Chapter 7

Sustainability of sugarcane bioethanol: the Brazilian experience

In a general sense (ie, beyond energy issues), important features of energy systems are not only their condition of renewability, but also their sustainability. As defined by the Brundtland Commission in the 1980s, it is expected that energy systems be capable of «meeting the needs of the present without compromising the ability of future generations to meet their own needs», while serving social and ecological equilibrium as well as the needs of the poor [United Nations (1987)]. In sum, measuring the sustainability of an energy system is not a simple task and depends not only on the energy vector itself, but also, fundamentally, on the context where it is produced and used. In this regard, it is usually easier to demonstrate the non-sustainability of an energy system (non-renewable, polluting etc.) than to guarantee the sustainability of systems based on renewable energy, especially bioenergy.

Even though the debate regarding the sustainability of bioenergy is still ongoing, and it is often polarized between utilitarian and preservationist visions, human societies have used the energy flows associated with biomass production for millennia in all types of ecosystems. As such, bioenergy should be considered as an energy alternative, one to be better understood and utilized in those contexts where it is most appropriate. In that regard, this chapter presents bioethanol and sugarcane production from the perspective of sustainability, where sustainability is defined as the possibility that bioenergy systems maintain their production over the long term – without overt depletion of the resources that originally gave rise to them, such as biodiversity, soil fertility, and water resources –. Such focus is based on one of the classical definitions of sustainability: «the amount of production that can be sustained indefinitely without degrading capital stocks, including natural capital stocks» [Goodland (1992)].

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After the United Nations Conference for the Environment and Development, the Earth Summit, held in Rio de Janeiro in 1992, sustainability came to be understood by its three pillars – environmental, social and economic – thereby making the concept widely used and a permanent presence in debates on the growth of nations. In the present chapter, sustainability will be approached from the both local and global perspectives. Aspects of the economic and social viability of bioethanol will also be analyzed with respect to the Brazilian model, a model which could be adopted by other countries with sufficient availability of arable land and similar soil and climate conditions. And as themes touching on the issue of sustainability, the use of soil and agroecological zoning for sugarcane cultivation in Brazil and advances and perspectives related to certification of biofuels will also be discussed.

7.1 Environment and sugarcane energy

The first point to mention regarding the environmental implications of bioethanol production is the importance of legislation to guide producers toward best practices and prohibit actions which harm the environment. To this end, for the implementation and operation of sugar and bioethanol plants in Brazil, in accordance with CONAMA Resolution 237/1997, there are three phases of environmental licensing that must be complied with, characterized by obtaining the following licenses:

a. *Licença Prévia (LP)* Preauthorization - approves the site and plan and establishes basic requirements and conditions to be met in subsequent phases.

b. *Licença de Instalação* (LI) Facility License – authorizes the facility and includes environmental control measures.

c. *Licença de Operação* (LO) Operating License – authorizes operations after complying with requirements established in the previous licenses and subject to periodic renewal.

Basic documents for the licensing process are the Environmental Impact Study and the Environmental Impact Report (EIA/Rima). A public hearing to present the project and the definition of Environmental Compensation (such as the planting of native species or the formation of a permanent natural reserve) are obligatory. The requirements for carrying out the studies and requirements to be complied with are established by the legislation, in accordance with the processing capacity of the agroindustrial units. In the case of small projects or process changes that are not potential causes of environmental impacts (eg, enlargement of cogeneration systems), a *Relatório Ambiental Preliminar* (RAP) (Preliminary Environmental Report) may be required. This is a simple procedure.

This section includes some comments regarding the most relevant isssues associated with environmental impacts of sugarcane and bioethanol production in Brazil. They include emissions with global impacts (greenhouse effect gases), local impacts (especially associated with pre-harvest burning), water use and the disposal of effluents (including stillage), use of agricultural pesticides and fertilizers, erosion and protection of soil fertility and biodiversity.

Emissions of gases with global impacts

Because of high photosynthesis yields in sugarcane production and biofuel conversion process efficiency, the utilization of sugarcane-based bioethanol significantly reduces greenhouse gas emissions compared with the use of fossil fuels (gasoline) in cars with similar characteristics.

This contribution to the mitigation of climate change is, possibly, one of the most important features of sugarcane bioethanol. The subject was presented in detail in Section 3.5 (Productivity, emissions and energy balances). There, not only was it shown just how positive the impact of ethanol is, but also, how relatively ineffective other inputs are in this regard considering the technologies currently used.

Table 28 shows a summary of the balance of carbon dioxide emissions from sugarcane planting through bioethanol end-use, for typical agricultural and agroindustrial conditions. Neither other gases nor second-order effects are taken into account, but all production and use operations for conditions observed in Brazil's Center-South region are included. The values in this table were calculated taking into account the composition of various sugarcane products and typical agroindustry mass balances. The values also assume that 12.5 tons of sugarcane yield one thousand liters of bioethanol. With future advances, these results should be improved.

***Table 28* – Summary balance of carbon dioxide emissions in the bioethanol and sugarcane agroindustry for the Brazilian Center-South region (kg/thou liters bioethanol)**

Stage	Photosynthesis CO_2 absorption	Release of CO_2	
		Fossil	Photosynthesis
Planting		173	
Growth	7,464		
Harvest and transport		88	2,852
Ethanol manufacture		48	3,092
Ethanol use			1,520
Total	7,464	309	7,464

Source: Elaborated by Luiz Augusto Horta Nogueira.

As can be seen, carbon released into the atmosphere corresponds to the sum of carbon of photosynthetic origin, absorbed during the growth of sugarcane and then released in four stages – the burning of straw, fermentation (conversion of sugars to bioethanol), the burning of bagasse in boilers and the burning of bioethanol by engines – and carbon of fossil original, corresponding to a net addition to the atmosphere and resulting from agricultural and industrial operations and the production of inputs and equipment. As such, only carbon of fossil origin should be considered, since photosynthetic carbon released corresponds to that absorbed by sugarcane. Comparing the net contribution of fossil emissions (of the order of 309 kg of CO_2 per thousand liters of bioethanol produced) with estimated gasoline emissions (of 3,009 kg of CO_2 including an increment of 14% of emissions during production), and assuming identical performance in terms of final use, there is a resultant reduction of approximately 90% in carbon emissions. These results do not significantly change when second order effects (associated with other gases besides carbon dioxide) are taken into consideration, as shown in Section 3.5, as previously mentioned. Similar results supporting the advantages offered by sugarcane bioethanol in terms of reductions in greenhouse gas emissions and the consequent mitigation of climate change have been presented in several studies [Concawe (2007), Esmap (2005) and IPCC (2008)].

According to the Brazilian Communication to the United Nations Framework Convention on Climate Change (1994 figures), the utilization of sugarcane energy has reduced carbon emissions by 13% in the energy sector. Considering Brazilian agroindustry production volumes (2003), the substitution of ethanol for gasoline and the generation of energy using bagasse reduced equivalent CO_2 emissions by 27.5 million and 5.7 million tons, respectively [Goldemberg et al. (2008)]. Calculations for similar situations indicate that for each 100 million tons of sugarcane used for energy, the emission of 12.6 million tons of equivalent CO_2 could be avoided (taking into account ethanol, bagasse and surplus electric power provided to the grid) [Unica (2007)].

Emissions of gases with local impacts

In bioethanol production, the local-impact emissions that are of the most concern come from pre-harvest burning and boiler chimneys. Straw burning increases production, but it is considered to be an environmental problem that affects mostly local cities in sugarcane regions. Brazilian public agencies are, therefore, strongly inclined to restrict this practice (which implies, indirectly, cutting by hand, a process which is harder when the sugarcane is unburned).

The best example of this stance can be seen in São Paulo, where State Law 11.241, 2002 established a deadline for unburned sugarcane harvesting to be implemented in all areas to be mechanized by 2021, while permitting the remaining areas and areas smaller than 150 hectares to continue burning until 2031. Due to pressures from environmental organizations and the Public Attorney, an agreement between the state government of São Paulo and sugarcane agribusiness has moved these deadlines up to 2014 and 2017, respectively, with additional burning restrictions in areas undergoing expansion. In the same vein, the authorization for 56 new São Paulo ethanol plants starting in 2008 was made contingent on the adoption of mechanized-raw sugarcane harvesting. The results of this process can be seen by remote satellite monitoring and show that unburned sugarcane harvesting accounts for 47% of the area planted in São Paulo for the 2007/2008 harvest. This has enabled the avoidance of 3,900 tons of particulate matter from being released into the atmosphere [Cetesb (2008)]. In other states, such as Goiás e Mato Grosso, similar initiatives to establish schedules for the elimination of burning can be seen, although thus far, results have not been measured. Besides environmental issues, it is also possible to utilize the energy from straw burning for power generation and this is one of the positive factors for raw sugarcane harvesting.

With the introduction of modern boilers in the plants (ie, less excess air and higher flame temperatures), chimney gas nitrogen oxide levels have reached levels similar to those observed in other thermal energy systems. Levels are now controlled by environmental agencies in accordance with specific legislation that entails limits and penalties regarding emissions (CONAMA Resolution 382, 2006). In this regard, boiler emissions can, and effectively are, abandoning conventional systems for cleaning chimney gases. Results have been positive, so this does not seem to be a relevant problem for the bioethanol agroindustry.

Water use and the disposal of effluents

From the hydro resources point of view, the particularly favorable conditions of countries in humid tropical climates such as Brazil, with plenty of well distributed rain, enables much of sugarcane culture to be carried out without irrigation. In the case of Brazil, it is estimated that irrigated agricultural areas amount to 3.3 million hectares, or around 4% of the area cultivated. Annual average runoff in Brazil is 5.74 thousand km^3, compared with an estimated water consumption of 55 km^3, ie, less than 1% of the needs and enabling an annual supply of 34 thousand m^3 water per inhabitant [Souza (2005a)]. However, in Brazilian regions with an annual availability below 1.5 thousand m^3 water per inhabitant the situation is critical. Implementation of water granting and charging systems is currently underway, which allow water to be charged according to the principle of «polluter/payer» (drafted by the Basin Committees, pursuant to Law 9.433/1997, The Water Law). This should encourage a more responsible use of water and a reduction of pollution in bodies of water.

Depending on the climate, sugarcane cultivation requires 1500 mm to 2500 mm of adequately distributed water during the growing cycle (a hot dry period for growth and a dry period for maturation and sugar accumulation). Irrigation is practically not used in the Brazilian Center-South region, being adopted only in the most critical periods in the Center-West region and, somewhat more frequently, in the Northeast region. In the latter case, irrigation is used as «salvation irrigation» at sugarcane planting, to ensure sprouting under dry conditions, and as «supplementary irrigation» under other rainfall conditions in periods of most critical growth development [Souza (2005a)]. To the extent that areas with less water availability become occupied by sugarcane, it is believed that irrigation could be an appropriate option (to be implemented in accordance with prevailing laws) in order to maintain agricultural output. Currently, in the opinion of Embrapa, sugarcane plantations have not impacted water quality [Rosseto (2004)].

Within the sphere of the industrial process, in addition to the volume of water used for processing sugarcane, a significant volume of water enters the plant with the sugarcane itself since water constitutes 70% of the cane weight. So, although the volume for processing is estimated at 21 m^3 per ton of cane processed, water consumption and waste is much lower. In relation to water consumption, 87% occurs in four processes: Cane washing, multi-jet/barometric condensers, cooling of fermentation vats and alcohol condensers. With the rationalization of water consumption (recycling and turning off of circuits, as well as certain process changes, such as dry washing, and reduced cane washing enabled by mechanical cutting), net water use has been significantly decreased. Studies performed in 1997 and 2005 point to an average reduction in water use of from 5 m^3 to 1.83 m^3 per ton of cane processed, with expectations of reducing this to 1 m^3 per ton of cane processed in the medium-term [Elia Neto (2005)].

The principal effluents from bioethanol production and treatment systems are presented in Table 29. A survey of 34 plants showed that the treatment used reduces organic load by 98.4%, with a residual of 0.199 kg BOD/t cane [Elia Neto (2005)]. Fertirrigation, in which stillage is applied to sugarcane, is the main form of final disposal of the organic load, one which has both environmental and economic advantages. Given its importance, the issue of stillage is worth analyzing more deeply.

***Table 29* – Liquid effluents from the bioethanol industry**

Effluent	Characteristics	Treatment
Water from sugarcane washing	Average polluting potential and high solids content	Decantation and stabilization pools in the case of disposal into bodies of water. When reused, treatment consists of decantation and pH correction.
Water from multi-jets and barometric condensers	Low pollution potential and high temperature (~ 50° C)	Spray tanks with cooling towers, with recirculation or release
Water for cooling vets and alcohol condensers	High temperature (~ 50° C)	Cooling towers or spray tanks for reuse or release
Stillage and residual water	High volume and organic load	Applied during cane farming along with residual water

Source: Elia Neto (2005).

The stillage, produced at a rate of 10.85 liters per liter of bioethanol, constitutes the most important effluent from sugarcane agroindustry. It contains high levels of potassium (close to 2 kg per m^3) and organic matter, but is relatively poor in other nutrients. At the beginning of Proálcool, stillage was released directly into rivers causing severe environmental problems. This was attenuated by the use of infiltration basins and finally resolved 1978 with fertirrigation systems.

