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TOWARDS PROALCOOL II—A REVIEW OF THE BRAZILIAN BIOETHANOL PROGRAMME

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Abstract—Since the creation of the National Alcohol Programme (NAP) in 1975, commonly known as "ProAlcool", it has gone through a number of fluctuations reflecting Brazilian political, economic and energy priorities. In 1996–1997 over 175 Mt of sugarcane (65% of 270 Mt harvested) was converted to ethanol fuel. The ProAlcool started as a highly innovative programme, but in recent years has lost part of its technological zeal and in certain areas is becoming stagnant. This is due to a combination of reasons, e.g. unclear energy policy, high sugar prices in the international market and lower investment in ethanol production as a result of low international oil prices. A new impetus is needed to reflect changing economic and energy policy in Brazil. This paper reviews the implications for ProAlcool of the new economic policies and the possibilities for restructuring the programme to guarantee its survival as a pioneering and sustainable renewable energy source. This will bring new challenges, costs and opportunities to Brazilian society. © 1998 Published by Elsevier Science Ltd. All rights reserved

Keywords—ProAlcool; biomass energy; ethanol fuel; energy policy; Brazil.

1. INTRODUCTION

The sugarcane industry has historically played a significant political and economic role in Brazil. Currently this industry employs directly between 0.8 and 1 million people, produces annually some 11.2 Mt of sugar and about 13 billion l of ethanol, and saves 220 000 barrels/day equivalent of gasoline imports. The annual turnover of the industry is about US$9 billion. Since 1975 the National Alcohol Programme (NAP) has saved the country US$28.7 billion in foreign exchange by substituting for oil imports.[1]

The use of ethanol fuel in Brazil goes back to the early part of this century, although it was not not until the 1930s that ethanol–gasoline blending took place on a significant scale.[2,3] The energy crisis of the 1970s threatened the so-called "economic miracle" in Brazil. About the same time, the sugar industry made a large investment in a modernization drive in response to high sugar prices in the international market which was then put at risk when the sugar prices almost collapsed in the mid-1970s. The combination of these factors led to the creation of ProAlcool.

2. A BRIEF HISTORICAL ACCOUNT OF PROALCOOL

Different phases can be identified, each reflecting mainly the prevailing political climate of the country.

2.1. *Phase I, 1975–1979: creation and establishment of ProAlcool*

The ProAlcool was set up in November 1975 when energy supply became a main priority. The Brazilian government strategy was to prevent a slow down in energy consumption in order to maintain economic growth and, thus, the aim was to substitute imported petroleum by domestic sources as fast as possible. To this end many other plans were initiated, e.g. the Nuclear Programme and the ProOleo for vegetable oil production to substitute diesel.

The ProAlcool's main target was gasoline substitution by ethanol obtained from biomass, e.g. sugarcane, cassava and sorghum. For a variety of reasons sugarcane became the sole source of ethanol production. To implement the programme the Government cre-

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ated a full institutional framework to evaluate and finance new projects, involving various ministries and an inter-ministerial commission (CINAL) created for this purpose.

During the first few years of the programme the objective was to use the existing productive structure to install annexed distilleries to existing sugar mills and to produce anhydrous ethanol to be blended with gasoline. This first phase was marked by a difficult relationship between the Government and the multinational automobile corporations established in the country. However, it was largely thanks to government determination that the ethanol-fuelled passenger car finally succeeded.

2.2. *Phase II, 1979–1985: consolidation of ProAlcool*

The main characteristic of this phase was the agreement between the Government and the automobile industry in 1979, settling the differences and establishing a common denominator which led to the consolidation of the programme. After 1979, the Brazilian Government created the National Council for Alcohol (CNAL) and the National Executive Commission (CENAL), responsible for overseeing ethanol production targets. Although this could have resulted in a significant increase in the sugarcane plantation area, in reality this did not occur as a large part of the additional demand was met by increases in productivity.

This phase was marked by strong state intervention (although the programme was run by the private sector), the installation of autonomous distilleries in pioneering areas and large-scale production of hydrated ethanol which was used for the first time as neat ethanol. The large-scale production of ethanol was stimulated by higher oil prices and the worsening balance of payments in Brazil. The rapid growth in production of hydrated ethanol resulted in large surpluses of gasoline which had to be exported, forcing Petrobras to make costly changes to the oil refining structure.

