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ENERGY CANE

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INTRODUCTION

Sugarcane has been developed and cultivated in different parts of the world, through the centuries, always as a source of food with sugar evolving from an expensive spice to become the cheapest source of food calorie. Its basic components, sugars and fibers, are treated quite differently in breeding programs in the world: the sugar components are valued in the selections of cultivars while the fibers of the cane stalk is limited, because of their effect on performance of mills and diffusers dragging sugars in the bagasse, the fiber of straw (leaves and tops) are not even evaluated. In the processing of sugarcane, sugar is the main product and ethanol and surplus electricity are by-products.

In Brazil, this concept of the food industry for sugarcane has been slowly driven by the growing commercial importance of ethanol and, more recently, electricity. Ethanol has been produced consistently in Brazilian plants for more than a century, when it began to be part of the fuel options for the newly introduced car using the Otto cycle engines. Since the 1920s the National Institute of Technology (INT) has worked systematically to develop the technology of the Otto cycle engines operating on ethanol; the interest of the Brazilian Government at this time was to find an alternative to over-production of sugarcane, which constantly depressed sugar prices. Thus, in 1931 the requirement was instituted to blend 5% ethanol in all imported gasoline consumed in the country. This requirement was extended to all gasoline consumed in Brazil from 1938.

However, it was only after the launching of National Alcohol Program – Proalcool in November 1975, that ethanol reached the status of the main product of the mills, along with sugar. It started to emerge then the Brazilian model of mill with the simultaneous production, and increasingly integrated, of sugar and ethanol. This means that no longer the residual alcohol was produced from exhausted molasses (final molasses), but started using the mixture of final molasses partially exhausted and sugarcane juice. The acceleration in production, since 1979, brought the independent distilleries that produce only ethanol; most of these independent distilleries have been converted to sugar mills with annexed distilleries in the 1990s.

In the area of thermal energy and electricity, plants evolved from the situation of external energy consumers in the form of electricity purchased from utility companies, to become fully self-sufficient and bagasse as the only form of primary energy that the industry used in the mid-1990s. With the changes of institutional and regulatory framework for the electricity sector in Brazil it has become feasible for the mills to generate surplus electricity to inject to the grid to sell to third parties. Today the new plants being built are increasingly equipped to generate surplus power and total utilization of bagasse for this purpose. With the increase in cane harvesting without burning the straw appears as a new fiber source for energy that begins, tentatively, to be used to supplement bagasse for extending the period of generation of electricity.

This situation sets the scene of a new era for the sugarcane – to become the feedstock for energy. The technologies called "second generation" to produce biofuels and electricity from lignocellulosic materials are under development for some decades now, starting to reach levels of performance and economy that encourage thinking about its proximity to commercial scale. It is therefore reasonable to begin to rethink the sugarcane from the viewpoint of energy and no more of food, from the breeding to processing and final products. This chapter introduces some aspects to be considered in this difficult and important task of defining the new model of ideal cane.

THE SUGARCANE TODAY

Before thinking about the future sugarcane it is interesting to understand the current state of genetic development of sugarcane, and its processing, and the parameters and driving forces that led to that stage.

At the beginning of Proalcool, about four varieties of sugarcane dominated the Brazilian plantations. Alone, the Argentine variety NA56-79 occupied more than half the planted area. The two main breeding programs of sugarcane were created around 1970, and therefore prior to Proalcool: the one of CTC (Sugarcane Technology Center, until 2004 Copersucar Technology Center), with the varieties SP and CTC, and Ridesa (University Network for the Development for the Sugarcane Sector, former Planalsucar), with the varieties RB. To these two programs should be added the IAC, and the CanaVialis, the most recent. Today there are over 500 commercial varieties, but just about twenty of them cover more than 80% of the area planted with sugarcane in Brazil (Macedo, 2005). And productivity and Pol% of cane grown in the state of São Paulo between 1975 and 2000 increased 33% and 8%, respectively. In addition, were also developed varieties resistant to major diseases known and most appropriate for different production environments; the major pests are controlled or in process to be under control. The breeding programs started to rely on molecular biology and there are already several transgenic varieties in field testing and close trying to reach the commercial stage.

