Chapter 2: Impacts on the use of materials

Agriculture takes sunlight as its basic input and may lead to sustainable production of materials. The low production costs in the cane culture in Brazil and the availability of bagasse as an energy source make sucrose very attractive to dozens of other products; some amino acids, organic acids, sorbitol and yeast extracts are already being produced. Developments in plastics and other large scale products (including ethanol derivatives) are being considered.

2.1 Introduction

Sustainability in the use of materials and resources should be evaluated as to the level of those resources (what the resource utilization rate is relatively to the stocks) and the level of waste released to the environment. Both levels have grown significantly in some regions, and in an "unsustainable" way in many cases. In 1992, each person in the United States was responsible for the extraction and use of 50 kg of materials a day; that amount increased by 10 percent up to 2002.[1] On the other hand, the environmental impacts of the consumption of resources have grown around 15 percent in that period. The figures differ in other regions of the world, but it is clear that the governmental policies have not been appropriate to reverse the trends. It has been proposed that taxes should gradually move from labor and income to materials and energy (as in Norway and Sweden), and that any subsidies which contribute aggravating environmental problems should be eliminated. The actions (and implications) are very different from one country to another, and even regionally within the same country, which hinders a fast implementation; but the necessary direction is clear.

Agriculture has a very interesting characteristic in terms of sustainability: a major input is sunlight energy (renewable). If the use of water and consumables (pesticides, fertilizers, fuels) can be limited, then agriculture is a source of "renewable" materials. This has been attained by some but not all production systems. In adequate systems, the use of materials (fertilizers, pesticides, fuels) may be relatively small when the energy production (which already occurs) or the potential production of a wide range of materials (such as sugar cane) is taken into consideration.

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

Over the past fifteen years, environmental concerns have led to the use of biological products as substitutes for petrochemicals to be considered "environmentally sound and desirable". Several mechanisms have been used to foster new energy technologies. Practically all of them originally sought feasibility through direct subsidies. That occurred with PURPA – Public Utilities Regulatory Policy Act for decentralized generation of electrical power from biomass in the United States, the sugar cane ethanol in Brazil, the corn ethanol in the United States as well, biodiesel programs in the US and Europe, etc. Generally, the main concern was energy production indeed (due to the need of oil substitution), but the possibilities to produce renewable materials began to be explored.

Under an exceptionally successful program, it was possible to remove the initial subsidies to sugar cane ethanol, in Brazil, on the back of the industry's technological and managerial evolution. That program brought along a very interesting non-energy component in the field of products of biological origin, replacing petrochemicals: alcohol chemistry, in the 1980's in Brazil.

A fast-growing bio-products program is based on corn starch glucose in the US. Supported by interesting technological breakthroughs, several products have been introduced in different markets over the past ten years. Genetic engineering technologies should bring more results over the next few years.[2]

Sugar cane sucrose is a natural candidate to become a main raw material in many processes. This is beginning to happen in Brazil.

2 NREL, USA, "Fostering the bioeconomic revolution in biobased products and biotechnology", Biomass Research and Development Board, Interagency Strategic Planning; January 2001

2.2 Sugar cane fiber and sucrose

Between 1998 and 2002, the mean sugar and fiber contents of sugar cane residue (Center-South) were 14.53 sucrose % of sugar cane and 13.46 fiber % of sugar cane. Around 80 percent of the sugar cane were burned (Brazil) before the harvest, thereby eliminating the trash. The total production amounted to 380 Mt of sugar cane (2004), which refers to the sugar cane stalk mass (without the trash).

For each ton of sugar cane stalk (sugar cane ton), the biomass generated is (see **item 1.4.1**) 0.28 t (DM) of bagasse and trash, and 0.145 t (DM) of sucrose. Therefore, the amount of materials produced is very big even when compared to the petrochemical context, for example; about 55 Mt of sucrose, and 100 Mt (MS) of lignocellulosic residue.

Works conducted in Brazil seeking to develop trash collection/transportation technology, including an assessment of its actual availability, have concluded that 50 percent of the trash can be recovered at costs of US$ 0.6-1.0 / GJ, depending on the process.[3] The legislation that gradually restricts the pre-harvest burning should play a positive role in causing the residue to be incorporated into the energy generation system over the next few years. On the other hand, commercially available technologies may (probably) lead to consumption decreases in mill processes, resulting in excess bagasse of up to 45%.

3 Reports of the project "Biomass power generation: sugar cane bagasse and trash", UNDP-GEF / Copersucar, Centro de Tecnologia Canavieira, 2003

This surplus amount of bagasse and straw are important in the energy context. Their use in energy production (with competition between electrical power and ethanol production by hydrolysis) can be expected to be implemented on large scale over the next few years. The costs of those residues are lower in Brazil (today and in the foreseeable future) than overall energy biomass costs in many other countries.

The possibilities offered by new sucrose products are much greater than those currently implemented.

2.3 Sucrose as a raw material for other products

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Sucrose is a very versatile raw material, being a very reactive molecule from the chemical and enzymatic standpoints. With its eight hydroxyl groups, it may act as a base for several "blocks" to build molecules of interest. Additionally, it is produced in more than 80 countries around the world abundantly (nearly 200 million tons a year) and at a high purity degree. Its production cost is relatively low, especially in Brazil (see **Chapter 11**). There are additional advantages: sucrose products may have lower environmental impacts than petrochemicals (as in the biodegradability of some plastics, and the renewability of the energy used in the processes, particularly in the use of sugar cane sucrose).

In the early 1990's around 60 products obtained from direct sugar fermentation could already be listed, some with several natural producing microorganisms. In many cases, secondary products were developed from those primary products by fermentation or enzyme catalysis. Of all those products, a much smaller number are now commercially important, but several have been added to the list over the past ten years,[4] and research in this field is intensive.