2.3. *Phase III, 1985–1989: expansion and constraints*

The 1980s was a decade of important economic and political changes in Brazil. The economy had serious problems with very high inflation rates and foreign debt, e.g. some US$120 billion costing over US$10 billion/year to serve. Politically the country began a process towards democracy. This coincided with low international oil prices and hence oil supply problems received lower priority.

In 1984 under the new administration (the first civilian administration after the military regime), public investment and subsidies were cut. The ProAlcool credibility was still high with 94.4% of passenger cars fuelled by ethanol (Table 1). However, a downward trend was initiated caused by a combination of factors: rapid increase in ethanol-fuelled passenger cars, stagnation of ethanol production precipitated by low prices of ethanol paid to the sugarcane growers (this in turn combined with higher prices of sugar), political uncertainty toward the programme, the negative attitude of Petrobras, lower costs of imported ethanol and methanol, increased domestic oil production, international political changes after the collapse of the U.S.S.R., etc. By 1989, only 51% of new passenger cars were ethanol powered.

2.4. *Phase IV, 1990–1994: political uncertainty*

Faced with rapidly falling car sales the government issued new incentives to revive "popular" automobile models. By 1991 production increased from around 700 000 to 1.4 million cars/year. However, the major beneficiaries were popular vehicles using gasoline blended

Table 1. Sales of gasoline and ethanol automobiles 1975–1996[7]

Year	Gasoline cars[a]	Ethanol cars	Ethanol cars (%)
1975	778 920	0	0
1976	808 729	0	0
1977	748 071	0	0
1978	877 295	0	0
1979	905 706	3114	0.3
1980	626 467	240 638	27.0
1981	344 428	136 241	28.3
1982	365 399	232 575	38.9
1983	78 610	579 328	88.1
1984	33 481	565 536	94.4
1985	28 653	645 551	95.8
1986	61 915	697 050	91.8
1987	31 190	458 683	93.6
1988	77 312	566 482	88.0
1989	260 821	397 734	60.4
1990	542 740	81 650	13.1
1991	526 479	148 494	22.0
1992	476 351	194 566	29.0
1993	786 421	264 235	25.1
1994	1 134 570	141 870	11.1
1995	1 556 000	40 709	2.5
1996	1 585 000	12 000	0.8

[a]All gasoline is blended with anhydrous ethanol in varying proportions, usually 22%.

with ethanol, and not neat ethanol-powered cars, despite impressive technical advances with the ethanol engine.

In 1994 the Plan Real was launched with the objective of stabilizing the Brazilian economy and reducing inflation rates to single digits. Control of inflation became the key political issue of the time. The Federal Government policy was to force the sugar and ethanol industry to cut costs through higher productivity.

2.5. *Phase V, 1995 onwards: towards ProAlcool II*

The new administration lacked a convincing overall energy policy and especially with regard to the ProAlcool. The newly elected government's key concern was controlling inflation and subordinated many other aspects of the economy to this end. The Plan Real rapidly reduced annual inflation to 10% in 1996 and, thus, initiated a more stable economy but at the same time postponed other important reforms that needed Congress approval. The Plan Real also included the liberalization of the economy and privatization of important sectors of Brazilian economy, including areas previously considered important for national security such as the steel, mining and energy. The new administration has done little, although it has re-opened policy discussion with regard to the future direction of the ProAlcool.

The administration presently (1997) intends to speed up the privatization process and this could have profound implications for the country in general and for the energy sector in particular. The extent of such reforms will be determined by the political support of Government in Congress. For example, the Government of the State of São Paulo has already announced that the State's hydro plants will be sold to the private sector in 1997, while at the Federal level, the government has passed legislation aiming at the eventual privatization of Petrobras and the energy utilities.

The long-term future of the ProAlcool requires a clear policy and a commitment to change by those involved, who must adapt to changing circumstances. In the 1970s energy policy was a central concern, but this was replaced in the 1980s by environmental concerns. In the 1990s the main issues are privatization, increased competition, globalization and decentralization of the energy sector.

The energy industry, thus, needs to rethink its future since it is going through many changes that will have profound implications for the country in general and the ProAlcool in particular. The State oil monopoly (Petrobras) will eventually come to an end and this will mean greater competition; the same applies to the electricity generation industry.

