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ALCOHOL FROM PLANT PRODUCTS: A BRAZILIAN ALTERNATIVE TO THE ENERGY SHORTAGE

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I. INTRODUCTION

The "oil crisis" of 1973 has affected Brazil in a very harsh way mainly for two reasons:

I. The development patterns of the country in the past have been such that the participation of petroleum in the energy balance has increased from a very modest 9.2% in 1941 to 28.0% in 1952 and to 44.8% in 1972 (Wilberg, 1974).(Fig. 1)

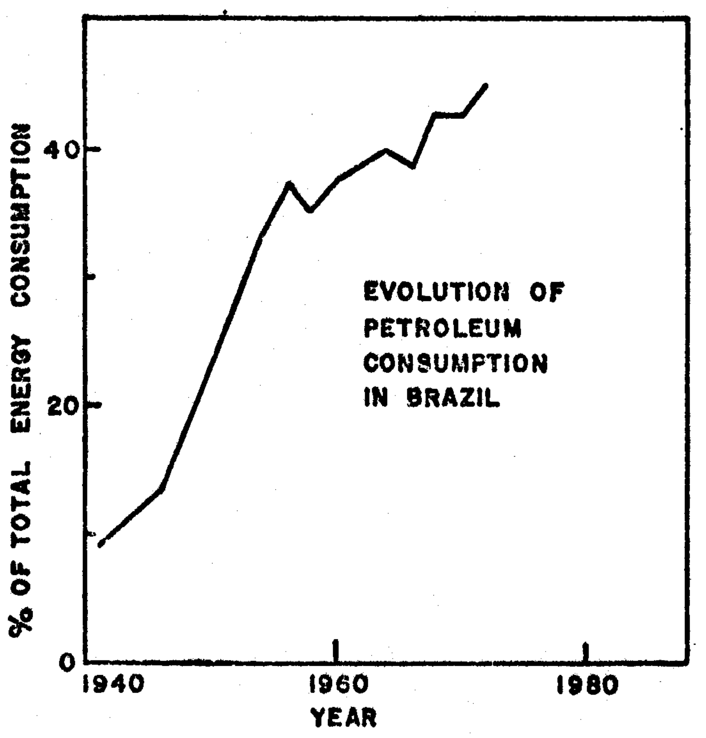

Fig. 1

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These patterns are apparent in the usual way well known to americans for many decades: cities and roads clogged with cars, air polution and deterioration of the quality of life in urban centers.

II. Brazil produces only 20% of the petroleum it consumes despite the efforts of PETROBRAS - the state owned oil company - to find oil so far with little success except in the continental platform near Campos, in the State of Rio de Janeiro, in the southern part of the country. The remaining 80% (approximately 700.000 barrels per day) has to be imported at a cost of more than 3 billion dollars a year in 1976. This weights strongly in the foreign trade balance of the country which has to make an enormous effort to export products (mainly minerals and agriculture products) to compensate for that.

The development patterns which "modernized" the southern part of Brazil - in the sense of introducing the last gadgets and products of industrialized countries - benefited so far only approximately 20% of the inhabitants concentrated in large cities with the unpleasant consequences pointed above. This fraction of the population corresponds to almost 20 million people which is in itself a large population.

An interesting quantitative indication of the "patterns of consumption" adopted in the last decades in Brazil is the number of automobiles that has grown from a few thousandts 30 years ago to about 5,000,000 in 1975. The country has clearly entered in the vicious circle of more cars, more roads, more cars and so on. The transportation of goods and services shifted to road transportation thanks to often disguised subsidies for road construction with the result that the energy spent in road transportation is approximately 83% of the total (Colombi,1975) as can be seen in Table I.

TABLE I

Energy in transportation of merchandise	
Sector	Energy used (%)
Road	82.82
Rail	4.88
Ship	7.14
Air	4.41
Others	0.76
Total	100.00

Some efforts have been made in the last two years to change this situation and the bulk of the government actions have been in the direction of reducing gasoline consumption in private cars in roads and cities. An interesting point to stress is that most of the suggestions to that effect originated in the academic comunity, in particular on the studies of our own group at the University of São Paulo.