4 Godshall, M.A.: "Future directions for the sugar industry", SPRI, Int. Sugar Journal, vol. 103, no. 1233, 2001

Such growing diversification of sucrose applications to produce intermediate and end products (besides ethanol and sugar) is mainly motivated by the low sugar production costs that Brazil has attained. We can consider the production cost of raw crystal sugar from Brazil's Center-South region in 2002 at US$ 0.13 / kg (with sucrose in the juice corresponding to US$ 0.08 / kg, and in the HTM to US$ 0.11 / kg; US$ 1 = R$ 2.7, 2002). In comparison, the corn glucose costs would be US$ 0.13 / kg, beet sucrose or wheat hydrolysate (Germany) at ~0.19 and 0.17 in the juice.[5] There have been cost increases due to higher land costs (with the large expansion since 2005), and labor costs; and for export considerations, the strong appreciation of the Real against the US$ is also important. The production of sugar cane sucrose derivatives can also be totally supplied with energy independently (through the bagasse), as is ethanol today.

5 Based on Henniges, O.; Zeddies, J.: "Fuel ethanol production in the USA and Germany – a cost comparison", F. O. Licht's World Ethanol and Biofuels Report, vol. 1, no. 11. Feb 11 2003

Prospecting works with respect to commercially available products or products at a relatively advanced development stage are under way in several product categories. Sucrose has some exclusive applications, and can substitute for glucose in almost all fermentation cases of interest. The main categories are: sweeteners, polyols, solvents, biodegradable plastics, amino acids and vitamins, polysaccharides, organic acids, enzymes, yeasts, and esters. Some may include products that would use large amounts of sugar (plastics, solvents, some organic acids), while others would correspond high value-added products for smaller amounts.

The "average" mill in Brazil could add (as an annexed production plant) up to ~ 40,000 tons per year of a new product using ⅓ of the sugar cane it processes; some products that are already commercially available reach the scale of 1 Mt / year worldwide. There would be waste water treatment synergies in the annexed plants, and energy independence is possible in all of them. By using the bagasse and standard (commercially available) generation systems already in use, around 2.4 kWh / kg of sucrose (thermal energy) and 0.6 kWh / kg of sucrose (electricity) can be made available for processing.

In Brazil there is today commercial production of citric acid, amino acids like lysine and MSG, yeast extracts and derivatives, and sorbitol. Some plastics (commercial polylactic, abroad; poly-hydroxybutyrate, pre-commercial stage, in Brazil) are being considered for local production here. In addition, some of the ethanol derived products from the 1980's (especially ethylene and derivatives) are being considered again. The world's current (growing) markets in amino acids, some organic acids and polyols already use a few million tons of sugars on a yearly basis; the plastic markets may increase that demand considerably.

2.4 Ethanol derived products

The wide range of ethanol products (chemically processed) that were marketed in the 1980's and then left behind because of the relative costs of ethanol and naphtha have certainly to be reconsidered now. Routes based on ethylene, acetaldehyde and, in several cases, direct transformations have been developed and implemented in Brazil. They are all widely known processes without any major complexities; the country masters dozens of technologies. In the 1980's, the relative prices for naphtha and ethanol and the national oil based chemical industry development policy made alcohol chemistry unfeasible.

In the ethylene route, important products include polyethylene, polyvinyl and ethyl chlorides, ethylene glycol, and acetaldehyde.

In the acetaldehyde route, important products include acetic and chloroacetic acid; ethyl, vinyl, polyvinyl and cellulose acetates, acetic anhydride, and butadiene.

Direct transformations lead to butadiene, acetone, n-Butanol, ethyl ether, and vinyl ethyl acetate, acrylate, chloride and ether.

Alcohol chemistry actually started in Brazil in 1917 [6] from the production of ethyl chloride (Elekeiroz). By the 1960's, several companies (Rhodia, CBE, Eletrocloro, Butil Amil) had introduced intermediates and products like ethylene, polyethylene, acetates, ethyl chloride, and acetic aldehyde. The coming of Coperbo, Oxiteno, Salgema, Cloretil, Stauffer and Cia. Alcoolquímica Nacional marked a period of great development as early as the 1970's and 80's.

6 Boto, Dantas R.: "A alcoolquímica no Brasil", Simpósio Internacional de Avaliação Socioeconômica da Diversificação do Setor Canavieiro, PLANALSUCAR/IAA e PNUD, Águas de S. Pedro, SP, 1988

The use of ethanol for other products reached 0.494 Mm^3 in 1985. In 1987,[6] the production levels for some key items, using 3.6 percent of Brazil's ethanol production, were as follows:

Dichloroethane	0.300 Mt
Acetic acid	0.125 Mt
Acetic aldehyde	0.100 Mt
Vinyl acetate	0.074 Mt
Ethyl acetate	0.041 Mt

In 1993 there were around 30 ethanol derivatives in production in Brazil. Of these, 14 had installed capacities in excess of 100,000 tons per year. There was an installed capacity in excess of 400,000 tons per year for dichloroethylene (1 M ton / year), LD polyethylene (660,000 tons /

year), ethyl-benzene (500,000 tons / year), vinyl chloride and HD poly-ethylene.

In the current assessments, the ability to work on much smaller scales than those of oil based factories, the decentralized production and the ability to get synergies with the mills' traditional production continue to be important.

2.5 Summary and conclusions

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

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

• Brazil's sugar cane production corresponded (2004) to 55 Mt of sucrose and 100 Mt (DM) of lignocellulosic residue. Sucrose is currently used in sugar and ethanol production, but other important products are being considered. Fifty percent of the residues are used with low efficiencies in energy generation, and more than 25 percent (trash) are recoverable at costs compatible with energy uses.

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

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

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

II

Impacts on the environment

The impacts on the environment considered in general agricultural production should be viewed in respect of the sugar cane culture, as should those pertaining to industrial production and end use. They include local air pollution by sugar cane burning and the use of ethanol as a fuel, greenhouse gas emissions throughout the life cycle, and the impacts of the use of new areas, including the biodiversity, as well as the impacts on soil conservation, erosion, the use of water resources, the quality of water, and the use of pesticides and fertilizers.

In assessing the environmental effects of the growth of sugar cane production, it is important to consider that such assessment is always relative, and always refers to alternative uses of land. The impacts (erosion, production base production, biodiversity, use of chemicals, etc.) are much different if sugar cane should substitute (as it has occurred in most cases) for extensive pastures or orange crops, or if it should directly occupy savannah areas of even forests. These considerations are usually made at the time of substitution of soil uses in order to check whether there is any potential degradation or the new use will foster environmental recovery.

