Sugarcane for energy – recent results and progress in Brazil

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Ethanol is being used as a fuel in the transportation sector in Brazil and in a few other countries. It started to be used in significant amounts in Brazil in a blend with gasoline in 1975 and as a neat fuel in automobiles in 1980. The first use continues and all gasoline sold in the country contains 24% ethanol. The second use showed a rapid evolution, covering more than 90% of the new cars produced in 1989; after a shortage of supply in that year the number of new neat ethanol automobiles decreased very fast, reaching less than 1000 cars by 1997-98. By 1999 a modest reverse of this trend had occurred. Considering both types of use, ethanol demand has stabilized since 1995, but at present some decline in demand is foreseen for new neat ethanol cars for several years in the first decade of the 2000s.

The government has an interest in maintaining the use of this alternative fuel because of several merits, e.g., the large number of jobs created in the field and the significant amount of hard currency saved on oil imports. On the other hand, most of the subsidies provided to ethanol producers have been removed because they have been in existence for a long time. Some subsidies are still in force, such as the over-price paid to producers in some states where it is understood that they are not capable of competing with the major producers of the South/ Southeast region. There is enough evidence that through the "learning by doing" process ethanol fuel producers are learning how to bring down costs and they already have the ability of competing with gasoline, which is heavily taxed to cover the sales of some petroleum products at prices below production costs.

Technology has improved and further progress may be made, allowing a reduction in the ethanol fuel production cost. Nevertheless, oil prices for several years up to 1999 also declined, making the competition between gasoline and ethanol difficult. By 1999, with the rebound in oil prices, the federal government reinvigorated its interest in the ethanol market through some political initiatives. Such evidence of interest and the present increase in oil price may offer the opportunity required to restart large scale production of neat ethanol automobiles.

The electricity market is opening up space for the use of large amounts of biomass residues, obtained during ethanol processing, as a fuel in steam boilers. The interest is growing and more modern technologies can be used, allowing the production of up to 6000 MW of electricity using the sugarcane residues, bagasse and barbojo.

Another technology which is under consideration is the development of suitable re-formers to allow the use of ethanol in fuel cell-powered vehicles.

Considering the significant success of ethanol as an automobile fuel and for electricity generation this paper tries to make an assessment of the future trend. It is very useful to recognize that during the last 40 years, average sugar prices (the only alternative market for ethanol from sugarcane) have been continuously declining, while average gasoline prices have moved in the opposite direction. This trend helps commercial competition between the two fuels. In addition, the potential economic value of a renewable fuel through carbon emission certificates can impact positively on ethanol. Significant carbon abatement results from the use of ethanol derived from sugarcane due to the very favorable energy balance of the entire process.

1. Introduction

From 1975 to 1998, total energy consumption in Brazil increased from nearly 4500 PJ to 9900 PJ [BEN, 1999]. Yet during the same period gasoline consumption dropped from 520 PJ (12% of the energy market) to 490 PJ (5%), a clear indication of the success of the alcohol program which started in 1975. Other effects of the oil substitution program include an increase in ethanol production, which accounted for 19.7% of the total fuel consumed by the transportation sector and 3.5% of total energy consumed, and sales of more than 700,000 automobiles powered by neat ethanol (95% of total sales) in 1989, the peak year

of ethanol participation. In that year an ethanol supply shortage, caused by the large increase in the share of neat ethanol cars and the unavailability of reserves, reduced the credibility of ethanol suppliers, leading to a drop in offtake of such cars. Since 1989, continuous reduction in the number of neat ethanol cars produced led to sales in 1998 of less than one thousand units. Despite these circumstances consumption of ethanol fuel continued to increase up to 1998 due to the existing fleet of neat ethanol cars and the increase in the number of cars which used a blend of 22% ethanol in gasoline. In 1998, ethanol represented 3.4% of the total energy consumed in the country.

Not only does ethanol participate significantly in the Brazilian energy matrix, but the biomass by-product of the sugar/ethanol mills, bagasse, is also an important source of primary energy. Sugarcane products (ethanol and bagasse) represented 11% of the total consumption of primary energy sources in 1998, surpassing firewood consumption, which is mainly used for charcoal manufacturing and for cooking. Hydroelectricity, sugarcane products, firewood, and other renewables provided nearly 60% of the total energy consumed in the country in 1998.

Such impressive participation of renewables was obtained through a significant investment effort by the nation. Many hydroelectric plants were installed due to the abundance of water and the participation of government-owned utilities capable of investing in long-term payback projects. Sugarcane products increased their participation due to a government program set up in 1975 with the purpose of reducing national dependence on imported oil; the program provided significant financial incentives for ethanol producers (essentially private entrepreneurs) while guaranteeing a final price to consumers lower than that of gasoline through taxation on the latter. Firewood use grew as a natural consequence of its wide availability, but also because of government programs to promote reforestation through provision of income-tax benefits during the 1970s and 1980s. Even so, firewood use has declined significantly due to its replacement by LPG in domestic cooking and stagnation of the use of charcoal in the pig-iron industry. Firewood represented 15.8% of total primary energy consumed in 1981 and went down to 10.0% in 1998.

The present trend is towards a less environmentally-friendly energy matrix due to emerging interest in the use of natural gas as a feedstock for electricity production. A natural gas transmission and distribution infrastructure is being installed, and together with the privatization of the electricity generation market a significant share (50%) of present supply expansion is being based on the installation of natural gas thermal electricity plants, with a decreasing interest in further hydroelectricity expansion. Private enterprises claim they cannot afford to invest in medium and large hydro plants due to their high unit investment costs and the long construction times compared with those needed for natural gas-based units. Even so, the environmental degradation due to the sector is modest compared with that in other countries where coal-based plants are common.

2. The alcohol program

2.1. Recent market developments

Production of neat ethanol cars has almost ceased since 1992, due to the worldwide oil price decline and the significant unreliablity of supply caused by the alcohol shortage in 1989-1990. Even so, total ethanol production (pure ethanol to be blended with gasoline and hydrated ethanol to be used in neat ethanol cars) has continued to grow at a modest pace in the period 1992-1999.

The automotive industry received large offshore investments during the initial period of the Real plan (1996 to 1998), while the over-valuation of the national currency during the period 1994-1998 stimulated consumers to acquire cars. Annual sales increased from 1.2 million in 1994 to 1.6 million by the end of 1998 [DATAGRO, 1999]. With the increase in the number of new cars, gasoline consumption increased significantly, pushing up consumption of anhydrous ethanol. Such increase was sufficient to more than compensate hydrated ethanol demand decline, as shown in Figure 1.

Another push to ethanol demand occurred in the middle of 1998 when, through regulation, the government increased the compulsory blend of ethanol in gasoline from 22% to 24% and, at the beginning of 2000, when the compulsory blend of ethanol was increased again to 26%. Even under such favorable conditions sugarcane producers continued looking for further opportunities to sell ethanol, since low international prices of sugar were a stimulus to allocate more of the crop to ethanol, with its better returns.