Currently (beginning of 1997) there is not, as yet, a clear policy with regard to ProAlcool, although one is beginning to take shape. It will take some time to emerge because of the complexity, diversity and conflicting interests associated with the ProAlcool. For example, it is known that the Ministerio da Fazenda (Treasury) regards the control of public expending, the Plan Real, etc. as priorities rather than the ProAlcool, while the Ministry of Trade, Industry and Tourism (MICT) gives ProAlcool higher priority because of its concerns with socio-economic issues. On the other hand, there cannot be price liberalization without first ending the present energy structure, in particular Petrobras's oil monopoly.

2.5.1. *Price liberalization*. Price liberalization is feared by some, although it is welcomed by many, particularly the most innovative-minded ethanol producers. The reason is simple: through price policies, the government has exerted considerable control and influence on the programme and less government interference means more freedom of action for the sector.

With price liberalization, two main hypotheses are beginning to emerge in which subsidies will gradually be reduced: (i) creation of a "green tax" on all polluting fuels in favour of non-polluting ones such as fuel ethanol; and (ii) the abolition of taxes currently charged to ethanol by the state governments, although there is some opposition as they are an important source of income to the State. Two further alternatives are being suggested for ethanol fuel:

2.5.2. Anhydrous ethanol. Anhydrous ethanol is blended with gasoline in varying proportions, but usually about 22%. This poses little problem since the price difference with gasoline is small (about 4–6%) so that any price increase could easily be absorbed in the price of gasoline.

2.5.3. Hydrated ethanol. This is used as neat ethanol in 100% alcohol-fuelled passenger cars and presents major problems, because it still requires subsidies to be able to compete with gasoline, thus, satisfactory alternatives need to be found. However, in the short term at least, a solution is apparent with the gradual phasing out of ethanol-fuelled cars, as shown in Table 2. The problem is that the anhydrous ethanol market must grow much faster to absorb the surplus of hydrated ethanol.

This will require modifications of the autonomous distilleries to convert hydrated ethanol to anhydrous ethanol. The required equipment modifications include the azeotropic recovery and concentration columns. Investment and operational costs can be high, but since many distilleries are already equipped this should not be a difficult problem to overcome in most cases.

In the immediate term there seem to be three possible alternatives: (a) simply end the production of hydrated ethanol while increasing the requirement for anhydrous ethanol, e.g. by increasing ethanol blends to, say, 25% and through higher car sales; (b) finding other alternative uses, e.g. agricultural machinery, public transport using diesel–ethanol blends in modified diesel engines, expansion of the ethanol-based chemical sector, etc.; and (c) continue to use the so-called "conta-petroleo" to subsidize hydrated ethanol, currently estimated at R$1.4 billion annually (about US$1.3 billion). However, this last option should only be considered as a short-term solution.

The State of São Paulo could consider the following alternatives: (a) increase the price of anhydrous ethanol to parity with gasoline; and (b) maintain subsidies to hydrated ethanol using the "conta-petroleo". This State is responsible for 70% of sugarcane production, contributing US$6 billion annually to its economy and 26% of taxes. Approximately 1.8 million ethanol-powered cars (40% of Brazil's total) are registered in São Paulo State.[1]

The present Federal government inherited an old and complicated domestic energy price structure that will take time to change. The most important policy change so far has been the ending in 1994 of the "unifying fuel price", e.g. the application of a single price for the whole country regardless of transportation and transmission costs. The ending of the unifying fuel price will have important implications, since gasoline prices may come down in some parts of the country while going up in others. For example, under the old structure a barrel of diesel oil cost the same in São Paulo as in the Amazon, yet to transport this barrel of diesel to such remote areas consumed a further two barrels. While these changes can make local energy sources more competitive, the immediate result will be higher energy prices in remote areas of the country.

