# SUGAR CANE'S ENERGY

*Twelve studies on Brazilian sugar cane agribusiness and its sustainability*

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*Twelve studies on Brazilian sugar cane agribusiness and its sustainability*

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# Foreword:
# Between oil and hydrogen, ethanol is much more than just a transition in this 21st century

*Eduardo Pereira de Carvalho*
UNICA – São Paulo Sugar Cane Agroindustry Union

For a very short period of twenty months, commencing when the first edition of this compilation came out, the global energy base started to go through an intense transformation phase. This is taking place for a simple but strong reason: at last the leaderships in the world's major nations have bowed to the evidences and now acknowledge the decisive impact of carbon emissions from human activities as a primary cause of the global warming. This triumph of the science has finally opened the door to a new era in which the oil civilization will give ground to renewable energy sources, thereby reversing a trend that has ruled unrivalled since the mid 19th century. Bound up for many generations by the consistent, vigorous predominance of prospecting for oil and consuming it, powerful societies, which have for centuries been used to dictate solutions to all others, now suddenly find themselves compelled by internal pressures to recognize concepts and provisions negotiated in a multilateral context. The climate change worries everyone, and the answer to the related fears lies not in the set of palliative measures that had been proposed since the early 1990's. Mankind feels compelled to go deeper in order to solve the problem that it created in the course of its undoubtedly successful history.

For Brazil, that represents an opportunity of a kind that hasn't been seen for a long time: it is now time for renewable energy, and, with it, mankind finds that its future is linked with the properties of fuels recovered from newly harvested plant mass. The list of complements that are now indispensable to oil is extensive; standing out from that list due to both its competitiveness and unmatched environmental performance is an old acquaintance of our social lives: the wholesome sugar-cane.

This turn of events in the energy paradigm is taking place so fast because the disturbance caused by the global warming is becoming palpable. Highly elaborated counter-arguments have ruined before the eyes of billions of people with common sense. In the face of the overwhelming evidence of more and more predictable climate disturbances, the benefit of the doubt turns into irresponsibility. There is time to correct the path of unbridled greenhouse gas emissions, which are a decisive, primary cause of the acceleration of the global warming phenomenon. But action must be taken in a realistic, decisive way to bring on new components for the fuel blend that moves the day-to-day lives of people who depend on oil to eat, dress, work and have fun.

In addition to the traditionally rich part of the planet, there are several billions of new consumers, a vast majority of whom consisting of citizens in emerging countries, who can now for the first time own goods that make their lives less tiresome thanks to the work of engines. In view of this massive pressure on the demand, the human society now bows, in a turn-around that very few people of goodwill would assume to be plausible in such a short period, to the evidence that fossil fuel reserves are finite and even rather limited.

The change in the energy supply scenario in light vehicle transportation is now a definitive fact not only in people's minds, but also on the political plane. This is just why it is opportune to rephrase the title and most of the introductory note to the first edition of this paper that was prepared by Brazilian scientists and researchers invited by UNICA and published in the second half of 2005. The original Twelve Studies, compiled herein from sources that are respectable but not immune nonetheless to the formidable ignorance of sugar cane growing and the manufacturing of ethanol that prevails in the Northern Hemisphere, address challenging issues facing Brazilians who deal with this tropical grass.

The data that have been collected over decades in Brazil on both the environmental impact of the activity and the cost of the fuel that comes from a renewable source and is used without any kind of subsidy by a significant portion of the national fleet of light vehicles are undisputable. Nevertheless, the colonizing wisdom has kept monotonously casting doubts. Hence the careful, substantive tone used at all stages of the paper – using special care in the preparation of the texts. The result, based on experiments, plenty of statistic information and, whenever possible, original research, was intended to speak to people of science, who may be coming from an antagonistic position, but do not hesitate when they acknowledge strengths in the arguments opposing their own. As a matter of fact, this approach was thoroughly maintained in this edition, which gathers together the latest information on the industries under analysis.

It also happens that in the second half of 2005 major multilateral organizations, particularly the World Bank and the International Energy Agency, circulated the conclusions of independent papers on energy from renewable sources. Those papers showed that the primary sources used by developed countries have acknowledged for the first time that sugar-cane ethanol is competitive with oil at very comfortable prices – while recognizing that the Brazilian ethanol program is free of subsidies and that the environmental balance of sugar-cane growing and processing is broadly beneficial to the planet, especially as regards carbon emissions.

Now reviewed and updated in depth, the papers prepared by Brazilian researchers are therefore validated to a rather unusual extent in competitive situations in these globalization times. Brazil no is longer required to claim to high heavens the great quality of a fuel that for three decades has played a role on the streets of its large cities, as well as every corner of the continent-sized country. That doesn't mean that multiplying the supply of that product will be just a cruise over the next few years. There are substantial problems to be examined and solved. However, before considering them, it is worth pointing out the success that has been achieved over time. There is an effective answer to the world's question as to what the complement would be to the overly pollutant oil, and it is now acknowledged that such answer is given by an emerging nation: ours! Therefore, it's time to add ethanol to the list of fuels that transform life in the human society: between oil and hydrogen, which are a revolution of the past and a revolution envisaged for the future, respectively, lies a contemporary revolution in which Brazil plays a major role.

As a matter of fact, the tropical origin of the best-proposed fuel available from a renewable source is quite understandable: it is in low-latitude zones that the sunlight provides the best results for crops that capture solar energy through photosynthesis. However, there is yet another reason for emerging countries to mobilize in search of answers to face the energy challenge. Since 1973, on occasion of the first oil shock, the share of those nations, which are known as developing countries in the world demand for energy, has grown by ten percentage points. The International Energy Agency itself projects that emerging countries will account for 56 percent of the demand by 2030. Therefore, in just two generations' time, the core of the issue will be radically displaced, as the OECD (Organization for Economic Cooperation and Development) nations, which were responsible for 62 percent of the consumption in the early 1970's, will account for just 44 percent of it in 2030.

Now, when one looks towards the future, energy security means a different thing: emerging markets feel compelled to ensure their own supply, irrespective of effectiveness, and seem less prone to make strategic decisions, leaving the environmental emissions theme to the developed world's agenda, where it's in an important position already. In the course of the 21st century, these two realities will certainly converge. The conditions for such convergence now seem well-accepted by most of the analysts and intervening parties: the severity of the problems involved in the prospective depletion of oil reserves; the dangerous geographic concentration of that raw material; the alarming global warming problem; the imperative need to improve the living conditions – and, therefore, the economic development – of most of the world's population; and the very wide range of interests of the oil industry. Due to all of these factors, the issue should not and cannot be left exclusively at the whim of market forces.

The pace of this transition, which began in a hesitating way, now speeds up. Back in the early 1970's, when the fossil fuel-powered locomotion paradigm seemed unshakable, professor Nicholas Georgescu-Roegen was practically banned from the academic community when he published his *The entropy law and the economic process*, which warned about the physical difficulties that he was then the only one to see in the horizon of human evolution, and that would break out soon afterwards with the first oil shock, on November 1973. Disregarded at that time, his conclusions have become more and more of a reference source for the study of economic prospects for the next few decades. It is based on views that sounded notably pessimistic that the knowledge and even the relations between peoples and continents gained dimensions and even a language radically new.

It is in this scenario that Brazil assumes a privileged position to argue about the sustainability of the energy model currently in place, which is underpinned by liquid fossil fuels. Of course, the starting point of such experience was necessity: a country fascinated by the automobile, but which depended on imports and had no access to hard currency. In 1974, the oil bill represented 40 percent of the country's export revenues. No other society would suffer more than Brazil's with the OPEC's gesture, as the limitation on access to fuel stations by rotation, which was considered and even tried at many places, became a stressful situation in the Brazilian's day-to-day lives.

That gave rise to a growing, intensive addition of ethanol to gasoline, as a state program – followed in the early 1980's by the experience with cars running exclusively on ethanol and, starting in 2003, with flex-fuel engines. The successful evolution of this model, along with a tradition of intensive use of hydroelectric power, have placed Brazil in a unique position among nations with an industry base: the share of energy from renewable sources in the country's entire energy base, which was around 41 percent earlier this decade, exceeds by far the world average of around 14 percent.

With these credentials, sugar and ethanol producers based in São Paulo, the world's leading sugar-cane growing and processing center, offer to start showing through UNICA, by means of this paper prepared by experts renowned in their respective fields of expertise, the reasons for the success of a value chain that has tripled in size over the past thirty years and is now going through an investment phase that is expected to add 50 percent to the region's installed capacity by the 2010/11 crop.

This may become a historic moment for the sugar and ethanol industry in view of the convergence between Brazil's and the United States' interests in this renewable energy issue. Together, the two ethanol producers account for three quarters of the world production. If they continue to be truly willing to combine their respective competitive advantages for a common effort towards researching into and encouraging the activity along with other potential producing countries, then the development of biofuels may become a decisive factor for overcoming the climate deadlock. That applies today, but it is also a great opportunity for the future.

There are many possible sources of biomass, just as well as the technological evolution can and should find successors to generate hydrogen at some point in this first half of the 21st century. However, the fact remains that Brazil has a strong scientific base to genetically work with sugar-cane varieties, makes massive investments of private funds to consistently expand the production, is watching a dramatically fast-growing demand for light vehicles equipped with flex-fuel engines, is capable of and has actually succeeded in delivering increasing amounts of ethanol at the world's most distant ports, sustains a subsidy-free agricultural policy that has been recognized as such by the World Trade Organization, seeks to maximize the utilization of sugar-cane waste for energy purposes, and has a strict policy to improve labor relationships and social conditions in the industry.

When major countries like the United States, to begin with, adhere to biomass as a strategic ingredient to reduce emissions without affecting the economic balance of their energy base, they add momentum for the same decision to be made in other centers where the activity is dynamic, such as the European Union and Japan. There is a constellation of other examples in all continents to name: China, India, Sweden, Thailand, Australia, Colombia, Guatemala, Canada, etc. Such diversity attests that the decisive move towards changing energy options has already been made.

Before that this globalized movement took shape and gained strength, the constellation of major light vehicle producers did what they could to move directly from gasoline to hydrogen. In other words, from the fuel that dominates the first century of automobile history to the answer that all scientists consider to be unbeatable in order to insure the primacy of individual transportation for the next one hundred years. However, between the two events, i.e. the fall of oil and the rise of hydrogen, these major industries have been unable to tackle the still insurmountable energy yield challenge, so that it can be stated that there exists a permanent solution for the automotive fuel problem.

It is right now that the ethanol produced from sugar-cane in Brazil can have a huge, positive impact on the energy base of advanced societies that consume energy intensively and are therefore responsible for a greater portion of the cleaning operation that takes shape at the same pace as natural disasters shock public opinion and force governments and business entities to invest in short-term solutions. As can be demonstrated by the data gathered together in this paper, producing ethanol from sugar-cane saves energy while preventing pollution thanks to the intensive use of a fuel that results from the very process, from the harvesting to the fermenting and distillation process, the main energy source of which being combined heat and power generation from the sugar-cane bagasse and straw that are left at the crushing facilities. In addition, sugar-cane ethanol ensures more energy for end use per energy unit that is spend to produce it than any other currently known renewable source.