The sugar cane production in Brazil today has interesting aspects, environmentally speaking. It uses small amounts of pesticides, it relies on the largest biological pest control implemented in the country, it features the lowest soil erosion rate in Brazilian agriculture, it recycles all of its waste, it does not compromise the quality of water resources, and it actively participates in innovations by having, for example, the country's largest organic production area (as a separate culture).[1]

1 ROSSETTO, R.: "A cultura da cana, da degradação à conservação", Visão Agrícola, ESALQ-USP, Ano 1, jan 2004

The legal restrictions on soil use aimed at protecting the environment are the subject of extensive legislation in Brazil. An overview of the scope of such legislation is provided below.

Aspects of the environmental legislation for the sugar cane industry

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Centro de Tecnologia Canavieira (Sugar Cane Technology Center)

The considerations about environmental pollution have evolved over the past few decades from case-specific analyses of the most apparent environmental degradation (water and air pollution, deforestation) into a more comprehensive view, including socioeconomic and cultural affairs, and biodiversity, for example. In Brazil, this change appears in the environmental legislation with CONAMA (National Environment Council) resolution no. 01/1986, which requires the conduct of Environmental Impact Studies (EIA) and preparation of the corresponding Environmental Impact Reports (RIMA) before any license can be obtained for activities that may significantly alter the environment. This legislation applies to all undertaking projects in the sugar and ethanol industry, [2, 3] and their main aspects are discussed below.

2 ELIA NETO, A.; NAKAHODO, T.: "Aspectos da análise ambiental no setor industrial sucroalcooleiro - Relatório parcial" - Relatório Técnico n.º 1077-00/01, CTC – Centro de Tecnologia Canavieira, Piracicaba, SP, 2001

3 SALLES, L. da S.: *Elementos para o planejamento ambiental do complexo agroindustrial sucroalcooleiro no Estado de São Paulo: Conceitos, aspectos e métodos* – Dissertação de Mestrado Escola de Engenharia de São Carlos-USP, São Carlos, SP, p. 113, 1993

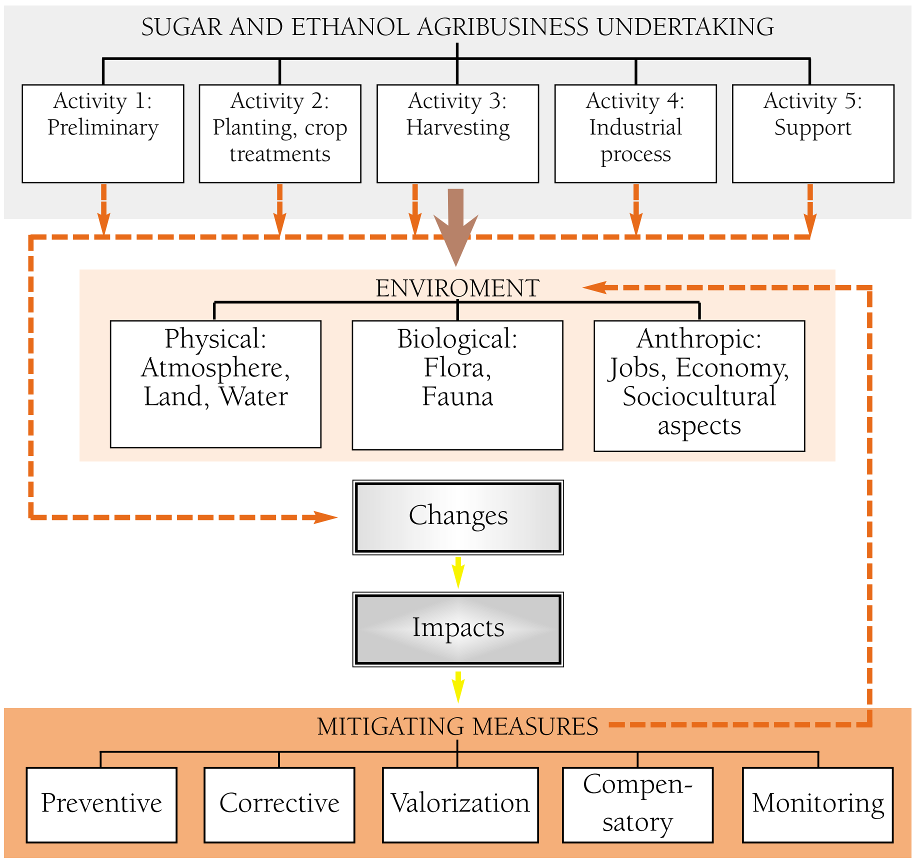
Environmental Impact Study (EIA)

CONAMA resolution no. 01/86, of January 23, 1986 (article 10), defines "impact" as "*any change in the physical, chemical and biological properties of the environment (…) resulting from human activities which may directly or indirectly affect: the population's health, security and well-being; social and economic activities; the biota; the sanitary and aesthetic conditions of the environment; and the quality of environmental resources.*" Article 20 lists the activities that depend on EIA/RIMA to get a permit; these include highways, bridges, industrial and agribusiness units (including ethanol distilleries), and several other activities the dimension and/or location or the environment-altering potential of which "*shall have their impacts identified, and interpreted as to their magnitude or relevance, reversibility degree, cumulative and synergic properties, and distribution of social costs and benefits.*"

Figure 1 shows a diagram of the structure for analyzing the environmental impacts when conducting/preparing EIA/RIMA for the sugar and ethanol industry. The impacts result from the crossing of each of the agribusiness activities considered with possibly affected environments: the physical environment (atmosphere, land and water), the biotic environment (flora and fauna), and the anthropic environment (jobs, economy and sociocultural aspects). Many of the mitigating measures taken in the sugar and ethanol industry have been in use for many years, and are usually incorporated into the agribusiness process.

CONAMA Resolution no. 237, of 1997, provided new criteria for granting environmental permits, including sugar production and refining as an activ-

Figure 1: Environmental analysis structure for EIA/RIMA: sugar cane agribusiness



ity subject to Previous Permit (LP, in Portuguese) and also EIA/RIMA (as it previously occurred in the case of ethanol distillation). Effective periods were provided for the permits: Previous Permit (LP), up to 5 years; Installation Permit (LI, in Portuguese), up to 6 years; and Operating Permit (LO, in Portuguese), effective for 4 to 10 years. In São Paulo State, the LOs must be renewed every 2 to 5 years; every 2 or 3 years for ethanol distilleries or sugar mills, respectively (executive law no. 47397, of 2002).