Petrobras's future is very important as this will certainly have a significant impact on ProAlcool. A new law is currently being discussed in the Brazilian Senate that will end the Petroleo Brasileiro S.A (PETROBRAS) oil monopoly. The main points of the new law are: (a) creation of an National Council for Energy Policy (CNPER), answerable directly to the president and coordinated by the Ministry of Mines and Energy (MME); (b) regulation of the oil industry by the newly created National Oil Agency (ANP), which will be responsible for oil exploration, development and production and oil companies will have to bid for new contracts; (c) petroleum and natural gas derivatives will be sold directly by the distribution companies; (d) the main consumers of oil and natural derivatives, e.g. chemical, petrochemicals, etc., will be able to purchase their raw materials directly from oil refineries; and (e) Petrobras will remain a

Table 2. Sales of gasoline and anhydrous and hydrated ethanol in Brazil 1975–1996 (in thousand litres)[7]

Year	Gasoline[a]	Anhydrous ethanol	Hydrated ethanol
1975	14 618 813	0	0
1976	14 724 042	0	0
1977	14 103 308	0	0
1978	15 246 397	0	0
1979	15 646 105	0	0
1980	13 690 912	2253	429 179
1981	12 088 387	1 146 095	1 391 641
1982	12 427 312	2 020 912	1 674 346
1983	10 895 644	2 196 681	2 950 166
1984	9 894 057	2 081 947	4 468 165
1985	9 721 127	2 120 764	5 932 015
1986	11 005 931	2 442 431	8 226 134
1987	9 642 132	2 135 775	8 772 293
1988	9 275 811	1 986 185	9 644 107
1989	9 724 165	1 723 287	10 880 119
1990	10 123 512	1 217 548	10 211 578
1991	12 686 280	1 646 723	10 251 086
1992	11 283 320	1 902 039	9 630 725
1993	12 088 662	2 546 832	9 471 972
1994	13 365 756	2 871 024	9 767 988
1995	15 882 244	3 525 312	9 889 615
1996	19 508 504	3 959 643	9 772 097

[a]See note on Table 1.

state-owned company with 51% of the capital remaining in government hands. For the first 3 years, price adjustments to oil and gas derivatives will be determined by the MME.

It is possible to infer that the abolition of the State oil monopoly and the eventual privatization of the energy sector could enhance the ethanol program since it is already run by the private sector. Such privatization of the energy sector is likely to create a more competitive environment in which the most efficient ethanol producers will have greater freedom and opportunities, while the less efficient producers would be forced out of business. However, some experts think that such privatization could eventually kill the programme given the high cost of ethanol production and the subsidies it receives.

3. SOME ACHIEVEMENTS OF PROALCOOL

The ProAlcool has gone through many ups and downs in the last 20 years, but many achievements have resulted from its existence.

3.1. *Agricultural and industrial achievements*

The ProAlcool was characterized by its innovative approach in its first 10 or so years, responding well to the programme's agricultural and technological needs. The institutional changes that took place affected more directly the sugarcane sector than the ProAlcool itself. For example, the abolition of the IAA (Sugar and Alcohol Institute), and PLANALSUCAR (National Plan for the Development of Sugarcane Agriculture), did not have any serious negative effects as many of their activities were also being carried out by Copersucar, the sugarcane cooperative. The introduction of new varieties, better field management, the introduction of stillage as fertilizer, modern harvesting systems, are good examples of improved productivity. Ethanol production increased from 2400 l/ha in the early years of the programme to 5000 l/ha and even 7900 l/ha in recent years.[4,5]

Average sugarcane yields are 79 t harvested weight/ha (55 t/ha in the northeast and 85 t/ha in the centre-south). The northeast region uses 2.2 times more labour per tonne of cane harvested than the central-south, where mechanization is much higher compared with the northeast.[6,7] A decade or so ago sugarcane was paid according to its weight regardless of the sucrose content. Today payment is according to sugar concentration (pol), which has forced the industry to select varieties with higher sucrose content.[6]

There are 143 autonomous distilleries and 203 sugar mills which are relatively well placed to invest in different opportunities, such as cogeneration of electricity, if and when electricity prices become attractive. Alternatives must be found that make the ProAlcool more competitive and in which ethanol production is just one and not the only product. More effort is still needed to cut the cost of feedstock. Improved varieties together with a better integration between agricultural and industrial sectors, promoting both green sugarcane harvesting and residues utilization, are particular points in mind. Currently over 50 sugarcane varieties are grown in Brazil, but improvement has been done mostly through traditional plant breeding methods; new biotechnological techniques are now being applied to accelerate selection and breeding.