As for the processing of sugarcane, the efficiencies and productivity sectors of the mills have already reached values close to the feasible maximum, which reduces the expectation of further significant gains. Moreover, economies of scale, automation and management improvements have led to significant reductions in production costs making Brazil the most competitive country in the world in the production of sugarcane, ethanol and sugar, dominating the international market for these two products.

This picture of success could lead to an accommodation in breeding programs and in industrial processing steps. However, some changes are appearing in the future scenario threatening the sector's success which has been achieved primarily with a focus on sugarcane as feedstock for food. These changes are guided by the increasing use of sugarcane for energy that made it to become the second largest source of primary energy in the Brazilian energy matrix, behind only to oil. This sugarcane originally developed to maximize the sucrose and later on the content of total reducing sugars (TRS), also became the best feedstock for agro-energy due to its high primary energy content per cultivated area and low production cost. This fact has led the most progressive members of the sugar/ethanol sector and new investors to start to consider about introducing a new model of production and processing of sugarcane, a model focused entirely on energy-ethanol and electricity. In this new model it is clear the importance of the sugarcane fiber in addition to fermentable sugars. It is also obvious to the technical sector that the ideal cane model needs to be redefined, but it is not at all clear what should be the characteristics of this new ideal cane. Moreover, we must continue to develop the sugarcane and processes to the traditional model of production: sugar, ethanol and some surplus electricity.

The main features of the cane grown on the South-Central region are listed below (MACEDO *et al.*, 2004):

- Pol%cane 14.5;
- Fiber%cane 13.5;
- AR%cane 0.56;
- Straw%cane (dry basis) 14.0;

- Productivity (t/ha/year) 68.7 (82.4 t/ha harvested).

This cane has a total of 7,400 MJ primary energy, considering also the straw per tonne of clean stalk, as detailed in Table 1 (LEAL, 2007).

This typical sugarcane, when processed in a modern plant would produce 86 liters of anhydrous ethanol and 60 kWh of electricity surplus, which corresponds to a conversion efficiency of cane primary energy into secondary useful energy – products – of only 30%, as detailed in Table 2, which was developed considering the cane used in Table 1 and an overall efficiency of the distillery of 84%.

Another aspect that is becoming increasingly important is the need for land to produce bioenergy. This is true not only for the economic aspect, because most of the production costs depends only on the acreage, but also in the sustainability aspects (use of natural resources) and the controversial emotional dispute food versus energy. In this aspect the sugarcane is the unbeatable choice, but it can still be improved. The sugarcane described above provides a primary energy of 510 GJ / ha / year (610 GJ / ha harvested) and a total of 150 useful energy GJ / ha / year (185 GJ / ha harvested), considerably higher than the useful energy in the form of biodiesel from castor beans (17 GJ / ha / year). This performance needs and can be improved for the long-term sustainability, as will be seen below.

TABLE 1 Primary energy from sugarcane (for 1 tonne of clean stalk).

Component	Energy (MJ)
150 kg sugars	2,500
135 kg of fibers in the cane stalk	2,400
140 kg of straw	2,500
Total energy per tonne of cane (MJ)	7,400 (0.176 tep)
Total energy per cultivated area (GJ/ha/year)	510

Source: LEAL, 2007.

TABLE 2 Efficiency of energy utilization of sugarcane in a modern distillery.

Item	Energy (MJ/tc)*
Cane	7,400
Products	
Ethanol (86 liters)	2,000
Electricity surplus (60 kWh)**	216
Total	2,216
Conversion eficiency (%)	30.0

* MJ per tonne of clean stalks, based on HHV, dry basis.

** First Law of Thermodynamics.

THE FUTURE

To define the desirable characteristics of the future cane it is first necessary to understand how this cane will be processed and how these features affect the cost and processing efficiencies of the new technologies and also of the conventional process. The first complication is that these second generation technologies are not mature yet and much less commercial, which implies in a low knowledge of the real productivity and efficiencies, and on which technologies will prevail. It's like shooting at a moving target, but does not prevent the making of some preliminary analysis that will be important to gain understanding of the impact of each feature of the new cane; considering the long period required for the development of new varieties, the earlier we start the sooner we will be able to optimize the whole feedstock / process path.

Table 1 above shows the current stage of the sugarcane primary energy, using the values presented by Leal (2007).

It is important to understand that the main reasons for the low current efficiency are not related to energy quality of the cane, but the model cane sugar / food prevailing today:

- The fact that cane trash fibers are not presently used which is either burned before harvest or left to decompose in the field.
- High energy consumption of the production of ethanol, which results in the use of more than 90% of bagasse available.