Preliminary Environmental Report (RAP, in Portuguese)

Still in São Paulo, the SMA (Office of the Secretary of the Environment) Resolution no. 42/94 introduced the Preliminary Environmental Report (RAP) as an initial study to demonstrate the environmental feasibility of undertakings. There is a resolution from the SMA/DAIA (Environmental Impact Analysis of the Office of the Secretary of the Environment) that considers the RAP enough for obtaining the Previous Permit for new mills with capacity of up to 1.5 million tons of sugar cane / year.

Sensitive Areas

There are more sensitive areas from the environmental viewpoint which have received special treatment in respect to the establishment of agribusiness activities: they are the Environmental Protection Areas (APA, in Portuguese),[4] and the Aquifer Recharge Areas[5] (such as the Guarani Aquifer).

The APAs are extensive areas with regionally important ecosystems and whose land arrangement is oriented towards a sustainable use of natural resources, as set forth in a specific law. In practice, environmental preservation and recovery are sought to be placed in harmony with human needs. The environmental permit for undertakings in APAs follows usual procedures that have been set up by the São Paulo State SMA, but the legislation in such areas either is or will be more restrictive using specific agreements to prevent or forbid activities which could lead to environmental degradation.

The Guarani aquifer, covering a total area of approximately 1.2 million km^2 – 839,800 km^2 in the Center-West and South regions of Brazil –, stores around 46,000 km^3 of water. The sustainable extraction considers the demand from 360 million people, with a *per capita* consumption of 300 l / inhab·day. The conserved volume could supply water to Brazil's population for 3,500 years. One of the large recharge areas of that aquifer is located in the north of São Paulo, including an important sugar cane producing center; this leads to further restrictions on these areas and the fertigation rates used.

Trends

The sugar and ethanol industry in Brazil is known today for the environmental benefits of using ethanol in substitution of a fossil fuel, of producing sugar using a renewable fuel exclusively, and of starting to use the potential excess electrical power production.[6, 7] On the other hand, its relationship with the environment, which improves the position of ethanol as a "clean product with clean production," can go further than meeting legal requirements, seeking a continued environmental improvement of the production process. This will be an imposition, especially because of Brazil's position as the most internationally competitive producer.

The normal trend in the environmental legislation is to become increasingly restrictive; important areas where the producers' evolution is already sensitive include control over effluents and rationing of water use, such issues being addressed in specific items below. Brazil's legislation has a strong dynamics, and the Operating Permits must be renewed periodically (every two to three years, in the case of mills or distilleries).

4 SMA – Secretaria de Estado do Meio Ambiente, Áreas de Proteção Ambiental do Estado de São Paulo, site http://www.ambiente.sp.gov.br/apas/apa.htm , (22/02/2005)

5 SMA – Secretaria De Estado do Meio Ambiente, Gestão Ambiental do Aqüífero Guarani, site www.ambiente.sp.gov.br/aquifero/principal_aquifero.htm , acessado em 22/02/2005, GT-Guarani, São Paulo, SP, 2005

6 Elia Neto, A.: "Análise dos impactos ambientais da colheita de cana crua e do aproveitamento energético da palha", Relatório n.º RLT-073, MCT/PNUD Contrato de Serviço n.º 137/97, CTC – Centro de Teconologia Canavieira, Piracicaba, 1999

7 Ometto, J.G.S: *O álcool combustível e o desenvolvimento sustentado*, São Paulo, PIC Editorial, 1998

Chapter 3:
Impacts on air quality: cities and rural area

Ethanol utilization (straight, or blended with gasoline) has led to important improvements in air quality in urban areas, through the elimination of lead compounds in gasoline and sulphur, and the reduction of CO emissions and the reactivity and toxicity of organic compound emissions. Controlling the undesirable effects of cane burning practices (risks to forests, traffic in roads, transmission lines and dirtiness) is being efficiently implanted with the current legislation in São Paulo.

3.1 Introduction

The impacts on air quality from ethanol use in urban centers and sugarcane burning prior to the harvesting in rural areas are highlighted in this chapter.

Air pollution is a major challenge facing sustainable development worldwide. It causes damage to human health and ecosystems in several ways. Carbon monoxide (CO), particulate matter (PM), sulfur oxides (SOx), nitrogen oxides (NOx), volatile organic compounds (VOC), tropospheric ozone (formed from atmosphere reactions involving mainly VOC and NOx) and lead have all been causing serious problems in many urban centers around the world. Particulate matter (in association with NOx and SOx) have been related with dozens of thousands of premature deaths in the United States[1] and elsewhere; CO is associated with several cardio-respiratory and neurological problems and is a greenhouse gas (GHG); tropospheric ozone, also a GHG, attacks materials, harms agriculture in addition of being an irritant of the respiratory system; NOx and SOx also affect health and contribute the formation of acid rain, which has various undesirable effects such as reduction of agriculture productivity. Last but not least problematic, lead is highly toxic and accumulates in living organisms. Agenda 21 sets the goal of eliminating "unacceptable or unreasonable" risks of air pollution "to the extent economically possible." Agenda 21 also provides for air pollution control actions across the geographic borders. Acid rain, tropospheric ozone, fine PM and GHG certainly deserve undivided attention in this context.

1 DRIESEN, D. M.; "Air pollution", *in* DERNBACH, J.C. (Ed.): *Stumbling toward sustainability*; Washington DC, Environmental Law Institute, 2002

Despite of important advances observed in many countries over the last decades to mitigate air pollution, the challenge for air quality improvement, particularly in developing countries, is enormous. Transport, energy production and industrial processes are the leading sectors that contribute to air pollution worldwide and the vast majority of air pollutants result from the intensive use of fossil fuels. The efforts to prevent and control air pollution have been intensified, with market-derived strategies being associated to increasingly stricter regulations on fuels and utilization systems. Even though such extremely serious cases as the use of lead-based additives in gasoline have been almost entirely eliminated, it is apparent that there is still a lot to do. With this perspective the use of renewable fuels such as ethanol and bagasse, in substitution of fossil fuels, is a step towards an energy matrix in line with sustainable development goals.