An old opportunity [Bendel and Ventura, 1980] was taken afresh, and testing of the use of an ethanol-diesel blend restarted at the beginning of 1998. Tests with 3% and 11% ethanol blends are being carried out. The lower blend was tested at bench scale and in a few buses running in the city of São Paulo, and results were very satisfactory. The amount of ethanol added is constrained by the very low cetane number (50) of the diesel fuel sold in Brazil. The major benefit of ethanol-blending is a significant reduction in particulate emissions, which were measured as 40% less than with neat diesel fuel. The higher ethanol blend requires an additive, as is being used in Sweden. The additive is a proprietary product and its cost and the quantity required inhibit the present interest in the mixture. A fleet of a few buses operated for several months with the blend showing good drivability. A major incentive for such projects is the search for further ethanol markets, especially for the next 6 to 8 years when a reduction in ethanol demand is expected as the old fleet of neat ethanol cars retires and the increase in the number of new cars is not sufficient to guarantee consumption of the present level of ethanol production (13 million m^3/year). After 2006-2008 the annual expected growth rate of the automobile fleet should guarantee a continuous increase in demand.

The "learning curve" for alcohol production continues to guarantee declining production costs but at a lower rate than has been observed for the first 80 million m^3 (Figure 2). Nevertheless, the producer's revenue per liter (l) of

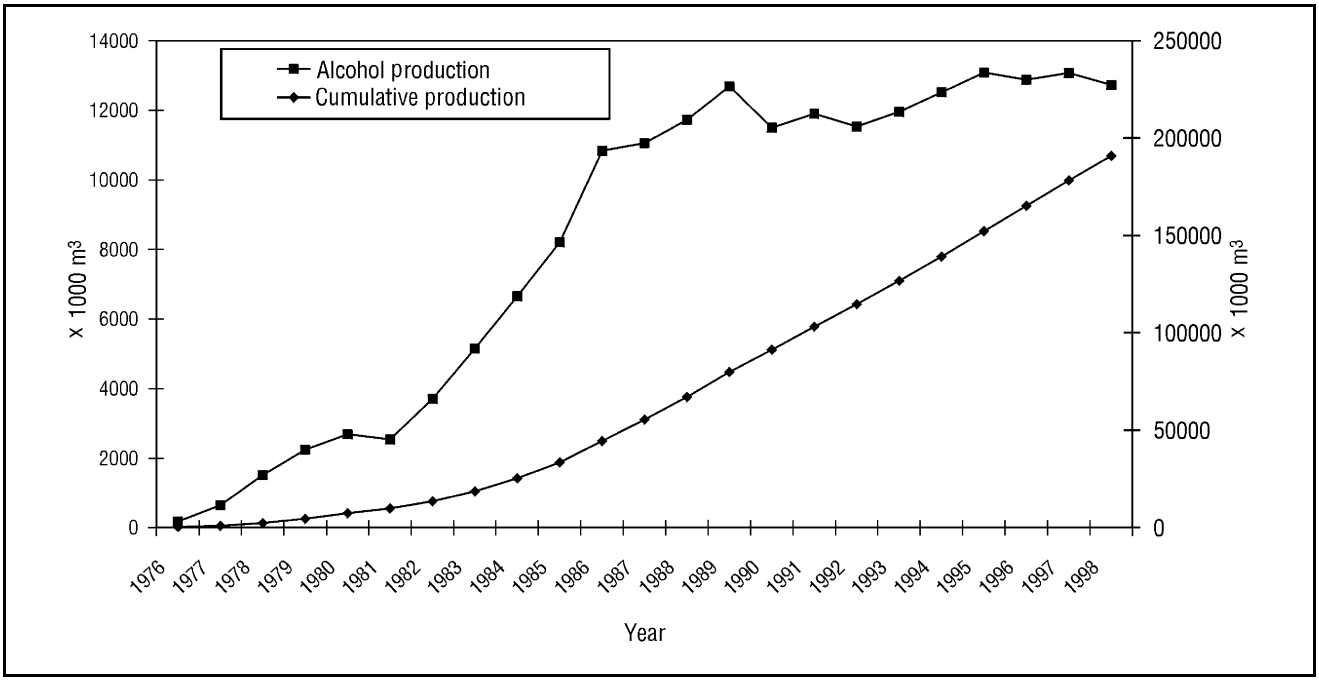

Figure 1. Alcohol production (1976-1998).

Source: BEN, 1999

ethanol has been declining for the last 120 million m^3 by almost 1.5%/yr.

At the begin of 1999, the Brazilian economy was adversely affected by a significant devaluation of the national currency, the real, which pushed up domestic prices of imported products, including oil and petroleum products. Fortunately, the average internal rate of inflation was smaller than the devaluation (9% against 50%), resulting in an increase in gasoline prices of 30% (40% of the oil consumed is imported). Such increase, which could be an opportunity for ethanol price scale-up due to the traditional price linkage between the two fuels, did not occur. The observed trend was in the opposite direction since sugarcane production and sugarcane productivity increased significantly in 1997 and 1998, while total ethanol demand has stabilized due the simultaneous effects of annual retirement of old neat ethanol cars balanced by the continuous increase in the number of cars using gasohol. The presence of 2 billion l of surplus ethanol (in a 14 billion l annual market) pushed the price down. At service stations, prices as low as US$ 0.21/l were observed, while mills were selling the product at a low price of US$ 0.14/l during some months.

In such extremely adverse conditions the government decided to help producers by acquiring ethanol, building a reserve, which had for long been required by law, while stimulating increased demand for ethanol. The federal and some state governments required that their own fleets of automobiles be replaced by neat ethanol cars (when they are available in the market), prohibited the use of MTBE (methyl ethyl butyl ethene) in Rio Grande do Sul state (the only one which was not following federal regulations regarding the compulsory blend of ethanol in gasoline), stimulated further tests on diesel/ethanol blends, and agreed to create a private company to acquire surplus ethanol from the market. By the end of 1999, the ethanol price escalated, but only to the same level (in R$) that held before the currency devaluation, which means a real decline in its price. This is reflected by the last 2 points shown in Figure 2.

During most of 1999, Brazilians started to demonstrate an interest in the acquisition of neat ethanol cars and as orders were placed for new cars, automobile makers decided to restart production, even at a slow pace.

The situation was very favorable for increases in neat ethanol cars up to the end of the year, when surplus ethanol disappeared from the market, international sugar prices increased modestly and Brazil was able to export 11 million t, which is almost half of the total sugar traded in the free international market. By October ethanol prices increased to the level of US$ 0.39/l at service stations (which was still well below gasoline at US$ 0.62/l), pushing up prices of gasoline (since gasoline had a 24% ethanol blend) at a moment when international oil prices were gaining momentum. The rate of price increase affected the national inflation index, causing dissatisfaction among government officials and scaring, once again, potential new users of ethanol. Even so, 5000 neat ethanol cars were produced in the last 3 months of 1999, and higher sales were seen at the beginning of 2000.

2.2. Technological advances

The yield of total reduced sugar in sugarcane has continuously improved (Figure 3), which partially explains the increase in sugar and ethanol production without any significant change in area under sugarcane. Better agricultural practices have also been responsible for higher sugarcane yields.