The pace at which the energy base has been transforming has never stopped surprising since the human society became aware that oil was indeed a finite resource. However, no answer has been more dynamic than that given by Brazil. For example, the introduction of light vehicles equipped with flex-fuel engines sounded like an obscure chimera as recently as 2002. Reliable estimates prepared just two years ago indicated that two thirds of all cars produced would be flex-fuel vehicles in 2007. Reality shows that the actual rate has turned out to be around 90 percent, as consumers realized that they gain great bargaining power by having equipment that can function just as effectively whatever the proportion of the gasoline-ethanol blend.

Reason always prevails in economic decisions of major impact. The events arising out of the heavy pollutant load that the intensive use of fossil fuels has imposed on the world in the last two centuries give place to the efforts to find a competitive and sounder alternative. It is one of those situations that could even trigger spectacular changes in the hierarchy of nations. It is something as big as what our forefathers were able to witness when the United States went ahead and placed all of their economic and strategic chips on the potential of oil. Ironically, Henry Ford, who was then taking the first steps of his lonely adventure that would endow each American home with an unfailing black Ford Model T, originally intended to motorize his cars with ethanol driven engines.

The room available for biomass-derived fuels tends to grow, creating prospects for all countries – particularly those located in the tropical belt or, in other words, the least developed ones. Diversified sources are welcome. Ethanol can be produced not only from sugar-cane, but also from grains and lignocellulosic materials, the latter being a source that is still being tested in laboratories, but with promising results that suggest they will be, within a few decades, in a prominent position among world's most used energy raw materials. It is on societies in need of real opportunities that the efforts towards growing plants that are more suitable for energy purposes should be focused. With intelligent trade rules that actually move forward to free access to currently super-protected markets, humanity will take its most significant step towards achieving the necessary security in energy supply, while contributing to a greater income generation in the least favored parts of the world – thereby creating a both effective and peaceful method to defeat terrorism by redeeming those who are hopeless today.

# Acknowledgements

The idea of preparing this report arose from the realization by the Board and Advisors of UNICA of the need for a more solid knowledge of the sugar cane industry's position in the Center-South of Brazil regarding its sustainability in the context of the expansion of its activities. The definitions of scope and coverage must be credited to many people from these groups, particularly Eduardo Carvalho.

The administrative and financial support for some of the studies was provided by UNICA, and it was essential to get the quality work we wanted.

The technical support provided by many advisors of UNICA was consistent and went beyond the preparation of reports in their fields of expertise; we highlight the work performed by Maria Luiza Barbosa in interaction with the mills.

Finally, the power of this study is based on the contributions provided by twenty-three professionals who were selected for their renowned competence. These individuals agreed to go out of their way in order to produce the texts and adapt them to the context, and work with the coordinators on many occasions to improve the whole of the report.

Our thanks to you all.

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*Unassigned essays and texts have been written by the Organizer.*

# Preface

*The purpose of this report is to present a unified view of the various aspects of the sugar cane agribusiness' sustainability in the Center-South of Brazil.*

The evolution of such industry over the past twenty years and its growth prospects for the next few years demand a much different position from the traditional sugar producer, who should include the role of energy producer and do a lot more business in the world markets. The last twenty years also saw an extraordinary improvement in our knowledge of the consequences of human interaction with the environment, as well as the social consequences of political and economic action in a much more interrelated (globalized) world.

This is the context in which we gathered 23 experts for preparing this report, which also relied on the informal participation of a number of other professionals. The scope of the themes, the complexity and, in some cases, the insufficiency of knowledge indicate that said purpose can only be fulfilled in a limited way, and that the concepts, analyzing methods and, as result, conclusions and recommendations contained herein need permanent reviews.

A very appropriate remark by Dernbach[1] in the much more general context of today's society is that our present actions lead us "stumbling toward sustainability." In the face of Brazil's sugar cane industry, both the current situation reflected in this study and the great opportunities for growth and sustainable development make up very appealing scenarios, thereby allowing researchers, businessmen and governmental players to hope for successful work. We hope this study can help determine the paths for this future.

1 Dernbach, J.C. (Ed.): *Stumbling toward sustainability*, Washington DC, Environmental Law Institute, 2002

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*Coordinator*

# Synthesis

The interaction of the industry's activities with the environment, society and economy is complex; instead of treating it according to activity type (agriculture, industrial process, marketing, end use), we chose to group the topics by type of impact. Accordingly, we considered the *Impacts on the use of material resources* (especially energy and materials); the *Impacts on the environment* (air quality, global climate, water supply, soil occupation, biodiversity, soil preservation, use of pesticides and fertilizers); the *Sustainability of the agricultural production base*, including resistance to pests and diseases; the *Impacts on commercial actions*, covering competitiveness and subsidies; and, in conclusion, some *Socioeconomic impacts*, with great emphasis on the creation of jobs and income. These topics are covered in the following twelve chapters.

## I. Impacts on the use of material resources

Even though it is known that there is a need, as well as possibilities, to reduce specific consumption of energy and materials in developed countries without compromising the quality of life, that has not been accomplished. The analysis of *Impacts on the use of material resources* of the sugar cane industry's activities point to a very positive situation (and possibilities): the industry is an energy *supplier*, replacing fossil energy, and may become a supplier of (renewable) materials, such as plastics and chemicals.

The world supply of energy is based on fossil fuels (75%); the scale on which fossil fuels are used quickly leads to depletion of resources, leaving a heavy burden for future generations. Additionally, the use of fossil fuels is responsible for a large amount of local pollution and most of the greenhouse gas emissions. The use of energy should grow as a result of advances in many of the world's developing regions. The current challenge is to seek renewable energy sources and to increase efficiencies in energy generation and use on an unprecedented scale.

Brazil has an intermediate consumption level (1.1 toe / inhab·year), with a deep focus on renewable energy sources (43.8%, compared to 13.8% in the world). Brazil can significantly increase the use of biomass and other resources to improve generation and use efficiencies. In this respect, among other initiatives, Brazil should implement the distributed generation of electrical power (based on combined heat and power), which could reach 10-20 percent of the total within 10-15 years, and establish a fuel policy for the transportation sector.

*The sugar cane industry already provides a major contribution (responsive sustainability) to the substitution of fossil fuels, going much further than energy self-sufficiency (electrical and thermal power).*

√ It generates 11.3 TWh of electrical and mechanical power (3% of the electrical power generated in the country)

√ It uses bagasse as a fuel: 20.2 Mtoe (equivalent to the sum of all of the natural gas and fuel oil used in the country)

√ It produced nearly 50% of all the gasoline used in the country in 2004

The sugar cane industry's improved energy performance (use of sugar cane trash, and the implementation of efficient co-generation) can lead to an additional 30 TWh of electrical power. Alternatively, the implementation of processes for bagasse and trash conversion to ethanol in the future can increase ethanol production by 40 percent for the same sugar cane production level.

If the expected sugar cane production increases for the next years materialize, for every additional 100 Mt of sugar cane, the industry would supply 3.8 percent of the current electrical power consumption and 4.9 $Mm^3$ more ethanol (assuming that 58% of the sugar cane are used in ethanol production). The alternative ethanol production from bagasse and trash, when technically possible, would lead to an additional 3.4 $Mm^3$ of ethanol.

The *per capita* consumption of materials and resources worldwide has continued growing over the past ten years, and so have the resulting environmental impacts. As in the case of energy, governmental policies have not been sufficient to reverse the trends that are aggravated by the advances of large developing areas.

Agriculture (having solar energy as an input) is a field that can lead to a sustainable production of materials in some cases. This perception promotes biological products as "environmentally sound". Ethanol based products (Brazil, 1980's and 1990's) have brought several examples, as have recent advances in sucrose chemistry.

Brazil's sugar cane production corresponded (2006) to a production of 60 Mt of sucrose and 120 Mt (DM) of lignocellulose residue. Sucrose is currently used in sugar and ethanol production, but other important activities are beginning in new products development. Of the residue, 50 percent are used at low efficiency rates in energy generation, and more than 25 percent (trash) are recoverable at costs compatible with energy uses.

The production costs in Brazil and the availability of bagasse energy make sucrose very attractive to dozens of other products. In Brazil, there is commercial production of amino acids, organic acids, sorbitol, and yeast extracts, as well as developments concerning products for large amounts (plastics). Over the next few years, it will be possible to use 1.5 Mt of sucrose in these processes.

In the 1980's and 1990's, more than 30 products were produced from ethanol in Brazil, several of which relied on installed capacities in excess of 100,000 tons / year (via ethylene, acetaldehyde or direct transformations). They became unfeasible in the 1990's because of the national policy for oil derived chemicals and the relative cost of ethanol. The new oil-ethanol cost ratio now leads those processes to be reconsidered.

The large-scale production of renewable materials from sugar cane in Brazil is a possibility, but is still at an early implementation stage. It is growing somewhat rapidly in the use of sucrose, and may grow in alcohol chemistry again, while having a great unrealized potential in terms of residue utilization. It would certainly contribute a lot to the sugar cane agribusiness' "responsive sustainability" position.

## II. Impacts on the environment

The *Impacts on the environment* consider the sugar cane culture, industrial processing and end use. They include effects on local air pollution and the global climate, on the use of soil and biodiversity, on soil conservation, on water resources, and the use of agrochemicals and fertilizers. Those impacts may be either positive or negative; in some cases, the sugar cane industry has very important results, such as the decrease in GHG (Greenhouse Gas) emissions and the recovery of agricultural soils. The environmental legislation (including restrictions on soil use) is advanced in Brazil, and efficiently applies to sugar cane crops.

The deterioration of air quality in urban centers is one of the world's most serious environmental problems. For the most part, it is caused by the use of fossil fuels, which also contribute to cross-border pollution, such as acid rain, for example. Mitigating efforts include an increasingly restrictive legislation on fuels and utilization systems.

The sugar cane agribusiness has two very distinct points of connection with the impacts on air quality: ethanol use has been leading to considerable air quality improvements in urban centers; and the sugar cane burning in the field, on a very different scale, causes problems by dispersing particulate matter and because of the risks associated with the smoke.

The main effects of ethanol use (whether straight or as an additive to gasoline) on urban centers were as follows: elimination of lead compounds from gasoline; reduction of carbon monoxide emissions; elimination of sulphur and particulate matter; and less toxic and photochemically reactive emissions of organic compounds.

The burning of sugar cane trash (used in most producing countries to make harvesting easier) was the subject of many papers in the 1980's and 90's (in Brazil and other countries); they were unable to conclude that the emissions are harmful to human health. Such undesirable effects as the risks (electrical systems, railways, forest reserves) and dust (particulate matter) remained. In São Paulo State, legislation was passed which gradually prohibits the burning, with a schedule that considers the technologies available and the expected unemployment, including immediate prohibition in risk areas. That solution is in force, and is an important example given the size of the São Paulo production.

The 30-percent increase in the concentration of greenhouse gases in the atmosphere since pre-industrial times corresponds to an average increase of 0.6 ºC in the surface temperature of the planet. In the 21$^{st}$ century, the mean temperature may increase by more than 3 ºC if the current trend is not changed. The Kyoto Protocol represents one step towards (increasingly consensual) preventing an increase of up to 2 ºC by 2050.