The area of sugarcane plantation covered by fertirrigation depends on the topography and distribution of the lands around mills – some mills apply stillage to 70% of the area under cultivation; for others, it is considerably less. Currently, the intention is to increase the area covered by stillage to increase yields and reduce the use of chemical fertilizers (which can be then used at lower doses thereby lowering the risks of salinization and contamination of the water table) [Souza (2005b)]. Among mills in the state of São Paulo, stillage is predominantly spread using pumping and spraying systems, although conventional tanker trucks are also used for distribution.

Long-term studies on the effects of stillage on sugarcane plantations (taking into account nutrient leaching and groundwater contamination) confirm the physical, chemical and biological benefits to the soil. These include increased pH, increasing ionic exchange capacity and availability of certain nutrients, improved soil structure, increased water retention and development of soil microorganisms. Used at appropriate rates (lower than 300 m^3 per hectare, and taking into account the characteristics of the soil and the location of springs), stillage acts to revitalize soil fertility, even below the surface, as well as providing water and nutrients [Souza (2005b)]. Stillage is currently considered to be an organic fertilizer, being approved for the production of «organic» sugar, in which chemicals such as herbicides, insecticides or synthetic fertilizers cannot be used.

Some traditional sugar-producing regions of the State of São Paulo are located in environmentally vulnerable areas, such as catchment areas for important São Paulo aquifers. In these cases, the intensive and frequent use of stillage could cause long-term groundwater pollution. In such areas, the applicable environmental regulations for stillage use have been evolving. In 2005, the Secretary of the Environment of the State of São Paulo published a technical regulation regarding criteria and procedures for the application, transportation and disposal of stillage on agricultural land [SMA (2005)]. The regulation mainly stipulates measures for the protection of surface and ground water, requiring leak proofing of storage tanks and residue distribution channels, locations subject to application and a maximum rate of 185 kg K_2O per hectare, calculated based on stillage potassium ion levels being limited to 5% of the soil ion exchange capacity [Bertoncini (2008)]. Such legislation is compulsory in the State of São Paulo and, patterned on other environment-related regulation, tends to be adopted in the rest of the country.

Regardless of the results obtained by fertirrigation, the interest in exploiting the residual energy content in stillage remains, through biodigestion and biogas production. Another line of research is to concentrate the stillage, for example, by recirculating during fermentation combined with pre-concentration of the liquor, or by using reverse osmosis, in order to reduce volumes to facilitate transport over longer distances [CGEE (2005)]. Neither of the alternatives has reached economically viable levels, as already observed in Chapter 4. But, with the evolution of processes, they may come to be adopted in the medium-term, especially in those contexts in which topography and distances make fertirrigation more difficult.

As an important indicator of the evolution of the sugarcane agroindustry in the treatment and reduction of effluent releases into water bodies, Cetesb undertook a study of 16 hydrographic basins in the State of São Paulo where bioethanol production exists. It was estimated that there was a potential discharge of 9,340 thousand tons per day of Biochemical Oxygen Demand (BOD) associated with sugar and bioethanol plants and an effective release of 100 thousand tons, equivalent to a 99% decrease in pollution potential, based on organic load [Moreira (2007)]. Naturally, these significant results were stimulated by law-enforcement inspections, but they demonstrate the availability and use of technologies capable of significantly mitigating impacts of effluents on watercourses.

Despite the results obtained, permanent efforts for maintaining or reducing the environmental impacts of these effluents are justified by virtue of the sheer size of the sugarcane planted area and the amount of bioethanol produced. In this direction, interesting measures are being adopted for the protection of watersheds, particularly with respect to the progressive abandonment of sugarcane cultivation in *Áreas de Preservação Permanente* (APP) (Permanent Preservation Areas), which enables them to recuperate spontaneously or with the help of reforestation (especially in the case of riparian forests) with positive impacts on biodiversity [Ricci Jr. (2005a)].

Use of agrochemicals

Chemical products such as insecticides, fungicides, herbicides and flower-promoting or retarding products are regularly used in sugarcane production at levels which are considered low in comparison with averages used in other important commercial crops.

***Table 30* – Use of agricultural pesticides in the main crops in Brazil (In kg active ingredient per hectare)**

Product	Year	Culture				
		Coffee	Sugarcane	Orange	Corn	Soy
Fungicide	1999	1.38	0.00	8.94	0.00	0.00
	2003	0.66	0.00	3.56	0.01	0.16
Insecticide	1999	0.91	0.06	1.06	0.12	0.39
	2003	0.26	0.12	0.72	0.18	0.46
Miticide	1999	0.00	0.05	16.00	0.00	0.01
	2003	0.07	0.00	10.78	0.00	0.01
Other agrochemicals	1999	0.06	0.03	0.28	0.05	0.52
	2003	0.14	0.04	1.97	0.09	0.51

Source: Arrigoni and Almeida (2005) and Ricci Jr. (2005b).

As presented in Table 30, agrochemical application rates for some of the main Brazilian crops, according to the *Sindicato Nacional da Indústria de Produtos para Defesa Agrícola* - SINDAG (National Union of Agrochemical Producers), varies according to the crop. In the case of sugarcane, fungicide consumption is practically zero and insecticides are used in proportionately small quantities.

The reduced use of these pesticides is the result of pest combat procedures such as the choice of more resistant varieties in genetic improvement programs and above all by the adoption (with excellent results) of biological methods of control of the main sugarcane pests, which include the sugarcane borer (*Diatraea saccharalis*), a species of moth combated using a wasp (*Cotesia* *flavipes*), and the sugarcane spittle bug (*Mahanarva fimbriolata*), controlled by applying fungus (*Metarhizium anisopliae*) [Arrigoni and Almeida apud Macedo (2005)].

Sugarcane borer larva (*Diatraea saccharalis*) and the parasitic wasp (*Cotesia flavipes*).

Biological control employs parasites or predators to control agricultural pests with a high degree of accuracy and low impacts. This method has economic advantages in relation to the use of conventional insecticides since chemical products are not indiscriminately applied and pests are kept at tolerable levels. Restrictions on sugarcane burning will probably increase the need to use such controls on the spittlebug.

To combat weeds, sugarcane needs more herbicides than coffee or corn, but less than citrus, being equivalent to soybean in terms of requirements. Meanwhile, with the progressive adoption of raw (unburned) sugarcane harvesting, the straw that remains on the soil surface suppresses the germination and emergence of invasive plants, enabling significantly less herbicides to be applied [Urquiaga et al. (1991)]. With respect to the use of agrochemicals, it is important to mention that Law 7.802/89 establishes the *receituário agronômico* (agrochemical register), which defines responsibilities, application methods, and container disposal procedures.

Fertilizer use

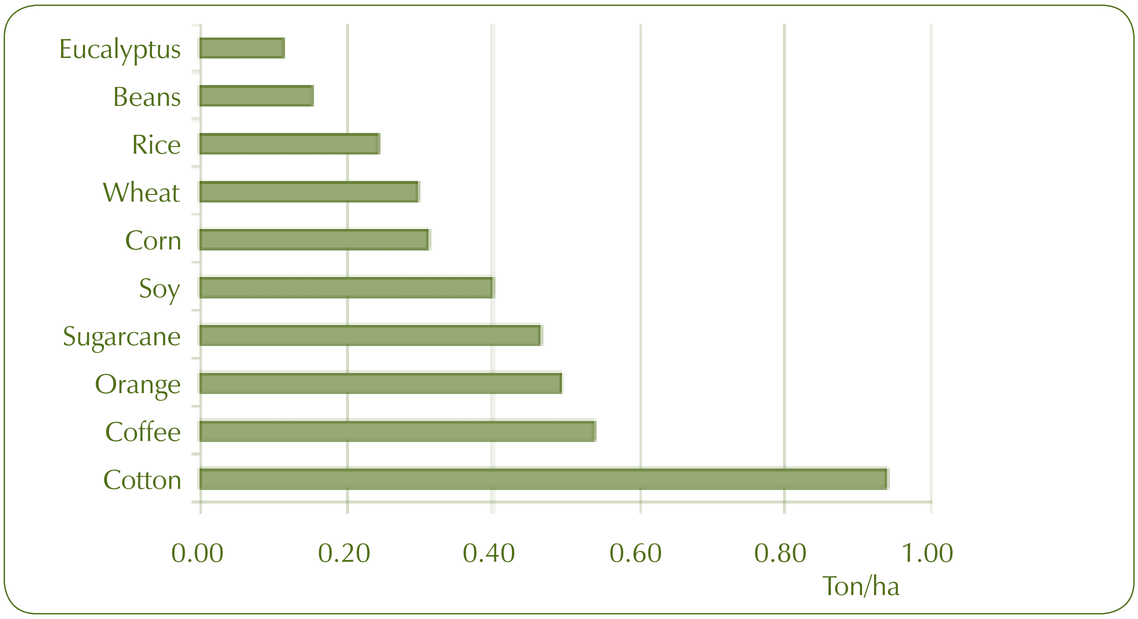
Sugarcane culture in Brazil consumes a relatively low quantity of conventional fertilizers, given he importance of recycling of nutrients. In effect, fertirrigation with stillage substantially reduces potassium requirements, and in conjunction with industrial process wastewater and boiler ashes, supplies a significant proportion of the nutrients for sugarcane, with both economic and environmental benefits. Considering a typical full cycle of sugarcane planting (plant-crop and four ratoon-crops), under average Brazilian conditions, the application of stillage and filter cake, although it does not have much impact on nitrogen supply, does reduce phosphorous demand (P_2O_5) from 220 kg/ha to 50 kg/ha and potassium demand (K_2O) from 170 kg/ha to 80 kg/ha, while maintaining similar yields [CGEE (2005)]. Note that for bioethanol production, only sugars and fiber (comprised of carbon, hydrogen and oxygen) are of importance. In as much as possible, all other nutrients removed from the cane should be returned to the soil.

Additionally (and of particular interest), it has been observed a much higher availability of nitrogen in sugar plantations than that provided by fertilizers, signaling the existence of biological nitrogen fixation by bacteria colonies of the genus *Azospirillum*, a diazotrophic bacterium – capable of converting atmospheric nitrogen in forms that can be assimilated by other organisms – living freely in the rhizome area or associated with gramineae like sugarcane. The pioneer studies in this area were conducted in recent decades by Johanna Döbereiner, a Brazilian researcher from Embrapa; those studies could well open up perspectives for significantly increased yields in the sugarcane agroindustry [CNPAB (2008)].

Considering plantations with cultivated areas above one millions hectares, sugarcane is in fourth place with respect to the consumption of chemical fertilizers in Brazil (as seen in Graph 24), based on data provided by the *Associação Nacional de Difusão de Adubos* - Anda (National Fertilizer Dissemination Association) and IBGE surveys. This level of consumption of fertilizers by sugarcane is considered relatively low, compared with other countries. Given the values suggested by CTC for fertilizing ratoon cane and plant cane in the Center-South Region, with the application of, respectively, 290 kg and 260 kg of average formula N-P_2O_5-K_2O, fertilizer levels for sugarcane in Australia are 30% and 54% higher than for Brazil [Donzelli (2005a)].

Fertilizer, when used as a complement to recycled by-products, is important to ensure that yields are maintained under current conditions; without it, productivity would fall substantially. However, fertilizer use represents a significant portion of agricultural costs, which justifies the increasing adoption of new technologies to diminish the demand for fertilizer and lime, rationalizing their use. With respect to this point, new methods of fertilizer distribution can be cited in which losses due to volatilization are reduced, organic material is increased (as with raw cane harvesting), and precision agriculture methods are applied. By using yield maps with physical and chemical soil attributes (granulometry, macronutrient and micronutrient levels, acidity, density and penetration resistance), significant fertilizer savings can be obtained by substituting the uniform application of fertilizers with variable-rate applications, based on detailed soil information. By using precision agriculture techniques the *Usina Jales Machado*, in Goianésia (GO), achieved a reduction of 34.5% in the application of lime and 38.6% in the application of phosphorus. This was equivalent to an economy of 36% in costs for these products, per fertilized hectare, maintaining the same productivity [Soares (2006)]. Experimental studies in the Araras region of São Paulo indicated that reductions of 50% in the consumption of phosphate and potassium fertilizer can be expected with the adoption of variable application rates [Cerri (2005)]. At present, it is estimated that around 10% of sugarcane plantations in Brazil already use some form of precision agricultural technique for the application of phosphorus and lime at variable rates (Molin, 2008).

Graph 24 **– Consumption of fertilizers by the main crops in Brazil**



Source: Donzelli (2005a).

In short, the use of fertilizers, highly important to yields for Brazilian sugar plantations, has been practiced at lower levels due to recycling of industrial process nutrients; application of conventional fertilizers has tended to decrease with the progressive introduction of new fertilizer technologies.