Agricultural practices are changing due to compulsory legislation requiring that the practice of pre-harvest burning be eliminated except in hilly areas where mechanical

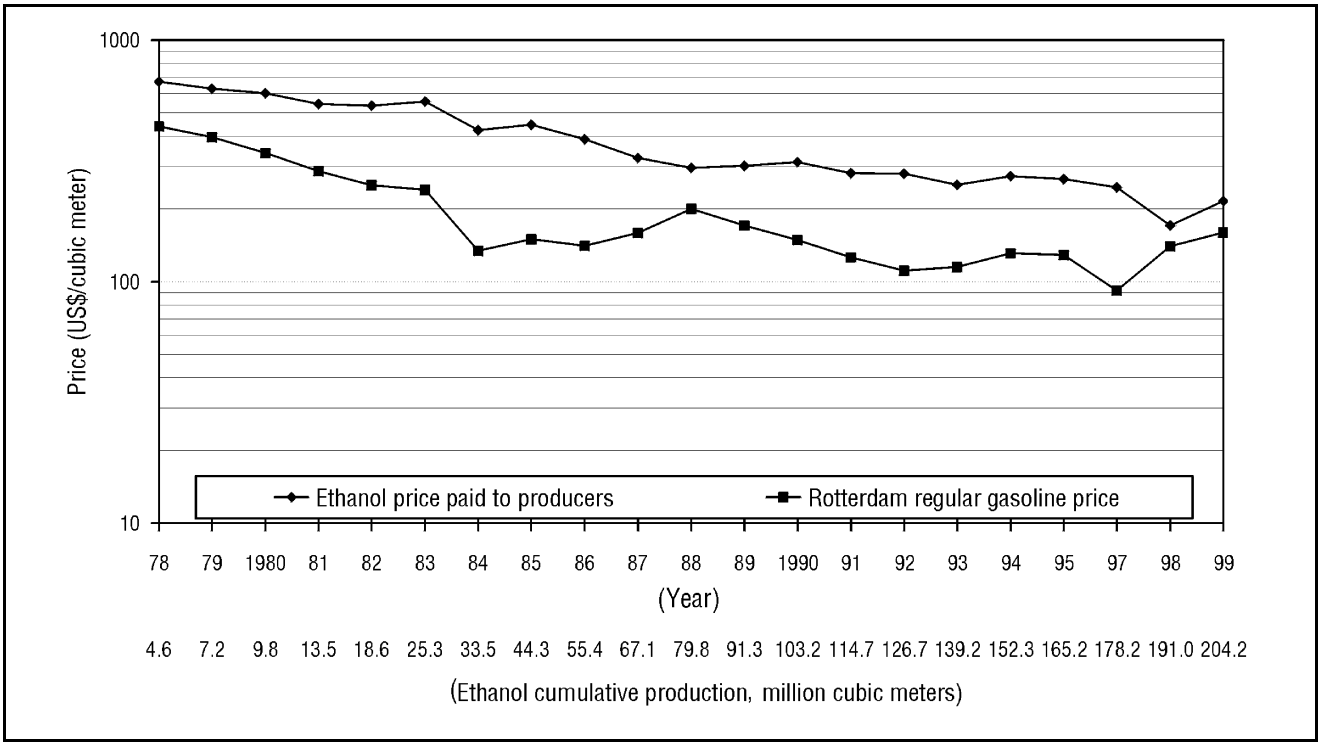

Figure 2. Ethanol cost "learning curve"

Source: BEN, 1999, BESP, 1999; DATAGRO, 1999

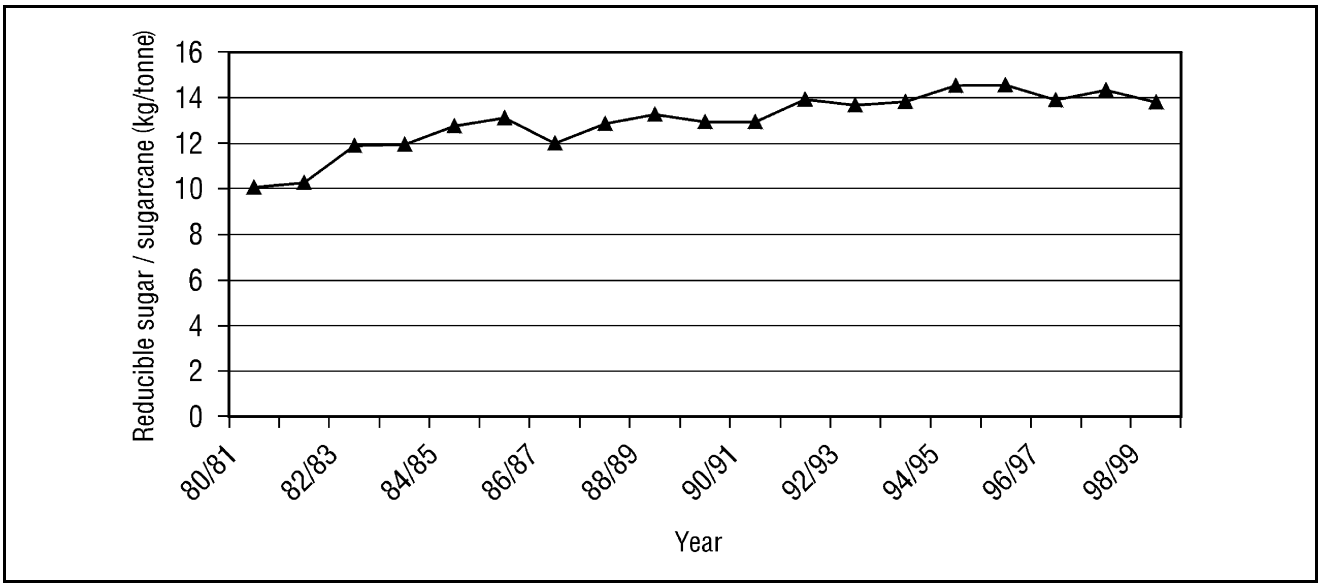

Figure 3. Evolution of total reducible sugar per unit of sugarcane harvested – Brazil 1980-1999

Source: DATAGRO, 1998, 1999

harvesting is still unfeasible. Legislation requires that year after year a larger area of sugarcane be handled without pre-harvest burning. This pressure increases interest in mechanical harvesting and presently in the state of São Paulo (responsible for 60% of Brazil's sugarcane production) more than 20% of harvesting is done by machines. Such transformation is decreasing the number of workers in the field, weakening an important argument in favor of ethanol use: the large number and the low cost of the creation of job opportunities for the unskilled rural population. On the other side, sugarcane producers claim harvesting costs have declined.

Another important consequence of the new harvesting practice is that a significant amount of extra biomass becomes available. As shown in Table 1, sugarcane straw has a higher energy content than bagasse or ethanol. Even assuming that soil preservation measures recommend 50% of the straw be left in the field (in practice, tests are being performed and 50% looks like the upper limit), total energy availability per t of sugarcane, in a well managed plantation, increases from 3750 to 4700 MJ if straw is used. For such a plantation (100 t/ha of yield), this means 480 GJ/ha/yr, a remarkable result when compared with other biomass production systems (Table 2).

2.3. Electricity

Since the end of the 1980s sugar mills have been selling electricity to the grid. Figure 4 shows a continuous increase in the volume of power involved in this transaction, but the quantity is still small. In 1995 electricity purchased by utilities in the state of São Paulo from all suppliers totaled 96 GWh, which was 0.12% of electricity consumed in the state. Sugar mills are the major suppliers with 69.7 GWh.

The figure is modest considering that 620 MW is installed in mills operating in the São Paulo state and that at least 26 MW is surplus power. Studies have shown that 2,000 MW of electricity could be produced using conventional technologies to modernize the installed potential and approximately 6,000 MW if biomass gasifiers and gas turbines were installed at all mills.