The global climate models, still evolving, always point to temperature rises in Brazil, but the uncertainties about the rainfall are large. The models indicate temperature increases of 1-4 ºC (low emission scenario) or 2-6 ºC (high emission scenario). There is no agreement on the rainfall results, but climate extremes (droughts, severe storms) are expected to occur more often. In the models that indicate a greater amount of rainfall (GFDL, US) the savannah would expand to the Northeast. In the other scenarios (for example, the HADCM3, England), the savannah would expand to parts of the Amazon, and the *caatinga* in the Northeast would become a desert.

A vulnerability assessment of the agricultural sector should consider the simultaneous effects of the temperature (and rains) and the "fertilization" by the increased concentration of $CO_2$. There are only a few studies for Brazil, and they are focused on coffee and wheat in specific regions.

The evaluation of GHG emissions from Brazil for the 1990-94 period indicates "*Change in the use of land and forests*" as the factor accounting for the most emissions (75%), followed by "*Energy*", with 23 percent.

In the sugar cane industry, the "renewable energy produced to fossil energy used" ratio is 8.9 for ethanol production. *The consequence of this is an extraordinary performance of the industry, which avoids GHG emissions equivalent to 13 percent of the emissions from Brazil's entire energy sector* (reference 1994).

| Emissions avoided in 2003: | |
|---|---|
| With ethanol substituting for gasoline: | 27.5 Mt CO2 equivalent |
| Bagasse in sugar production: | 5.7 Mt CO2 equivalent |

For every additional 100 Mt of sugar cane, emissions of 12.6 Mt $CO_2$ equivalent could be avoided over the next few years using ethanol, sugar cane bagasse and the added excess electrical power.

Even though Brazil has the greatest water availability in the world, with 14 percent of the surface waters and the equivalent of annual flow in underground aquifers, the use of crop irrigation is very small (~3.3 Mha, compared to 227 Mha in the world).

Sugar cane crops are virtually non-irrigated in Brazil, except for some small areas (supplementary irrigation). Efficient methods (subsurface dripping and others) are being evaluated.

The levels of water withdraw and release for industrial use have substantially decreased over the past few years, from around 5 $m^3$ / sugar cane t collected in 1990 and 1997 to 1.83 $m^3$ / sugar cane t in 2004 (sampling in São Paulo). The water reuse level is high (the total use was 21 $m^3$ / sugar cane t in 1997), and the release treatment efficiency was in excess of 98 percent.

It seems possible to reach rates near 1 $m^3$ / sugar cane t (collection) and zero (release) by optimizing both the reuse and use of wastewater in ferti-irrigation.

For the most part, environmental problems relating to water quality, which result from irrigation (water run-off, with nutrients and pesticides, erosion) and industrial use, are not found in São Paulo. In this respect, EMBRAPA rates sugar cane as Level 1 (no impact on water quality).

The Permanent Protection Areas (APP, in Portuguese) relating to riverside woods have reached 8.1 percent of the sugar cane crop area in São Paulo, 3.4 percent of which having natural woods, and 0.8 percent having been reforested. The implementation of riverside wood restoration programs, in addition to the protection of water sources and streams, can promote the restoration of plant biodiversity on the long term scale.

With 850 Mha, Brazil has a large portion of its territory with conditions to economically support agricultural production, while preserving vast forest areas with different biomes. Today, agriculture uses only 7 percent of this territory (half of which being taken up by soybean and corn crops), pastures use around 35 percent, and forests 55 percent. The expansion of agriculture over the past 40 years took place mostly in degraded pasture areas and *"campos sujos"* (grassland with some shrubs), rather than forest areas. The area currently occupied by sugar cane crops represents only 0.6 percent of the territory, and the area currently able to support the expansion of this kind of crop represents at least 12 percent.

The *cerrado* (24% of the territory) has been extensively utilized for agriculture and cattle-breeding over the past 40 years. The expansion of sugar cane crops in areas covered by the *cerrado* vegetation has been very small so far, and has replaced other covers that had previously replaced the *cerrado* (usually pastures).

The expansion of sugar cane crops has taken place essentially in Brazil's Center-South region over the past 25 years, in areas that are very far from the current biomes of the Amazon Rain Forest, the Atlantic Forest and the Pantanal. From 1992 until 2003, almost all of the expansion (94%) in the Center-South region occurred in already existing sugar fields; new agricultural borders were involved very slightly. In São Paulo, the growth has occurred through substitution of pastures and other crops.

For the next few years, there should be growth in the Center-South region, with an emphasis on western São Paulo, the borders with Mato Grosso, and in some areas within the state of Goiás.

Brazil concentrates the world's largest biological diversity (including the Amazon Rain Forest, the Atlantic Forest, and the *cerrado*), and a flora estimated at 50,000 to 60,000 angiosperm species. The biodiversity preservation priorities were set mainly between 1995 and 2000, with the contribution of hundreds of experts; protected areas were established for the six major biomes in the National Preservation Units System. This important initiative should undergo some reviews, so as to incorporate methodology advances and to consider the expansion of agriculture and the vulnerability to climate changes.

Since the discovery of Brazil, the Atlantic Forest was the first biome to be partially replaced with the exploitation of wood, agriculture and cattle-breeding along Brazil's entire coast. Among many others, the sugar cane culture (Center-South and Northeast) is now in areas originally covered by that biome. The process by far preceded any concern for preservation, and that preservation requires restoration of protected areas (riverside woods, hillsides).

The agricultural occupation of the *cerrado* is very recent, and includes areas occupied by cattle-breeding, as well as firewood and coal exploitation.

Its growth should be planned, taking into consideration the preservation of biodiversity and water resources, especially in sensitive areas (sources of rivers that flow to the Pantanal, and recharge areas of the Guarani Aquifer).

Harmonizing socioeconomic development with environmental preservation requires up-to-date information and appropriate tools for analyzing impact and vulnerability; programs like that of the IVB (São Paulo) and advances in the survey of geo-referenced data (in progress) are highly important in this context.

Sugar cane crops have been expanding in areas having poorer soils (especially "highly anthropized *cerrados*," mostly extensive pastures). They contribute to the recovery of those soils by adding organic matter and chemical-organic fertilizers, which also contribute to improving the physicochemical conditions of the soil, thereby incorporating them into Brazil's agricultural area.

Today, the sugar cane culture in Brazil is renowned for its relatively small soil erosion loss (compared to soybean and corn, for example). This situation keeps improving as harvesting without burning expands and reduced preparation techniques are introduced, thereby reducing losses to very low rates that are comparable to those for direct planting in annual cultures.

The concern about the impact of pesticides is present in many sections of Agenda 21, which provides specific control actions. The use of new technologies based on genetically modified plants is promising (reduction of pesticide utilization), but requires additional caution. Ideally, biological controls and, to the extent possible, "organic" agriculture techniques should be used.

The Brazilian legislation, including rules and regulations from production to use and disposal of materials, covers all important aspects.

Pesticide consumption in sugar cane crops is lower than in citric, corn, coffee and soybean crops; the use of insecticides is low, and that of fungicides is virtually null.

Among the main sugar cane pests, the sugar cane beetle (the most important pest) and the *cigarrinha* are biologically controlled. The sugar cane beetle is the subject of the country's largest biological control program. Ants, beetles and termites are chemically controlled. It has been possible to substantially reduce the use of pesticides through selective application.

Sugar cane diseases are fought against through the selection of disease-resistant varieties in major genetic improvement programs. This procedure has been sufficient to address the occurrences in large proportions, such as the mosaic virus (1920), the sugar cane smut and rust (1980's), and the SCYLV (1990's), through replacement of varieties.

Genetic modifications (at field test stage) have produced plants resistant to herbicides, smut, the mosaic virus, the SCYLV and the sugar cane beetle.

Weed control methods have been frequently changed because of technological advances (cultural and mechanical or chemical). In Brazil, sugar cane crops still use more herbicides than coffee and corn crops, less herbicides than citric crops, and the same amounts as soybean crops.

There is a strong trend towards an increase in "green" sugar cane harvesting, with the trash remaining on the soil. Today it seems impossible to totally eliminate herbicides as expected, especially because of the rise of unusual pests.

The use of fertilizers in Brazilian agriculture is relatively small, although it has increased over the past thirty years, thereby substantially reducing the need for new areas.

Among Brazil's large crops (area larger than 1 Mha), sugar cane uses smaller amounts of fertilizers than cotton, coffee and orange, and is equivalent to soybean crops in this respect. The amount of fertilizers used is also small compared to sugar cane crops in other countries (48% more is used in Australia).

The most important factor is the nutrient recycling through application of industrial waste (vinasse and filtercake), considering the limiting topographic, soil and environmental control conditions. Substantial rises in the potassium content of the soil and productivity have been observed. Nutrient recycling is being optimized, and the trash utilization is yet to be implemented. It will be very important in expansion areas.

A number of studies in respect to leaching and possibilities of underground water contamination with vinasse indicate that there are generally no damaging impacts for applications of less than 300 $m^3$ / ha. A technical standard by the Office of the Secretary of Environment (São Paulo) regulates all relevant aspects: risk areas (prohibition); permitted doses; and technologies.

## III. Sustainability of the agricultural production base

The *Sustainability of Brazil's sugar cane production base* requires the ability to respond to pests and diseases and to periodical climate changes, without seriously impairing it.

The production conditions in Brazil, with its diversity of regions and microclimates, have been responding appropriately to periodical climate changes.

Protection from pests and diseases is considered a strength of Brazil's production: it is based much more on a continued supply of disease and pest-resistant sugar cane varieties than on phytosanitary barriers, allowing growers to operate with a great diversification.

There are four operational sugar cane genetic improvement programs in Brazil (the two leading programs are private); they use one quarantine and two hybridization facilities, with germplasm banks. They work with approximately 1.5 million seedlings per year.

More than 500 varieties are grown today (51 have been released over the past ten years). The twenty most important varieties occupy 80 percent of the crop area, but the most widely used occupies just 12.6 percent. The substantial rise in diversification over the past twenty years has provided great safety concerning resistance to exogenous diseases and pests.

Brazil stands out from other producing countries for its sugar cane biotechnology, having had (non-commercial) transgenic varieties since the 1990's. In 2003 the identification of 40,000 sugar cane genes was completed in Brazilian laboratories. There are dozens of groups working on the functional genome, and they are already using the genes in genetic improvement programs (experimental stages). Commercial results may arise over the next five years.

More funds are recommended in order to properly integrate the germplasm banks for all programs and to support specific developments for each expansion area.

The efforts on the legislative front should be carried on in order to facilitate the development of biotechnological research at its final stages.

## IV. Impacts of production on commercial actions

The sugar cane ethanol and sugar production in Brazil's Center-South region today have no adverse economic impacts on the external environment; there is no externalization of costs to be paid by other sectors of society. The sugar cane products do not have any price support mechanism under governmental policies, and there are no subsidies to sugar production or trade today.