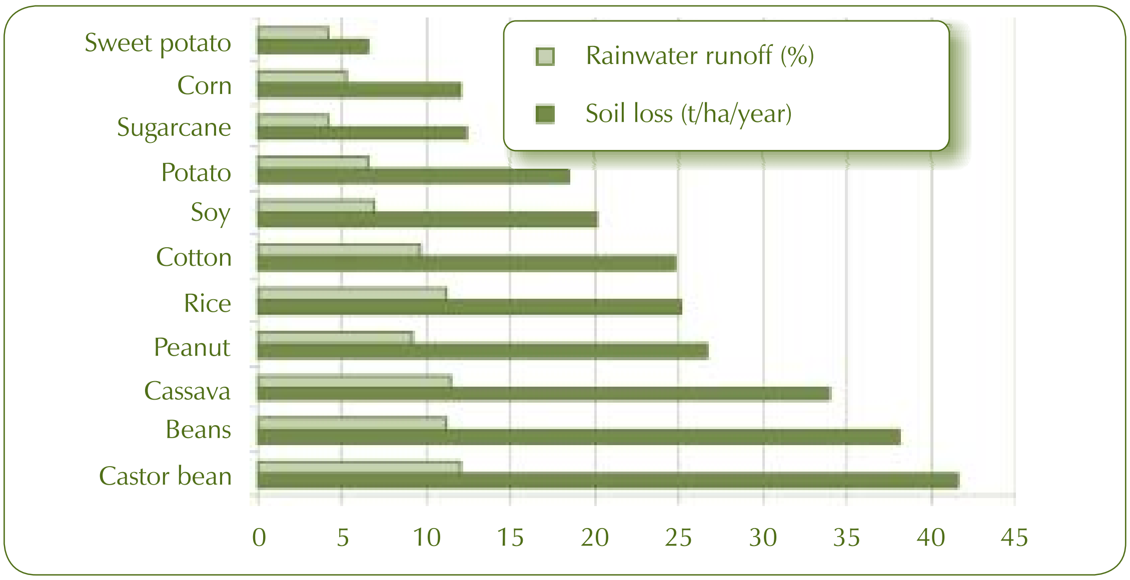
Erosion and soil protection

Frequently caused by inadequate agricultural practices, soil erosion is the largest cause of degradation of agricultural lands and it is often associated with the irreversible loss of arable land. Because of this, the productive use of land should take into account the type of soil (texture, diagnostic horizon types, and water infiltration rates), slope, precipitation regime, crop to be planted and establish plots, roads and cultivation lines, in order to protect the fertile topsoil. Since sugarcane production has been practiced for centuries in Brazil (in many cases, in the same area), there is already enough information regarding its impact on soil conservation [Donzelli (2005b)].

As a semi-perennial crop (a feature that reduces the number of agricultural operations that expose the soil to bad weather and subsequent loss of topsoil) sugarcane is recognized as being a soil-conserving crop, a fact supported by Graph 25 (topsoil loss and rainwater runoff for different crops in Brazil). For example, soil loss with sugarcane is only 62% of that for soybean. From the point of view of rainwater retention capacity – an important aspect for farming and for soybean. protection – sugarcane is demonstrably one of the most efficient crops, as Graph 25 confirms.

The increasing use of raw cane harvesting, reviewed in previous paragraphs (in which straw protects the soil against the direct impacts of raindrops and soil requires less preparation and tilling), should, in coming years, improve even more conservation levels of soil planted with sugarcane, resulting in a reduction of approximately 50% in the levels of soil loss and rainwater runoff currently observed [(Donzelli (2005b)].

Graph 25 **– Soil loss and rainwater runoff for some Brazilian crops**



Source: Donzelli (2005b).

Biodiversity

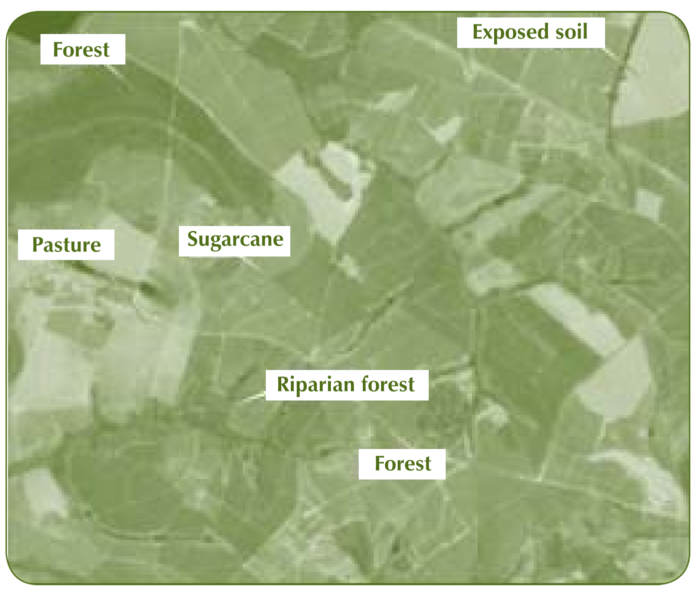
The efficient production of bioethanol in Brazil implies the planting of sugarcane, a monoculture whose environmental impact depends on the original characteristics of the land and on mitigation measures. Thus, with regard to endangering pre-existing biodiversity, the effects of sugarcane planting in areas previously occupied by other crops or where there has been extensive cattle farming are certainly distinct to planting in virgin areas, especially forests. In the first case, there is a change in land use; in the second case, significant negative impacts are possible.

Brazilian law (in particular, the *Código Florestal Brasileiro* (Brazilian Forest Code), Law 4.771, of 1965, and Law 7.803, of 1989) determines that farms have to preserve a *Reserva Legal*

- RL (Legal Reserve): This is an area located within a property or rural possession (except for permanent preserves), dedicated to the sustainable use of natural resources, conservation and rehabilitation of ecological processes, conservation of biodiversity and the shelter and protection of native fauna and flora. The Legal Reserve must be a minimum of 20% of the total area, depending on the region (in the Amazon, 80%); additionally the original vegetation must be maintained in *Áreas de Preservação Permanente* – APP (Permanent Preservation Areas) eg, hilltops, slopes and banks of water bodies.

Unfortunately, the expansion of farmland over the last decades has, in general, ignored these rules. Currently, due to increased environmental awareness, reinforcement of the responsible institutions and availability of satellite monitoring systems (see Figure 26), such legal provisions have been enforced by government agencies at several levels and have been effectively incorporated into the farming practices of several plants, both operating and under construction. For example, in many plants in the State of São Paulo, during the last decade, there has been a reduction of sugarcane planting in gallery (riparian) forest areas, as well as forest regrowth in water springs: even with the significant expansion of farming, a marginal increase of the state's forest coverage, estimated in 3.5 million hectares, has been discerned [Instituto Florestal (2004)]. In new units, especially in the Brazilian *cerrado*, concern with acting in an environmentally correct way is evident at many companies. Motivated by the legal risks of noncompliance and by the positive image associated with being environmentally friendly, they seek, from the outset, to comply with the legislation applicable to Permanent Preservation Areas and Legal Reserves.

Figure 26 **– Example of satellite image from monitoring of vegetation coverage**



Source: CTC (2008).

Although sugarcane is less aggressive than other crops and its cultivation makes extensive use of byproduct recycling and biological pest control, it is essential that the bioethanol agroindustry strictly complies with environmental legislation and be duly penalized for any infractions, given the size of the area planted with sugarcane. The current experience in many Brazilian plants (with good results vis-à-vis agroindustry/the environment) combined with the current availability of low-environmental-impact farm and industrial technologies confirm the possibility of producing sugarcane bioethanol in a rational way: conservationist environmental practices make economic sense [Smeets et al. (2006)].

Nevertheless, it is very important to note that effective application of the law and a more favorable attitude towards nature, in all the aspects mentioned above (eg, biodiversity, water and soil resources) derives, above all, from the clear and active presence of the State, implementing and enforcing compliance with environmental laws. Higher environmental awareness in public and private entities helps to bring pressure in favor of a responsible development of bioenergy in Brazil, as it is one of the few alternatives capable of promoting alternatives capable of promoting change (for the better) in the worrisome status quo of global energy [FBDS (2005)].

Other environmental aspects

Recently, two new environmental issues related to sugarcane bioethanol production have arisen: the emission of greenhouse gases associated with land use changes (with loss of original vegetation, when sugarcane farming is implemented) and the indirect process of deforestation caused by the occupation of rangeland by sugarcane, which causes the transfer of livestock to the agricultural frontiers where new cattle raising areas may be created. These are certainly complex subjects, still under discussion, but some important and relevant information can be put forth.

The impact of land use change on greenhouse gas emissions has been considered in several studies. Depending on the previous vegetation in the area used for biofuel production, the disturbance provoked by the land use change could release a quantity of carbon – previously sequestered in the vegetation and soil – into the atmosphere, possibly in levels high enough to outweigh the environmental benefit. However, there is still much uncertainty as to the magnitude of this effect, because in-balance soil carbon levels depend, among other factors, on crop, soil type, farming practices and local climate. Carbon release and accumulation rates, after the cyclic planting of biofuel crops, also depend on many factors. Though preliminary, assessments of this type of impact suggest sugarcane bioethanol produced in the Brazilian *cerrado* has the lowest impact among the biofuels studied [Fargione (2008)]. This is an area that deserves attention and more research is still necessary to estimate, in a consistent way, the real share of these emissions in the biofuel lifecycle.

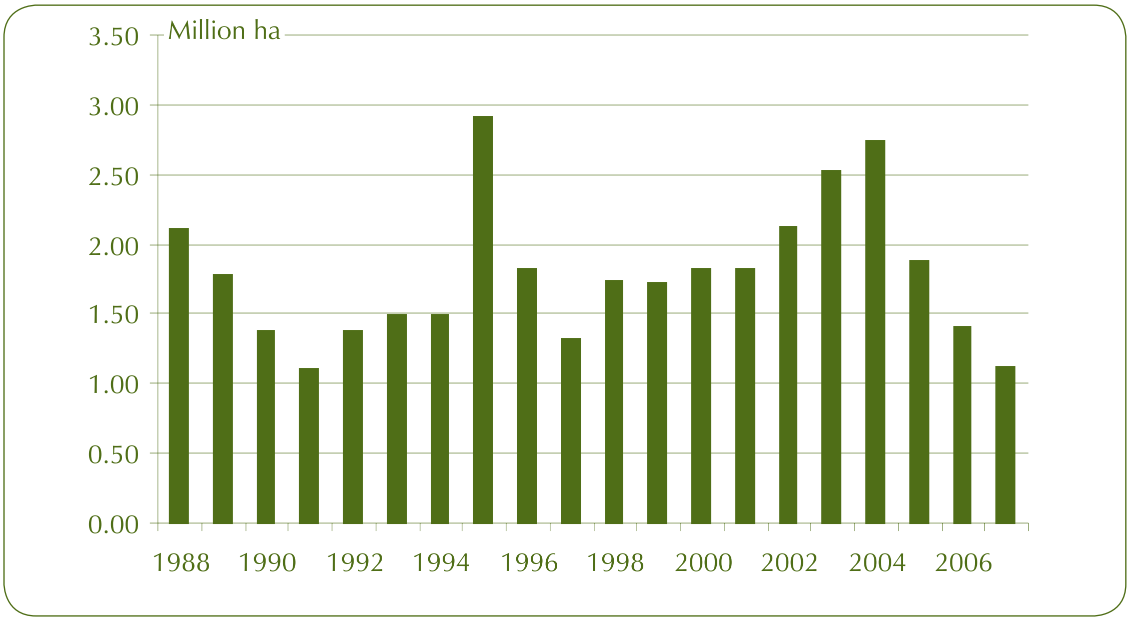
Moreover, in the case of bioethanol in Brazil it is very unlikely that forest cover losses can be attributed to bioethanol production because the expansion of sugarcane farming has occurred basically in areas previously occupied by low productivity pastureland or annual crops (such as soybean, mostly destined for export). In both these cases, the root system and the above-soil biomass are generally of lesser magnitude than in the case of sugarcane. Another aspect to be kept in mind is the increased practice of raw sugarcane harvesting, in which more of the straw (and, therefore, carbon) is incorporated into the soil [Macedo (2008)].

Indirect deforestation caused by the expansion of sugarcane production is an argument difficult to sustain in regard to criticism of bioethanol, since there is not much data on a causal relationship; however, it is an issue that deserves attention. Rainforests all across the planet suffer from enormous pressures regarding the use – rational or not – of their timber resources and the possibility of providing new land for agriculture. In Brazil, deforestation is an old problem and reducing it remains a significant challenge. This is despite growing governmental efforts to organize protection of the Amazon Forest, including the definition of protected areas, increased inspections, coordination of a variety of agencies and deployment of modern technology (such as remote sensing).

The loss of forest cover in the Amazon Forest in Brazil reached an annual average of 1.8 million hectares between 2000 and 2006 but has diminished lately, as shown in Graph 26, based on results of satellite image monitoring. However, only during the course of the next few years it will be possible to confirm whether deforestation rates have really been contained [Inpe (2008)]. It is estimated that around 17% of the original coverage of the Amazon Forest has been cut down, mainly for wood, charcoal for the steel industry and farmland occupied by extensive livestock systems and soybean plantations [ISA (2008)].