In the last three years a significant transformation has occurred in the electricity sector. Previously owned by the government, it has undergone radical privatization, and today most of the distribution utilities are managed by private owners. During this major transformation period little dialogue has taken place between utilities and independent power suppliers. The only addition in electricity sales in 1999 has benefited the Santa Elisa mill, which sold an extra 5 MW to the grid using the spot electricity market. More recently (2000) an independent power producer signed a power purchase agreement with a public utility (CESP) for supplying up to 300 MW, 100MW in the first and 200MW in the second year, using sugarcane residues distributed over several projects. Such transactions may be the first of many. Since 1999 there has been a significant slow-down in construction and planning of natural gas-based plants, which are considered the best new supply options by the private investors. The slow-down was dictated by the devaluation of the real at the beginning of 1999, pushing up in inverse proportion the cost of the fuel, which is mostly imported. With an electricity tariff increase of 20%, the difference in fuel price was not fully passed on to the consumer, and most investors

Table 1. Sugarcane: energy value per tonne

		Energy[1] (MJ)
80 l	Ethanol	1700
280 kg	Bagasse (50% moisture)	2100
290 kg	Straw (50% moisture)	2150
	Total	5950

Source: BEN, 1999; BESP, 1999

Note

1. LHV

Table 2. Global data on current and feasible biomass productivity, energy ratios and energy yields for various types of crops and conditions

Crop & global conditions	Energy output-input ratio	Yield (dry t/ha/yr)	Net energy yield (GJ/ha/yr)
SRC (US, Europe) (e.g., willow and hybrid poplar)			
– short term	10:1	10-12	180-200
– long term	20:1	12-15	220-260
Tropical plantations (e.g., eucalyptus):			
1. No genetic improvement and fertilizer use & irrigation	10:1	2-10	30-180
2. Genetic improvement and fertilizer use	20:1	6-30	100-550
3. Genetic improvement, fertilizer and water added		20-30	340-550
Miscanthus/switchgrass			
– short term	12:1	10-12	180-200
– long term	20:1	12-15	220-260
Sugar cane (Brazil)	18:1[1]	15-20	250-300
Wood (commercial forest)	20/30:1	1-4	30-80
Sugar beet (NW Europe)			
– short term	10:1	10-16	30-100
– long term	20:1	16-21	140-200
Rapeseed (including straw yields; NW Europe)			
– short term	4:1	4-7	50-90
– long term	10:1	7-10	100-170

Source: Hogner, 1999

Note

1. The value quoted in Moreira and Goldemberg, 1999 (1:9) includes energy expenditures in transportation and processing of sugarcane to ethanol. Also it is assumed the only final product is ethanol.

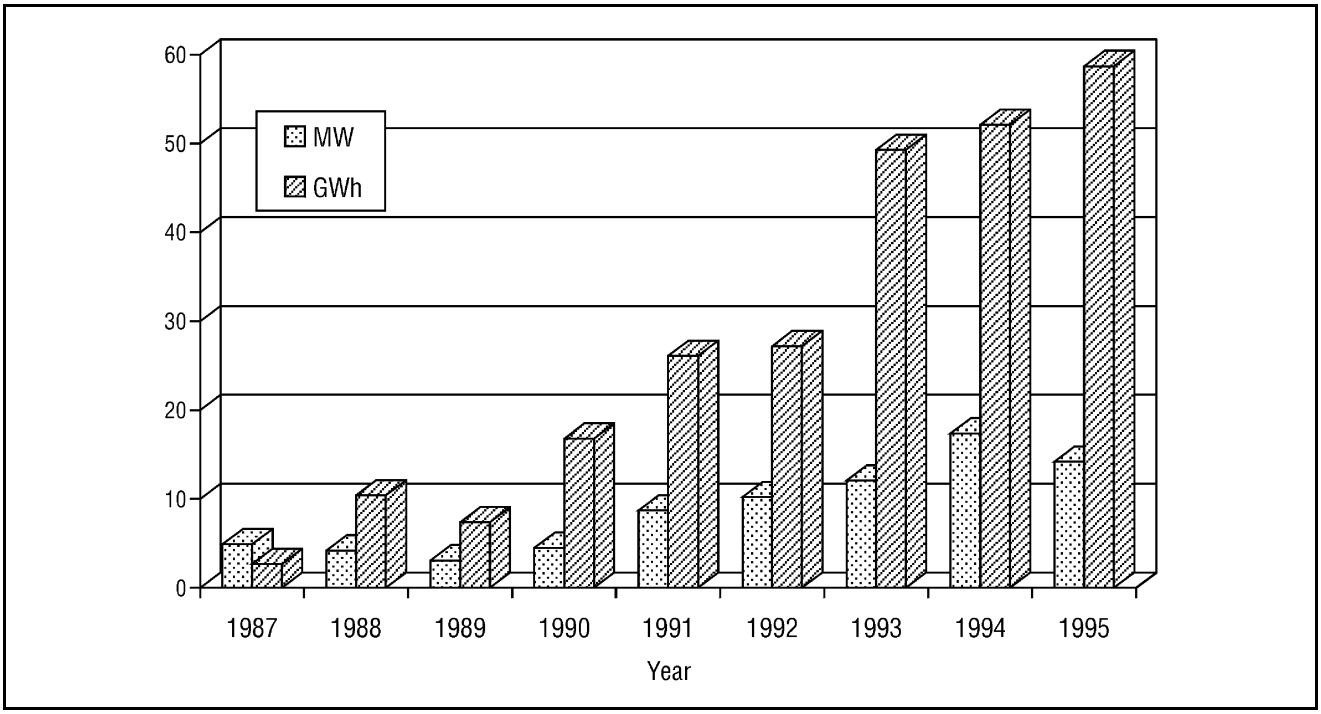

Figure 4. Evolution of cogeneration from sugar mills – sales to grid, São Paulo state

Source: CPFL, 1996

delayed construction or postponed the decision to construct new capacity. Since privatization at the generation level has been planned since 1997, government-owned utilities also reduced their investments in new supply. Both these effects, on top of the lack of investments in generation by privately-owned utilities in 1998 and 1999 (when most of them were privatized), are increasing the mismatch between supply and demand. Demand continuously increased even in an adverse economic situation (by 4.1% in 1998 and 2.1% in 1999).

The National System Operator – a non- profit organization supported by all electric utilities and responsible for the optimized operation of the complex interconnected system that supplies more than 90% of the country's electricity consumers – was very concerned at the beginning of December 1999 with potential shortage of supply caused by a year of below normal rain in all parts of Brazil. Even so, there were almost no negotiations for further electricity procurement from sugar mills, probably because utilities are not sensitive enough to potential electricity shortages or because they have very little interest in the small quantity of power immediately available from this sector. It is true that the sugar sector needs time to make investments to significantly increase sales to the grid, but this is a chicken-and-egg situation, and requires a push from the utilities to solve. Furthermore, utilities must be aware that with a significant shortage of supply they can use almost all the 600 MW installed in mills to power the grid during the non-harvesting season, when the mills are shut down (180 days in the year). Electricity supply from the mills during the sugarcane harvesting season (covering six months from late spring, through summer, and into early autumn in the major producing states) dovetails well into the pattern of hydroelectric supply, since rainfall is reduced and water reservoirs are being depleted during this period. But with the future growth in natural gas-based electricity (14,000 MW thermal are planned to be operational before 2005), complementation of the nowadays almost purely (95%) hydroelectric system will take place, facilitating the use of any installed power capacity all round the year, provided that stored biomass or other fuels are available. The possibility of electricity shortage, particularly in the year 2000-2001, can present a significant opportunity for the sugar sector to expand its electricity sales.