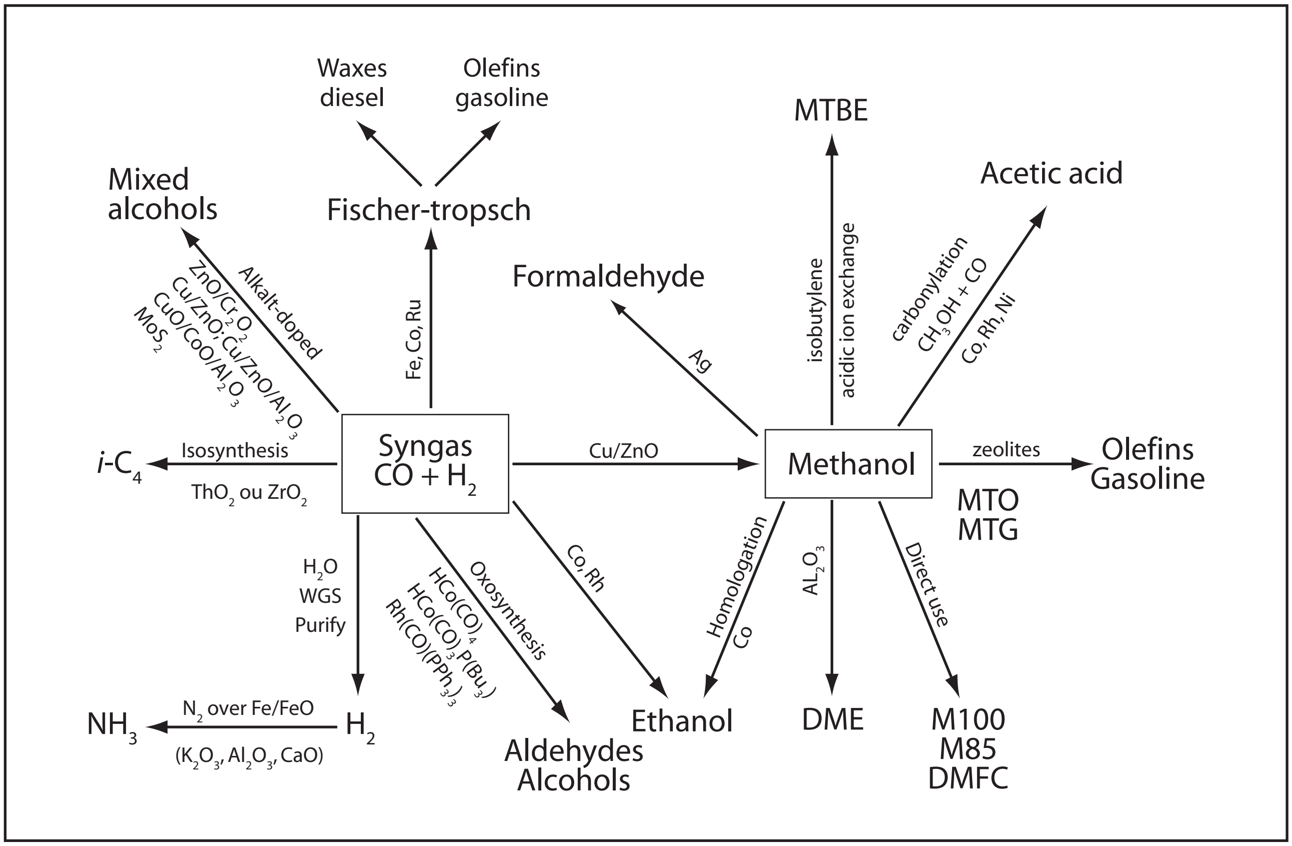
This means that even with the present sugarcane, there is still much that can be done to improve this efficiency. For example, an increase in overall efficiency of the distillery from 84% to 88% and the recovery and use 50% of the straw to supplement bagasse for surplus power generation with boiler pressure of 100 bar and, condensing / extraction turbo-generators this efficiency would rise to 35.6%, a significant gain. It is important to say that the technologies for these improvements are already commercially available (except the recovery and use of straw) and are used in some modern plants. There is not yet the energy crop concept and perhaps lack of economic incentives.