Nineteen billion hectares of the Brazilian Amazon Forest have been cleared during the last decade (1998–2007). This is 10 times greater than the expansion of the area planted with sugarcane to produce bioethanol in the same period. Bioethanol production does not imply deforestation; moreover, deforestation in the Amazon Forest region is a complex problem that imposes the need for land-use planning to regulate the expansion of agriculture, as well as reinforcement of inspections and law enforcement. Brazil, like several other countries located in the humid tropical region of the planet, has sufficient land for a significant expansion of agricultural production and can produce food and bioenergy in a sustainable way without giving up its forest assets (as will be covered in more detail in the next section).

Graph 26 – **Annual deforestation of the Brazilian Amazon**



Source: INPE (2008).

7.2 Land use

A recurring theme in the discussion of perspectives for bioethanol is the issue of farm land use in relation to its availability and eventual impacts on the availability of food. This section analyzes such aspects from the viewpoint of sugarcane bioethanol production in Brazil, followed by an assessment of the evolution of farmland use during the last decades. Perspectives on agricultural zoning are also discussed, concluding with a vision of the estimated potential for the expansion of sugarcane production in Brazil.

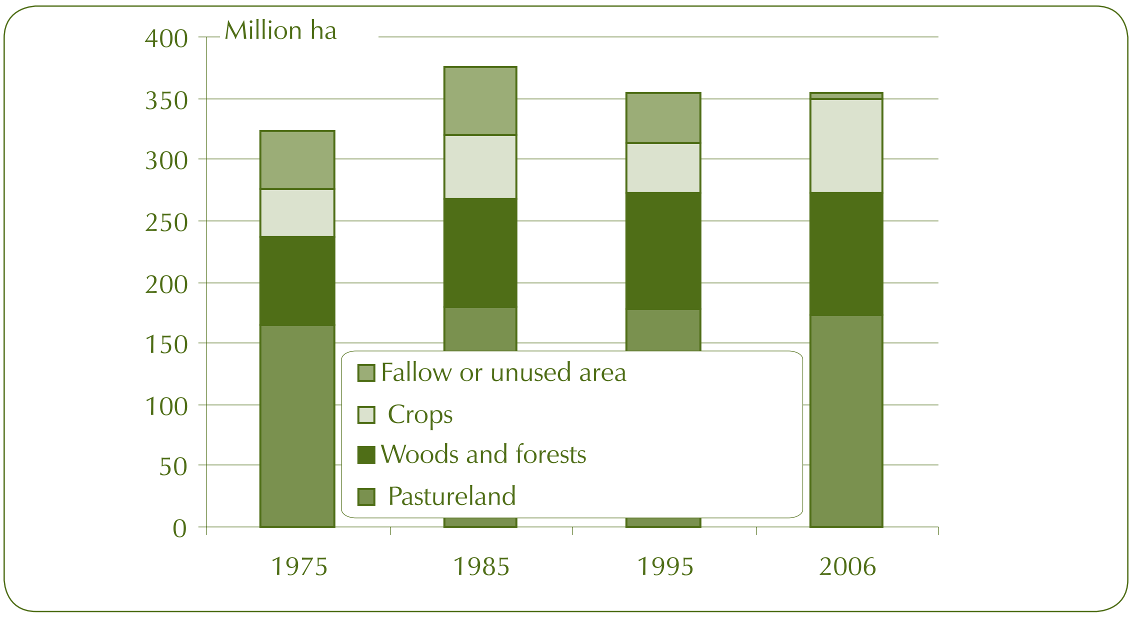
In the following chapter the relevant causal links between bioenergy production and food safety will be analyzed. The scope will be a global one, taking into account not only Brazil and also including the production of other biofuels.

Development of agricultural land use in Brazil

Brazil has a total surface area of 851.4 million hectares, mostly covered by tropical forests. Based on 2006 Agricultural Census results, the area of Brazilian rural properties (which excludes protected areas, water bodies and areas unfit for agriculture and includes legal reserves of native formations) amounts to 354.8 million hectares (42% of the total area of the country), dedicated to natural and planted pasturelands, forestry, native forests and annual and perennial crops. The evolution of the different types of land use in the last 30 years can be seen in Graph 27, which shows the relatively small variation in the total area of rural properties and the significant expansion of crop land in the last decade.

Between 1995 and 2006, Brazilian crop land expanded by 83.5% to occupy 76.7 million hectares, around 9% of the national territory. Such growth essentially took place in unused or fallow areas and, to a smaller degree, in pastureland, which shrank by 5.4 million hectares, to represent approximately 20% of the Brazilian territory. This growth of crop land in pasturelands has been happening systematically since the 1970s and has made the ratio of pasture land to cropland shrink from 4:5 in 1970, to 2:2, in 2006.

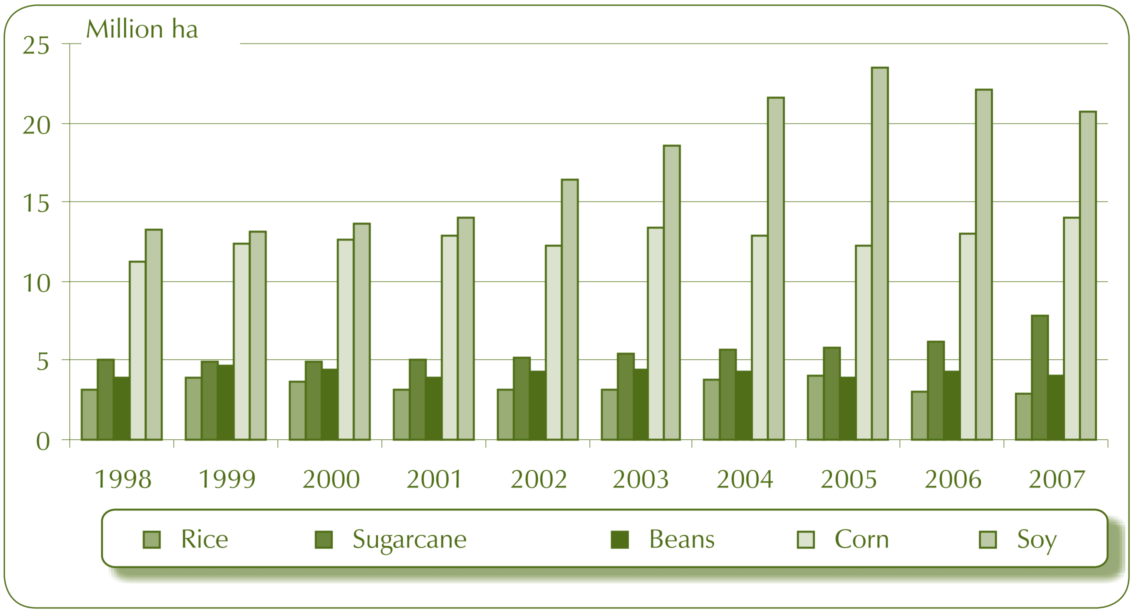
***Graph 27* – Rural Brazilian property land-use**



Source: IBGE (2007).

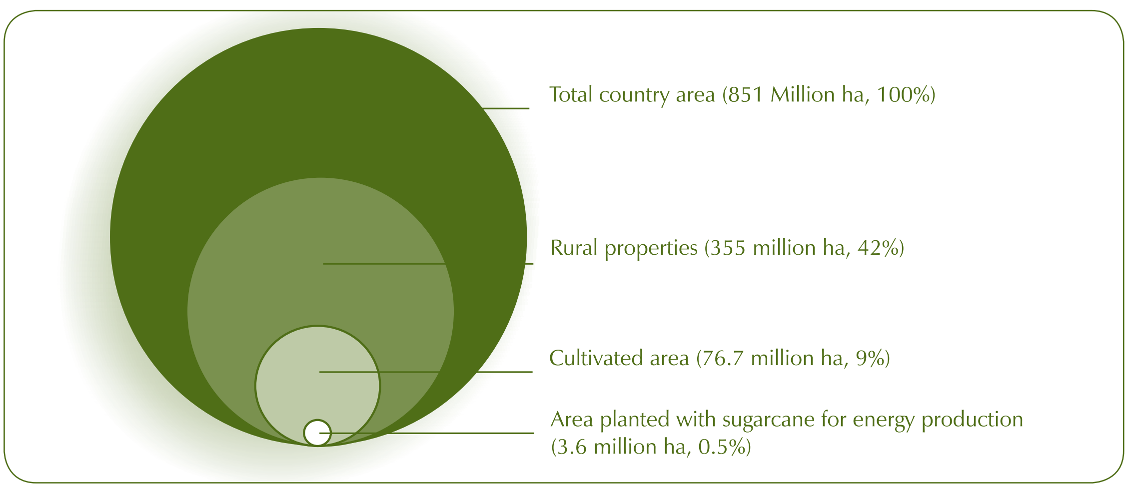
In 2007, sugarcane production in Brazil occupied 7.8 million hectares, around one third of that occupied by soybean and half of that planted with corn, as shown in Graph 28. Approximately half the sugarcane production goes to bioethanol production. Hence, sugarcane plantations for fuel production in Brazil correspond to 5% of cultivated land, 1% of the area of agricultural property, 2.3% of pastureland and 0.5% of the area of Brazil. Both the sheer size of the country and the efficiency of sugarcane in solar energy capture contribute to the size of these numbers: any other bioethanol input, with current technologies, would require a greater extension of land. Graph 29 presents the relative importance of the area dedicated to sugarcane production for energy purposes, compared to Brazil's total and cultivated areas.

***Graph 28* – Evolution of the area used by the principal crops in Brazil**



Fonte: IBGE (2007).

***Graph 29* – Land-use in Brazil**



Source: IBGE (2007).

The significant increase in the area planted with sugarcane in Brazil's Central West region between 1998 and 2007, confirms the tendency of this agroindustry to expand in regions close to traditionally producing areas and which have adequate topography, soil and climate conditions. Although weak infrastructure (especially transportation) needs to be addressed, this region effectively constitutes a new and important center for Brazilian sugarcane agroindustry. In this region, sugarcane expansion has mostly taken over pasturelands, as well as over some soybean fields (which were Cerrado a few decades earlier).

Agroecological zoning

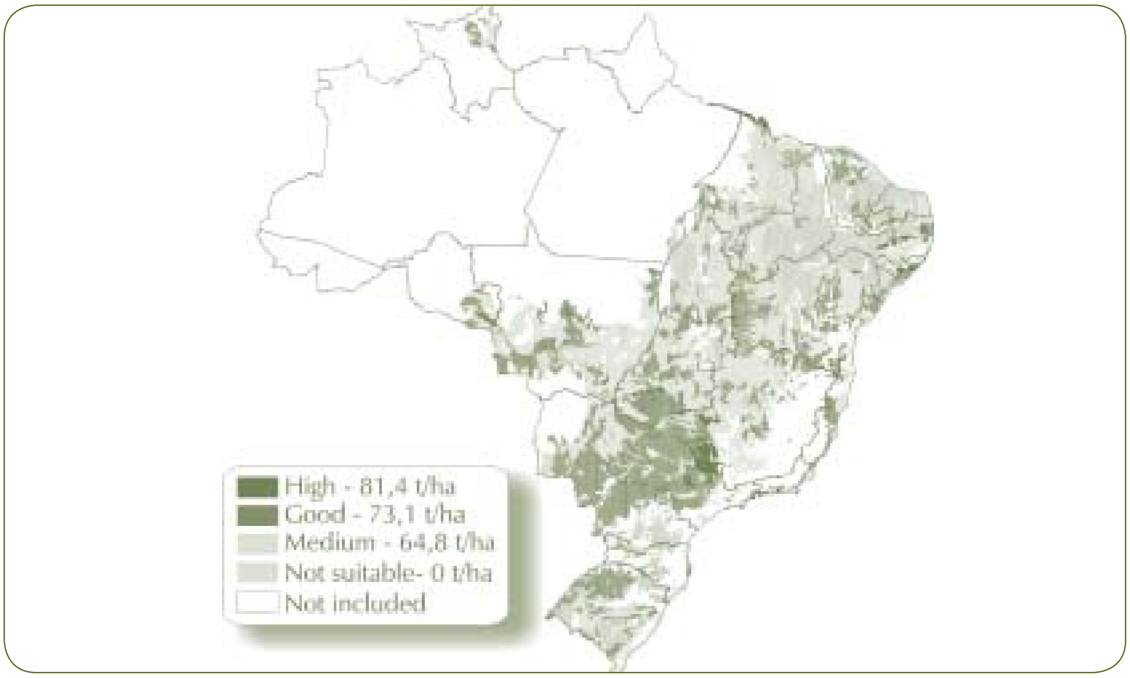
In an effort for planning the expansion of sugarcane agroindustry in Brazil, under the auspices of the Ministry of Agriculture and Supply (MAPA), the Sugarcane Agroecological Zoning (ZAE-Cana) was organized, the first results of which should be available this year. This is a comprehensive study, led by *Embrapa Solos* (EMBRAPA Soils), involving dozens of institutions and researchers. The purpose is to define which areas and regions are appropriate/inappropriate for large-scale sugarcane farming. The zoning is to be used to orient financing policies, infrastructure investments and tax regime improvements, and may also be useful for socio-environmental certification to be implemented in the future [Strapasson (2008)].