3.2 Impacts of the use of ethanol on vehicle emissions in urban areas

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Brazil has been the largest laboratory in the world with regard to the use of ethanol as an automotive fuel. Since 1977, in compliance with the National Alcohol Program requirements, blending of ethanol into gasoline gained nationwide scale and strategic importance. Presently the renewable fuel makes up 20% to 25% of the blend (named gasoline C). Exception made to aviation gasoline, all gasoline sold in the country contains ethanol. Furthermore, since 1979 ethanol has been widely used as a straight fuel (E100); as a result over 5 million dedicated ethanol vehicles have been produced. Flex-fuel vehicles (able to run on gasoline C or E100 or any blend of both) were introduced in the Brazilian market in 2003 and have gained consumers preference very quickly. In December 2006 the market share of new flex-fuel vehicles reached 78.1% with sales totaling 2.7 million units since 2003.[2]

2 ANFAVEA, 2007

Although the National Alcohol Program was not specifically designed to reduce motor vehicle emissions, blending of ethanol to gasoline and use of E100 in dedicated alcohol vehicles resulted in significant emission reductions, contributing therefore to important environmental benefits. The decrease in emissions can be seen in Table 1, which shows the progress of the main pollutants until 1994. Emission levels are compared for straight gasoline, certification grade gasoline C (78% gasoline and 22% anhydrous ethanol) and E100 hydrous ethanol.

Irrespective of the technological upgrades implemented by the automotive industry until 1988 period and the adoption of emission control technologies since 1989, dedicated ethanol vehicles generally showed greater reductions of CO, HC and NOx emissions than those fueled with gasoline C.

Table 1: Mean exhaust gas emission by new vehicles (g/km)[3]

Year-model	Fuel	CO	HC	NOx	R-CHO
Pre-1980	straight gasoline	54.0	4.7	1.2	0.05
1980-1983	gas. C	33.0	3.0	1.4	0.05
	A	18.0	1.6	1.0	0.16
1984-1985	gas. C	28.0	2.4	1.6	0.05
	A	16.9	1.6	1.2	0.18
1986-1987	gas. C	22.0	2.0	1.9	0.04
	A	16.0	1.6	1.8	0.11
1988	gas. C	18.5	1.7	1.8	0.04
	A	13.3	1.6	1.4	0.11
1989	gas. C	15.2	1.6	1.6	0.04
	A	12.8	1.4	1.1	0.11
1990	gas. C	13.3	1.3	1.4	0.04
	A	10.8	1.3	1.2	0.11
1991	gas. C	11.5	1.1	1.3	0.04
	A	8.4	0.6	1.0	0.11
1992	gas. C	6.2	0.6	0.6	0.013
	A	3.6	0.6	0.5	0.035
1993	gas. C	6.3	0.6	0.8	0.022
	A	4.2	0.7	0.6	0.04
1994	gas. C	6.0	0.6	0.7	0.036
	A	4.6	0.7	0.7	0.042

gas. C (C grade gasoline) = 78% gasoline and 22% anhydrous ethanol, in volume
A = 100% hydrous ethanol
R-CHO = aldehydes
Source: CETESB, **Note 3**

3 CETESB, Relatório de Qualidade do Ar no Estado de São Paulo, 2005

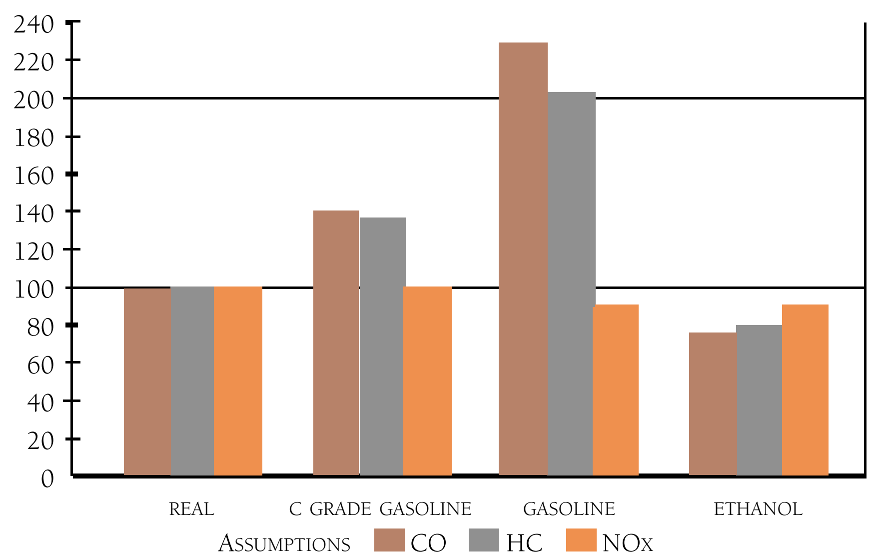
In order to evaluate the environmental importance of ethanol during this period, a study conducted in 1989 for the São Paulo Metropolitan Region (SPMR) compared the emission of pollutants by vehicles fueled with E100, gasoline C, and straight gasoline.[4] The existing light-duty vehicle fleet mix –

4 Confederação Nacional da Indústria, Veículos Automotores: "O Proálcool e a Qualidade do Ar", Rio de Janeiro, 1990

76% of vehicles fueled with gasoline C and 24% with E100 – was adopted for reference. The study shows that if the fleet were to be fueled exclusively with straight gasoline there would be an increase of 130% in CO emissions, 100% in HC emission and a decrease of 10% in NOx compared to the reference scenario. If the fleet were to be fueled only with gasoline C, there would be an increase in CO and HC emissions of 40% and 37% %, respectively, and no change in NOx. Finally, if the exclusive fuel were to be E100 then emissions would decrease 23% for CO, 20% for HC and 10% for NOx.

Accordingly, the study shows the environmental importance of ethanol use, either straight or blended with gasoline, points out that the decision to use the renewable fuel was wise. It can be inferred from the study that the air pollution levels in the SPMR that were quite high at that time, particularly for CO, would have been more critical if no ethanol had been used. Because the beneficial effects of ethanol are not limited to the SPMR, the study highlights the environmental relevance of ethanol to other urban areas in the country.