Ethanol production cost (without taxes) in the Center-South mills, was estimated at R$ 647/m$^3$, which is highly competitive with international gasoline prices. Ethanol production costs in Brazil are also significantly lower than the costs for corn ethanol in the US or wheat and beet ethanol in Europe.

The ethanol cost reductions in Brazil since the program was introduced have occurred due to advances in technology and management and investments in infrastructure. A broader implementation of existing (commercial) technologies may further reduce costs in the Center-South, but the best prospects relate to new technologies being developed. These include precision agriculture, new sugar cane and trash transportation systems, and genetic modifications of sugar cane.

In addition, the production diversification will contribute to the rise in competitiveness, as it did upon introduction of ethanol. Such diversification includes the increase (in progress) in the use of sucrose and some ethanol-based routes, and the production of excess energy from sugar cane biomass in several ways (also in progress).

The sugar from the Center-South has had the world's lowest production cost for many years now, amounting to R$ 410 / t. The world production cost is currently evaluated at US$ 120 / t, for up to 20 Mt (the production of Brazil's Center-South region); for 20 Mt to 65 Mt, the cost goes up to US$ 200-250 / t; and for 65 Mt to 100 Mt, it rises to US$ 400 / t. The total sugar production and export cost in the Center-South represents 65 percent of the mean cost of other exporters.

The high availability of appropriate land for expansion and the lack of governmental policy-supported prices in Brazil would make the country even more competitive in a trade liberalization scenario (as expected). Analyses of the ethanol and sugar markets point to a demand of 560 Mt of sugar cane / year in Brazil for 2010.

## V. Socioeconomic impacts of the sugar cane agribusiness

Brazil has had an unemployment rate of 9 to 10 percent over the past few years. Job quality and income distribution are serious problems; the Gini coefficient was 0.607 (1998) and 0.554 (2003). Notwithstanding the increase in income, social inequalities have not been significantly reduced over the past 20 years. Workers who do not contribute to the social security system are estimated at 55 percent. The rates of child labor (2.4%, 10-14-year-olds) and functional illiteracy (23.9%, less than 3 years at school) have been significantly lowered, but are still high. The *per capita* income in 2002 was US$ (PPP) 7,600.00.

In the consideration of *Socioeconomic impacts of the agribusiness*, the most importance its attached to job and income creation for a very wide range of workforce capacity building programs, with the flexibility to support local characteristics using different technologies. It should also be remembered that the industry fosters substantial foreign currency savings by avoiding oil imports, and the business and technological development of a major equipment industry.

The replacement of gasoline with ethanol between 1976 and 2004 represented savings of US$ 60.7 billion (exchange rate of December 2004), or US$ 121.3 billion, considering the interest rates.

The Brazilian industry supplying equipment for cane, sugar and ethanol production developed into a leading position; the largest manufacturer, alone, produces 726 distilleries (distillation units), 106 full plants, 112 combined cogeneration plants, and 1,200 boilers (including exported units).

Brazil's labor legislation is renowned for being advanced in worker protection; the union organization is developed and plays a key role in employment relationships. For sugar cane, the specific aspects of employment relations in agriculture (specific unions) and industrial operations (unions of the food and chemical industries) are well-defined, including the conclusion of collective agreements, which advanced during the last decade. Compared to the Brazilian 45-percent mean rate of formal jobs, the sugar cane industry's agricultural activities now have a rate of 72.9 percent (from the 53.6% of 1992). In the Center-South, the rate of formal jobs in sugar cane production is 85.8%, reaching 93.8 percent in São Paulo (2005).

The differences in regional development are reflected in the industry's occupational indicators; poorer regions are characterized by lower salaries and a much larger use of labor, consistent with their technological levels (automation, mechanization).

In the early 1990's, there were 800,000 direct jobs; for every 1 Mt of sugar cane produced and processed, there were 2,200 direct jobs (73% in agriculture); in the North-Northeast, three times as much as in the Center-South. In São Paulo, non-specialized workers (sugar cane cutters) were paid US$ 140 / month (US$ at that time), which was higher than the amount paid to 86 percent of agricultural workers in general, and 46 percent of industrial workers. The mean family income of those workers was higher than that of 50 percent of all Brazilian families.

The seasonal index for jobs was 2.2 in São Paulo in the early 1980's, 1.8 in the late 1980's, and 1.3 in the mid 1990's. This decrease was motivated mainly by the mechanical harvesting of sugar cane, which also enabled more training and career planning.

In the late 1990's, with 650,000 direct jobs and 940,000 indirect jobs (plus around 1,800,000 induced jobs), the number of jobs per product unit in the Center-South region was still 3.5 times higher than in the North-Northeast; there is a correlation between the difference in the mean job quality (according to years of education) and salary levels.

The *formal, direct jobs* in the industry are now increasing in number and reached 982,000 in 2005. Of those formally employed, 90.8 percent are aged 18 to 48 (0.2% under the age of 17). Industrial jobs increase more than jobs in agriculture. People having studied for less than 4 years represent 35.2

percent of the workers, 11.3 percent being illiterate (4% in the Center-South).

Considering both formal and informal jobs (2005 PNAD sample), the income of working people in Brazil was as follows: all industries, R$ 801 / month; agriculture, R$ 462 / month; industrial operations, R$ 770 / month; services, R$ 821 / month; sugar cane agricultural jobs: Brazil, 495; N-NE, 316; C-S, 697; São Paulo, 810; Sugar industry: Brazil, 742; N-NE, 600; C-S, 839; São Paulo, 837.

The amounts for ethanol are a higher than those for sugar, reaching 960 for Brazil and 1196 for São Paulo.

In agriculture, the mean education level in the North-Northeast is equivalent to half the level (years at school) of the Center-South.

In the Center-South, the income of people working in sugar cane crops is higher than in coffee and corn crops, equivalent to citrus but lower than in soybean crops (highly mechanized, with more specialized jobs). In the North-Northeast, the income in sugar cane crops is higher than in coffee, rice, banana, manioc and corn crops, equivalent to the income in citrus crops, and lower than in soybean crops.

The income in formal jobs does not include the 13th salary or any benefits. Mills maintain more than 600 schools, 200 daycare units and 300 ambulatory care units. In a sample of 47 São Paulo-based units, more than 90 percent provide health and dental care, transportation and collective life insurance, and over 80 percent provide meals and pharmaceutical care. More than 84 percent have profit-sharing programs, accommodations and daycare units. Social Balance Sheet Indicators for 73 companies (UNICA, SP, 2003) show that funds equivalent to 24.5 percent of the payroll are used for such purposes as profit-sharing programs (6.72%), food (6.54%), healthcare (5.9%), occupational health and safety (5.3%), and education, capacity building and professional development (1.9%).

# Introduction

*The purpose of this report is to present a unified view of the various aspects of the sugar cane agribusiness' sustainability in the Center-South of Brazil.* In this introduction we list some basic sustainable development concepts and the main issues relating to agriculture. Brazil's sugar cane agribusiness is characterized by some production indicators and data. Also a brief description of the production processes is provided for an identification of the interactions of the production system with the environment and society.

**Sustainable development**

With the end of the Second World War and, particularly, the explosion of atomic bombs in the Japanese cities of Hiroshima and Nagasaki, humanity found itself in the face of a real possibility of undermining its life and survival on the planet through its actions. Over the following years, the exuberant industrial expansion and exponential increase in environmental contamination problems added to that perception.

As a result of those concerns, the First World Environment Conference was held in Stockholm by the United Nations in 1972. In addition to matters pertaining to pollution and problems caused by the ever-more intensive use of natural resources, it became evident thereafter that there is an unbreakable link between the need to fight misery and human exploitation and the need for development and quality of life (and, therefore, the quality of the environment we occupy).

However, outside expert circles, peace and security, economic development and social development, the latter translating as respect for human rights, were understood as basic conditions for "human development" until a little more than ten years ago. In 1992, at the UN Conference on Environment and Development (Rio de Janeiro), the nations around the world agreed to implement an ambitious project to promote a "sustainable development." The principles established in the Rio Declaration, and the resulting actions and responsibilities that were detailed in Agenda 21 in 1992 added environmental protection to the list of basic conditions for human development, as it is considered essential to prevent future generations from being unable to accomplish their development.

Accordingly, the main goals of mankind (freedom, equality, and quality of life) became valid not only in the present, but also for future generations: a development that, by meeting present requirements, would not undermine the future generations' ability to meet their own needs. Rather than development with harm to the environment, or environmental protection with harm to development, a sustainable development would seek both the "traditional" development and environmental protection (or restoration).

Agenda 21, as an action plan, defines the current challenge as overcoming "a perpetuation of disparities between and within nations, a worsening of poverty, hunger, ill health and illiteracy, and the continuing deterioration of the ecosystems on which we depend for our well-being".[1] Misery and environmental degradation are destabilizing factors. The central idea of Agenda 21 is that each country is responsible for seeking sustainable development, either by itself or in cooperation with other countries.

The implementation of these actions has been considerably delayed for reasons that include some governments' disagreement with essential topics. However, it is undeniable that there has been great progress in many fields on the part of governments, and that the decentralizing nature of Agenda 21 has very effectively led to many actions "from the bottom to the top" through municipal and state decisions, NGOs and private sectors of the economies. Such movements are growing in number and influence, and should be expected to eventually determine governmental actions even in more hesitating countries. In fact, the experience over the past few years has shown that even though the environmental legislation plays a key role in the evolution of sustainability, it takes more than just laws and policies: the involvement of many other sectors of society.

The following are some of the basic principles of Agenda 21:

- integrated decision-making process (development and environmental protection)
- the "polluter-payer" principle (not transferring the costs to others)
- seeking sustainable population and consumption levels
- the precautionary principle: in cases of serious risks, the lack of scientific certainty should not delay environmental protection measures
- inter-generation equity
- participation of the population
- common but differentiated responsibilities (among developed and developing countries)

1 U. N. Conference on Environment and Development, Agenda 21, U. N. Doc. A/CONF. 151.26, 1992

The topics addressed in Agenda 21, which have been detailed since its introduction, cover a wide range of aspects of our civilization, including regional differences. As the main examples, we can point out: population and consumption (demographic policies, consumption of materials and energy); international trade, development financing and support; preservation and management of natural resources (potable water, oceans and estuaries, seashore waters, and sea pollution; air pollution; climate changes; biodiversity; land use, agriculture, forestry); toxic waste and chemical control (agrochemicals, radioactive and non-radioactive waste); education; institutions and infrastructure (transportation, health).

The recent ratification of the Kyoto Protocol is yet another statement of how important sustainable development has become over the past few years.

**Agriculture and sustainable development**

Agriculture is enormously relevant to human development. Clearly, today's food supply is insufficient for the six billion inhabitants on the planet, and in spite of the efforts set forth in Agenda 21 with respect to rational demographic policies, the world population should reach nine billion within a few decades. Agriculture is a business that will grow together with the global demand. The question that has been asked more and more often is as follows: can agriculture be performed without harm to the ecosystem?

As a matter of fact, according to the concepts of the "green revolution," including the intensive use of materials and water, the sustainability of agriculture is an open question in the best-case scenario; many of the practices are clearly unsustainable. However, we should acknowledge that they have been essential in diminishing hunger around the world over the past few decades. Considering that human development and environmental protection should not be exclusive of each other, what is the proper breakeven point, and how can we evolve into sustainability?