Agroecological zoning is focusing on agricultural and cattle raising areas where sugarcane is not yet grown, but has potential. It combines information on soil, climate, environmental reserves, geomorphological and topographical maps. It also identifies current land use, examines federal and state environmental legislation, and presents information on sugarcane cultivation, such as ideal growth temperatures, compatible soil types, water requirements, etc. Thus, areas of greatest potential for planting sugarcane are defined and classified, as well as those areas where it is not recommended or not possible. As a requirement for this work, a minimum productivity threshold was established, based on the national average of 70 tons of sugarcane per hectare.

Potential for the expansion of sugarcane production in Brazil

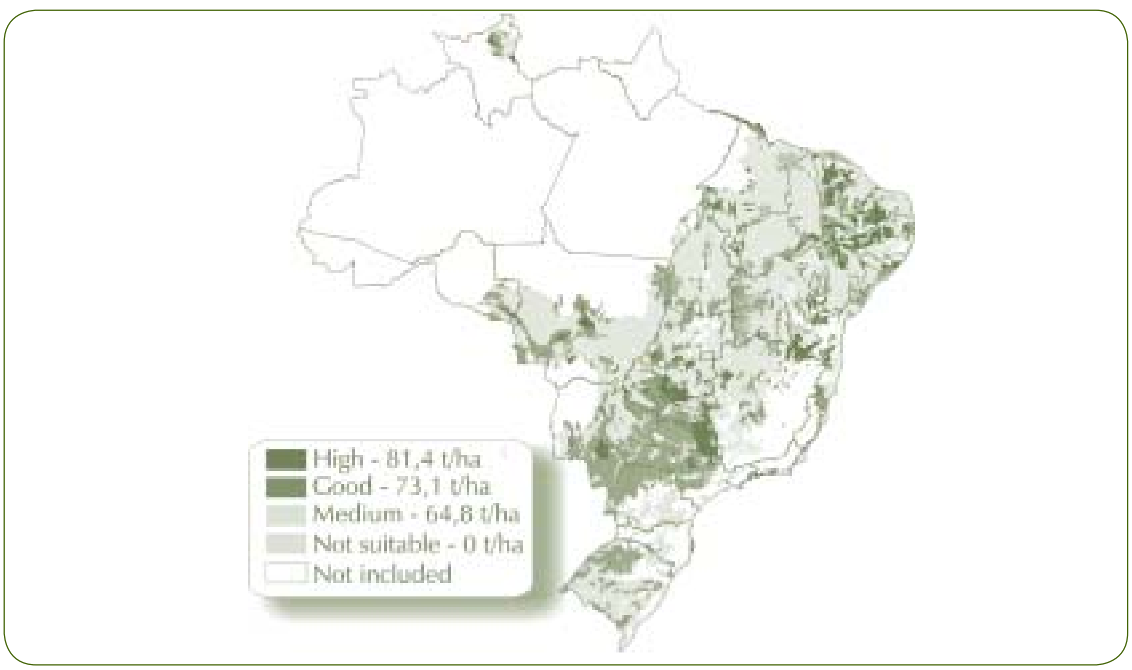
The study developed by *Centro de Gestão de Estudos Estratégicos* - CGEE (Center for Strategic Studies and Management) in conjunction with the *Núcleo Interdisciplinar de Planejamento Energético* - NIPE (Interdisciplinary Center of Energy Planning) of the State University of Campinas is less detailed than the agroecological zoning under development by MAPA; however, it has a similar goal of prospectively examining the possibilities and impacts of large-scale bioethanol production, under the assumption of partial substitution of gasoline on a global scale. The study is a survey of areas with sugarcane production potential based on soil and climate maps. It also considers water availability and gradient (slopes of less than 12° to facilitate mechanical harvesting), and excludes protected or preservation areas (eg, the Pantanal (Brazilian Wetlands) and the Amazon Forest) and forest and Indigenous reserves [CGEE (2005)]. The results of this study are shown in Figures 27 and 28, with areas classified in accordance with their suitability for sugarcane production, both with and without «salvation irrigation». Salvation irrigation is so called because it is only used on growing sugarcane, where an increase in production is of secondary importance; less than 200 mm of water is applied during more critical periods of water shortfall (equivalent to total annual irrigation of less than 2,000 m^3/ha/year).

Figure 27 – **Potential unirrigated sugarcane cultivation**



Source: CGEE (2005).

Figure 28 – **Potential sugarcane cultivation with "salvation irrigation"**



Source: CGEE (2005).

The map of unirrigated sugarcane production potential (Figure 27), shows that most of the areas with high and medium potential, equivalent to 121.8 million hectares (33.7% of the total), are located in Brazil's Central-South region. These areas are flat or mildly hilly and do not have significant soil or climate limitations. On the other hand, when salvation irrigation is contemplated (see Figure 28), high and medium potential areas increase in size to 135.9 million hectares (37.6% of the total), including in this case areas of the Brazil's semi-arid Northeast region [CGEE (2005)].

A summary of these results is presented on Table 31. It should be noted that, in the classification of expected yields, the value of 65 t/ha defined for low potential is equal to the world average sugarcane yield; therefore, an additional 167.5 million hectares (46.4%) of the total can also be included, for purposes of expansion of this crop.

***Table 31* – Potential sugar cane yields in Brazil**

Potential	Expected yield (t/ha)	Area with potential use			
		Unirrigated		Irrigated	
		Million ha	%	Million ha	%
High	> 80	7.90	2.2	37.92	10.5
Medium	>73	113.90	31.5	98.02	27.1
Low	> 65	149.22	41.3	167.65	46.4
Not suitable	< 65	90.60	25.1	58.00	16.0
Total	–	361.62	100.0	361.59	100.0

Source: CGEE (2005).

The bioethanol agroindustry has significant prospects for growth. Guided by environmental protection regulations and encouraged by high potential yields, it does not face significant restrictions in terms of land availability in Brazil. The following estimates reinforce this view.

As an exercise in calculating the existing potential, let us consider the global numbers for the 2007/2008 crop: in Brazil, around 22 billion liters of bioethanol were produced on 3.6 million hectares. In order to substitute (based on this empirical data, under current conditions) 10% of the gasoline consumed worldwide (1.3 billion cubic meters) with anhydrous alcohol, 136.5 billion liters of bioethanol would be necessary. Again, under Brazilian conditions, this would require 23 million hectares, equivalent to the area currently occupied by soybean in Brazil. Under similar conditions of productivity and energy efficiency, this production could be distributed over the humid tropical regions of the planet, in Latin American and the Caribbean, Africa and Asia, where sugarcane is traditionally grown, as discussed in Chapter 3 and shown in Figure 29. Biofuel production based on other crops or by any other technological routes currently available would require much larger cultivation areas.

Figure 29 – **Areas cultivated with sugarcane**

Source: Adapted from Tetti (2005).

Looking forward to 2025, the CGEE study predicts an effective availability of 80 million hectares for the expansion of sugarcane production in Brazil, based on cluster development scenarios (ie, grouped ethanol production units), the existence of sufficient logistics and area requirements for other permanent or temporary crops. In terms of demand, this same study estimated 205 billion liters of bioethanol would be necessary to substitute 10% of the projected global gasoline consumption for 2025. Assuming two levels of bioethanol/gasoline fuel blend (5% and 10%) and two (current and improved) technological scenarios, the required area was calculated to supply the Brazilian and global sugar and bioethanol market (also taking into account that 20% of the area is kept as environmental reserve). Results are summarized in Table 32 [CGEE (2005)].

Sugarcane agroindustry productivity increases, which should continue, and the introduction of innovative fuel production technologies can significantly reduce area requirements for fuel crops. In Table 32, the last line indicates the areas required (assuming technological progress) to supply domestic and foreign sugar demand (4 million hectares), as well as to produce sufficient bioethanol to supply the domestic market (6 million hectares) and include a 10% bioethanol content in global gasoline consumption (30 million hectares), with a total requirement of 40 million hectares (including 8 million hectares to be reserved for environmental protection). This area represents half of the available areas in Brazil for bioenergy production. This suggests that the availability of suitable land does not seem to be the limiting factor for rational promotion of bioethanol for domestic consumption and exports in the production regions [CGEE (2005)].

Table 32 **– Area requirements for bioethanol production for the 2025 global market**

Scenario	Global ethanol consumption	Technology	Area cultivated in sugarcane (million ha)				Use of available land
			Sugar production: domestic market and exports	Bioethanol production		Total required area	
				Domestic market	Exports		
E5	102.5	Current	4.5	8.5	19.0	32	40
		Improved	4.0	6.0	15.0	25	31
E10	205.0	Current	4.5	8.5	38.0	51	64
		Improved	4.0	6.0	30.0	40	50

Source: CGEE (2005).

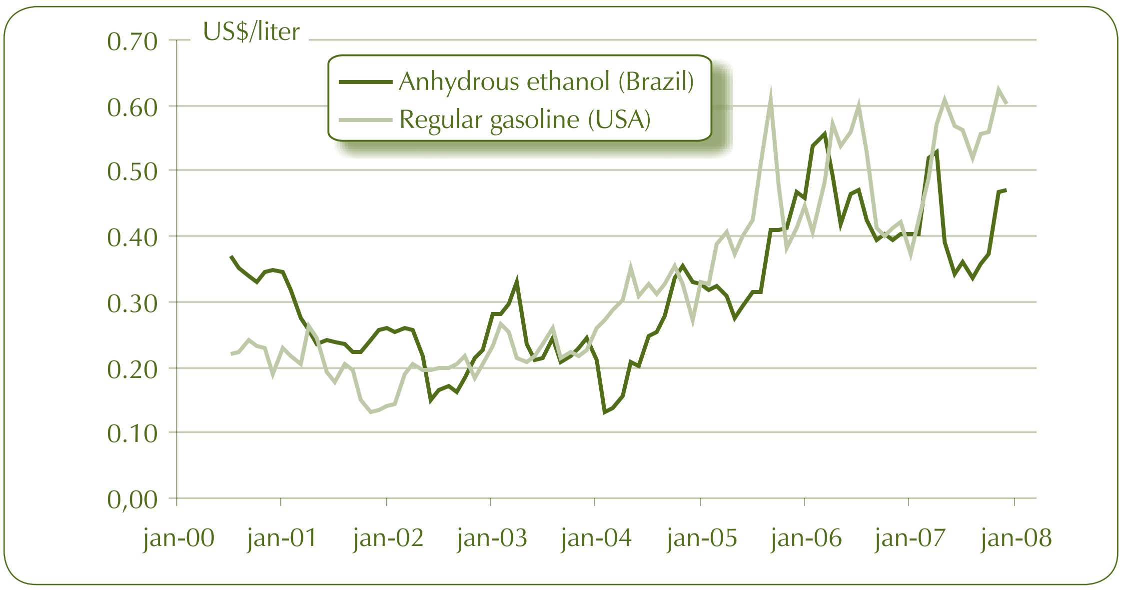
7.3 Economic viability of sugarcane bioethanol

Clearly, for the sustainability of bioethanol production it is fundamental that production costs – comprising all agroindustrial activity and investments for growing sugarcane and industrial plant implementation – are covered by the returns. In previous chapters, some economic aspects have been discussed, such as price formation mechanisms, bioethanol competitiveness compared to sugar production, the economic importance of the sugar-alcohol industry and the learning curve reflecting the sustained reduction of costs over the last decades. In this section the bioethanol economics analysis is taken up once again, presenting aspects of competitiveness vis-à-vis oil, the cost structure of bioethanol in Brazil and the projections of prices for this biofuel in the next years. It is important to acknowledge that in recent years there has been significant volatility in prices and exchange rates making the task of analyzing costs and prices more difficult. However, for purposes of general conclusions, the results presented below are sufficient.

The low cost of sugarcane bioethanol production in Brazil is a well-known fact. Several sources estimate that costs are between US$ 0.25/liter and US$ 0.30/liter (including all inputs and factors), which corresponds to an oil price of between US$ 36/barrel and US$ 43/barrel. This estimate assumes gasoline prices are 10% higher than crude oil prices in terms of volume and that substitution with anhydrous bioethanol is done on a one-to-one volume basis (a consistent assumption, especially when bioethanol blends such as E10 are assumed). Under such conditions, substitution of gasoline with bioethanol is patently viable, but a more complete confirmation of the advantage of this biofuel can be seen by comparing plant prices prior to taxation.

Graph 30 shows how prices paid to sugarcane bioethanol and gasoline producers have evolved (excluding freight and taxation), referring, respectively, to the price of anhydrous bioethanol in the State of São Paulo (data from *Centro de Estudos Avançados em Economia Aplicada* – CEPEA (Center for Advanced Studies in Applied Economics), part of the *Escola Superior de Agricultura Luiz de Queiroz*, (Luiz Queiroz School of Agriculture at São Paulo University), and US Gulf Coast Conventional Gasoline Regular Spot Price FOB data from US Energy Information Administration (EIA, 2008). CEPEA regularly monitors anhydrous and hydrated bioethanol prices in four Brazilian states (São Paulo, Alagoas, Pernambuco and Mato Grosso), constituting one of the most reliable information sources in this market.