The package of measures adopted about one year ago is the following:

a. limitation of the maximum speed on roads to 50 mph.
b. gradual banning of cars from the center of large cities to discourage people to drive their own cars to work or shopping.
c. improvement of the bus system with the introduction of "executive" buses and exclusive bus lanes.
d. closing of gasoline stations in the evenings and weekends.
e. gradual price increase which makes gasoline in Brazil one of the most expensive in the world.

A precise evaluation of these actions does not exist yet but no great increase in gasoline consumption occurred in the last year which is encouraging.

However some of the more drastic suggestions made by us were not adopted, such as allowing the circulation of cars only in alternate days according to the last digit in their license plates (odd digit, odd days; even digit, even days) or just plain rationing of gasoline according to quotas. Limits to the power of cars produced by the manufacturers (which is a better gasoline saving measure than velocity limitation) were also not accepted.

Under these conditions although many industries, buses and trucks are shifting away from gasoline to Diesel oil (which is cheaper) prospects for the future are bleak.

The Brazilian Energy Balance of 1977 shows that quite clearly. (Figure 2)

Projections are made up to 1985 and what can be seen is that the consumption of liquid combustibles is expected to grow steadily to the equivalent of 1.200.000 barrels a day in 1985 (a 50% increase in 10 years).

II. SOLUTIONS

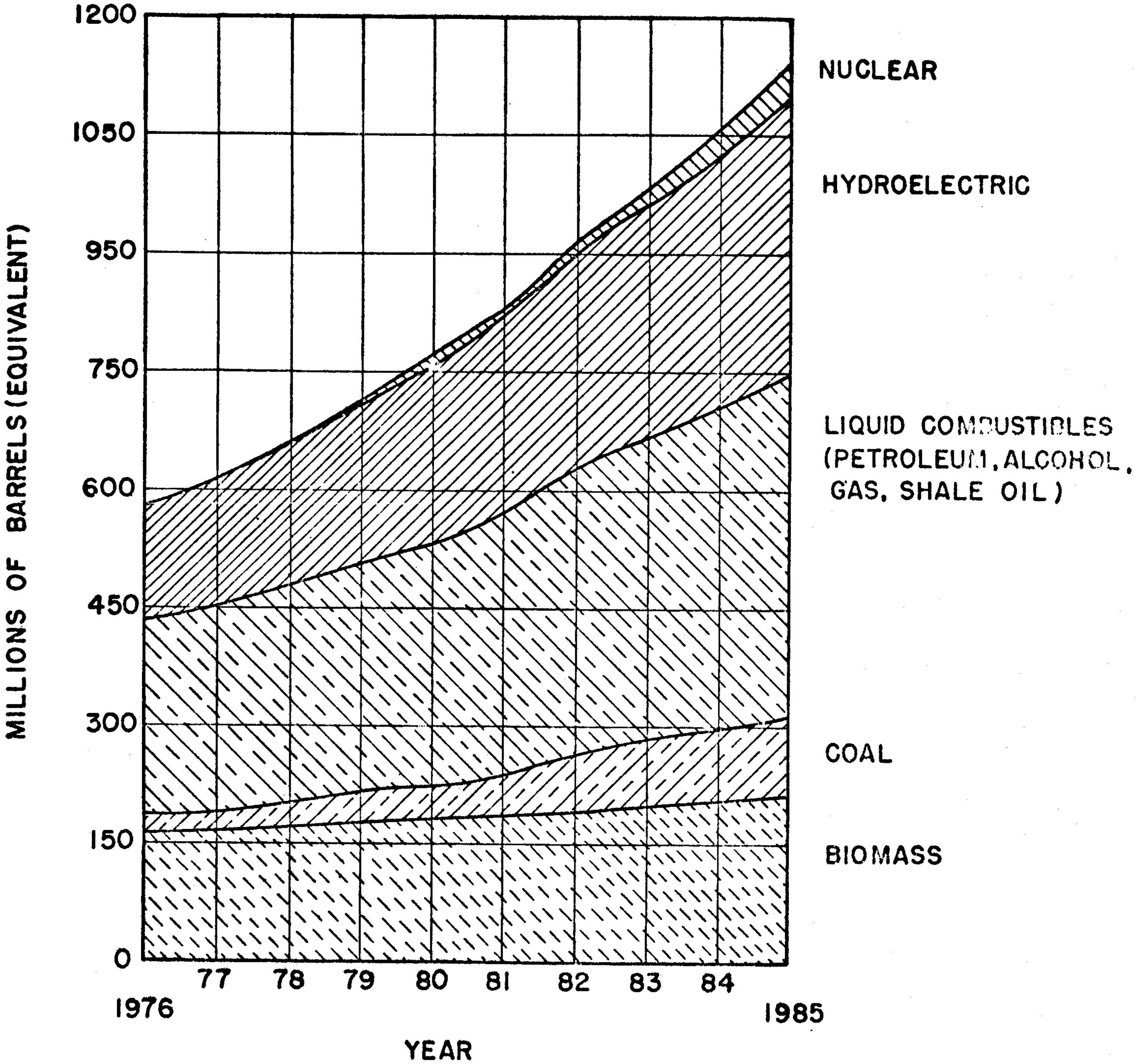
To attenuate this situation a larger emphasis is being put in hydroelectric power production because the country still has many untapped water resources . Unfortunately most of the remaining large waterfalls are located in the large affluents of the Amazonas River (Tocantins, Araguaia, Xingu, Tapajós, Cotingo and Trombetas) which are at least 1,000 miles from the large consuming centers in the southern part of the country (Goldemberg, 1976). There exists here a great challenge to move production centers near these energy sources or to develop methods of carrying energy to very large distances either by transmission lines or in the form of processed materials such as aluminum or other products which are energy intensive. In addition to that there are hundreds (may be thousandts) of small rivers which can be used for hydro electric production using the new techniques of "bulb type" generators. The emphasis on bigness which is copied from industrial nations has relegated these projects to a low priority with the present results: large urban concentrations that require huge power plants and as a result high pollution and a deterioration of the living conditions of cities.