3.2. *Ethanol production and consumption, 1975–1996*

There is a deficit in ethanol production caused mainly by increasing sugar exports (Table 4) and increased gasoline consumption (Table 1) due to the rapid growth of car sales. Ethanol shortages appeared particularly serious during the 1988 crisis and again in 1995, when ethanol consumption jumped from 11.5 billion l to 13.5 billion l leaving a deficit of 1.8 billion l of fuel alcohol which had to be imported (Tables 2, 3 and 4).[7,8]

Due to economic growth, the automobile industry foresees an annual production increase to 2 million cars in the coming years which will push up the demand for ethanol

Table 3. Exports and imports of ethanol and methanol (tonnes)[7]

Year	Exported alcohol	Imported[b] methanol	Imported[b] ethanol
1989	na	91 586	78 333
19990	29 776	459 948	677 953
1991	7111	447 476	632 947
1992	166 716	417 334	191 092
1993	213 088	403 577	374 289
1994	234 590	493 008	936 796
1995	256 064	566 991	986 441
1996	125 907[a]	555 378	683 625

[a]January–July 1996.
[b]Imported methanol January–April 1997, 235 016 t. Imported ethanol January–April 1997, 168 923 t.

Table 4. Foreign trade in the sugar and alcohol sector in Brazil, in US$ 1000 FOB[7]

Year	Sugar exports	Alcohol exports	Total exports	Ethanol imports	Methanol imports	Total imports	Net[a] balance
1989	305 671	0	305 671	15 681	11 223	26 904	278 767
1990	525 596	7407	533 002	205 533	42 574	248 107	284 895
1991	440 303	2276	442 578	225 896	71 464	297 360	145 219
1992	598 476	55 911	654 386	51 220	37 191	88 412	565 975
1993	778 942	78 534	857 476	159 474	36 220	195 695	661 781
1994	991 470	88 293	1 079 763	417 331	135 000	552 330	527 433
1995	1 918 198	106 916	2 025 114	555 474	115 783	671 257	1 353 857
1996	1 608 674	54 965[b]	1 663 639	298 031	62 942	360 937	1 302 702

[a]Net balance (positive) refers to both sugar and alcohol.
[b]January–June 1996.
Figures for January–April 1997 are as follows: sugar exports, 245 965; ethanol imports, 72 246; methanol imports, 35 957.

fuel, particularly anhydrous ethanol. Thus, a mechanism must be found to produce more anhydrous ethanol at the expense of hydrated ethanol as old ethanol-fuelled passenger cars are gradually phased out.

The coming years will be crucial for the ethanol fuel market in Brazil as much will depend on internal politics and on the economic reforms planned by the present administration. A more realistic energy policy seems likely to emerge that should include a gradual reduction of energy subsidies, including ProAlcool.

3.3. *Costs and investment in ProAlcool*

Productivity increases brought reduction in costs averaging 3·5%/year from 1976 to 1994.[5] Goldemberg[9,10] estimated that combined savings from both the agricultural and industrial sectors could reduce ethanol costs a further 23%. The potential for decreasing production costs by introducing new sugarcane varieties, improving agricultural management practices, creating new markets for sugarcane by-products, such as bagasse and other fibrous residues, co-generation, etc., is still quite considerable. However, it is particularly difficult to discuss the data on ethanol costs and subsidies because of the difficulties in finding reliable figures for both ethanol and oil derivatives. Table 5 summarizes estimated production costs of ethanol fuel from various authors. These costs excludes external costs.[11] That is, costs that are not explicitly accounted for in private decision-making which are not borne by society as a whole.

Total investment in the ProAlcool has been estimated at US$11.3 billion since 1976. This has saved the country US$28.7 billion in foreign exchange, and helped to create and maintain large employment opportunities. The industry has an annual installed capacity of 16 billion l, and has reduced car pollution levels by about 20%. In addition, fuel ethanol contributes 3% of Brazil's primary energy supply, being consumed by some 4 million ethanol-fuelled vehicles plus a further 6 million on gasoline–ethanol blends.[1]

3.4. *Social and policy issues*

The sugarcane sector employs directly between 0.8 and 1.0 million people (depending on sources), the largest in the agro-industry sector in terms of formal jobs, with 95% of

Table 5. Production costs of ethanol fuel (barrel oil equivalent)[11]