A long-term performance of second generation technologies would help bring some insight to the requirements of future sugarcane for energy use, called from now on energy cane. This type of cane has been studied since the 1980s, initially in Puerto Rico and Cuba, and more recently in Barbados in the West Indies Central Sugarcane Breeding Station (Rao and Albert-Thenet, 2005). But in all these efforts it was sought only the increase in cane biomass production per hectare, while maintaining a minimum of Pol% cane to meet the sugar aspect still on focus. Now we must make an assessment based on the needs of second generation technologies; for this it will be presented below a summary of the main features of these technologies in their long-term projections. The values reported here are taken from the latest literature and reflect expectations that not necessarily will be realized, but it will serve to consolidate the concept of energy cane. Further details on these technologies can be found in the chapters dealing with second generation technologies in this part of this book.

Second generation technologies

It is possible to divide these emerging technologies into two broad categories according to the main feature of each route:

- **Biochemical Technologies:** characterized by the use of microorganisms to convert cellulosic material into biofuels. They use a process of hydrolysis, chemical or enzymatic, to convert cellulose and hemicellulose into sugars which are then fermented and distilled; the main biofuel obtained is ethanol. The lignin is separated and used, along with other wastes, to produce thermal and electrical energy for the process. Since the cogeneration system is used, it can also generate an amount of surplus electricity to improve the overall efficiency and the technology economic return. The raw material for these processes should preferably have high levels of cellulose and hemicellulose and low lignin (this makes more difficult the access of enzymes to cellulose); low levels of mineral impurities (ash) are highly desirable. The biomass moisture content is not important and it can be tolerated the values found in the biomass freshly harvested. This technology route has had more visibility and therefore appears to be closer to commercial success, which is not necessarily true, since major problems remain to be solved as the definition and consolidation of the pretreatment of biomass, the cost reduction of enzymes and the fermentation of pentoses (five-carbon sugars).
- **Thermochemical technologies:** these technologies are characterized by the use of heat as a way of turning biomass into liquid or gaseous components which are then converted into biofuels, which can be ethanol, methanol, higher alcohols, gasoline, diesel, dimethyl ether (DME) and other. These routes are benefiting from the substantial investments in technologies CTL (coal to liquids) and GTL (gas to liquids) by the fossil fuels sector. The processes for biomass (BTL – biomass to liquids) are similar, despite some peculiarities mainly in the cleaning of the gases. The level of problems is more related to engineering than to R&D. The biomass most important features are the levels of certain contaminants such as alkali, chlorine, sulfur, ash and moisture contents. This last item is very important in the energy balance, because if the moisture content of the feedstock as received is too



Source: NREL/TP-S10-34929, dez. 2003.

FIGURE 1 Routes for production of biofuels and chemicals from synthesis gas from biomass gasification.

high will translate into energy expenditure to bring it to values compatible with the processes. These technologies are very versatile in terms of final products as shown in Figure 1.

The energy balances in the literature are quite varied, because they depend on routes, characteristics of feedstocks and, especially, the assumptions for the efficiency of energy conversion and integration of the processes. Table 3 shows the results obtained from the conversion efficiencies presented by ZUUBIER and VAN DE VOOREN (2008) and KREUTZ *et al*. (2008) for technologies in the long term.

Despite the efficiencies differ in Table 3, the trend is that they remain close in the case of hy-

TABLE 3 Performance of long-term 2nd Generation technologies

Products (per t of biomass, dry basis)	Hydrolysis	Gasification/F-T	BIG/CC*
Biofuel (l of ethanol eq.)**	408	346	–
Electricity (kWh)	400	500	1,950
Overall efficiency (%)	61	55	39

* Biomass Integrated Gasification/Combined Cycle: only electricity

** Liters of ethanol equivalent: in the Fischer-Tropsch synthesis various biofuels can be produced

Source: ZUUBIER and VOOREN (2008), KREUTZ *et al*. (2008).

drolysis and FT maximized for biofuels, in the case of BIG / GT and FT maximized for the electricity efficiencies suffer the penalty of the 2nd Law of Thermodynamics and will remain slightly lower.