Figure 1: Emission scenarios for the RMSP



Source: **Note 4**, p. 81

The enforcement of stricter vehicle emission limits in the mid nineties resulted in substantial emission reduction, particularly for gasoline C vehicles. At that time, due to a number of reasons but mainly because of the relative low prices of oil the motor industry reduced its interest (and consequently investments) in the technological development of dedicated ethanol vehicles therefore restraining the evolution of its environmental performance. As a result levels of controlled exhaust emissions became equivalent on a quantitative basis, with some advantage for gasoline C vehicles. However the fundamental conditions that made E100 to be known as "clean" fuel are still in place. When E100 is used in flex-fuel vehicles average CO emission is still lower, VOC have lower toxicity and photochemical reactivity and emission of both PM and SOx is practically nil; not to mention the enormous advantage with regard to carbon dioxide (CO_2) emission, the main GHG.

Aldehyde (R-CHO) emissions need to be analyzed separately because this matter always comes up when environmental impacts of ethanol are discussed.

Although it is true that combustion of ethanol generates aldehydes this is also true to other automotive fuels like gasoline, diesel oil and natural gas, although less recognized. A first fact that needs to be acknowledged in this discussion is that fossil fuels generate a variety of aldehyde species with high toxicity and photochemical reactivity, such as formaldehyde and acrolein, while ethanol combustion generates primarily acetaldehyde, which has lower toxicity and smaller environmental impact. Another relevant fact is that emission of aldehydes from both gasoline C and E100 have been considerably reduced over the years due to advances in emission control technology (**Table 1**). For ethanol vehicles, the average observed with 1992 model-year cars (0.035 g/km) is lower than the level reported for the end of the 1970's for straight gasoline vehicles (0.05 g/km); 2003 model-year ethanol and gasoline C vehicles showed, respectively, a mean emission of 0.020 g/km and 0.004 g/km. With flex-fuels the average emission for 2005 model-year vehicles was further reduced reaching 0.014 g/km with E100 and 0.003 with gasoline C3. These values are substantially lower that the present emission limit for aldehydes (sum of acetaldehyde and formaldehyde must be lower than 0.03 g/km).

For comparison, it is worth mentioning a survey conducted by the CETESB (the São Paulo State environmental protection agency) in 2003 with diesel-powered light commercial vehicles[5] that likewise elsewhere are not subject to aldehyde emission control. The survey showed that depending on

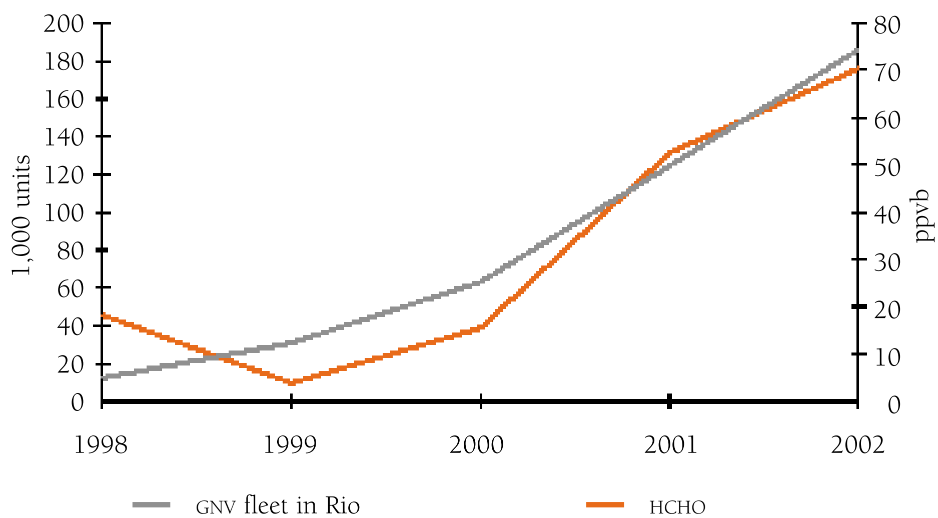
5 ABRANTES, R., "A emissão de aldeídos e hidrocarbonetos policíclicos aromáticos de veículos comerciais a diesel", SIMEA, São Paulo, 2003

the vehicle, aldehyde emissions ranged from 0.022 g/km to 0,160 g/km, thereby demystifying the belief that ethanol resulted in higher levels of emissions of that kind. It is also important to note a study conducted by the Rio de Janeiro State University that shows in Figure 2 a very close relationship between the growth of the fleet of vehicles converted to natural gas and the increase of the ambient concentration of formaldehyde.[6]

6 CORRÊA, S. M., UERJ, Rio de Janeiro, 2003

Moreover various studies carried out by CETESB in the São Paulo Metropolitan Region have shown that the large scale of ethanol use has not resulted in ambient aldehyde concentrations that might bring significant risks to the population.

Figure 2: Evolution of formaldehyde emissions and growth of the NGV fleet in the city of Rio de Janeiro



Because of its high octane rating, ethanol has brought the additional benefit of significantly reducing the use of lead-based additives in gasoline, thereby enabling the ban on these products from the domestic market on 1990. That way, the concentrations of toxic lead compounds in the atmosphere were reduced by around 75 percent in the RMSP.[7] The use of high levels of ethanol in gasoline has also made it unnecessary to produce gasoline with high contents of aromatic hydrocarbons such as benzene, toluene and xylene

7 CETESB, *Relatório de qualidade do Ar no Estado de São Paulo*, 1989

to substitute lead-based additives. Because these substances are known to be toxic and have high photochemical reactivity its content is being reduced in gasoline used in the most developed countries.

A point of paramount importance to this discussion is the impact of vehicle emissions on public health. Numerous research studies have demonstrated that there is a connection between air pollution, respiratory and cardiovascular diseases and premature deaths. An example is the relationship between asthma and air pollution in the vicinity of busy roadways. The literature on this subject is abundant and identifies SOx, PM and tropospheric ozone, pollutants strongly associated with fossil fuels combustion, as the main trigger of asthma attacks.[8] Data gathered by the Canadian organization Victoria Transport Policy Institute, shows that the average environmental cost due to the use of gasoline and diesel oil in automobiles is within US$ 0.6 – 5 cents/km.[9] A study conducted in Europe by the World Health Organization[10] shows that the social costs (diseases and premature deaths) related to fine PM pollution can be up to 190 billion Euro/year. The study emphasizes the contribution of diesel vehicles to the problem, which respond for about one third of the fine PM in the region.