A shift of emphasis on the direction of "small is beautiful" is not in sight but the pressures for alternative solutions are mounting with a non-negligible chance of success.

Established habits are however hard to change specially if these habits have behing them strong economic interests such as the car manufacturers. Facing however a strong public opinion pressure to save gasoline (and other oil products) a very determined effort by the government was made to "save" the automobile and the consumption habits that go with it.

This is probably the explanation for the adoption of the "Alcohol Program" by the brazilian government. Again the suggestions for this program originated in the academic community. The basic idea is to substitute gasoline partially (or totally) by ethyl alcohol (ethanol) in gasoline driven cars and Diesel engines (Goldemberg, 1976).

Technically the idea is feasible: present internal combustion engines can use or be converted to run on ethanol and the huge amounts of alcohol needed can be produced in Brazil.



SOURCE: O BALANÇO ENERGÉTICO BRASILEIRO - MINISTÉRIO DE MINAS E ENERGIA - 1976.

Fig. 2

III. TECHNICAL PROBLEMS IN THE ENGINES

At first glance it might seem that the use of ethanol is not such a good idea because it has a calorific content 39 % smaller than gasoline (Stumpf, 1975, 1976, 1977). Table II

TABLE II

Energy content of combustibles	
Gasoline	10.500 kcal/kg
Anidrous ethanol	6.400 kcal/kg
Anidrous methanol	4.700 kcal/kg

One could conclude from this table that the consumption of alcohol is $(\frac{10.500}{6.400} = 1.64)$ 64% higher than gasoline. That is not so: there are a number of other factors to be taken into account.

The first one is that the power of an engine does not depend on the calorific content of the liquid but on the energy contained in the combustible gas mixture in the cylinders (the combustion energy).