2.3.1. Other opportunities

An important high technology project for conversion of wood to electricity, which has relevance to future conversion of sugarcane biomass, has been under way since 1992 in the northeast of Brazil. The WBP (Wood Biomass Project) partially supported by the Global Environment Facility (GEF), intends to power a 32 MW gas turbine system through the use of an atmospheric pressure gasifier [WBP, 1999]. (See Carpentieri and Macedo, "The introduction of BIG-GT technology – possible future uses in Northeast Brazil", in this issue.)

An important complementary effort is the Biomass Power Generation: Sugarcane Bagasse and Trash Project, which is also being partially supported by the GEF. The project has already carried out several tests on bagasse and trash gasification and is very well advanced. GEF has granted an amount of US$ 3.75 million, and Copersucar, the technology research and development organization of the sugar industry in São Paulo state, is investing US$ 3.64 million.

Table 3 shows the aims of the different phases of the project. Several results are already available. Phase 1 results are shown in Table 4, and it is important to note the

high yield from sugarcane plantations. In particular cane variety SP79-1011 (1st cut and ratoon 3rd cut) yields an average of 102 t/ha/yr, while providing a high amount of trash – 15.9% (on average considering the first four results, which represent a pair of plots under similar harvesting sequence). From these figures, the average trash from cane plant and ratoon represents 16.2 t/ha/yr (0.159×102), with a moisture content far below 50%. Additionally, sugarcane bagasse (50% moisture) represents 25% of the green sugarcane, or 25.5 t/ha/yr. A better overview is provided in Table 5, where the heat content of trash (baled barbojo) is compared with bagasse (pelletized bagasse). They are very close as far as the heat value is concerned and have only 15% less energy content than aspen wood.

Handling the excess biomass material (trash) in an efficient way and processing sugarcane to final products (sugar and ethanol) with less energy expenditure are also important areas of investigation in the project. Table 6 shows it is possible to harvest green (unburned) cane with less sucrose losses compared with cane harvested after burning, the traditional approach (see last column). Nevertheless, impurities are high for green cane harvesting (see 4th column), which requires the installation of a cleaning station to remove impurities before delivering the cane to the mill. The initial and final impurities columns in Table 6 can be compared with impurities from the traditional harvesting process, which amount to 2.80% before the dry cleaning station processing. Since dry cleaning is not practiced with the traditional harvest approach, one can conclude that green cane harvesting, with intermediate cleaning station processing, can produce sugarcane with less sugar losses and with final impurity levels not significantly different from those obtaining with present harvesting practice.

Table 7 shows the feasibility of significantly reducing steam consumption during sugarcane processing. A 32% reduction in steam use is achievable in a first stage of process energy efficiency improvements, and a 44% reduction is achievable with a more aggressive set of measures. By reducing the amount of steam required in the process from 500 kg to 340 kg or to 280 kg per t of sugarcane processed (Table 7), additional electricity can be cogenerated at the mill: 24 kWh or 33 kWh per t of sugarcane (assuming 20% efficiency for the conversion of steam to electricity or 6.7 kg of steam for 1 kWh generation). At a sale price of US$ 0.045/kWh1][1], the investments to achieve the two different levels of steam economy described in Table 7 would yield simple payback times of 5.9 and 6.6 years, respectively. Such long payback times are a barrier to efficiency improvements. Nevertheless, the motivation may come with the use of gas turbines using gasified biomass. Less demand for steam helps the utilization of gas turbine-based cogeneration systems, which are characterized by higher electric efficiency than steam turbines and, consequently, produce less steam per unit of electricity generated. Thus, lower steam demand will facilitate the introduction of gas turbines. The gas turbine would be coupled with a gasifier, to convert sugarcane bagasse and trash to producer gas. As shown by Larson [1994], it is possible to export 600 kWh/t of cane processed if the mill installation operates with 280 kg of steam/t of cane and runs the year round, using baled barbojo as the off-harvesting season fuel.

Table 3. Phases of the Biomass Power Generation: Sugarcane Bagasse and Trash Project

1.	Evaluation of availability, quality and costs of sugarcane tops and leaves (barbojo) for use in gasifiers
2.	Evaluation/development of alternatives for green cane harvesting
3.	Atmospheric gasification tests using sugarcane bagasse and barbojo
4.	Integration of BIG/GT process in a typical sugar/ethanol mill
5.	Identification and evaluation of environmental impacts

Source: Leal, 1999

Table 4. Phase 1 results: Sugarcane residues availability (ODT, oven dry tonnes)

Sugarcane variety	Age at harvest (months)	Harvesting	Vinasse use as fertilizer	Sugarcane (t/ha)	Trash (t/ha)	Trash (% cane)
SP79-1011	15	1st cut	N	109	17.3	15.9
SP79-1011	13	3rd cut	N	88	15.5	17.6
SP79-1011	11	3rd cut	Y	79	12.7	16.1
SP79-1011	18	1st cut	N	131	18.2	13.9
SP79-1011	12	3rd cut	N	88	16.4	18.6
RB72-454	17	1st cut	N	132	17.4	13.2
SP80-1842	15	1st cut	N	131	13.6	10.4
SP80-1842	11	3rd cut	N	93	12.3	13.2
SP79-1011	7.5	5th cut	Y	60	10.8	18.0
Average from literature				86	15.21	7.9

Source: Leal, 1999

Table 5. Phase 1 results: Sugarcane residues (ODT) detailed analysis and heat content

Sample	Aspen wood	Pelletized bagasse	Barbojo from two cleaning facilities[1]		Baled barbojo
			I	II	
Detailed (ultimate) analysis % dry basis					
C	49.1	45.2	35.1	36.9	43.6
H	6.2	5.6	4.5	4.6	6.2
N	0.07	0.2	0.2	0.38	0.47
O (by difference)		43.9	31.1	32.6	39.7
Cl	0.041	0.03	0.09	0.09	0.26
S	< 0.001	0.03	0.05	0.05	0.12
Heat content, MJ/kg dry basis					
High heat value	20.0	18.3	14.31	15.12	17.4
Low heat value	18.8	17.1	13.33	14.12	16.1

Source: Leal, 1999

Note

1. Measurements performed using an intermediate station where barbojo will be sent from the field to a cleaning process to reduce impurities before being transported to the mills.

Table 6. Phase 2 results obtained from: the sugarcane dry cleaning station – Copersucar

Cane	Condition	Extractor	Initial impurity (%)[1]	Final impurity (%)[2]	Sucrose losses (%)[3]
Integral	Pre-harvest burning	-	2.80	0.74	0.21
Integral	Green cane	-	10.18	2.10	0.15
Chopped	Green cane	On	8.11	3.52	0.36
Chopped	Green cane	Off	12.32	4.88	0.92

Source: Leal, 1999

Notes

1. Total impurities (mineral, vegetable) on wet basis, before processing at cleaning station
2. Total impurities after processing at cleaning station
3. Sucrose in barbojo -- not recovered

Table 7. Phase 4 results: reduction in sugarcane processing steam consumption[1]

	Business as usual	First stage of economy	Second stage of economy
Steam consumption	500 kg/tC	340 kg/tC (for 50% anhydrous/ 50% hydrous facility)	280 kg/tC
Total investment (US$)	-	4.5 million	7.0 million
Amount of steam saved (kg/year)	-	115 million	158 million
Amount of steam saved per unit of additional investment (kg/US$/year)	-	25.5	22.6

Source: Leal, 1999

Note

1. For a mill operating for 180 days/yr with the following production statistics: amount of ethanol production 355m^3/day (63.540 m^3/yr); amount of sugarcane processed 4.000 t/day (720,000 t/yr).

