdly, they do not discuss operational results obtained in these tests such as the consumption of fuel in the boiler, or that burning sugarcane straw only had a reduction of almost 100%, and as to the mixtures of approximately 40%, or that there is an excess of air in the boiler, whose values should have been discussed by the authors. In short, the results are very interesting and show that studies have been carried out over the past years with encouraging results; however most of them need still to be consolidated, and this demonstrates the need for new research, development and innovation – P&D&I, in this area.

Currently tests of long duration are being curried out in Brazil, e.g. burning primarily sugarcane straw in boilers in mills during the harvest period. Such tests have been intensified as Brazil started large scale mechanization in the harvesting period. They are handling data of straw mixture with bagasse of up to 25% in mass. However, it is still not possible to find published data on the conventional technical literature about the outcome of this type of evaluations. The authors of this chapter have not been able to access information from companies involved in the sugar and ethanol sector, but it is well known that the problems associated with the formation of deposits have been verified in surfaces of thermal exchange, in addition to large amount of ashes.

Other important aspects related to biomass combustion are "fouling" and "slagging". The concentration of inorganic material in the composition of biomass may be one of the causes of the existence or not of "fouling" and "slagging". It is possible that "fouling" in the thermal exchange surfaces of steam generation systems, happens when the residues generated during the combustion and deposited in the surfaces of the heat exchange, come together with substances that vaporize during the combustion, and then condense on the colder surfaces. "Slagging" happens when inorganic materials are founded, or acquire high viscosity forming deposits directly in these conditions. Both types of phenomena generate deposits of low thermal conductivity and high reflection, harming the efficiency of heat change and the boiler operation, besides accelerating the corrosion phenomenon in surfaces of thermal change.

CERQUEIRA-LEITE (2007), states that bagasse and sugarcane residues main properties are indicative of high probability of formation of deposits at temperatures in the boiler furnace from moderate to high, these are: the content of silica, potassium, sodium, and of phosphorus in the ashes, and content of chlorine in the biomass. A quantitative analysis of potential problems posed by this type "fouling" and/or "slagging" indicators have already been drawn. This is the case of the "alkalis index" – AI. According to the authors of this chapter, tests have been done with cane residues in Brazil (the authors have used cane stem); in three different tests the "alkalis index" was superior to 0.32, so it is possible to think it is correct the hypothesis of "fouling" in surfaces of thermal change of boilers. In these tests the content of alkalis in the ashes of sugarcane residues (or of the cane stem) corresponds to the sum of the concentrations of potassium oxide (K_2O) and of sodium oxide (Na_2O).

We pointed out that there are already a relatively high number of publications on aspects of combustion of solid fossil fuels, mainly mineral coal, when mixed with biomass (co-fired), in boilers using mineral coal or boilers than burn biomass (mineral coal is an auxiliary fuel in this case). Obviously, a detailed knowledge of biomass, and mineral coal properties is required, together with the interactions between these two fuels (MAGASINER *et al.*, 2002).

Table 12 summarizes data from chemical analysis of the ashes of a sugar-cane straw sample (PELÁEZ, 2007).

The author identified differences between his values and the values obtained by other authors, and explains that such differences can be attributed to factors such as the cultivation and the handling of the sugarcane.

Regarding the crop, the amount and the fertilizer type may also influence in the mineral characteristics present in the sugar-cane, and the handling is responsible for the aggregation of strange particles of mineral origin that may depend on the place where the biomass is stocked and pretreated.

RESEARCH, DEVELOPMENT AND INNOVATION – RD&I

In terms of recovery and pretreatment processes, as well as hydrolysis, combustion, pyrolysis and gasification processes being carried out with sugarcane agricultural residues, sugarcane straw specifically, investigated worldwide given its theoretical and technological development, is close to commercial scale production in the case of lignocellulosic biomass (as bagasse combustion of the sugarcane, for example). However, it is possible to say that major research and development work still need required to improve our understanding of biochemical and/or thermochemical conversions to attain better yields and more efficient process, while decreasing the environmental impacts. Thus for this to become true, it is vital to:

- Elaborate a data bank with the physical, structural, chemical, thermal, energetics, fluid-dynamics and biological properties, plus biodegradation, among others, in relation to sugarcane straw. Establish new rules and analytical methodologies specifically for this material.
- Theoretical-experimental studies of the physical pretreatment of the sugarcane straw.
- Theoretical-experimental research on the influence of the physical and chemical properties of the particulate material of sugarcane and kinetics of these processes, both in laboratory and pilot plant scales.
- Mathematical modeling of conversion processes of the sugarcane straw particles.
- Development and evaluation of physical systems in order to study the phenomena involved in the processes of interest, at various scales.
- Changes and reformulation studies plus repowering of power systems into thermochemical conversion.
- Development of continuous reactors and cleaning systems and bio-oil and tar recovery in units of pyrolysis and gasification in fluidized bed respectively, for sugarcane pretreated straw.
- Studies for obtaining synthetic gas, synthetic fuels and chemicals in pyrolysis and gasification systems.
- Study of the properties of bio fuels obtained through thermochemical routes of sugarcane straw conversion and other lignocellulosic materials.

TABLE 12 Ash chemical analysis results of sugarcane straw.

Chemical composition	Content (% in mass)
Fire Loss	0.57
Silicium dioxide (SiO_2)	52.62
Aluminum oxide (Al_2O_3)	15.8
Iron oxide (Fe_2O_3)	3.93
Calcium oxide (CaO)	5.76
Magnesium oxide (MgO)	5.27
Sulfur trioxide (SO_3)	2.73
Sodium oxide (Na_2O)	0.12
Potassium oxide (K_2O)	7.8

Source: PELÁEZ, 2007.

- Long term tests in demonstrable units, aimed technical viability in production scale and consolidation of technologies.
- Reliable estimates on economic viability and environmental and social/economical impacts of the processes, where the sugarcane straw will be used.
- Reliable estimative recovery costs and pretreatment processes of the sugarcane residues for bio energy production.

FINAL CONSIDERATIONS

This chapter introduces some of the main characteristics of biomass residues of sugarcane mills – SAR, presenting properties which are not widely covered in conventional technical literature e.g. physical, morphological, chemical and energetic properties, related to the straw fraction of sugarcane. This is considerable relevance for the evaluation, processes and equipment. Some possible applications of this fraction, focusing in energy production by means of its spontaneous combustion in industrial boilers, are discussed, showing the importance to search for the technical viability of this technology for sugarcane residues–SAR. Moreover, some research experiences on sugarcane straw combustion and their mixtures with sugarcane bagasse in boilers of sugarcane power plants are also discussed. In addition, major operational technological hindrances have also been identified in experimental tests carried out with these materials. The authors are open to further discussions to these lines of research that, accordingly, must be considered in Research and Development & Innovation – RD&I, when using sugarcane straw as an energy source.

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