Source[a]	Hydrated ethanol US$/barrel	Anhydrous ethanol US$/barrel	Observations
Borges (1992)	51.6	42.3	Average for 1992 (Copersucar)
Borges (1992)	37.9	30.7	Estimated cost year 2000
Borges (1984)	25.8	20.6	Includes social costs
CENAL (1984)	39.1	31.7	Includes social costs
Mello & Pelin (1984)	88.4	73.1	Private cost at distillery[b]
Bird (1984)	29.8	23.9	Includes social costs[c]
CNE (1987)	22.0	17.4	Includes social costs
CNE (1987)	39.9	26.4	Includes private costs

[a]For details see Ref. 11.
[b]These costs reflect an inefficient distillery in the northeast region.
[c]Includes social costs of an efficient distillery in the centre-south region.

workers legally employed with a minimum wage 1.35 times greater than the national minimum wage.[1] Ethanol production also has a relatively low index of seasonal work[12,13] contributing to stable employment in sugarcane growing areas. In addition, in order to create a job in the sugarcane–ethanol industry requires an investment of about US$11 000, compared with US$220 000 in the oil sector, US$91 000 in the automobile industry[1] and US$419 400 in the metallurgical industry.[14] A large number of the new jobs are manual intensive, e.g. harvesting, which is very important in a country where low cost employment generation is vital for its large semi-skilled and unskilled labour force.

Increasing mechanization, e.g. harvesting of sugarcane, is becoming a serious issues in many sugarcane producing areas. Currently 20% of São Paulo sugarcane is mechanically harvested and this is expected to reach about 50% in the next decade. This will certainly cause an impact on employment, e.g. in 1996 alone some 1500 sugarcane workers lost their jobs in São Paulo since manual harvesting costs US$4/t compared with about US$2/t by mechanical means. It is increasingly clear that the industry is heading for important changes that will have a significant impact on the labour market, e.g. there will be less manual jobs and an increase in the semi-skilled and skilled jobs, linked to harvesting equipment. Experts agree, however, that topography will limit the mechanization process to about 50% of the whole crop.[15]

4. ENVIRONMENTAL IMPLICATIONS OF PROALCOOL

It is widely accepted and documented that, in general terms, the positive environmental aspects of ProAlcool far outweigh its potential damage. The environmental impacts of ProAlcool have to be assessed both at the production and consumption levels. Burning sugarcane fields, for example, which is still a common practice in Brazil, is a major concern because of the environmental and health hazards associated with this activity. Burning sugarcane facilitates harvesting but it reduces a significant part of its energy potential, in addition to being responsible for about 25% of total CO_2 emissions produced by the sugar and ethanol industrial sector. It is estimated that about 100 Mt of trash is burned annually in Brazil. Some preliminary results from field temperatures measured during sugarcane burning[16] seem to indicate a loss of between 0.7 and 3% of sugar before harvesting caused by high temperatures during burning. Another interesting finding is that the higher the field temperature and the lower the air humidity, the higher the sugar losses.

Mechanical harvesting requires a significant amount of water for cleaning, due to the large amounts of soil attached to sugarcane stalks (about 5 kg dirt/t of sugarcane), requiring good cleaning before the fermentation process. However, it is generally accepted that the dirt could be reduced to below 1 kg/t if current engineering knowledge was applied in machine design. Although in many parts of the world cleaning when dry is the most commonly used method due to lack of water, this is not necessarily the case in Brazil, where often between 500 and 2500 l of water/t sugarcane are used in this process at the mills where the cleaning takes place. Improved cleaning methods could decrease the amount of water use and, in certain cases, eliminate water use altogether if dry cleaning methods were used.

The production of stillage on a large scale has been another major environmental preoccupation because of its large pollution potential. Various methods have been used with varying degree of success, e.g. use as a fertilizer, pond disposal, biogas production, etc. Most of the technical problems have been overcome, but associated disposal costs often remain a problem. New biodigestion alternatives are being investigated that could significantly reduce the pollution potential of stillage while reducing costs.

Ethanol fuel has played a significant role in reducing pollution in large urban centres, especially in the São Paulo metropolitan area, where the air quality would otherwise be much worse. Specific details are not available, but estimates put the pollution at about 20% lower than without ethanol-fuelled cars. Other pollutants such as CO and HC have also declined, while NO_x emissions are comparable with gasoline.[17] Table 6 illustrates the level of emissions from ethanol and gasoline in a typical 6-year-old car in Brazil as determined in the PROCONVE (the Automobile Air Pollution Control Programme).