Part of the answer to that question lays in the appropriate use of the production factors: technologies and investment. The stronger emphasis on sustainability is a very recent thing; many of the "modern agriculture" paradigms of twenty years ago are now contested from the emerging standpoint. On the other hand, it is clear that the definitions contained in Agenda 21 are very general, which demand additional efforts towards application to such a diverse sector as agriculture. Agriculture – as well as urban concentrations and most human activities –, in practice, breaks natural ecological functions; there will always be some kind of conflict between it and the "environmental" part of sustainability.

2 Davidson, J.H.: "Agriculture", *in*: Dernbach, J.C. (Ed.): *Stumbling toward sustainability*, Washington DC, Environmental Law Institute, 2002

Examples that are replicated in many countries are evidence of the distance between the systems in use and the sustainability ideals. A recent analysis[2] of agriculture in the United States shows the origin of the system that somewhat prevails today: strong federal intervention, starting in 1930, combining price and income (subsidies) with a subsidized "conservationist" agriculture. Here, "conservation" is different than "environmental protection": it is about maintaining potential resources, preventing waste and maximizing productivity, focusing on utilization for the population. The following are two important examples:

- Irrigation projects in the western United States (such as that of Yakima Valley), initiated in 1902. There are 46 million acres of irrigated soil in the West (water depth of 0.9 m) with infrastructure paid by the federal government; the water is still strongly subsidized today. The sustainability of that is questioned (water availability limitation, competition for land for other purposes, soil contamination, dragging of fertilizers and pesticides). In the western states, irrigated crops are responsible for 89 percent of the contaminated river sections and more than 40 percent of the pollution in contaminated lakes.
- Drainage projects in grain and cotton-growing areas; drainage was intensively used since 1930, with federal resources, to increase production areas. States like Iowa, Illinois and Minnesota were converted from systems that were rich in water into large dry, arable areas (according to "conservationist" concepts). Such "dry land agriculture" has been very important to the US and the world. But the price to pay is the large volume of polluted waters which the drainage system discharges without soil filtration to rivers and lakes.

This is how Agenda 21 (properly) defines the tough problem of agriculture for the next few years: "*By the year 2025, 83 percent of the expected global population of 8.5 billion will be living in developing countries. Yet the capacity of available resources and technologies to satisfy the demands of this growing population for food and other agricultural commodities remains uncertain. Agriculture has to meet this challenge, mainly by increasing production on land already in use and by avoiding further encroachment on land that is only marginally suitable for cultivation*".

Any intervention in nature and living organisms (even when the purpose is to cure diseases and degenerative processes) implies the choice of options that are selected according to predetermined goals and considering the uncertainties inherent in these choices. The same applies to sustainable development proposals.

In the search for effective alternatives for achieving sustainability in agriculture, and considering the pressures that this activity intrinsically puts on the environment, a suggestion made for the American agriculture[2] seems appropriate: agriculture should be both internally and externally sustainable, while serving as an available resource with which to assist other sectors of the economy and society.

2 see p.42

- Internal sustainability includes the ability to preserve its resources by preventing soil and water degradation, and to respond to pests and diseases of the relevant plants, to climate changes, and to market changes. This should occur without any dependence on direct financial support from the government.
- External sustainability means not imposing costly externalities on the "non-agricultural" society or the local environment.
- Responsive sustainability is the ability to assist other sectors (for example, generating "clean" energy from biomass, restoring degraded soils and riverside woods, producing excess to satisfy the needs arising out of any falls in other locations, and creating jobs and income).

These practical guidelines can be very helpful in planning and assessing sustainability in agricultural sectors. The will be used in the course of this study in respect of Brazil's sugar cane production. Despite not seeking absolute parameters in many cases, these guidelines help by putting the current situations and trends in perspective. The guidance resulting from these observations will contribute to have the steps appropriately oriented towards the industry's sustainability.

### The sugar cane agribusiness in Brazil

Sugar cane growing in Brazil covers an area of nearly six million hectares in all geographic regions, reaching a production of approximately 420 million tons in 2006/07, which represents a quarter of the world production. Around 50 percent of that was used in sugar production (30.6 Mt), and 50 percent in ethanol production (17.4 $Mm^3$), in 320 industrial units. There are around 77 new units in construction or in advanced project stage today, and they are expected to start up within the next six years.

Sugar cane production increased from around 120 to 240 million tons from 1975 until 1985, especially as a result of PNA, and remained stable on that level between 1985 and 1995. Another growth cycle started in 1995, basically motivated by sugar exports. In 1990, sugar exports amounted to 1.2 Mt, and then increased to 19.6 Mt in 2006, demonstrating the Brazilian product's extraordinary increase in competitiveness.

Meeting the domestic and international demand for ethanol and sugar (estimations: see **11.3** and **11.5**) would require a production of around 680 Mt of sugar cane per year by 2012-2013 (an increase of 60% the current production).

The production system comprises mills having very different capacities (from 0.6 to 6.0 Mt of processed sugar cane / year); on average, the mills produce sugar cane on their own land, or on leased land or agricultural partnerships (around 70%), and the remaining 30 percent are supplied by independent growers, which amount to around 45,000, most of whom use less than two agricultural modules. The two producing regions are the Northeast (15%) and the Center-South (85%).

Governmental controls (production and export quotas, prices, and subsidy grants for production and transportation of both sugar and ethanol) have been eliminated by a transition system implemented in the early 1990's and concluded in 1998. Today, the government is present in the regulation of hydrous and anhydrous ethanol specifications and in the determination of the ethanol content of gasoline. The prices are free at all levels of the supply chain, and ethanol is sold in nearly 29,000 fuel stations all over the Brazilian territory.

The pertinent themes of a sustainability analysis of any important sector of human activity entail a number of fields of knowledge if appropriately addressed in the entire life cycle. The interdependence among these fields may cause any such analysis to be "incomplete," allowing for an increase in scope and depth, and the consideration of new points of view. In this study, we try to be critical in a constructive way, relying on many experts and different views. The intention is to apply the formalized sustainability concepts to the sugar cane industry as it is today in the Center-South region of Brazil with greater clarity and depth, and seeking opportunities to strengthen it.

A number of "uncertainties" are facing world agriculture today (including the sugar cane agribusiness), and they affect each country in a slightly different way. For example: uncertainties about the future of transgenic plants and their implications; uncertainty about the magnitude and timing of global climate changes (heating and rainfall); and uncertainty about the world markets, which is deepened by protectionist practices (or elimination thereof).

One of the most important facts demonstrated in this study is that under the present conditions of Brazil's sugar cane agribusiness, there is a very relevant set of responsive sustainability activities in the industry (a part of which being already in progress, and another part appearing as potential) which can make it a promising example in the international context.

## Production processes in Brazil

A simplified description of the production processes helps one understand the relations between the sugar cane agribusiness and the environment. There are sugar cane crops in more than 80 countries around the world, with variations concerning growing periods and techniques, depending on local conditions. It is characterized as a very highly photosynthesis-efficient culture (thereby featuring great biomass production per unit area).

In Brazil, sugar cane is grown mainly in large areas in the Northeast and Center-South regions. Five or six harvesting cycles are completed before the sugar cane crop is reformed, and the harvesting period extends for six to seven months. The entire production process is labor-intensive, especially the harvesting, while the expansion of mechanical harvesting has been reducing the number of jobs (per production unit) and also the seasonal index. Sugar cane crops use fertilizers and agrochemicals moderately, and recycle all industrial waste from ethanol and sugar production as crop fertilizers. The use of sugar cane burning before harvesting (removing the leaves to facilitate harvesting) is gradually decreasing by virtue of environmental and safety restrictions in some areas, but still prevails.

Sugar cane transportation to the industry (in fact, the integrated harvesting, loading and transportation operation) has evolved very much to avoid agricultural soil compactation and reduce costs using high-capacity systems within the legal limits of the highways.

The sugar cane crop is used to produce ethanol and sugar; a part of the cane is washed for removing mineral impurities (manually harvested sugar cane only). An extraction system (in Brazil, almost exclusively milling: the sugar cane is chopped, shredded, and goes through a series of milling equipment) separates the juice, which contains sucrose, from the fiber (bagasse). For sugar production, the juice is cleaned (settling and filter-press, whereby the filtercake is removed), concentrated and crystallized. A part of non-crystallized sugars and impurities (molasses) is separated. In Brazil, it is usually much richer in sugar, avoiding the final crystallization stage, and it is used as a fermentation material added to the juice.

Such mixture is taken to the appropriate concentration and fermented with yeasts; most systems are fed-batch type with yeast recycling, but there are continuous processes. The resulting wine is distilled, whereby ethanol is produced (hydrous or anhydrous) and vinasse is left as waste (the sugar cane water and the water added in the milling process, the organic matter and important minerals, such as potassium, which came along with the sugar cane).

The entire energy consumed by the process (electrical power; mechanical energy, for activating some pumps, fans and milling equipment; and thermal energy, for the juice concentration and distillation processes) is supplied by combined heat and power systems that use only the bagasse as the energy source; the mill is self-sufficient and usually has excess energy.

The waste of the industrial processes consists of vinasse, filtercake, and bagasse boiler ashes. There are totally recycled to the crops: vinasse in liquid form, for ferti-irrigation; the filtercake is transported on trucks as a fertilizer. The industrial processes use water (collected from rivers and wells) in several operations; there is intense recycling to reduce both withdraw and the level of treated waste disposal.

# I

# *Impacts on the use of material resources*

One of the important contributions provided by the socioeconomic analyses that began to include such parameters as consumption of energy and materials in the 1960's and increasingly in the 1970's was the reaffirmation that beyond certain levels (which are relatively low), human well-being ("quality of life") is independent of the increase in consumption of such items.

However, what has been noted until the present day is an important increase in specific consumptions by the planet's populations, with a greater emphasis on developed countries, especially those which were major consumers already.

In 1997 that situation was well quantified in the argument[1] that it would be possible to double the humanity's well-being while reducing the use of energy and resources by half; the factor 4 could be proposed as a target productivity increase for the use of resources. There are those who propose utilization of a factor 10 for the flow of materials in the OECD countries.

1 Weizsacker, E.; Lovins, A.; Lovins, H.: "Factor four: doubling wealth, halving resource use", 1997

Energy and raw materials are usually the topics considered in such studies, and fresh water is a theme that increasingly arouses great concern. In the case focused on herein (sugar cane production and processing), these three items will be considered separately, with energy and raw materials in **Chapters 2** and **3**, and water in **Chapter 5**. The use of other agricultural and industrial materials (pesticides, fertilizers, lubricants) is relatively small, and will be approached in the following sections.

In the considerations on energy and raw materials, one of the most important characteristics of this agribusiness is noted: it is essentially an industry that uses the extraordinary efficiency in sugar cane photosynthesis to produce basic materials (lignocellulosic materials and sucrose) from solar energy. Therefore, its role in the impacts on energy and material resources both potentially and actually is not that of a *user*, but rather a *supplier*. In this respect, it is a classic case of "responsive sustainability," as it helps other industries; today this is very important in terms of energy, and is now starting to be explored for other material resources.