***Graph 30* – Evolution of prices paid to producer, not including taxes: US gasoline and Brazil sugarcane bioethanol**

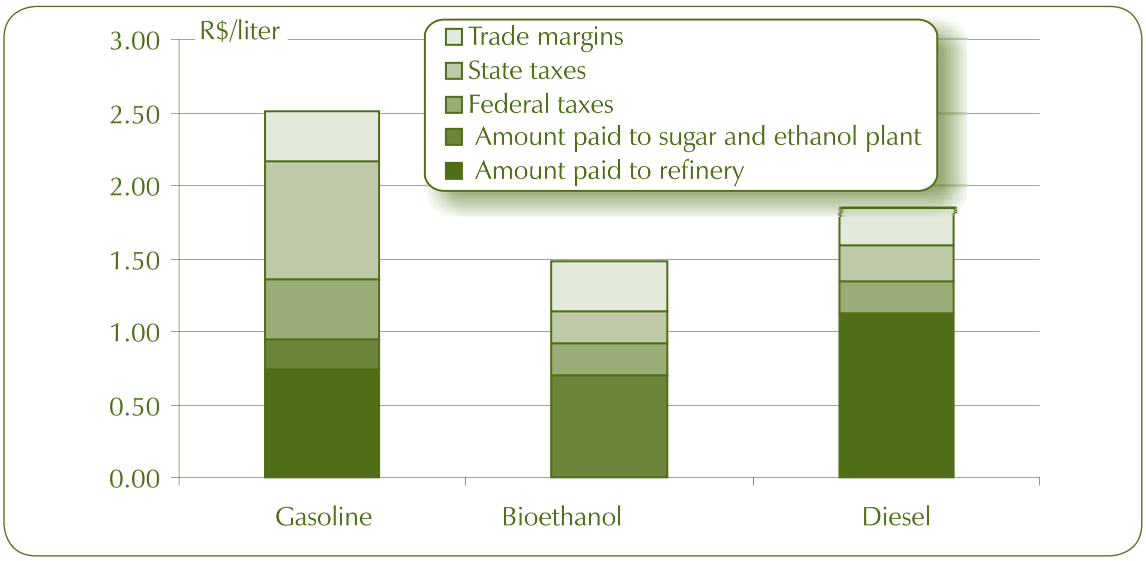


Source: Data from CEPEA (2008) and EIA (2008).

Although the adoption of the US dollar enables USA and Brazil prices to be compared, this should be done with caution taking into account the significant depreciation of the US dollar starting in 2005. The US dollar lost close to 30% of its value in two years leading to overestimate the value of Brazilian bioethanol. Regardless, these graphs show that in recent years, sugarcane bioethanol has brought consistently better prices than gasoline at the producer level, without including taxes or subsidies. In sum, under these conditions, the addition of anhydrous bioethanol leads to lower average market fuel prices.

In Brazil, federal and state taxes differentiate between different types of vehicle fuels, depending on the economic implications and typical applications of each; diesel oil and biofuels receive preferential treatment. Hence, higher taxes are levied on gasoline in comparison with hydrated bioethanol, natural gas, or diesel oil. Although there is a reasonable amount of variation in state tax rates (ICMS - Service and Goods Tax), the taxes, freight and sales margins that are levied on manufacturer prices for gasoline, hydrated bioethanol and diesel increase prices by 239%, 112% and 63%, respectively. These reference values reflect the situation in Rio de Janeiro, March 2008 and can be seen in Graph 31. Note that in the graph, the amount paid to the gasoline producer refers to a volume of 0.75 liter, since the product as delivered to the consumer contains 25% anhydrous ethanol.

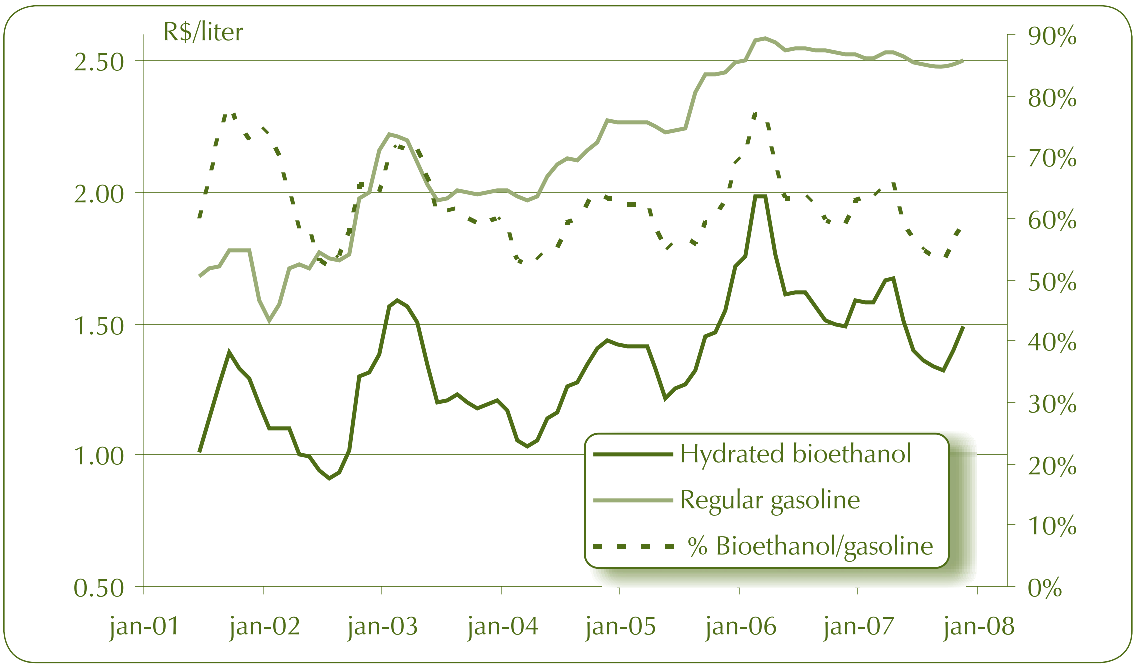
***Graph 31* – Price structure of regular gasoline, hydrated bioethanol and diesel oil (Rio de Janeiro, March 2008)**



Source: Values based figures from on ANP (2007), CEPEA (2008) and Petrobras (2008).

Another way to assess the relative attractiveness of bioethanol vis-à-vis conventional fuels is to compare the average consumer sale prices of hydrated bioethanol and regular gasoline. In this case, surveys of fuel prices can be used. These are made available on regular basis by the *Agência Nacional do Petróleo, Gás Natural e Biocombustíveis* – ANP (The National Agency for Petroleum, Natural Gas and Biofuels), using a broad sample covering the whole of Brazil [ANP (2007)]. Examining the series of prices, it can be seen that hydrated bioethanol is competitively priced with gasoline, in terms of cost per kilometer traveled. This is due to the lower manufacturer price, as well as the more favorable tariff structure (as noted in the previous paragraph). In the case of flexible fuel vehicles, where the user selects the fuel at the time the tank is filled, bioethanol is usually chosen when priced at up to 70% of the price of gasoline. In this respect, it can be seen that in the majority of recent years, choosing bioethanol over gasoline has made sense, except for some short periods lasting a few weeks as shown in Graph 32. The graph also shows a regular pattern of price variation, rising at the end of the harvest and falling at the beginning, around the middle of the first semester.

Graph 32 – **Evolution of average consumer prices for hydrated bioethanol and regular gasoline in Brazil and the relationship between them**



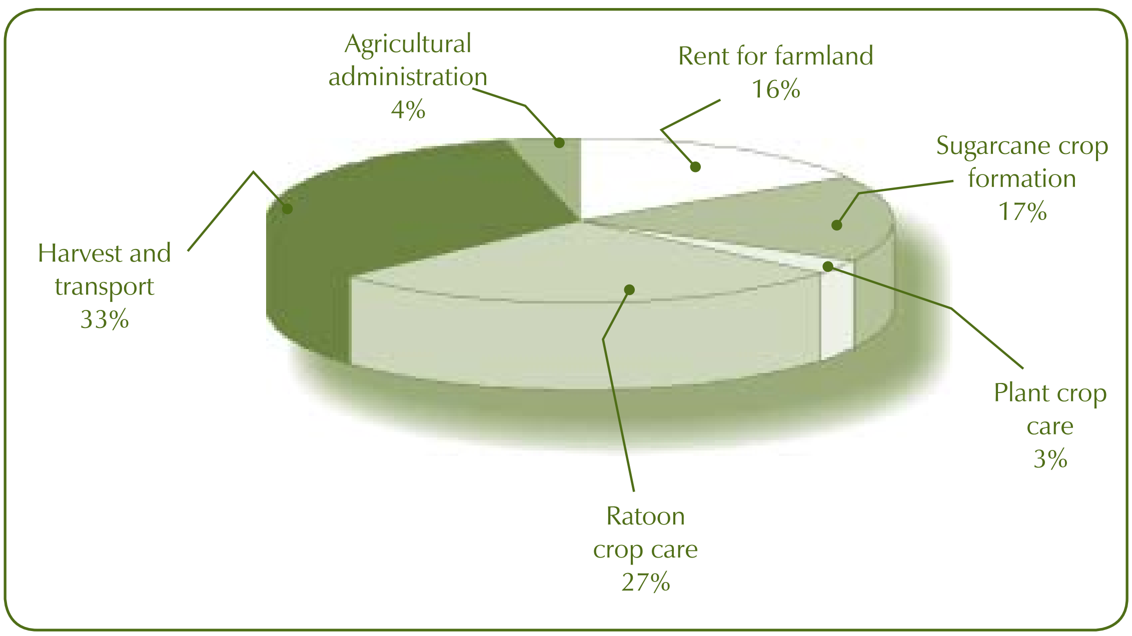
Source: Based on ANP (2007).

The previous data refer to prices as actually practiced in fuel markets, thus clearly demonstrating the competitiveness of bioethanol for consumers. It is equally interesting, however, to assess the production costs of this biofuel to see if producers are being adequately compensated. For many years, the Brazilian Federal Government audited sugar-and alcohol costs and set prices throughout the chain, from production to sale. However, as of the 1998 harvest, government controls of this agroindustry were eased, a process which finished in 2002, as described in Chapter 6. Currently, economic agents set prices independently, based on marketing strategies, and taking into account stocks and future prospects for the sugar and fuel markets. In this competitive environment estimating costs is often complex. Besides the variety of scenarios, with different yields and different technologies being used, bioethanol's main cost component is raw material: this may be produced by the processing company itself, on rented land, or grown by independent producers. The difficulty of knowing production costs is not just confined to the bioethanol market: detailed production costs for oil and natural gas are also seldom available.

In a study carried out by NIPE/Unicamp, an average sugarcane cost of R$ 33.16 per ton (ex-works) was estimated for the Central-South region in 2005. The breakdown is shown in Graph 33 [CGEE (2005)]. In this same study, a per-ton cost of R$ 24.59 in Goiás is estimated for sugarcane, mostly due to lower land costs.

The *Associação Rural dos Fornecedores e Plantadores de Cana da Média Sorocabana* – ASSOCANA (Média Sorocabana Rural Association of Sugarcane Producers and Suppliers) has made a more recent assessment of sugarcane production costs, assuming a cycle of five cuts in six years and including plantation implementation activities, soil preparation, planting, harvest and transport, and taking into account all production factors (ie, inputs, equipment, land, labor) [ASSOCANA (2008)]. For April 2008, this study estimated an average cost of R$ 2,513.50 per hectare, for each cut, resulting in an average sugarcane cost of R$ 35.00 per-ton. Assuming a raw material cost of between R$ 26.00 and R$ 35.00, an exchange rate of R$ 2.00 = US$ 1.00 and an industrial yield of 85 liters of bioethanol per processed sugarcane ton, the raw material share of the cost of bioethanol equals US$ 0.153 to US$ 0.206 per liter. These values seem to represent the current average costs of the Brazilian Central-South region and are substantially higher than the US$ 0.12 per liter often cited as the raw material share of the cost of bioethanol at the end of the 1990s. Note that this price has been greatly affected in recent years by increased costs, including equipment, fertilizers and agrochemicals. From the perspective of the alternative applications for this raw material, the per-ton cost of sugarcane will naturally depends on the price of sugar, which rose to US$ 0.27 per liter of bioethanol equivalent in the middle of last year.

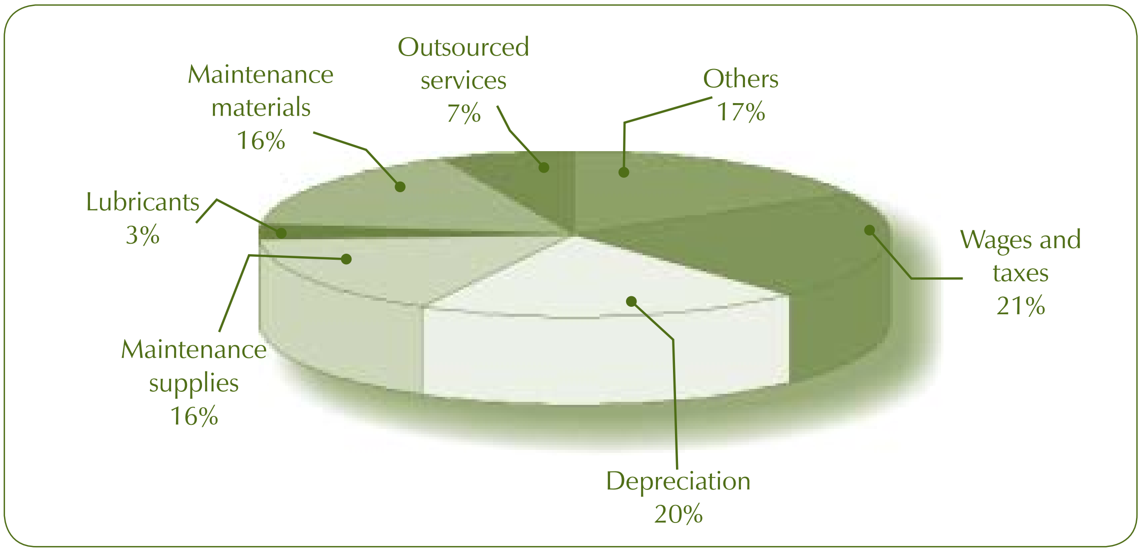
***Graph 33* – Structure of sugarcane production costs in Brazil's Center-South in 2005**



Source: CGEE (2005).