Such technology would improve payback times to 3 or 4 years.

Another important aspect of the use of biomass as a source of energy deals with the environment. Results from the UNDP/Copersucar project identify the net potential reduction in C emission (from CO_2 only) due to the use of sugarcane residues in a range of 11.2 to 7.0 MtC/yr, with the higher value associated with transportation of all residues to the sugar mill and the lower one with transporting only 50% of the residues as chopped cane from the field to the mill. Such figures are considerable, since they will add to the 9.5 MtC/yr already saved in the ethanol fuel program, yielding 19.7-16.5 MtC/yr abatement of CO_2 emissions in the energy sector. This compares with the estimated 12.74 million tC/yr that is being abated as a consequence of the current use of the liquid (ethanol)

and solid (bagasse only) part of sugarcane as sources of energy (Table 8).

2.4. New technologies for ethanol production

As discussed earlier, large amounts of electricity can be generated using all solid residues from sugarcane. But an economic analysis shows that better revenue can be obtained if solids can be converted to ethanol. Another strong argument to pursue this route is that sugar-mill owners have much more expertise in the alcohol business than in the electricity sector. And, finally, from a much broader viewpoint electricity can be produced from an endless series of primary fuels, while oil-derived liquid fuels can only be replaced by few renewable alternatives (ethanol and vegetable oils) and, at commercial scale, essentially by ethanol.

Conversion of lignocellulosic material, such as bagasse, to ethanol is an evolving technology. Light acid hydrolysis and mainly enzymatic hydrolysis are promising routes. In recent years, enzymatic hydrolysis advances allowed the PCAST [1997] to conclude that the product will be commercially available by 2005. A recent report [CEC, 1999] concludes it should be possible to produce ethanol in California at a cost of US$ 0.26/l in a few years.

Copersucar has been involved in the commercial development of a light acid hydrolysis process – Organosolv – for many years. In 1999 it began assembling a pilot unit with a capacity to process 10t of bagasse (50% moisture) per day in an existing mill where all the necessary infrastructure is available. Since the raw material is already available at no cost, no investment is required for infrastructure, and the low sugar concentration obtained in the juice that is sent to fermentation would not affect the processing cost since it will be blended with the much larger amount of high sugar content juice obtained from sugarcane milling. It is highly probable the process will be commercially feasible.

Preliminary results show that ethanol produced from only C6 fraction of sugars, with a theoretical limit of 110 l per t of bagasse (50% moisture), may yield 90 l [Leal, 1999]. This means an additional production of 22 l of ethanol on top of the 88 average l already produced per t of cane.

The enzymatic route has attracted the interest of many foreign investors and project developers but no real business has been clinched. One of the latest interested partners is 2B AG from Switzerland. The company has technology to convert bagasse and trash in ethanol, protein and fiberboard and has demonstrated an interest in constructing a pilot plant in Brazil.

3. Ethanol and fuel cells

The emerging interest in fuel-cell cars in the near future is increasing the interest in liquid fuels since most experts believe that fueling a car with hydrogen is complex and conflicts with the present liquid fuel distribution system, which represents almost US$1 trillion in investment worldwide.

Initially, fuel cells cars will use methanol (derived mainly from natural gas) but a significant effort is being made by oil companies to transform naphtha into H_2 in a simple and inexpensive way on board the vehicle.

Table 8. Net CO_2 (equivalent) emissions due to sugarcane production and utilization in Brazil (1996) (measured as carbon)

	10^6 tC (equiv.)/year
Fossil fuel utilization in the agro-industry	+1.28
Methane emissions (sugar cane burning)	+0.06
N_2O emissions	+0.24
Ethanol substitution for gasoline	-9.13
Bagasse substitution for fuel oil (food and chemical industry)	-5.20
Net contribution (carbon uptake)	-12.74

Source: Carvalho, 1997

Ethanol producers in Brazil, considering their economic interest and the environmental advantage of a renewable fuel, are interested in its use in fuel cells. On the other side, Daimler-Benz-Ballard (DBB), probably the leading organization in the development of a commercial fuel-cell automobile, is also interested in the use of ethanol. An agreement has been established between DBB and the National Reference Center of Biomass (CENBIO), in Brazil, to optimize an on-board re-former suitable to convert ethanol into H_2. The agreement involves the development of the ethanol re-former by DBB, while CENBIO will design the necessary changes in ethanol processing and handling to guarantee that impuritiesdo not impair fuel cells operations.

4. Future trends

From the analysis presented here, it is clear that biomass energy in Brazil is strongly based on sugarcane plantation. The total sugarcane plantation area (4.1 million ha in 1999) is being exploited more for energy production (2/3 of the planted area) than for food (1/3 of the planted area).

The planted area, the national sugar demand, the size of the international sugar market, and the future of the ethanol program are all interlinked parts of this economic activity. In 1999 Brazil exported 11 million t of sugar – a little less than half the amount traded internationally on the free market. The outlook for keeping such a large share of the international market is uncertain due to the wide availability of sugar produced in several countries from sugar beets, corn, potatoes and wheat (in temperate countries) and from sugarcane (in tropical countries). Furthermore, sugar, as with most commodities, shows a long-term trend of price decline (Figure 5). The trend is 15% price decline per decade. Obviously, price spikes will always occur as a consequence of seasonal variations in global yields and demands. On the other hand, Figure 6 shows a trend of rising prices for gasoline. This means that as time goes by economic competition between ethanol and gasoline will improve in favour of ethanol. On top of that, opportunities to improve process efficiency are greater for ethanol than for gasoline, which is being