In addition the power depends also on other facts such as the thermal efficiencies and a cylinder filing factor that has to do with the number of molecules after combustion; this number is larger for alcohol than for gasoline. Taken all these factors into account it turns out that

$$\frac{(\text{Power})_{eth}}{(\text{Power})_{gas}} = 1.18$$

A motor running on ethanol has 18% more power than a motor running on gasoline and this is the reason for using alcohol in racing cars. Consumption however is not the same as power . To help in this problem there is first the question of densi - ties: the density of ethanol is 0.81 and of gasoline 0.73 .

Therefore alcohol has per liter more molecules than gasoline.

There are in addition a number of other factors to be taken into consideration; the ratio R of the consumption of the two combustibles is given by

$$R = \frac{\text{consumption of ethanol}}{\text{consumption of gasoline}} = \frac{(\text{calorific power})_{eth}}{(\text{calorific power})_{gas}} \times \frac{(\text{efficiency})_{eth}}{(\text{efficiency})_{gas}} \times$$

$$\times \frac{(\text{density})_{eth}}{(\text{density})_{gas}}$$

The efficiency (liters per hp-hour or grames per kw-hour) is given by the expression

$$\text{efficiency} = \frac{\text{thermal equivalent of 1 hp-hour}}{\text{calorific power x specific consumption}}$$

and represents the energy effectively converted in mechanical energy at the axis of the motor.

Putting numbers on this expression one finds

$(\text{efficiency})_{gas} = 0{,}27$ (27%)

$(\text{efficiency})_{eth} = 0{,}42$ (42%)

which is quite a surprising result: <u>a motor running on alcohol has a greater efficiency (42%) than a motor running on gasoline (27%)</u>.

The numbers used in obtaining this result are:

	ethanol	gasoline
thermal equivalent of 1 hp-h	632.000	632.000
calorific power (kcal/kg)	6.400	10.500
specific consumption (g/hp-h)	250	220

All together one gets for R the value

$$R = \frac{(\text{consumption})_{eth}}{(\text{consumption})_{gas}} = \frac{10.500}{6.400} \times \frac{0{,}27}{0{,}42} \times \frac{0{,}73}{0{,}81} = 1.014$$

The consumption of ethanol in liters is only 1.4% greater than the consumption of gasoline.

Alcohol can be mixed to gasoline without any modification in the motors in any amount up to 20% as shown in Figure 3.