Fuel ethanol also helps to slow global warming by recycling carbon dioxide since the production process uses only a small amount

Table 6. Automobile air emissions as established by PROCONVE[a] and emissions of a typical 6-year-old car in Brazil, g/km[11]

	CO	HC	NO_x	Aldehydes
Gasoline	22	2.0	1.9	0.04
Ethanol	16	1.6	1.8	0.11
PROCONVE (1988–1991)	24	2.1	2.0	—
PROCONVE (1992–1996)	12	1.2	1.4	0.10
PROCONVE 1997	2	0.3	0.6	0.02

[a]Programa de Controle de Poluicao de Veiculos (Automobile Air Pollution Control Programme).

of external fossil fuel, mainly diesel for farm machinery operation. The bagasse provides all the required thermal energy and 92% of the electricity needed in the process. The carbon dioxide is released at different stages: (i) when sugarcane is burned in the field; (ii) when the bagasse is burned in the boilers; (iii) in the fermentation process; and (iv) when the ethanol burns in the car engines. Some estimates indicate that the production and use of 1 l of ethanol to replace gasoline avoids the emission of 0.54–0.57 kg of carbon as carbon dioxide, which is a 90% reduction over gasoline.[9] In addition, all carbon originates from sugarcane photosynthesis presenting a net savings in CO_2 emissions of about 12 Mt carbon/year or 46 Mt CO_2 equivalent, corresponding to about 20% of the CO_2 emissions from fossil fuels in Brazil.[17]

5. SOME POSSIBLE ALTERNATIVES

A major concern of the sugar and ethanol industry has been to find new economic opportunities, in particular to solve problems posed by residues, such as bagasse, stillage and other by-products. A number of possibilities have been tried or are being investigated, with varying degrees of success: (i) co-generation of electricity from bagasse and tops and leaves; (ii) utilization of bagasse as building material, furniture, paperboard and for charcoal production; (iii) production of animal feed; (iv) production of furfural, paperboard; (v) utilization of by-products, e.g. yeasts; (vi) improved methods of stillage disposal, etc. (it is clear that ProAlcool's future will be enhanced greatly when the distillery becomes an integrated production system in which ethanol production becomes just another product); and (vii) production of additional ethanol from residues, e.g. bagasse and trash, using hydrolysis technology.

Co-generation using sugarcane bagasse, tops and leaves is regarded as one of the most promising and cheap alternatives if: (i) a satisfactory price structure for electricity can be agreed; and (ii) this can be combined with the introduction of advanced gasification technology. Brazil is facing a serious energy supply challenge due to a combination of previous low investment in the energy sector, high energy demand (e.g. 8% increase in 1995 in the electricity sector), and the increased exploitation of the most economic energy sources. Privatization of the electricity utilities is being seen as a partial answer to the problem but cannot be the solution unless other alternatives can be found. It is estimated that to cope with the extra electricity demand some US$6.4 billion would need to be invested before the year 2000. Brazil's current installed capacity is about 60 000 MW, but the need is 80 000 MW by 2000 and 97 000 MW by 2005.[18]

Co-generation is a potential source of revenue in the short term if investment is made to install updated technology. This could represent an additional installed capacity of about 9000 MW and could generate electricity throughout the year. The estimated energy potential from surplus bagasse, after supplying all the energy needs to the sugar mills and ethanol distilleries is 6000 MW.[19] However, only a small fraction is being presently used mainly due to policy differences over the electricity price to be paid to the producers. In 1995 there were 12 distilleries with a installed capacity of 114.8 MW and with a surplus capacity of 17.6 MW. Excess capacity has been sold to the electricity utilities in the State of São Paulo at prices between 0.011 and 0.035 Reais/kWh, but resold to consumers at 0.07 Reais/kWh.[11] Currently such tariff are equivalent to between US$19–22 MWh and in some cases US$30 MWh against a marginal cost of approximately US$47 MWh. In 1991 the World Bank estimated the marginal cost of co-generation in the southeast region at US$67/MWh. Currently the electricity utilities pay US$32/MWh for electricity bought from Itaipu Dam.[18] Co-generation is also attractive because it complements hydroelectricity during the dry winter months.