# Chapter 1: Share in the use of fossil energy

The production of ethanol from sugar cane in Brazil leads to important savings in fossil energy; for instance, ethanol from corn in the United States needs a ratio between renewable energy production and fuel fossil utilization that is under a fourth of the Brazilian equivalent. This relation can still be improved in Brazil with better use of the bagasse and cane trash for electricity or other energy utilization.

## 1.1 Introduction; the global context

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Energy is essential to mankind in its search for a healthy and productive life; it is necessary for the production of foods, clothing and other basic goods; for buildings, homes, trade, hospitals and healthcare, education; and the transportation of cargo and people. On the other hand, the production of energy based on fossil fuels (more than ¾ of the world's current total production) has resulted in environmental pollution associated with extraction, local air pollution, regional pollution by acid rain, and global pollution by greenhouse gas emissions. Its utilization on a large scale is clearly leading to the depletion of resources, leaving a heavy burden for future generations.

For the energy sector, sustainable development should consider a more efficient use of fuels based on non-renewable sources, new technologies to significantly reduce the local and global pollution resulting from fossil fuels, and an increased development and implementation of the use of renewable energy sources.

The use of oil over the past fifty years is probably the most spectacular example of depletion of non-renewable resources caused by mankind. As early as 1989 it was possible to foresee, even considering all the possible ways to extend the oil supply (natural gas conversion, non-conventional oil, shale oil, bituminous sands), that the supply peak would take place around 2020 (conventional oil: before 2010). The large-scale use of coal (if at all possible with its environmental limitations) could postpone by ten years that supply peak.[1] More recent evaluations are no longer optimistic, quite the opposite: the Global Hubbert Peak (time when the world supply of conventional or non-conventional oil and liquid natural gas ceases growing, starting to decline year after year) is expected to occur before 2020,[2] and some estimations point to some time before 2010 (for the most part, because of the present instability that may prevent the increase in oil supply from the Middle East).

1 Bookout, J.F.: "Two centuries of fossil fuel energy", Episodes, vol. 12, 1989, pp. 257-262

2 Olson, R.L.: "The end of the oil age: How soon? How real? How critical?", Institute for Alternative Futures, 2004

The world use of energy by resource in 2000 was 77% from fossil sources (half of which of oil, and the rest consisting of natural gas and coal); 15% from hydraulic energy and traditional biomass, 6% nuclear, and 2% from "new" renewable sources.[3] "New" renewable sources include biomass as commercial energy, such as ethanol, whereas "traditional" biomass is essentially firewood and residue, of which the production is neither organized nor sustainable.

3 SAWIN, J.L.: "Renewable power: on the brink of an energy revolution", Worldwatch Institute, 2004

Most important (and preoccupying) is the consideration that ten years after the oil supply peak, a substitute will be needed for around a half of the oil that we use today, i.e. a substitute for 10 to 15 billion barrels a year.

A strong restriction that will be imposed on the solutions being sought derives from today's acknowledgement that fossil fuels are responsible for the most anthropogenic GHG (Greenhouse Gas) emissions, and that the increased concentrations of atmospheric $CO_2$ are responsible for global climate changes. From the pre-industrial concentration level (~250 ppm), we have now reached around 380 ppm; annual emissions increased from 1.9 Gt C per year (1954) to 7.0 Gt C per year in 2003. If the emissions are maintained on that level (7.0 Gt C / year), we may reach over the next decades an equilibrium concentration of ~500 ppm.[4]

4 SOKOLOW, R.; PACALA, S.; GREENBLATT, J.: "Wedges: early mitigation with familiar technology", 7th Int. Conference on Greenhouse Gas Control Technologies, Vancouver, 2004

The magnitude of the problem and the very scarce time to implement solutions (or, in fact, to develop them) have been somewhat "ignored" by a large portion of those responsible, partly based on vague considerations about the coal reserves and new, "cleaner" technologies for its use, and even the return of nuclear energy on large scale. Those who are already convinced of the need for environmental sustainability view renewable energies (sunlight, biomass, wind, water) and all possibilities of energy conservation (including a rationing of the end use) as the natural answer.

Challenges are posed to the implementation of any source as an alternative to oil. For non-renewable sources (natural gas, coal, shale oil), the cost, the need for carbon sequestering, other environmental impacts, and availability (natural gas) are the main challenges. Energy conservation is very important, but it would not be enough. Among renewable sources, hydraulic, biomass and wind are important, but not enough either. Wave, geothermal and solar energy (PV) still feature very high costs. Nuclear (fission) entails radioactive waste treatment and security problems.

The global energy consumption has a strong motivation to grow (rather than stabilize or especially decrease) because of the enormous regional unevenness of its use. Around one third of the world's population today (two billion people) have no commercially available energy to so much as cook food. In 1992, a single country that has 5% of the world's population (the United States) used 24% of all the energy on the planet; ten years later, in 2002, that same country had increased its energy use by 21%. The high growth rates seen in China and India, for example (and their environmental consequences), are indicative of the changes that are already taking place.

In this difficult, complex context, the aim of sustainable development goals concerning energy generation and use is for the activities and sectors of the economy to try to reduce the demand for natural resources (fossil sources), seeking diversification and renewable sources, while trying to diminish the environmental impacts from the use of every source. In general, any progress in this respect can be assessed by three sustainability indicators:

- energy intensity (used energy / GNP)
- the share of renewable energy in the total energy consumption
- the $CO_2$ emissions resulting from energy production/use (Mt C).

As a reference, the energy intensity the United States[5] dropped from 19.7 to 13.1 (MJ / US$GDP) from 1972 to 2000; the share of renewable energy increased from 6.2 to 6.9 percent in the same period; whereas the total $CO_2$ emissions from energy use increased from 1,224 Mt C to 1,562 Mt C. Considering a set of 23 industrialized countries (excluding the United States), in 1998 the energy intensity was around 30 percent lower than that of the United States, and the total $CO_2$ emissions (energy-related) were the same as in that country.

5 Price, L.; Levine, M.: "Production and consumption of energy", *in:* Dernbach, J.C. (Ed.): *Stumbling towards sustainability*, Washington DC, Environmental Law Institute, 2002

## 1.2 Supply and use of electrical power and fuels in Brazil

Brazil's domestic supply of energy in 2004 amounted to 213.4 Mtoe: around 2% of the energy used worldwide for 3% of the world's population (Brazil: 181.6 million inhabitants). The dependence on foreign energy sources was only 15.9%. The end use of energy was 191.1 Mtoe. The final energy consumption per inhabitant (denoted in "toe", or "oil-equivalent t") evolved from 0.7 toe / inhab.·year in 1970 to 1.1 in 2004. The evolution to only 1.1 seems small, but the ratio (OIE)/GDP was greatly influenced by the rate of 0.64 between 1970 and 1980, when there was a major substitution of "traditional" biomass (firewood) with LPG.[6]

6 Ministério das Minas e Energia, BEN-2003 – Balanço Energético Nacional (National Energy Balance), Brasília, 2004

For comparison: the United States use 8.1 toe / inhabitant·year.

In 2002 Brazil used more than three times as much energy as in 1970, and the distribution among energy sources changed considerably. Very different from the world profile, such distribution is an important feature of Brazil's energy sector.

**Table 1:** Energy sources, Brazil and the World, 1970-2004

| Energy source | Brazil, 1970 (%) | Brazil, 2004 (%) | World, 2002 (%) |
|---|---|---|---|
| Oil | 37 | 39.1 | 34.9 |
| Natural gas | - | 8.9 | 21.1 |
| Coal | 3 | 6.7 | 23.5 |
| Uranium | - | 1.5 | 6.8 |
| Hydropower | 5 | 14.4 | 2.3 |
| Biomass | 55 | 29.4 | 11.5 |

The two energy sources at the bottom are renewable.

Electrical power (14.4% of the total energy supply) reached 424 TWh (8.8% being imported, and only 8.9% from self-producers), around 75% being produced by hydroelectric power plants. There was an installed power of 90.7 GW, 8% from self-producers.

Oils and derivatives (including LNG), accounting from 39.1% of the supply, corresponded to a production of 1.54 M barrels / day and a net dependence on imports of 10%, especially concerning diesel, LPG and naphtha.

Natural gas corresponded to 18.9% of the supply, with 32% to imports.

The supply of firewood (13.2% of the total supply) was used in the domestic and industrial sectors, as well as for charcoal production.

The sugar cane industry accounted for 13.5% of the total supply, producing 0.23 M barrels / day of ethanol and 6.97 TWh of electricity, 14% of which were sold (surplus production). Bagasse production (102 M t) was used in co-generation for eletricity and heat in the sugar mills

On the other hand, the final consumption of 191.1 Mtoe occurred mainly in the transportation (26.9%) and industrial sectors (37.8%), as well as in the residential sector (11.2%).

Between 1970 and 2004, our share of "renewable energy" dropped from 58.4 to 43.9%. Such reduction corresponded to the coming of LPG and fuel oil as substitutes for firewood, with much more efficiency (for home and industrial use), and also the substitution of charcoal with metallurgical coke in steel works. In the early 1970's, most of the firewood production was not renewed, partly predatory, with energy production as the main use. In the 1980's Brazil's energy production drifted away from the model that still widely predominates in developing countries: extensive use of "traditional" biomass coming essentially from deforestation firewood. A remarkable example is that the commercial availability of energy (LPG in this case) for cooking in Brazil reaches 98% of all homes today, whereas one third of the world's population have no access to it.

The current trend is again towards an increase in biomass energy, but on a sustainable basis; charcoal from planted forests is an example. During this period, there were major increases: in hydropower (5.1 to 14.4%) and sugar cane products (5.4 to 13.5%); the total renewable energy (43.9%) is substantially larger than in the rest of the world (14%). The relative share of natural gas, uranium and charcoal in Brazil is around one third of the world's share (%).

One of the consequences is that Brazil appears in a privileged position, with emissions of 1.62 t $CO_2$ eq. / toe, against a world average of 2.32. It is very possible that the sugar cane industry may substantially increase ethanol production because that product currently competes with gasoline, and the international demand has been growing. That will have effects on electrical power production as well (combined heat and power in sugar mills).

We can say that the supply of energy for Brazil's growth arouses no concerns as to a lack of options; the country has abundant renewable resources (biomass and hydropower); even on the fossil fuel front, oil and natural gas can meet the foreseeable requirements in the short term. There is room to increase the utilization efficiencies and reduce energy waste.[6]

6 see p. 53

On the other hand, there is, to some extent, a deficiency in a solid, sustained, integrated planning on the energy sector. The following are two critical cases where policies are deficient: in the electrical energy sector, for complementary thermal generation and, generally, for distributed generation; and in the field of transportation fuels (a sector that uses 27% of all the country's energy), where fast variations in the options (fleet "dieselization"; ethanol; NGV, flex-fuel vehicles, etc.) have been causing high losses.

Those two cases are pertinent to the analysis of the sugar cane producers' role in the substitution of fossil energy in Brazil (in the present situation and the prospects for the next few years).