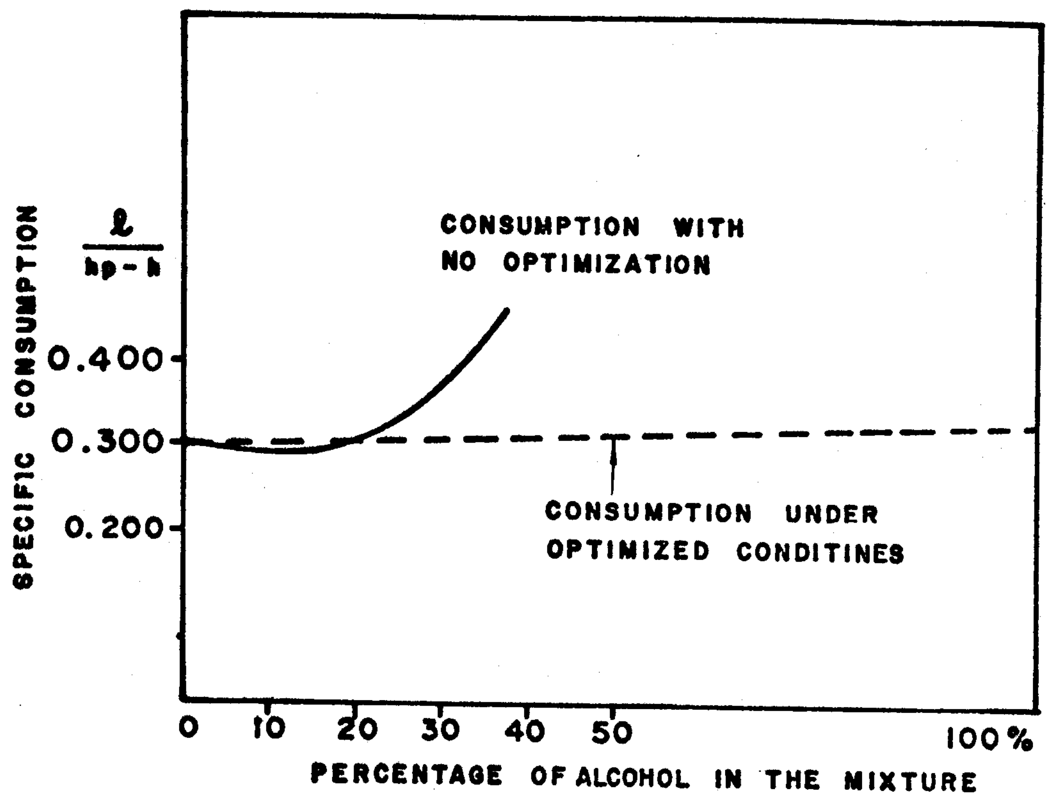


Fig. 3

Above 20% the consumption becomes prohibitively high and is not feasible. In reality one could use 100% alcohol but that would require an optimization of the motor which might be appreciable.

From the point of view of air pollution alcohol has wider limits of inflamability than gasoline which permits air-combustible mixture that burn better with the consequence that carbon and nitrous monoxide production can be lowered to a large extent. In addition to that the lead additives can be eliminated.

IV. AGRICULTURAL PROBLEMS IN THE PRODUCTION OF ALCOHOL

The estimated consumption of gasoline in 1980 is 15 billion/ liters, if no special measures to reduce it are taken.

A typical goal of the alcohol program is therefore to replace 20% of gasoline by alcohol in 1980 which will require 3 billion liters of alcohol. Table III summarizes this and other hypothesis (Licio, 1976)

TABLE III

<u>Goals of the Alcohol Program in Brazil</u>

Production (liters/year) x 10^9		Cultivated area needed in 1.000 ha of sugar cane*
Hypothesis I (1)		1.100
Hypothesis II (2)	16	4.400
Hypothesis III (3)	22	6.000
Hypothesis IV (4)	33	9.000

(1) - 20% alcohol in gasoline plus 10^9 liters for industry

(2) -100% alcohol plus 10^9 liters for industry

(3) -100% alcohol plus 50% of the Diesel oil consumption

(4) -100% alcohol plus 100% of the Diesel oil consumption

The amounts of land needed under some of these hypothesis are large but not unduly so. Brazil has a total area of 850 million hectares. Of these approximately 70 million ha are fertile lands.

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* The average agricultural productivity was taken for simplicity as 60 ton/ha and industrial output as 70 l/ton.

1 ha = 1 hectare = 10.000 square meters = 2.47 acres

One assumes that by the year 2000 the total amount of fertile land will increase to 14% (120 million ha) of the brazilian territory of which less than 20% would be necessary to produce all the alcohol needed by then (almost twice the hypothesis IV of the table above). This will correspond to only 3% of the brazilian territory (Gomes da Silva, 1977).

This situation is depicted in the map shown bellow. (Fig. 4)