Costs related to the plant investment, to the operation and maintenance of the sugarcane processing unit and the production of bioethanol have also increased considerably in recent years, in particular because of increases in the prices of equipment and materials. The study developed by NIPE/Unicamp estimated that a plant with an annual processing capacity of two million tons of sugarcane could cost around US$ 97 million (corresponding to capital costs of US$ 0.13 per liter estimated at an internal rate of return of 12%, a ratio debt/capital of 50%, with an 8% interest rate and production of 40 kWh of surplus electrical power per ton of processed sugarcane marketed at US$ 57 per MWh. For this unit, operation and maintenance costs (including depreciation) were estimated at US$ 0.07 per liter of bioethanol produced, with the breakdown shown in Graph 34 [CGEE (2005) and Almeida et al. (2007)].

***Graph 34* – Breakdown of operation and maintenance costs for an independent sugarcane bioethanol production distillery in the Central-South in 2005**



Source: CGEE (2005).

Therefore, considering all the factors – inputs, operation, maintenance and investments – the cost of sugarcane bioethanol is somewhere between US$ 0.353 and US$ 0.406 per liter, amounts which correspond to oil at US$ 50 to US$ 57 per equivalent barrel.

It is likely that bioethanol costs are lower for plants being established in new production frontiers, bearing in mind the location of these plants, which have greater sugarcane crop density (lower transport costs) and the fact that they are dedicated to biofuel production, which reduces input costs and investments. On the other hand, the older and fully amortized plants of bioethanol should have lower financial costs, the same way that higher levels of electrical power production based on bagasse tend to improve the indicators of this agroindustry. Another important exception refers to the impact of the adopted exchange rate, because the sharp appreciation of Brazilian currency in recent years has considerably increased the value of sugar-alcohol agroindustrial products in terms of foreign exchange.

Considering the possibilities of continuity in the incremental process of agricultural and industrial productivity previously presented, it is reasonable to expect that the costs of sugarcane bioethanol production will remain stable or somewhat lower in relative terms, while the expected scenarios of fossil fuels maintain high price levels with no prospects of a decline to the price levels of a few decades ago [IEA (2007)]. Therefore, from an economic point of view, the production of sugarcane bioethanol appears to be sustainable, with essentially viable prices and costs, without the need for subsidies to compete with conventional fuels.

7.4 Job and income generation in the bioethanol agroindustry

The important relationship between the production of sugarcane bioethanol and the demand for labor is a central bioenergy topic in Brazil and certainly a determinant for its social viability. The sugarcane agroindustry is a major job generator: based on the *Relação Anual de Informações Sociais* - RAIS (Social Information Annual Report), from the Ministry of Labor and Employment and the *Pesquisa Nacional por Amostragem de Domicílios* - PNAD (National Household Survey), carried out periodically by IBGE, it is estimated that in 2005 there were 982 thousand workers directly and formally engaged in sugar-alcohol production [Moraes (2005)]. According to a 1997 study based on the Input-Output Matrix of the Brazilian economy, there are 1.43 indirect jobs and 2.75 induced jobs for each direct employee in this sector [Guilhoto (2001)].This allows an estimate for 2005 of a total of 4.1 million working people dependent on the sugarcane agroindustry, if these relationships have been maintained. These jobs are widely distributed throughout a large part of the Brazilian territory and include a range of competencies and training; however, most of them are low qualification jobs.

With the evolution of the technologies employed, less growth can be observed in labor demand, along with higher required qualifications and an increase in quality of the work performed. This dynamic has been the driving force for many studies in the realm of rural economics and sociology, which provide a comprehensive view of the processes in progress and their implications. In the next paragraphs, issues related to the generation of jobs and income within the scope of bioethanol production will be covered. First, information about the levels of employment and their recent evolution will be reviewed and then their perspectives discussed, especially those associated with the expansion of mechanization in sugarcane harvesting.

From the total number of direct and formal jobs in the sugar-alcohol agroindustry (which has expanded significantly in recent years, as Table 33 shows) 63% are in the Center-South, where more than 85% of Brazilian sugarcane is produced. This is evidence of higher labor productivity in this region. On the other hand, the number of workers per production unit in the Northeast is three to four times greater than the numbers observed in the Center-South region [Macedo (2005a)]. Indeed, relating all the sugarcane production data [Mapa (2007)] to the number of employees in the sector [Moraes (2007)] reveals the productivity per worker indicated in Graph 35. According to this graph, the significant gain in productivity in agro-industry in the Center-South region is evident, with levels of over 500 tons of sugarcane per worker; however, no change in the numbers for the Northeast is observed.

***Table 33* – Direct formal jobs per activity and region in the sugar-alcohol sector**

Activity	Region	Year			
		2000	2002	2004	2005
Sugarcane production	North Northeast	81,191	86,329	104,820	100,494
	Central-South	275,795	281,291	283,820	314,174
	Brazil	356,986	367,620	388,121	414,668
Sugar production	North Northeast	143,303	174,934	211,864	232,120
	Central-South	74,421	126,939	193,626	207,453
	Brazil	217,724	301,873	405,490	439,573
Bioethanol production	North Northeast	25,730	28,244	26,342	31,829
	Central-South	42,408	66,856	80,815	96,534
	Brazil	68,138	95,100	107,157	128,363
All	Brazil	642,848	764,593	900,768	982,604

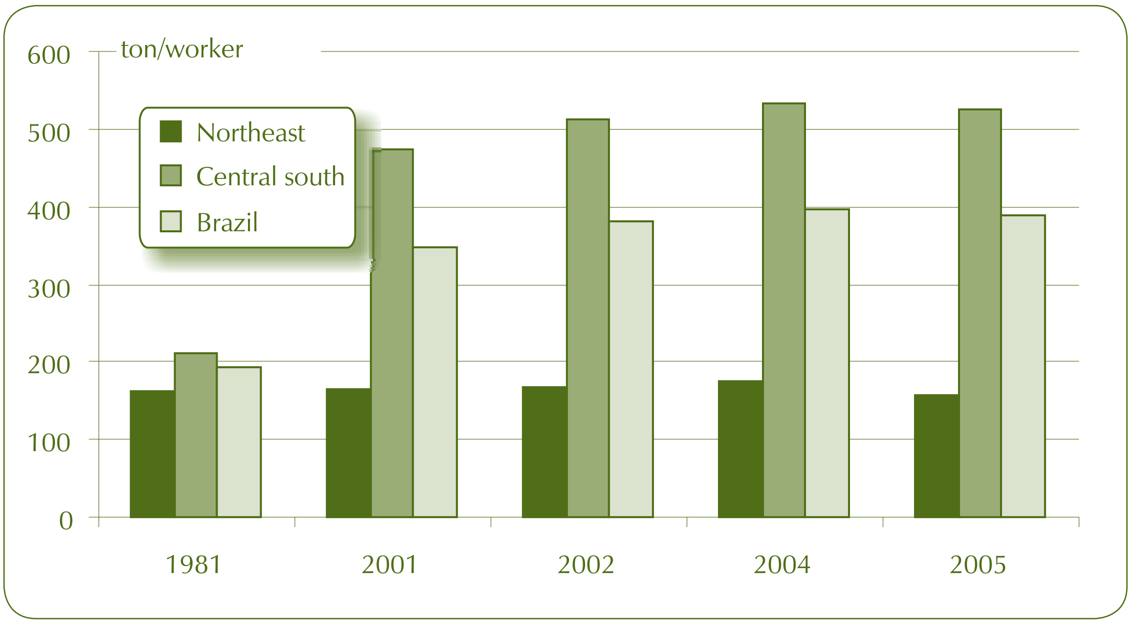
Source: Moraes (2005).

Sugarcane planting, pest control and harvesting in particular represent the greatest demand for temporary personnel in a sugar and bioethanol plant, corresponding to approximately 70% of hired labor, with different levels of employment for harvest and non-harvest periods. For a modern agroindustrial unit, which processes two million tons of sugarcane annually, nearly 2,500 workers are needed, a number that can vary considerably depending on the technological and mechanization levels of the plant [Macedo (2005a)]. In the study carried out by NIPE/Unicamp on groups of 15 bioethanol production plants with a milling capacity of two million tons of sugarcane each, a total generation of 22 thousand jobs was estimated. [CGEE (2005)].

The relationship between levels of employment at harvest and non-harvest time is called the seasonal factor and makes it possible to determine how variable personnel demand is throughout the year. The seasonality of jobs in the sugarcane agroindustry has been decreasing as a consequence of extending harvests and higher levels of mechanization. The numbers in São Paulo dropped from 2.2 in 1980 to 1.8 at the end of the 1980s, and fell to 1.3 in the mid 1990s [Macedo (2005a)]. For reference, the seasonal factor of rice is 7, beans between

3 and 4.5, oranges 7.8, soybean between 3.5 and 12 and cotton is as high as 40, evidence that employment associated with these crops over time is much more seasonal than that of sugarcane [Leite (1990)].

***Graph 35* – Average productivity of sugarcane agroindustry workers in Brazil**



Source: Moraes (2005).

In addition to the number of jobs offered, the quality of these jobs is equally important. In this regard, it is interesting to review the work of Balsadi (2007) on the evolution of job quality in Brazilian agriculture between 2001 and 2004 for main crops and different types of job relationships. Based on detailed PNAD data, the educational level of employees, degree of job formality, income received for the main job and benefits received by employees were adopted as variables to define quantitative indices and establish an objective evaluation of job quality. The conclusions of the study indicate significant improvements in various socio-economic indicators for sugarcane farming workers in Brazil in recent years:

– an increase in job formality, with a high percentage of workers with labor ID cards (allowing access to retirement benefits and other rights, such as paid overtime and medical care), which makes sugarcane production one of the activities with the highest level of job formality in the rural environment;

– real gains in salary between 1992 and 2005, 34.5% for permanent employees with urban residence, 17.6% for permanent rural employees and 47.6% for temporary rural employees;

– increase and diversification of benefits received by workers, such as transportation and meal vouchers in all categories as well as housing benefits for rural residents and health benefits for permanent employees with urban residence.

Other positive facts pointed out in the study are the significant reduction in child labor (only 0.9% in 2004, compared with Pernambuco, 1993, when 25% of sugarcane cutters were between the ages of 7 and 17) and the increase in employees' schooling. Other researchers have revealed similar conclusions, strengthening the role of worker organizations, collective labor agreements and labor legislation as important components in achieving these improvements, especially in the Center-South region where the average schooling level of workers in sugarcane production and the bioethanol industry, in 2005, was over five and nine years, respectively. For the same conditions, in 2005 the average salaries were US$ 280.00 and US$ 509.00, respectively, for sugarcane and bioethanol production [Moraes (2007)].

In spite of the improvements achieved, there are still adverse situations, especially for temporary employees hired for manual sugarcane harvesting, where working conditions are much more arduous than in industry and payment is based on the amount of sugarcane cut. This system has been questioned because it causes extreme wear and tear on the sugarcane cutters [Alves (2006)]. Nonetheless, this is a controversial issue. There is no consensus about putting an end to piecework among the unions and there is a portion of workers in favor of keeping it. As a representative of the plants, Unica has been opposed to ending this method of compensation, although it stresses that it is seeking, along with the plants, to guarantee full compliance with current norms and is aiming for fair payment to the cutters as set forth in collective labor agreements [Moraes (2007)].

In this context of greater valorization of workers, the sugarcane agroindustry is undergoing an important transition. This transition is a consequence of the gains in agroindustrial productivity associated with mechanical, physicochemical and biological innovations, which make it possible to expand production by maintaining the demand for inputs and resources. Among these innovations, the growing mechanization of harvesting stands out, arising from the need to progressively eliminate straw burning during the coming years and reduce harvesting costs, among other issues. It is estimated that for the 2006/2007 crop, mechanized harvesting covered 40% of sugarcane crops in the Center-South, in a growing trend where more than 400 harvesting machines are sold every year, each of them doing the work of 80 to 100 sugarcane cutters [CGEE (2007)]. Sooner or later, this sugarcane production model will be replicated in other Brazilian regions, with obvious impact on employment levels. In the period from 2000-2005 the number of jobs grew 18%, vs. an increase of 28.8% in sugarcane production. It is estimated that by 2020 the manual cutting of sugarcane in São Paulo will be practically non-existent. It is also anticipated that between 2006 and 2020, the number of employees in the sugarcane agroindustry in that state will be reduced from 260 thousand to 146 thousand workers, even with an increase of 20 thousand employees in manufacturing [Moraes (2007)].