## 1.3 Distributed generation (and combined heat and power) in Brazil: the need and opportunity in the next twenty years

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The electrical power policies have long given priority to meeting the population's requirements through central generation (CG) systems based on large generators of which the locations are usually far from consumer centers. The idea is that only through large-scale production is it possible to assure moderate costs, despite the inconveniences associated with complex transmission systems where 10-15 percent of the energy production are lost, thereby requiring additional 20-30 percent power at the location of use.

That concept consolidated worldwide over the past century, when electrical power systems were shaped around large monopolies, several of which integrating the generation, transmission and distribution on a vertical basis. After successive oil crises, the search of new alternatives and a real technological revolution increasingly enabled what is called distributed generation (DG): electrical power generation near or next to the load.

Development took place mostly in countries where the supply of distributed natural gas increased, thereby facilitating the use of combined heat and power: a thermoelectric power plant where the heat that would be lost in the CG is used in the processes (production, heating or cooling). Such more efficient solution is typical of DG because the thermal power cannot be transported for long distances; the rejected heat used in DG contains more than half the energy of the fuel used, and that saving compensates for the costs associated with small-scale production. But DG is not limited to this technology, or size or specific source limitations. It can use solar cell panels, energy available from production processes in the form of gases and wastes. Like in the sugar cane industry and in many other sectors.

In Brazil, DG still has a minimal share in the electrical power supply, in spite of its great potential. To name one item, the sugar cane biomass that was processed for the 2004/05 crop had an energy content of 46 million toe[7]; it is being used at low efficiency rates in the sugar and ethanol industry because of the difficulty in exporting electrical power to the power industry. In comparison, the hydropower used in the same year was around 30 million toe, and the country's oil production was 77 million t.

7 Estimation based on the National Energy Balance – BEN 2005, adjusted to include the straw currently burned in the field, ethanol final use was 6.8 M toe.

Even though DG has not been formally prevented, it has been made difficult because it breaks a hundred-year tradition and changes the economic basis of the traditional service. For example, the full use of sugar cane energy recommended at the end of the second stage of the *Proálcool* program was left aside for not adapting to the electrical power industry's traditional culture. The lack of a well-structured policy for natural gas has led to the prioritization of its use in centralized generation, which is an unsuccessful option that contrasts the situation in Portugal, for example. Here NG (natural gas) was preceded by efforts to develop combined heat and power together with consumers, which went as far as to create a secondary market and increase operational flexibility. The development of DG also requires that the inert position of new players be overcome and that the opportunities be noticed. Such process can be accelerated if some of the cultural resistance is removed, provided that there is political will.

By acknowledging DG and removing some of the barriers to distributors, and in spite of some lack of definition concerning operational aspects, the new model of the electrical power sector (Law no. 10,848/04) and its regulation create the conditions for the full realization of that potential. The expansion of DG in Brazil should rely on two complementary facts. On one hand, the traditional electrical power sector has failed to prove itself capable of meeting the growing demand; on the other hand, the country has at least two very important vocations for DG which are going through a maturing process. It is worth detailing these points.

The successive crises in the electrical power sector have been taking place since the late 1990's, and have not been more acute only because the country had an installed overcapacity and the increase in demand over those years was mediocre. The model that would organize the sector on new bases, incorporating a broad privatization process, gave rise to a situation in which investments in new CG units were not made, which led the government to make an intervention, back in 1999, through a thermoelectric power plant (PPT) construction incentive program, which has proved completely wrong. The lack of energy wound up causing the 2001 crisis, which was solved mostly by shrinkage of the market and decisive actions in the conservation context. That was followed by a period of immobility, and the actions for construction of new CG units extended for nearly three years.

The crisis showed how convenient DG was, but in stead of developing the country's potential together with customers having a potential for DG, the country opted for a centralizing and "transitory" solution with the Brazilian Emergency Energy Seller (CBEE). The only successful aspect of the reform was the construction of transmission lines that were considered natural monopolies. Inasmuch the costs of that service were "packed" with other costs, especially those of the generation having already been amortized, they were not felt in their true dimension. However, upon adoption of a more realistic cost policy, transmission prices raised strongly and point to an increase in margins, which is a factor that further values the strengthening of DG.

Today a scenario based exclusively on CG to meet the new demand with private investment is not so likely to occur. On the other hand, the attractive points of DG began to grow again following the announcement in 2003 that important natural gas reserves were found near Brazil's main urban and industrial centers. Considering the problems of its destination to CG in the past, Petrobras has declared its intent to distribute that gas.

Ethanol, whose use as a fuel had been decreasing until the end of last decade, when at some government levels people were already working under the assumption that its use in transportation would substantially decrease, has also gained ground. The current demand for ethanol is going through a boom in both the international market (it is the only "clean" gasoline oxygenizer and has been adopted in several countries as a substitute for MTBE) and the domestic market, where sales of ethanol-powered and bi-fuel vehicles are growing on the back of an attractive price.

The sugar cane industry has been expanding its installed DG capacity even with the crisis, after which the construction of CG units was paralyzed. The incorporation of this new business with no linkage with others can reduce risks, thereby leading to a virtuous cycle of cost reduction for all products. A similar synergy took place upon implementation of the *Proálcool* program, when the industry used the sugar production modernization and intensively benefited from the new stimulus, improving agricultural and industrial productivity while lowering its costs, which are now the lowest in the world. The existence of reliable energy and raw material (sucrose) brings prospects for new products, as in the case of corn processing. This form of DG has several other interesting aspects. These include the greater reliability and quality of the energy, and the broader utilization of labor per energy unit generated. For the mills, it brings an opportunity to recover and modernize energy systems, making them more efficient and producing surplus power.

The energy is competitive, as demonstrated by the existing operations with distributors, and even the recent tender of more than 300 MW for R$ 93 per MWh within the scope of PROINFA (Alternative Electric Power Source Incentive Program), when the projected costs for new hydroelectric and thermoelectric power plants are R$ 105 and R$ 120 per MWh, respectively.

Therefore, a scenario that increasingly emphasizes DG seems to be the most effective way to meet the new demand for electric power, while being attractive to the private enterprise. With the introduction of a large number of new players, the demand would be met more consistently with its growth and with fewer idle investments. DG is the most advisable way of meeting the requirements of some specific consumers, but it indirectly benefits all consumers who are interconnected with the electrical power system. Since only some specific sectors can perform DG competitively, most electrical power consumers will continue to depend on the interconnected system that takes the energy to them regardless of the source, whether CG or GD. Even when they are inactive, DG units increase the power reserves together with the loads, thereby reducing risks of blackouts and dismissing improvised solutions like CBEE. Accordingly, DG does not compete, but it complements and improves both existing and future CG systems.

There is a lot of room for DG development to take place in harmony with, and as a complement to, the existing CG system, as well as that which is yet to be built; little by little, authorities and regulating agencies will consider this a natural scenario, perfecting the rules and guidelines that implicitly presuppose DG, as has occurred in several countries.

Recently the National Energy Plan for 2030 acknowledges the importance of DG, especially the generation derived from the so called alternative sources, forecasting an increase of more than 15,000 MW by 2030. For the sugar cane industry a conservative projection is made for 4,000 MW (till 2030), with 1,100 million t sugar cane being processed annually. Accordingly, the BNDES (National Social and Economic Development Bank) is including in its financing projects specific incentives for the use (by the sugar cane industry) of more efficient technologies for energy production in the sugar mills.

It is difficult to provide a quantitative overview of the role to be played by DG in Brazil. Studies conducted by INEE – National Institute of Energy Efficiency show that it is perfectly possible to account for 10 to 20% of Brazil's requirements within the next ten to fifteen years. Although it seems a small share, since the DG base is currently inexpressive (lower than 5%), an increase could represent a dramatic share of the new potential in an activity that will be turning over a few billion reals a year within the next few years.

## 1.4 Energy production by the sugar cane industry: fossil fuel substitution

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Brazil's sugar cane production has an important characteristic, among others: the production system has been designed and developed (varieties, agricultural practices) to be independent of irrigation. High levels of photosynthetic conversion (mainly sucrose/hectare) were sought using selected varieties and recycling of all by-products (including crop residue water in ferti-irrigation) for the field. The basic oritentation has never been towards a maximum biomass production. Much higher biomass values could be achieved by using irrigation and/or choosing specific varieties, which, however, would reduce (considering current options) the sucrose/ha values or, ultimately, increase the sucrose cost (in R$ / ton). This option is not being considered (at the moment).

### 1.4.1 Current energy supply from the industry

For the year 2002, based on a sample of mills located mainly in the Center-South region, the production characteristics were as follows[8]:

- Sugar cane harvest: the estimation for Brazil is 65% manual harvesting, and 35% mechanical harvesting (34% in 2005); 80% of the sugar cane is burnt.
- Sugar and fiber content of the crop residue: the mean values for the period between 1998 and 2002 were 14.53 sucrose % of sugar cane (14.2 in 2005), and 13.46 fiber % of sugar cane (Center-South).[9]
- Agricultural productivity: the mean value for several areas within the Center-South region from 1998 until 2002 was 82.4 t of sugar cane / ha·year (82 in 2005; on the harvest area); the mean age of reform was 5.33 harvests (2001-2002).[9] Considering 5 harvesting periods, the productivity (total area) is 68.7 t of sugar cane / ha·year.
- Brazil's sugar cane production evolved from 80 Mt / year (1970) to 149 Mt / year (1980), 222 Mt / year (1990), 256 Mt / year (2000), and 425 Mt / year (2006). In 2005/06, around 50 percent of the sugar cane was used in ethanol production, and the other half in sugar production. These figures refer to the weight of crop residue ready for industrial processing, excluding the vegetable matter on sugar cane tips and leaves.

8 SEABRA, J.E.; LEAL. M.R.L.V.; MACEDO, I.C.: The energy balance and GHG avoided emissions in the production / use of ethanol from sugar cane in Brazil: the situation today and the expected evolution in the next decade; XVI International Symposium on Alcohol Fuels, Rio de Janeiro, Nov 2006

9 CTC – Centro de Tecnologia Canavieira, Controles Mútuos Agrícolas Anuais – Safras 1998/1999 a 2002/2006

For each t of sugar cane (cane stalks), the biomass and its applications are now as follows:

| | |
|---|---|
| 0,14 t (DM) bagasse | 90% for energy at the mill |
| 0,14 t (DM) trash | burning in the field |
| 0,145 t (DM) sucrose | sugar, ethanol, and other products |

In the system operation, the mills use a certain amount of fossil fuels (agricultural, industrial and transporting operations, plus the energy embedded in the agricultural and industrial consumables, plus the energy used in equipment production, construction of buildings, etc.). With that (and solar energy), they produce sugar cane in the field (trash, bagasse and sucrose). A part of the bagasse is used to produce energy (combined heat and power for the sugar and ethanol production processes at the mill), and another part is used in outside industries. The trash is not yet used. Around half the sucrose produces ethanol (which substitutes for gasoline), and the remaining portion is used in sugar production. The electrical power produced by the mills today is enough to meet their own requirements, but standard technologies (vapor cycles, mean to high pressures) are starting to be used and produce large energy surpluses, which are then sold.