THE ENERGY CANE CONCEPT

It is easy to quantify the primary energy of sugarcane, from its basic components, and also the energy contained in the final products. However, it is not a trivial task to determine the economic value of the primary energy of each component (today, in the cane payment systems more widely used in Brazil, only the total recoverable sugars – ATR – have their economic value derived from the market value of final products and the conversion rate established), because the processing of fibers and sugars has the cost and efficiencies are quite different. To complicate matters further, the fibers of the stalks and leaves have different recovery costs and different impacts on the processing of sugarcane.

In item *The Future* above it was mentioned that the low efficiency of conversion of primary energy from sugarcane into useful energy is not a problem of the feedstock, but the processing of it, mainly due to the concept of sugarcane for food where only the sugars are sought for the maximum recovery. The fibers are still somewhat neglected. To increase the production of primary energy per unit of cultivated area it is necessary to seek varieties with higher biomass, whether it be in the form of sugars and fibers; however, the value of each component would be associated with the values of final energy products and the efficiencies and costs of conversion.

Table 4 shows the comparison, in terms of primary energy, between three types of cane: our reference sugarcane (described in item *The Sugarcane Today*), a clone being tested in the Mauritius Islands (WI 96912) and an energy cane (or fuel cane) being developed in Barbados.

The primary energy of sugarcane is a strong indication of its potential performance for energy, but can not be regarded as the sole indicator of energy quality sought. The economic value of each component will depend on the conversion efficiencies, costs of conversion and the total value of final products. Thus, the value of each energy variety will depend on the processing technology chosen, a very big complication in the task of creating a model for energy cane. Some considerations are possible, using the data available today to the expectations of performance and cost of processing for the main second-generation technologies, to begin to format the concept of energy cane. Initially will be seen some details of the processing of each component of the cane.

Sugars

Until recently, only sucrose entered the system of cane payment since the reducing sugars

TABLE 4 Energy comparison between three cane varieties.

Characteristic	Reference	Mauritius*	Barbados**
Pol%cane	14.5	19.9	12
Fiber%cane	13.5	17.5	26
Straw%cane	14	N.I.***	25
Productivity (tc/ha/year)	68.7	N.I.	100
Total fiber (t/ha/year)	19.3	N.I.	51
Primary energy GJ/ha/year MJ/tc	 520 7,400	 N.I. N.I.	 1,100 11,200

* Source: Autrey, L. J. C. and Kong Win Chang, K. T. K. F., 2006.

** Source: Rao, S. and Albert-Thenet, J., 2004.

*** N.I.: not informed.

(AR's) are not crystallizable in the mill process. With the recognition of the importance of ethanol, the AR's began to be considered and the sucrose is converted numerically in AR and added to them to obtain the Total Reducing Sugars (TRS). The stoichiometric conversion rate in ethanol is today, on average, around 84% and possibly reaching in the medium term, 88% or maybe even 90%. The distillery processes consume in average 28 to 30 kWh of electromechanical energy and 330 kWh of thermal energy per tonne of cane processed. This energy is entirely supplied from about 90% of the bagasse produced in the juice extraction process. As the energy system of the mills and distilleries operate in cogeneration mode (two or more forms of energy are produced from the burning of a single fuel), a little surplus power is increasingly being produced by mills. With conventional technology the power surplus can be maximized in an economically viable way through the use of steam at 100 bar/520 ºC and condensing/extraction turbo-generators (or separate condensing and back pressure turbo-generators).

Considering only the process of converting sugars into ethanol, we can consider two situations (see Appendix for details):

Today: 0.544 liters of ethanol are obtained from each kilogram of TRS (including sucrose converted to RS) processed, and 0.35 kWh / liter of ethanol are consumed (0.64 kWh / kg processed TRS) as electromechanical energy and 3.84 kWh / liter of ethanol (7.05 kWh / kg processed TRS) as thermal energy in the form of process steam. 90% of bagasse is consumed, leaving then 0.157 kilograms of bagasse (dry basis) / liter of ethanol (0.288 kg of bagasse, dry basis / kg of processed TRS).

The processing cost for ethanol is approximately R$ 0.175 per liter of ethanol.

Long term: 0.583 liters of ethanol will be produced for each kilogram of TRS by conventional technology (first generation). This process will consume 0.30 kWh / liter of ethanol (0.51 kWh / kg TRS) of electricity and 2.00 kWh / liter of ethanol of thermal energy (3.43 kWh / kg TRS).

The processing cost will be around R$ 0.145 / liter of ethanol (R$ 0,249 / kg TRS).