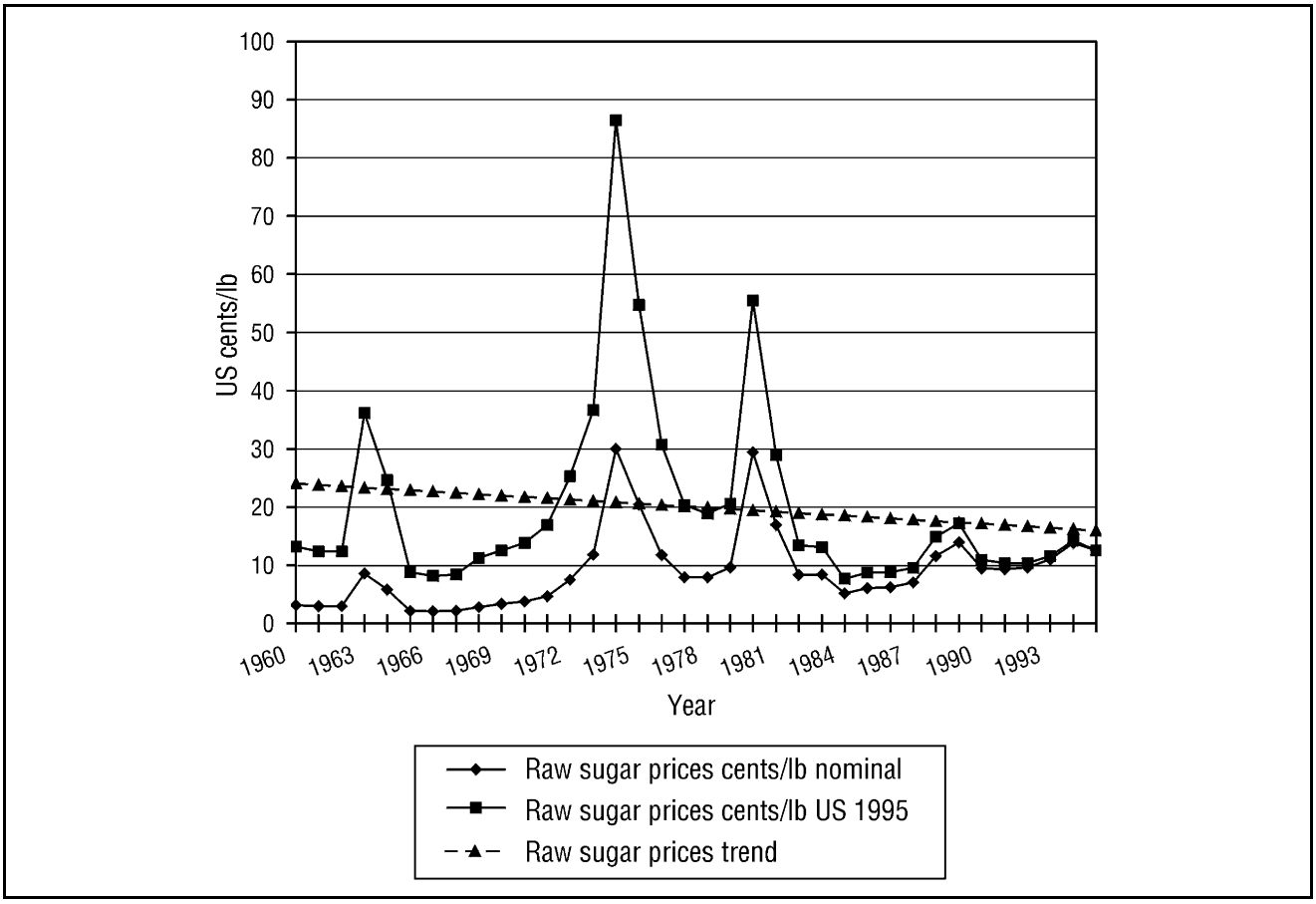

Figure 5. Raw sugar prices (1960-1996)

produced by large multinational companies in extremely optimized ways.

Presently, sugar exported at US$ 132/t (US$ 0.06/lb) is considered the minimum attractive price for Brazilian manufacturers. Assuming an equivalence between 1 l of anhydrous ethanol and 1.5 kg of sugar, this means ethanol could be exported at US$ 198/m^3. This is almost the price at which gasoline was being sold at refinery gates in the USA at the end of 1999.

An ethanol transportation cost of US$ 3/barrel adds 1.89 US¢/l, pushing the ethanol price in a potential importer country to 21.7 US¢/l. Correcting for the lower volumetric energy density of ethanol compared with gasoline yields a price differential of 3.26 to 6.52% that should be overcharged to the client for 10% and 20% blends of ethanol in gasoline, respectively. This means a real price, based on the fuel energy value, of US$ 0.224-0.231 per l of the blended fuel. Since not all countries are able to produce gasoline at the USA price ($0.198/l), the price differential may be smaller or even non-existent[2] in other countries.

The use of ethanol blended in gasoline could have a favorable impact on several categories of countries. In the less developed, ethanol could replace lead as an octane enhancer, thereby reducing human health costs associated with the use of leaded gasoline [WEA, 2000]. For Annex I countries it could be used as a way of reducing CO_2 emissions, by far the most significant greenhouse gas (GHG) emitted from the transport sector. Ethanol used in Annex I countries could be understood as a zero C emission fuel. All CO_2 released from its combustion is removed from the air by the next sugarcane crop. The small amount of fossil fuel use in the agricultural and industrial phase of ethanol production [Moreira and Goldemberg, 1999] is occurring in the tropical producer countries and could be totally allocated as emissions associated with the production process. Obviously this is a point requiring political agreement, but it is not an important argument against ethanol use as an environmentally sound energy source replacing some gasoline: considering the full cycle analysis, each l of ethanol avoids the emissions from the equivalent of 8 l of gasoline [Moreira and Goldemberg, 1999; Carvalho, 1998], abating 0.066 to 0.132 kgC/l when used in a 10 or 20% blend with gasoline. Each l of gasoline equivalent with 10 and 20% ethanol blend emits 0.066 to 0.132 kg C less than 1 l of pure gasoline. Considering the price differential above evaluated for USA (0.024-0.031 US$/l), this is equivalent to US$ 364-235/tC abated. The value is even lower since production of gasoline in the importer country requires fossil energy yielding further CO_2 emission. Assuming an energy balance of 1 unit of fossil energy to produce 0.79 units of reformulated gassoline (RFG) [USDOE, 1994] production from oil, the use of 10-20% ethanol blend will reduce the cost of abated C due to ethanol-gasoline blend to US$289-187/tC[3].

A program of importation of ethanol from tropical developing countries could, in the short term, stimulate the sugarcane industry and achieve quite easily 10 billion l