8 see p. 59

The overall energy balance in the system for ethanol production is summed up in **Table 2** below[8] (sugar production has the same energy "spending", but does not have ethanol as produced energy).

**Table 2:** Energy balance, sugar cane and ethanol production (MJ/t cane), 2005

| | |
|---|---|
| Cane production / transportation | 182.2 |
| Processing to ethanol | 43.1 |
| **Fossil Input (total)** | **225.4** |
| Energy in produced ethanol | 1,897.4 |
| Energy in surplus bagasse | 95.3 |
| Surplus eletricity | 19.8 |
| **Renewable Output (total)** | **2,012.4** |
| **Renewable Output / Fossil Input** | |
| **Ethanol + bagasse** | **8.8** |
| **Ethanol + bagasse + electricity** | **8.9** |

The value for surplus electricity is 2.1 kWh / t cane for 2005. Here the fuel needed for a combined cycle Natural Gas fired thermoelectic plant (40% LHV efficiency considered)

The ratio of 8.8 is extremely interesting, indicating the great capacity of the system to save fossil energy; in fact, no other production system gets close to that today (corn ethanol, in the United States, has been reaching 1.4 at best).

For the portion of sugar cane used to produce sugar, the balance is practically zero (which represents a major advantage over the sugar produced from beet or starch hydrolysis, the balance of which is negative).

In sugar cane processing the mills use energy:

- 12 kWh / t sugar cane (electricity)
- 16 kWh / t sugar cane (mechanical energy, drives)
- 330 kWh / t sugar cane (thermal energy for the processes)

The energy contained in the trash and bagasse is much higher than these values.

In addition, since the need for thermal power is much larger than that for electrical and mechanical power, the system can be supplied with power by vapor combined heat and power plants even with very low thermal-mechanical conversion efficiencies; that was the option used in the 1970's, when the abundance of hydro-electric power led to a legislation that virtually prevented the mills' surplus energy to be sold to the system (see 1.3). This situation is changing rapidly, and the technological evolution of the sugar and ethanol mills' electrical power generation systems has been a continued process over the past 20 years. Boilers with higher performance and capacity, and turbo-generators with rated power in excess of 20 MW and efficiencies in excess of 75% are on the market[10]; the systems are for pure combined heat and power, linked with the mill operation.

10 LEAL, M.R.L.V; MACEDO, I.C.: *Evolução tecnológica dos sistemas de geração de energia nas usinas de açúcar e álcool*, Viçosa, Renabio, 2004

For 372 Mt of sugar cane (2004), comparing the final consumption of the different sugar cane produced energies with the energies they partially substituted for in Brazil, we have the following:

| | | | |
|---|---|---|---|
| Bagasse: | 20.2 Mtoe | Fuel oil: | 6.5 Mtoe |
| Ethanol: | 6.9 Mtoe | Gasoline: | 13.6 Mtoe |
| Elect./mechanical energy: | 11.3 Twh | El. power. | 359 TWh |
| straw: | currently not used; with a 25% recovery, it is equivalent to 5.1 Mtoe | | |

Clearly, sugar cane has a very important role to play in the substitution of fossil fuels in Brazil. In 2002, Brazil's net importation of oil and derivatives was 0.274 M barrels / day (and its domestic production was 1.5 M barrels / day). Ethanol substituted for 0.187 M barrels / day of gasoline (equivalent) in 2004. From 1976 until 2004, ethanol substituted for 1440 M barrels of gasoline (around 11.0% of the proven and condensable oil reserves in Brazil). The final consumption of bagasse as a fuel for industrial use was equal to the sum of all final uses of natural gas and fuel oil in the country in 2004, and the electrical and mechanical energy generated (for internal use) corresponded to 3 percent of the electrical energy generated in the country.

### 1.4.2 Potential increase in supply with the current sugar cane production

The industry's goals generally include an increase in the bagasse use efficiency, and the development of trash recovery and use, as well as new sucrose products (high volume).

Two main alternatives are considered in order to increase the industry's energy production. The most immediate of which (under way) is to increase electrical power generation. The second one, which is dependent on ongoing technological developments, would be the production of ethanol from residues (excess bagasse and recovered trash).

The expected increase in combined heat and power efficiency, the reduction of internal energy consumption, and the recovery of trash for energy purposes have been extensively analyzed and are beginning to be implemented. Trash recovery is related to programs for reducing and controlling trash burning in the field, which are motivated by the need to control local air pollution (see **item 3.3**); the amount of sugar cane that is not burned already represents 24% of the production in São Paulo, and should increase over the next few years.

Estimations of increases in surplus electrical power have been prepared for various technology levels, whether standard or developing ones. The operation with standard high-pressure steam cycles with 40-percent recovered trash, if implemented in 80% of the systems, could lead to around 30 TWh of excess energy (9% of the current electrical power consumption in Brazil) at the present sugar cane production level.

The most promising technology to enable a considerable increase in the mills' generation of excess electrical power for the future (besides the implementation of trash recovery) is biomass gasification integrated with gas turbine combined cycles (BIG/GT). The processes are not yet commercial.

Alternatively, one of the processes that is much sought after is the hydrolysis of lignocellulosic materials (excess bagasse and trash) for ethanol production. These processes arouse great interest because the abundance of raw materials available in practically all regions of the world could turn ethanol into a commodity with a large number of producers. Of the countless developing processes,[11] the highlights are those which seek cellulose and hemicellulose conversion

11 U.S. Department of Energy: www.bioproducts-bioenergy.gov/pdfs/HistoryofOBPandCellulosicEthanol.pdf

using enzyme technology and simultaneous saccharification and fermentation. However, intermediate processes are more likely to be commercially available first. One of them is in development in Brazil for full integration with the sugar mill.[12]

The two main challenges facing these developments today are: for the enzymatic processes, a major reduction of enzyme costs is needed (cellulase) [13]; and for all, biomass costs near US$ 1.0 / GJ are needed so as to make the processes viable against gasoline costs (2002). Brazil's sugar cane industry currently has bagasse and can recover trash in the aforementioned amounts at costs ranging between US$ 0.6 and US$ 1.0 / GJ (amounts updated until 2004, with US$ 1 = R$ 2.7),[14] thereby becoming very attractive as a user of new processes also because of the synergy with current production processes.

Various specific studies and more general reviews of the hydrolysis work conducted over the past twenty years,[15, 16] and the expected results to be attained over the next few years[17] have indicated that considering the wide variety of processes, raw materials and assumptions, it is reasonable to work with around 300 l of ethanol/t of dry matter for the next few years, and that amount could increase (maybe by 15%) within ten years. On that basis, if a given mill should adopt a hydrolysis process to produce ethanol in stead of more surplus electricity, it could use 30% of the excess bagasse (improving the processes) and 50% of the straw to produce around 34 additional liters of ethanol per sugar cane t (all sugar cane: for ethanol or sugar).

### 1.4.3 Increase in energy supply associated with increased production

Two major increases in Brazil's sugar cane production took place between 1976 and 1983 (from 100 to 200 Mt of sugar cane / crop), and between 1993 and 1998 (from ~215 to 315 Mt of sugar cane / crop), the former having been motivated by the implementation of fuel ethanol, and the latter by sugar exports. The industry is going through a growth cycle again, this time because of the likely increase in demand for both ethanol and sugar.

It is noticeable that for every 100 Mt of additional sugar cane (considering 42% of such addition as the portion to be used in sugar production, as suggested by demand projections), if commercially available technologies were to be used to increase electricity production, we could have the following:

| | |
|---|---|
| Additional electricity: | 12.6 TWh (steam cycle, 40% trash) |
| Additional ethanol: | 4.9 $Mm^3$ |

Therefore, for every 100 Mt of sugar cane (42% for sugar), the industry could additionally supply 3.8% of the electrical power currently consumed, while increasing the current ethanol supply by 37%.

12 Olivério, J.L.: "Fabricação nacional de equipamentos para a produção de álcool de cogeração", Seminário BNDES: Álcool – Potencial Gerador de Divisas e Empregos, Rio, 2003

13 U.S. DoE: NREL; www.ott.doe.gov/biofuels.enzyme_sugar_platform.html , 2003

14 Macedo. I.C.: "O uso otimizado da cana-de-açúcar para Geração Distribuída", VI Seminário Internacional de Geração Distribuída, INEE – WADE, Rio, Oct 2003

15 Saddler, J.N. *et al.*: "Techno-economical evaluation of a generic wood to ethanol process: effect of increased cellulose yields and enzyme recycle", Bioresource Technology 63, 1998, pp. 7-12

16 Fulton, L.; Howes, T.: "Biomass for transport fuels: an international perspective", IEA/EET, 2004

17 Wooley, R. *et al.*: "Lignocellulosic biomass to ethanol process design and economy utilizing co-current dilute acid pre-hydrolysis and enzymatic hydrolysis: Current and futuristic scenarios", NREL / DoE, Jul 1999

Alternatively to electricity production, and depending on the time when the hydrolysis technologies will be commercially available, it would be possible to have an additional supply of 3.4 $Mm^3$ of ethanol, totaling 8.3 $Mm^3$.

## 1.5 Summary and conclusions

• Context: the world supply of energy is based on fossil fuels (75%); the utilization scale quickly leads to depletion of resources, thereby leaving a heavy additional load to the future generations. Additionally, the use of fossil fuels is responsible for a large load of local pollution and most of the greenhouse gas emissions. The use of energy should grow as a result of the advance of many of the world's developing regions. The current challenge is to seek renewable energy sources and to increase efficiencies in energy generation and use on an unprecedented scale.

• Brazil has an intermediate consumption level (1.1 toe / inhab·year), with a deep focus on renewable energy sources (43.8%, compared to 13.8% in the world). Brazil can significantly increase the use of biomass and other sources, and improve generation and use efficiencies. In this respect, among other initiatives, Brazil should implement the distributed generation of electrical power (based on combined heat and power), which could reach 10-20 percent of the total within 10-15 years, and set up a policy for the transportation fuel industry.

• The sugar cane industry already provides a major contribution (responsive sustainability) to the substitution of fossil fuels, going much further than energy self-sufficiency (electrical and thermal power).

√ It generates 11.3 TWh of electrical and mechanical energy (3% of the electrical energy generated in the country)
√ It uses bagasse as a fuel: 20.2 Mtoe (equivalent to the sum of all of the NG and fuel oil used in the country)
√ It produced nearly 50% of all the gasoline used in the country in 2004

• The sugar cane industry's improved energy performance (use of trash, DG implementation) can lead to an additional 30 TWh of electrical power. Alternatively, the implementation of processes for bagasse and trash conversion to ethanol in the future can increase ethanol production by 40% for the same sugar cane production level.

• If the expected sugar cane production increases for the next years materialize, for every additional 100 Mton of sugar cane, the industry would supply 3.8% of the current electrical power consumption, and 4.9 $Mm^3$ more of ethanol (assuming that 58% of the sugar cane are used in ethanol production). The alternative ethanol production from bagasse and trash, when technically possible, would lead to an additional 3.4 $Mm^3$ of ethanol.