Fiber from cane stalk (bagasse):

The bagasse, which is the residue of the industrial process of extracting the juice, is now the only source of energy for all the processing of sugarcane – electromechanical and thermal energies. Because it is a waste, it has no production nor transport cost, but has a value as fuel and therefore an opportunity cost. Also, since there are not many opportunities to be sold to third parties due to the high cost of transportation and requiring boilers and furnaces specifically designed to operate with a fuel with high moisture content and low density. Mills have evolved to get to the point of self-sufficiency in energy consuming almost all the bagasse. With the increased generation of surplus energy for sale the bagasse has become more valued, though not yet to the point of seeking energy sugarcane varieties with higher fiber content.. This is due to two main reasons: 1) the capacity of the milling tandem is related to the fiber, the higher the fiber content the lower the capacity of the mill in tc / h (tons per hour) or tons of sugar / h, resulting in a lengthening of the season in most cases, 2) the bagasse carries a certain amount of sugar (1 to 2% of wet weight of bagasse), thus reducing industrial efficiency (recovery of sugars). For these two reasons, cane fiber above a certain value is penalized in the cane payment systems, and cane breeders have produced varieties with fiber content ever lower. The lower limit is dictated only by the capacity of sugarcane to remain upright, and bagasse to be sufficient just to meet the energy needs of the mills.

Bagasse presents some interesting features as raw material for the second generation technologies: appropriate particle size, low ash (~ 2%) and alkali contents, and low amount of other contaminants. As negative characteristics has low density (physical and energy) and high moisture content (disadvantage only for the thermochemical route).

In the economic aspect, the value of bagasse as an energy feedstock must be deducted from losses caused by the reduction of milling capacity and by the sugar carryover. There are already commercial technologies in the market to dramatically reduce energy consumption in the mills, resulting in a surplus of bagasse above 50%, but at a cost of additional investment. It is necessary to start economic studies involving aspects of the fiber content putting on one side the benefits – increased generation of surplus energy and second generation fuel production – and the other side the negative points – a loss of sugar, the greater number of days of milling, investment in reducing energy consumption. Unlike the component sugars, where the value, conversion efficiency and costs of conversion are well known, the fiber component of the stalk does not have these parameters clearly defined and depend heavily on the choice of end-use and performance of technologies still under development.

Fiber of cane leaves (straw)

The fiber from the leaves of sugarcane presents some additional challenges compared to bagasse for its use. First, the technology for its collection, transport to the mill, processing and storing is not developed enough to be considered commercial. However, several field tests involving multiple routes of trash collection as, for example, the work of the CTC, the Sugarcane Technology Center Project BRA/96/G31 (HASSUANI *et al.*, 2005) from 1997 to 2005. In this project were carried out the quantification and characterization of straw, studies of the agronomic impacts of sugarcane straw in the cane fields, routes of straw recovery and estimated costs of collection and transportation, and processing test. Samples of bagasse and straw were sent to Sweden, where they were tested in a pilot plant of 2 MWt by the TPS-Termiska Processer AB. In some field tests it has been proven the beneficial features of straw as protection against erosion, retaining soil moisture, decrease of temperature fluctuation in the soil, recycle of nutrients and herbicide effect of the straw blanket. Some of these benefits have been preliminarily quantified, but additional studies and field tests will be needed to better understand the agronomic impacts of the straw blanket and to better estimate the economic value or cost thereof.

More recent studies are indicating the importance of the straw to enable the no or minimum tillage systems for sugarcane. All this shows the convenience of leaving an amount of straw in the field to obtain these benefits and the percentage of straw that should be in the field seems to be something around 50%. It is expected a dispute over the use of straw for its agronomic benefits and its value for energy.

The costs of collection raised by the CTC (Hassuani, 2005) are shown in Table 5.

According to Hassuani (2005), in the assessment of costs it is necessary to consider the integration of operations of straw recovery in the sugarcane production process, the agronomic impacts, the impacts on the mill and also the aspects relating to the quality of straw, which are the impurities, moisture content, processing needs and the amount to be collected. From Table 5 it is possible to assess that a fraction of 50% is feasible and reasonable to be collected.

From the standpoint of conversion of sugarcane components in final products there are three

TABLE 5 Costs of Straw Collection.