To face these new times, two lines of action directly related to the workers can be undertaken: first, offering and supporting alternative economic activities for potentially unemployed workers in their places of origin; and second, strengthening the preparation of human workers for the agroindustry. These are not trivial tasks: they must be treated as a priority. The raising of training requirements of personnel by the Brazilian plants in all their areas and on the various levels of responsibility has already motivated a great effort to meet this growing demand for specialized labor, especially through high school and college level courses focusing specifically on sugarcane and bioethanol production. A third possibility would be to adopt intermediary technologies such as the *Unidade Móvel de Auxílio à Colheita* - UNIMAC (Harvest Assistance Mobile Unit), which substitutes labor only partially, offering more security and comfort to workers in cutting raw sugarcane and in straw retrieval [Alves F. (2007)].

It is worth noting here that even with significant reductions in the demand for labor, sugarcane bioethanol production will continue to be labor intensive. Under current conditions, the production of bioethanol per unit of energy produced, compared with mineral carbon, hydroelectricity and oil, requires, respectively, 38, 50 and 152 times more human labor [Goldemberg (2002)]. As an interesting variation on the same theme, Leal (2005) shows that while each vehicle fueled with petroleum products requires one person-year of work to meet its consumption, the introduction of 24% bioethanol as a gasoline additive increases the demand for personnel to six person-year. If pure hydrated bioethanol is used, this same vehicle will need 22 workers to produce its biofuel.

The creation of job opportunities and the possibility of their distribution among workers with value added in the production chain are two of the most important characteristics of bioenergy, and in particular of sugarcane bioethanol, constituting a significant difference between this energy technology and similar technologies. Even with the adoption of technologies with high productivity and less impact on the demand for labor, bioethanol production continues to be a major generator of jobs of increasingly better quality and with a corresponding rise in qualification requirements and average remuneration. Additionally, it is important to recognize the important role of the agroindustrial activity as a generator of income and a stimulus to local and regional economic activities, with significant indirect benefits. In no way should exhausting and low-productivity activities be considered as inherent to bioenergy. The progressive reduction of manual sugarcane harvesting should be viewed as a desirable advance leading to greater sustainability in this agroindustry.

Sugarcane ethanol and the issue of land property

One issue correlated with the role of bioethanol in generating jobs and income in the rural milieu is the concentration of property associated with the expansion of production. Generally speaking, this topic has possibly become a part of one of the major challenges to the harmonious development of the Brazilian economy: making social demands compatible through access to land with the implementation of an efficient and competitive productive base in the rural milieu. In the case of the sugar-alcohol industry this question is all the more significant, because of the extent of occupied areas and because of the level of existing vertical integration, in spite of the existence of thousands of sugarcane suppliers and tenants. Indeed, sugarcane and bioethanol production show significant economies of scale, which increase with the progressive adoption of technologies of greater productivity and the corresponding dilution of fixed costs per greater product volume. Under these conditions, in the larger capacity units, a sharp cost reduction can be observed, justifying the gradual concentration of properties within the scope of agrarian legislation.

This trend is aggravated because of the low attractiveness of a large number of farming activities and the economic deprivation of some regions where sugarcane cultivation becomes one of the few viable alternatives, compared with traditional crops. As with other issues mentioned previously, it is incumbent on the state to stimulate not only bioenergy production, but also the production of other agricultural goods in order to preserve economic efficiency and small rural entrepreneurs. There does not seem to be an inescapable conflict here, especially considering the wide availability of lands and the perspectives of the agricultural markets, including innovative cultivation and breeding alternatives that allow more value added per product unit than bioenergy production.

Nevertheless, in order to preserve small scale agriculture and its agricultural production model it has been suggested that biofuel production be stimulated in a decentralized manner with scales that allow for the entry of the small-scale farmer as biofuel producers, associated with the implementation of agroecological practices and the eventual reduction of displacement between production areas and consumer centers. The viability of these possibilities has not yet been demonstrated, since they assume productive models that are quite different from those currently practiced. Given the reduced experience with micro and mini bioethanol distilleries (which produce one thousand and five thousand liters per day, respectively), their promotion requires an innovative vision of sugarcane-based bioethanol production technologies. To this end, an important point is the need to link bioethanol production with other agricultural and livestock raising activities that allow to compensate for the low productivity inherent to these units, characterized by simplified extraction, fermentation and distillation systems that produce 40 liters of bioethanol per ton of processed sugarcane, around half the amount observed in larger plants [Horta Nogueira (2006b)]. One possibility to be explored to improve this scenario would be to associate bioethanol production with cattle raising, which could make use of the bagasse from the harvest as forage. In any case, as efficient systems go, sugarcane bioethanol production has been proven more adequate, thus far, on an industrial scale. Possibly, production cooperatives associated with conventional plants are a more stable alternative than the small production units.

Also, concerning economic concentration and its implications, it should be noted that the bioethanol industry, as practiced in Brazil, could be considered relatively concentrative compared with some other agricultural activities. However, when compared with energy related activities (as it is classified), it is characterized as a highly decentralized industry with thousands of suppliers and the most important industrial groups not managing to control 10% of total production capacity. Indeed, decentralization is an inherent characteristic of bioenergy, which needs large spaces to capture solar energy.

Induced effects in other sectors of the economy

The extensive connection of the bioethanol agroindustry with other economic sectors and the upstream and downstream linkages of sugarcane production and processing, allow a distribution of the benefits generated in this sector in a very interesting way. A survey for this end, using an extended model of input-output matrices, shows how the entire national economy tends to expand with the growth of bioethanol production [CGEE (2005)]. Besides the sugarcane and ethanol production sectors and computing indirect and induced effects, the sectors more impacted are other farming activities, the chemical sector (including fertilizer), and the petroleum refining, commerce, logistics and real estate rental sectors.

***Table 34* – Direct, indirect and induced impacts of processing one million tons of sugarcane for alcohol production**

Sector	Production value (R$ million)	Value added (R$ million)	Employment
Sugarcane	44.5	20.8	1,467
Farming: other	14.3	8.1	697
Sugar	8.0	2.7	31
Alcohol	97.8	38.9	211
Electricity	6.8	7.3	37
Mineral extraction	0.3	0.2	4
Steelwork, mining and metallurgy	7.1	2.1	48
Machines, vehicles and parts	9.3	4.2	51
Oil and Gas	29.5	12.1	12
Chemical sector	13.9	4.7	41
Food	15.4	3.1	93
Civil construction	1.3	0.8	23
Transformation: other	16.8	5.7	287
Trade and Services	81.3	53.0	2,679
Families	–	7.3	–
Total	346.3	171.0	5,683

Source: Scaramucci and Cunha (2008).

Using an adjusted matrix for 2002 and assuming the results obtained are typical, it has been estimated in this study that, for each million cubic meters of bioethanol production capacity installed, R$ 119 million per year would be added because of investments. During the operation, nearly R$ 1.46 billion should also be generated annually, computing direct, indirect and induced effects [CGEE (2005)]. In an extension of this study, for conditions observed in the Brazilian Center-South, it was estimated that the processing of a million tons of sugarcane for the production of bioethanol corresponds to an increase of R$ 171 million in economic production and the generation of 5,683 jobs, considering analogically the direct, indirect and induced effects, separated as shown in Table 34.

7.5 Certification and sustainability in the bioethanol agroindustry

Certification systems have been proposed as one of the ways for ensuring observance of sustainability criteria in bioethanol and biodiesel production, mainly by industrialized countries, to ensure explicitly that biofuels are produced in a sustainable manner and consequently may be used to meet environmental goals.

The establishment of widely accepted sustainability criteria and standards must face the inherent complexity of bioenergy systems with their range of raw materials and production technologies and contexts as a basic difficulty. It should also be noted that the certification systems for biofuels, on a voluntary or mandatory basis, do not yet have an international legal framework for their support. Nevertheless these systems could be used within the scope of climate change mitigation commitments, biodiversity protection and trade agreements.

Certification is typically a requirement that consumers impose upon producers. Thus, the concept of certification demands an objective and careful treatment of the aspects of sustainability, and their implementation necessarily implies the existence of independent monitoring agents who ensure the required balance and impartiality. A risk that should not be ruled out is that poorly designed certification systems could serve as additional trade barriers and act as protectionist measures, restricting the development of truly sustainable alternatives in favor of inefficient bioenergies. Another concern, regarding producers, is the cost of certification systems, which could make small-scale production unviable.

The main efforts currently in progress for evaluating and eventually certifying the sustainability of biofuels include the following initiatives (GBEP, 2007):

- In January 2007, the European Commission established as a goal (non-mandatory) the introduction of 10% biofuel (ethanol and biodiesel) in fuels used for transportation in each member country by 2020, with an assessment system of sustainability, currently in development, being adopted.

- Associated with the requirement of 5% renewable fuel in all automotive fuel sold in the United Kingdom in 2010, as defined in the Renewable Transport Fuel Obligation (RTFO), biofuel producers must report the balance of greenhouse effect gases and the environmental impact of their products (House of Commons, 2008).

- In Holland, the development of bioenergy sustainability criteria began in 2006, with activities in progress to both test these criteria in pilot projects and define monitoring and certification systems. An extensive exercise of possible indicators has presented a favorable assessment of the bioethanol produced in Brazil, especially in the state of São Paulo [Smeets et al. (2006)].

- In Germany, legislation to support biofuels has been recently revised, including compulsory requirements to meet sustainability criteria, based on raw materials used, natural habitat protection and the reduction of greenhouse gas emissions.

- Within the scope of the United Nations Environment Programme (UNEP), there is a definition of sustainability criteria for biofuels under discussion, with suggestions that concrete goals and instruments be adopted for their implementation. To this end, UNEP has been working in close collaboration with governmental institutions, private entities and representatives of civil society, including the Global Bioenergy Partnership and the Roundtable on Sustainable Biofuels [UNEP (2008)].

- The Food and Agriculture Organization of the United Nations (FAO) is developing the Bioenergy and Food Security project to establish an analytical framework to evaluate impacts on food supply that could be attributed to the expansion of bioenergy production, taking into consideration systems based on food-related raw materials and the so-called second generation bioenergy systems [BFS/FAO (2008)].

- FAO and the United Nations Industrial Development Organization (UNIDO) are preparing a project for the Global Environment Facility – GEF to orient countries with respect to environmental and socioeconomic conditions for the sustainable production, conversion and use of biofuels.

- The Roundtable on Sustainable Biofuels – RSB, led by the Energy Center of the Federal Polytechnic School of Lausanne, in Switzerland, is an international initiative involving farmers, companies, non-governmental organizations, specialists, and international and government agencies interested in guaranteeing the sustainability of biofuel production and conversion. To this end, it has been holding a series of meetings, teleconferences and debates, seeking to arrive at a consensus concerning the principles and criteria for the production of sustainable biofuels. The principles considered for evaluating sustainability in the production of biofuels are available for analysis [Frie et al. (2006) and EPFL (2008)].

– The international work group IEA Task 40, within the scope of the International Energy Agency Bioenergy Agreement, develops activities focused on the international trade of biomass and bioenergy, especially their implications and perspectives. The group focuses in the development of certification, standardization and terminology systems to promote the international trade of bioenergy products on a sustainable basis, providing analysis and important information about efforts underway in this field [IEA Bioenergy (2008)].

– The governments of Brazil, the United States and the European Union (the main worldwide producers of biofuels and members of the International Biofuels Forum – IBF) published the "White Book of Specifications of Internationally Compatible Biofuels" in February 2008, with an analysis of current specifications conducted by an international group of specialists for the purpose of facilitating trade expansion of products. Initial efforts are to develop procedures, systems and reference materials for bioethanol and biodiesel quality tests, and even to make it possible, through analytical methods, to determine if a fuel comes from renewable sources [NIST (2008)].

The private sector in the fuel area, especially in Europe, considers sustainability an important factor in the development of bioenergy, and some companies are developing their own procedures to assure the acquisition of sustainable products. However, most companies interested in buying and selling sustainable biofuels are seeking to be involved in these processes with a more plural participation and to be seen as more legitimate by consumers. For example, BP, DuPont, Petrobras and other major companies participate in the Roundtable on Sustainable Biofuels (RSB). In the arena of other agricultural-related products, analogous systems for certifying aspects of sustainability have also been implemented, such as for wood, soy and palm oil.

As a final initiative to mention, which is aimed at ensuring standards of sustainability in bioethanol production, the Agro-Environmental Protocol, signed in 2006 by the São Paulo State Government, has implemented the Green Bioethanol Program to encourage best practices in the sugar-alcohol sector through compliance certification and to determine a positive standard to be followed by producers. In a phase of large-scale operation and application throughout the state, the instrument covers some of the main points for reducing the impacts of cultivation, such as the anticipation of deadlines for eliminating the burning of sugarcane straw, protection of springs and forest vestiges, control of erosion and adequate management of agrochemical packaging [Lucon (2008)].

Systems of sustainability certification having the characteristics described in this section, if adequately designed and well implemented, may serve as effective instruments for biofuel production to develop in a framework of rationality, since it has already been demonstrated that sugarcane bioethanol is competitive.