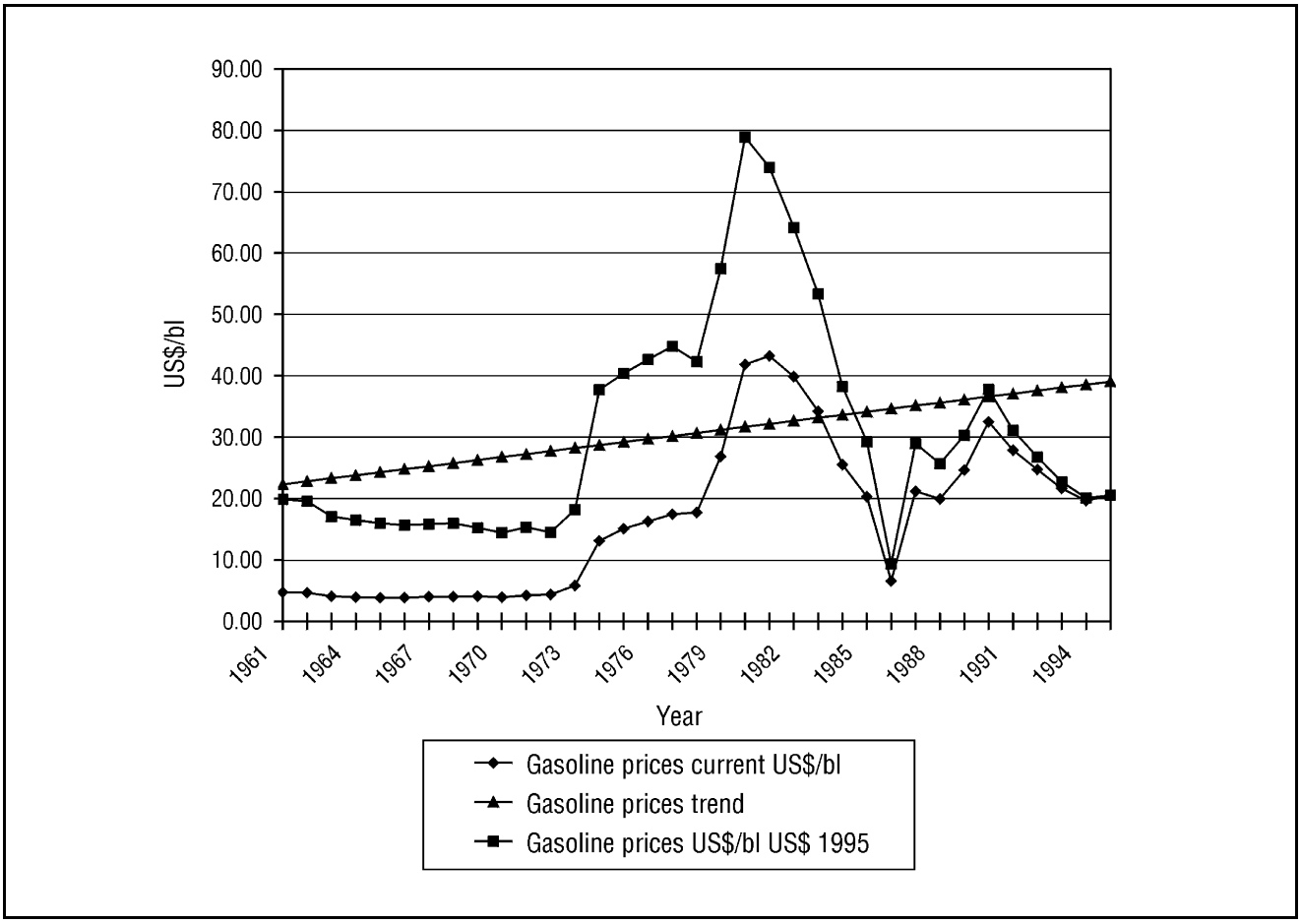

Figure 6. Gasoline prices

Source: Moreira and Goldemberg, 1999

per year of production in a few years. This would translate into 50 to 100 billion l of blended gasoline in the market, abating, in Annex I countries, 8.3 million tC/yr while pumping US$ 2 billion/yr into economies of ethanol producer countries. Such a program would involve very little transaction costs and could be expanded up to volumes of 100 billion l of ethanol per year (500 billion l of gasoline), abating 83 million tC/yr at a full cost lower than 12.0 billion US$/yr.

As fully demonstrated from the above results, such a program is limited not by economic but by political reasons. The possibility of importing 10% of gasoline consumption from countries other than the main oil exporters has economic impacts and such a program could trigger interest in the larger-scale use of ethanol in the future, displacing oil and affecting the oil industry complex worldwide.

On the other hand the creation of an international market for this new liquid fuel will help to reduce the large amount of subsidies given to the agricultural sector to keep sugar production in industrialized countries economically competitive with the low production costs of several developing countries. With emerging opportunities to commercialize ethanol, interest in sugar production may decline due to market forces or due to trade agreements between developed and developing countries involving sugar/ethanol exports.

Even considering the introduction of fuel-cell cars, ethanol has a significant opportunity for being used as fuel. Most oil industry experts believe that a hydrogen distribution network is not feasible, at least in the short and medium term. The amount of capital already invested in distribution of liquid fuel is too great to be replaced prematurely. If fuel-cell automobiles run with liquid fuels, methanol and naphtha are, at the moment, the major candidates considered.

Methanol will be used in the first commercial fuel-cell automobiles, which should be in the market by 2004. But the use of methanol has some disadvantages relating to risks involving human misuse, since it is highly toxic and accidents may happen. Another source of concern is the low cost of methanol as compared with oil derivatives. Methanol prices, at least for the existing demand, are half those of gasoline, since most of the natural gas used in methanol production is extracted from wells far away from natural gas consumers. If the new fuel yields half the present revenue of the oil sector a serious economic problem could arise.

Ethanol is a much safer product with respect to accidents and human health problems. It is widely known and the population is aware of its use and safe handling care. A disadvantage is the intrinsic lower efficiency in converting it to H_2 compared with that of methanol. The major advantage is carbon abatement, the large number of

jobs its production generates, and a delivery price similar to the price of gasoline. Naphtha is the preferred alternative for the oil industry. It is the nearest product to gasoline, but it has an even lower intrinsic efficiency in conversion to H_2 than ethanol has.

5. Conclusions

Several benefits have been obtained in Brazil through the production and use of ethanol as a fuel.

- Creation of more than 700,000 rural jobs with very modest investment costs.
- Development of technology for sugarcane production and processing into sugar and ethanol, increasing Brazil's capacity to act as the major player in the international sugar market.
- Creation of an alternative market for large-scale production of sugarcane, which may be very useful in the future in tropical developing countries due to the continuous price decline of sugar expected under a business-as-usual scenario.
- Demonstration at worldwide scale that a massive alternative and renewable fuel program can be carried out and implemented in less than 10 years.
- Significant savings in hard currency.
- Technological development of the Brazilian automotive sector due to the requirement of developing appropriate engine and injection systems.

Even so, many issues still must be addressed before the widespread production and use of ethanol can be expected to spread to other countries:

- Production cost must continue to decline as agricultural and industrial technologies are improved (mechanized harvesting, genetic engineering, better accounting of the proper harvesting time, reduction of energy consumed in the process, sale of electricity to the grid, etc.).
- Further interest in the automotive industry, which will be obtained through better marketing of ethanol, emphasizing its environmentally sound advantages over fossil fuel.
- Private investment, with back-up from the government, for the development of an ethanol re-former suitable for the short time operation of fuel-cell cars.
- Strong negotiation at global level, with the participation of representatives of private sector and government, to create an international ethanol market taking advantage of interest in GHG abatement in industrialized countries and the competitive cost of ethanol as compared with gasoline in some countries.
- Efforts within the Brazilian government to quantify, promote and negotiate, at an international level, the inclusion of externality costs in the price paid by consumers when using liquid fuels.
- The full use of the energy stored in sugarcane plantations is a "must" to promote its market as a renewable source of energy. Environmentally concerned societies will never buy the idea that large land areas are being immobilized for non-optimal energy production. ■

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This paper was prepared in memory of Prof. David Hall, an enthusiastic proponent of modern biomass use for energy production. His interest and knowledge in this area has been an important motivation for several Brazilians, including myself, to sustain hopes of bright prospects for ethanol.

Notes

1. Electricity may be produced and sold to the grid by independent power producers. Average sale price to the transmission network is around US$ 30.00/MWh. To promote renewable electricity generation the federal regulatory agency (ANEEL) sets maximum reference prices that can be paid by the utilities, and charged to all consumers, when acquiring such green electricity. The maximum reference price is a function of the renewable energy source and is US$ 45.00/MWh for biomass.
2. In reality the 10 to 20% ethanol blend with gasoline increases the octane rating of the fuel, which means that a higher compression ratio can be used in the engine, which increases engine efficiency. Or, for already existing engines, a lower quality gasoline can be used, saving money in its production. Any of these factors may imply a reduction of 10% in the equivalent price of the fuel blend, reducing significantly the price differential with gasoline.
3. Such values must be considered very carefully. A very small price differential between a liter each of gasoline and of ethanol yields a large value for the cost of abated C. The main issue is to calculate very precisely the cost of both fuels in a particular country. Our assumption of US$ 0.20/l for gasoline and $0.23/l of a 20% ethanol/gasoline blend in a consumer country yields a $0.03/l price differential. A 10% change in the production cost of gasoline can reduce the carbon cost to 1/3 of the value. A 10% reduction in the price of ethanol, which has been declining at 4.3%/yr in Brazil [Moreira and Goldemberg, 1999], has the same impact in two years.

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