Harvester condition	Recovery system	Recovery efficiency (%)*	Cost at the mill (US$/t, db)**
Conventional	Baling	67	18.5
Conventional	Hay harvester	53	22.5
No cleaning	Cleaning station	67	31.1
Partial cleaning	Cleaning station	46	13.7

* Average values of field tests.

** Including the agronomic impacts; db – dry basis.

Source: HASSUANI, J. S., 2005.

key points: value of final products, efficiency of conversion and conversion costs. Some of these have already been mentioned earlier but are repeated here in a different way and others will be introduced in order to have a more global view of potential use of the fibers of the cane.

- Economic value of final products

The two final products used in comparisons are anhydrous ethanol and surplus electricity.
Ethanol: U.S. $ 0.80 / L = R$ 38/GJ
Electricity: R$ 140/MWh = R$ 39/GJ

Thus, the values of the two products are practically the same when using the value of the energy content. So efficiencies and the costs of conversion will prevail.

- Efficiencies of conversion

The conversion efficiencies of the two main second generation processes are shown in Table 6 for the expected performance in the long run when these technologies are fully mature in terms of technological and commercial point of view (after 2020).

Under the aspect of conversion efficiencies of the two competing technologies are very similar, and the gasification / FT favors a little more the generation of electricity and has some flexibility in this regard.

- Costs of conversion

At this point the uncertainties are even greater in view of the low stage of maturity of these technologies today. There is the issue of scale that has a strong effect on production costs and unit investment, the cost or price of feedstocks and the performance of each technology. To illustrate this point, we present the projected values for the long-term investment, cost of operation / maintenance (O&M) and the cost of production of biofuel in Table 7.

Energy cane would be a group of varieties with high primary energy per hectare, and their components – sugar and fiber – should be suitable for processing by emerging technologies for second generation or the integration of conventional technology (first generation) with one of the second generation alternatives. As there is not, as yet, a clear picture of performance and production costs of these technologies, it is difficult to define what the optimal characteristics of sugarcane for energy should be.

TABLE 6 Long term conversion efficiencies of second generation processes.

Technology	Conversion efficiency (%)		
	Biofuels	Electricity	Total
Gaseification/F-T	45	10	55
Hydrolysis	53	8	61

Source: ZUUBIER and VOOREN, 2008.

TABLE 7 Values of long-term investments, O & M costs and production of second generation biofuels.

Technology	Investiment	O&M	Production cost
	(Euro/kWt)*	% Invest./year	Euro/GJ_f**
Gaseificação/F-T	540	4	7-9
Hydrolysis	180	6	5-7

Source: ZUUBIER and VOOREN, 2008.

* Euro per kW thermal of biomass entering the gasifier.
** Euro per GJ of fuel.

FINAL CONSIDERATIONS

The intention of this chapter was to present a range of energy aspects of the cane to enable researchers interested in this subject to start simulations and assessments with different values of TRS% cane, fiber% cane and straw. Only with a sequence of simulations and analysis of results and monitoring of development of technologies that enable better use of the cane fibers it will be possible to gain feeling and confidence to help when time comes that we will need to decide between more fiber in exchange for less TRS, since there will be a basis for discussions. It is more or less obvious that the energy cane should have a high value of primary energy, both per ton of cane and, especially, per unit of cultivated area. In a more refined form already, the discussion should extend to the composition of the fibers in their main components and their elements considered contaminants.

For now, we need to start rethinking the fiber content of the cane and put more effort in understanding the agronomic impacts of straw in the field. The collection, processing and storage of straw is far from a solved problem and we begin the journey towards optimizing energy cane for use in first-generation technology, which will continue in use for decades to come, even after consolidation of second generation technologies.

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APPENDIX

A. Basis of calculation

A1 Energetic values: Higher Heating Value (HHV) and Lower Heating Value (LHV)

Material HHV (MJ/kg, dry basis)
Fiber 18
Sucrose 16.5
Reducing sugars (RS) 15.6

A2 Anhydrous ethanol

HHV= 23.4 MJ/l
LHV = 21.2 MJ/l

A3 Conversion (Fernandes, A.C., 2003)

TRS= sucrose/0.95 + RS

Stoichiometric yield

1 kg TRS results in 0.6475 l absolute ethanol, 0.6503 l anhydrous ethanol or 0.6776 l hydrous ethanol.

Actual production of ethanol = (TRS in the sugarcane) X (stoichiometric yield) X (industrial efficiency)