8. Environmental Defense, www.environmentaldefense.org/documents/2655_MotorAirPollutionAsthma.pdf

9 Victoria Transport Policy Institute, Transportation Costs and Benefit Analysis – Air Pollution Costs, Canadá, 2006

10 World Health Organization, www.euro.who.int/mediacentre/PR/2005/20050414_1

Taking into consideration the earlier comments as well as the confirmation by the University of São Paulo's Experimental Air Pollution Laboratory that vapor and gases resulting from ethanol combustion are less toxic than those resulting from gasoline combustion, which was reported in several published works, it can be said that ethanol is a clean fuel and as such should be increasingly used.

3.3 Emissions by sugar cane burning; control

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The burning of sugar cane straw is a usual practice in almost all of the 97 countries where sugar cane is produced. That burning aims to improve the workers' safety and the harvesting yield by eliminating the straw and dry leaves.

3.3.1 Human health

In the 1980's and 1990's, several works were conducted in Brazil and other countries in order the clarify whether the emissions from sugar cane burning were harmful to health. Papers prepared by the Ribeirão Preto Medical School associate sugar cane burning with the increase in respiratory diseases, but fail to analyze other regions where there is no sugar cane burning at the same season (winter) to use it as a reference.

The local effect was considered in the paper for a research[11] jointly conducted by EMBRAPA (Brazilian Crops and Livestock Company), USP (University of São Paulo), UNICAMP (University of Campinas) and Ecoforça in order to assess the occurrence of chronic respiratory diseases in some regions of São Paulo State (Atibaia, Ribeirão Preto, São José dos Campos and Campinas). Taking Atibaia as a reference, it concludes that the risk increases by around 40 percent in São José dos Campos, gets close to 80 percent in Campinas, and is unchanged in Ribeirão Preto. The conclusion, therefore, is that Ribeirão Preto, Brazil's leading sugar and ethanol production park, has the same disease occurrence risk as a Atibaia, a municipality considered a climatic zone where there is no sugar cane production.

11 MIRANDA, E.E.; DORADO, A.J.; ASSUNÇÃO, J.V: *Doenças respiratórias crônicas em quatro municípios paulistas*, USP/UNICAMP/Ecoforça, 1994

In Hawaii, during the 1988-89 period, NIOSH – US National Institute for Occupational Safety and Health conducted an investigation into the chronic effects of exposure to sugar cane burning soot (which contains biogenic silica fibers – BSF) on the health of workers in the sugar cane agribusiness. The occurrence of respiratory diseases and mesothelioma (lung cancer) were not associated with BSF exposure.[12]

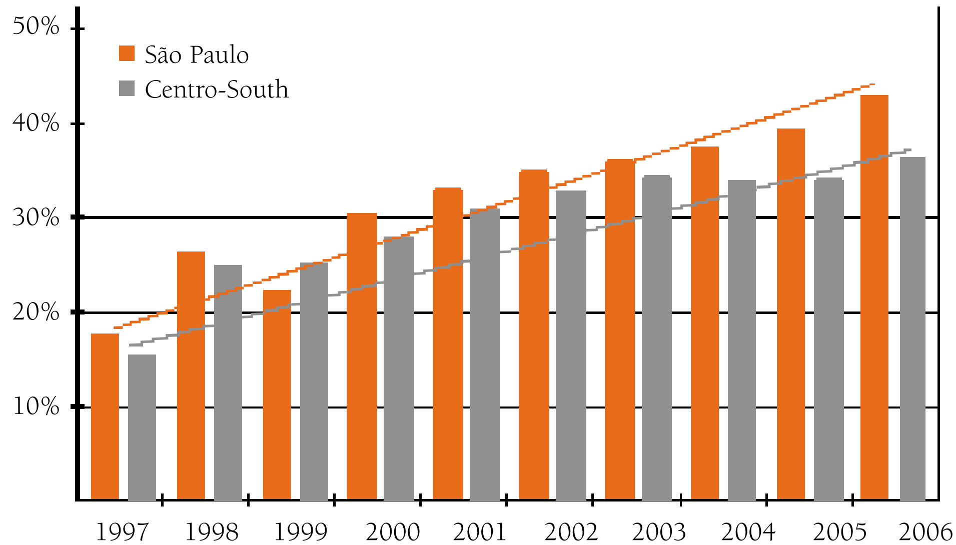
12 SINKS, T.H.; HARTLE, R.W.; BOENIGER, M.F.; MANNINO, D.M.: "Health hazard evaluation: Report", Hawaiian Commercial & Sugar Company/Hamakua Sugar Plantation (Health Hazard Evaluation HETA Report 88-119-2345), ago 1993, p. 44

Although several papers show no direct relationship between burning and damage to health, it should undoubtedly be noted that any kind of burning has some sort of effect on the environment, especially when performed incompletely, which is the case of sugar cane burning. In addition, sugar cane burning brings the discomfort caused by the emission of particulate matter (known as "*carvãozinho*") and some risk to areas having electrical networks and highways.