Despite the obvious potential of cogeneration, it has also its drawbacks: (i) legal restrictions, e.g. private capital is restricted in the electricity generation industry; (ii) long life cycle of existing electricity generation plants which limits large-scale investment in co-generation in the short to medium term (most investment has been limited to replacing old equipment); (iii) short harvesting cycle of sugarcane (6–7 months), which acts as a barrier to year-around generation unless appropriate storage occurs; (iv) difficulties in connecting to the national or regional grids in the more remote rural areas; and (v) low tariffs as discussed above.

The non-utilization of yeast from the ethanol industry is an example of a wasted commercial opportunity. For each litre of ethanol about 100 g of dry yeast is produced which can have many different uses e.g. vitamins, additives, etc. The market potential is 1.3 Mt worth US$260–325 million. It is only recently that this market has been exploited but almost all is exported. An additional factor, often not fully considered, is the role played by ProAlcool as a regulator of international sugar prices. For example, if the 1996–1997 sugarcane harvest of 270 Mt were all converted to sugar, this would have resulted in more than 27 Mt of sugar. The domestic sugar market in Brazil utilizes 24% of this production. This means that Brazilian sugar exports could theoretically increase from the 3.5 Mt to some 21 Mt in a very short time, which could have a major impact in the international sugar market.

Ethanol fuel production represents a notable source of income for many Brazilian households and, thus, if ethanol production was to be suddenly reduced, this would have a major impact on many Brazilians.

6. INSTITUTIONAL TRANSITION

The ProAlcool was officially ended on 15 February 1991, when the CNP, CNAL and CENAL were closed down. Only the interministerial commission for alcohol (CINAL) remained with the following tasks:

- coordinate actions of different governmental agencies with responsibilities in the sugar and ethanol sector and collaborate in policy formulation to develop the sector;
- follow the implementation of actions recommended by the commission;
- analyse and propose the necessary mechanisms to stabilize the sugar and alcohol sector and search for sustainable production
- support long-term planning of the sector;
- re-examine the level of governmental intervention and amend legislation accordingly;
- promote the scientific and technological development of the sector;
- promote the introduction of and utilization of new technologies for cost reductions, diversification of products and by-products, and increased productivity;
- follow the outcomes of proposed actions and recommend changes accordingly.

The bodies represented in the CINAL and their main functions are summarized in Table 7. However, this should not be regarded as the existence of a coherent energy policy, far from it, although a more coherent policy

Table 7. Official bodies represented in the National Interministerial Alcohol Commission (CINAL) and main responsibilities

1. Ministry of Industry, Commerce and Tourism:	Policy to develop the industry, commerce and services Sugar and alcohol policy formulation Industrial property, brands, patents and technology transfer Foreign trade
2. Ministry of Mines and Energy	Petroleum, fuel and electricity (including nuclear)
3. Ministry of Finances	Prices and tariffs in general
4. Ministry of Agriculture, Division of Supply and Agrarian Reform	Technology research in agriculture and husbandry Agrarian reform
5. Ministry of Science and Technology	National policy for science and technology research
6. Ministry of Environment, Water and Legal Amazon	Planning, coordination, supervision and control of actions related to environment and water resources
7. Ministry of Planning and Budget	Formulation of national strategic planning

may eventually be put in place. It is an irony that Brazil is reducing its support for renewable energy at a time when most of the industrial world is increasing it, as, for example, in the U.S.A. and the E.U. Most of the world future energy scenarios include renewables as a major component of the energy matrix, particularly biomass energy.

7. CONCLUSIONS

The ProAlcool has gone from a highly innovative period to almost technical stagnation. The high governmental intervention of the early years has been replaced by a more conservative attitude towards subsidies and by a lack of clear direction with regard to energy policy.

The most important advances in productivity, both agricultural and industrial, have taken place in São Paulo State and to a much lesser extent in the Alagoas State in the northeast. São Paulo State also has absorbed most of the increase in sugarcane planted area and ethanol production. This may have resulted in greater regional inequality but it has guaranteed internal ethanol demand while increasing sugar exports. The future of ethanol in Brazil will depend on the political reforms taking place in the country. Hopefully these reforms will create the grounds for a more realistic energy policy in which ethanol will play a vital role.

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