3.3.2 Technologies and evolution

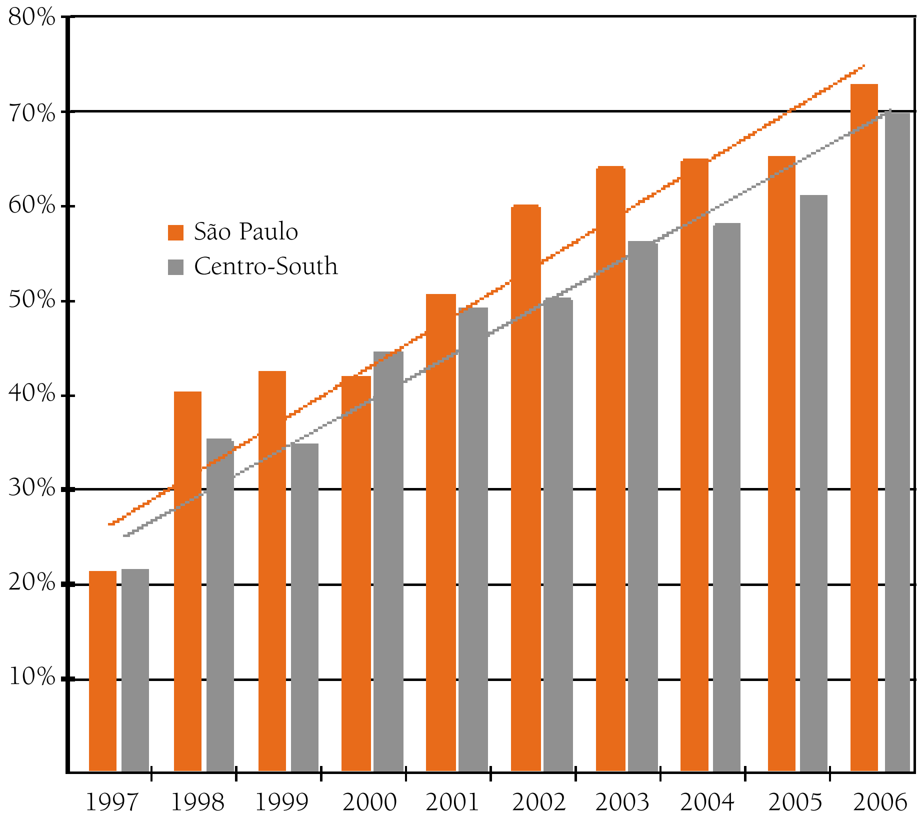
The introduction of mechanical harvesting of sugar cane in Brazil actually took place in the 1980's and has been growing over the years. The increase in the mechanical harvesting area is due to the need for mills to meet their schedules at times when the workforce became extremely scarce (*Cruzado* Plan, etc.), to cost reductions, and to the environmental pressure for harvesting sugar cane without burning it. **Figure 3** shows the evolution of mechanical harvesting in the leading producing state (São Paulo) and the Center-South region of Brazil, which accounts for more than 80 percent of the country's sugar cane production. Approximately 10 percent of the crop areas in the Northeast region have mechanical harvesting.

Figure 3: Evolution of mechanical harvesting in Brazil's Center-South region



Sources: 1997-2002: IDEA (Note **13**); 2003-2004: CTC (Note **14**)

Figure 4: Raw sugar cane share in mechanical harvesting



Sources: 1997-2002: IDEA (Note **13**); 2003-2004: CTC (Note **14**)

13 IDEA, "Indicadores de Desempenho da Agro-indústria Canavieira – Safra 2002/03"

14 CTC: "Programa de acompanhamento mensal de performance agrícola", Technical report, Piracicaba, 2004

The technological evolution of production equipment and processes, the environmental pressures and the legislation in force have motivated the increase in mechanical harvesting of sugar cane without burning. **Figure 4** shows the share of raw sugar cane in the mechanical sugar cane harvest. Today, in the country's main producing regions, approximately 70 percent of the mechanically harvested sugar cane don't use fire to remove the straws.

3.3.3 Legislation on sugar cane burning

The gradual prohibition of sugar cane burning in Brazil was originally provided for in an executive law passed by the São Paulo State government on April 16, 1997. Today, the legislation on the matter consists of Law no. 11,241, of September 19, 2002 (São Paulo State), and decree no. 2,661 passed by the Federal Government in July 08, 1998. Both of them provide for a burning elimination schedule and specify prohibition areas as protection ranges near urban perimeters, highways, railways, airports, forest reserves and preservation units, among other areas. **Table 2** shows the sugar cane burning reduction schedule set forth by the federal and state legislation.

Table 2: Burning reduction schedule

State Decree (São Paulo) 2002			Federal Law 1998		
Year	Area where mechanical harvesting is possible[1]	Area where mechanical harvesting is not possible[2]	Year	Area where mechanical harvesting is possible[1]	Area where mechanical harvesting is not possible[2]
2002	20%	-			
2006 (5th year)	30%	-	2003 (5th year)	25%	-
2011 (10th year)	50%	10%	2008 (10th year)	50%	-
2016 (15th year)	80%	20%	2013 (15th year)	75%	-
2021 (20th year)	100%	30%	2018 (20th year)	100%	-
2026 (25th year)		50%			
2031 (30th year)		100%			

1 Area where mechanical harvesting is possible: tilt <12%
2 Area where mechanical harvesting is not possible: tilt >12%

In order to comply with the legislation, the introduction of mechanical harvesting shall extend to 100 percent of the crop areas where the soil tilt is compatible with such practice within the next 13 years (2018).

For crop areas where the soils are on sharper tilt, the federal decree does not prohibit burning, while the state decree provides that the burning should terminate within 30 years, i.e. in 2031. Since those areas do not allow mechanical harvesting and the cost of manual harvesting of sugar cane without burning would reduce their competitiveness, the producing areas can be reasonably expected to migrate to regions featuring better topographic characteristics. Attempts to increase production in areas where mechanical harvesting is possible by incorporating new technologies into the production process are also likely to occur.

3.3.4 Burning reduction and impacts on employment levels

Brazil's sugar cane agribusiness plays an important role in job creation, an the number of people it directly employs is estimated at around one million (see **Chapter 12**), approximately 80 percent in the agricultural area. Sugar cane is one of the leading job-creating cultures per crop area unit. In São Paulo State, it employs around 35 percent of the agricultural workforce, totaling 250,000 workers.[15] The demand for labor in sugar cane production should be reduced by the increased introduction of mechanical harvesting and planting (reduction), and that reduction will be only partly compensated for by the likely introduction in the field of the straw collection process for energy generation, as discussed in **Chapter 12**.

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3.4 Summary and conclusions

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

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

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

• The burning of sugar cane straw (used in most producing countries to make harvesting easier) was the subject of many papers in the 1980's and 1990's (in Brazil and other countries) that were unable to conclude that the emissions are harmful to human health. Such undesirable effects as the risks (electrical systems, railways, forest reserves) and dust (particulate matter) remained. In São Paulo State, legislation was passed which gradually prohibits the burning, with a schedule that considers the technologies available and the expected unemployment, including immediate prohibition in risk areas. That solution is in force, and is an important example given the size of the São Paulo production.