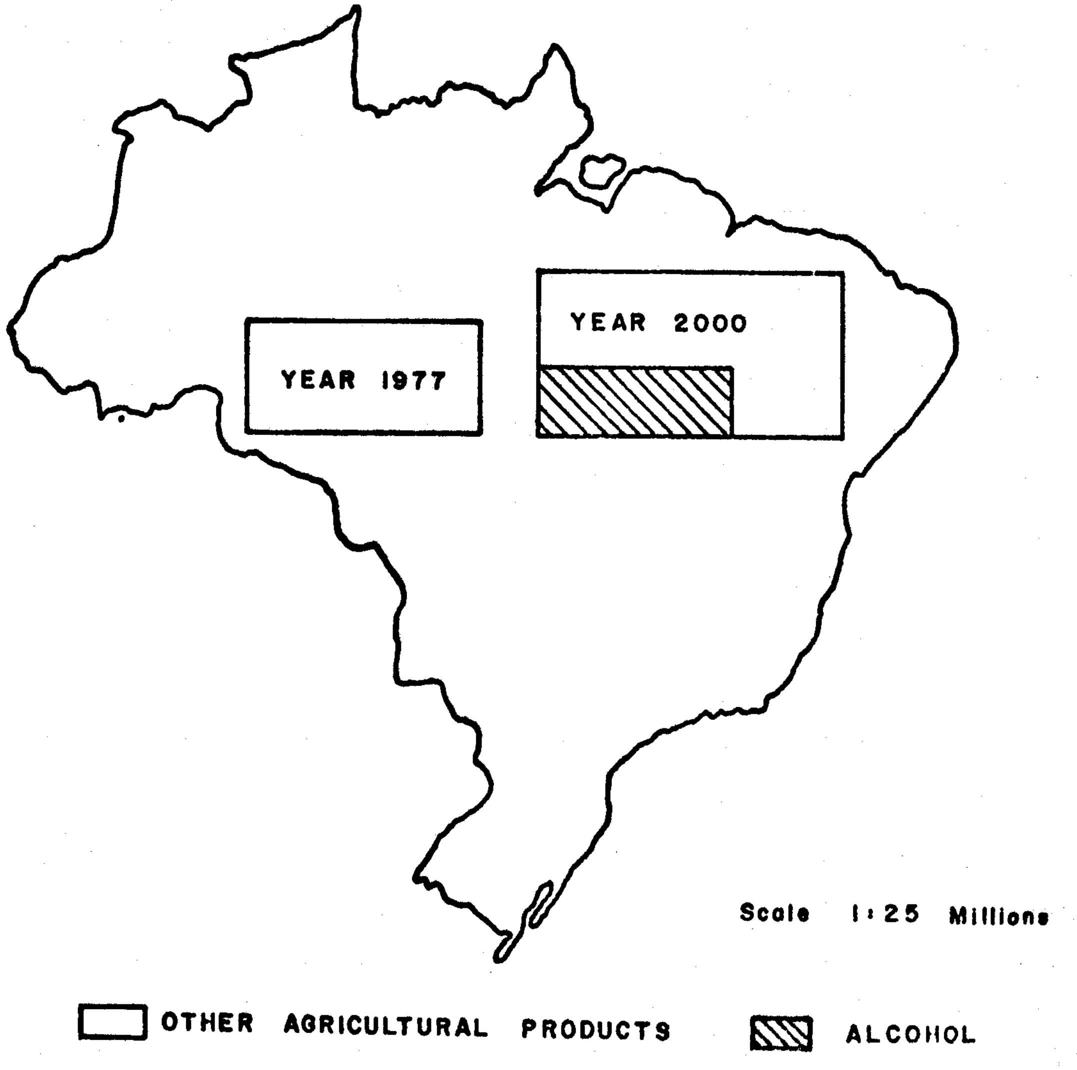

Fig. 4

One should add here the remark that cassava is also a strong candidate for ethanol production. The average agricultural yield of cassava is 29 ton/ha, which is smaller than sugar cane; its industrial output is however much higher (174 l/ton) as compared to 70 l/ton for sugar cane. Cassava grows in soils that are poorer than the ones needed for sugar cane and there are great hopes of using the "cerrado" for this purpose. Almost 12% of the brazilian territory (100 million/ha) are covered by "cerrado". A complete experiment of alcohol production from cassava is being conducted at present in land of this type in Curvello, State of Minas Gerais for a production of 100,000 liters of alcohol/day.

V. REMAINING PROBLEMS

The first important question to ask here is that since alcohol is being produced for burning in internal combustion engines what is the energy balance involved in this production. In other words what is the output energy contained in the alcohol as compared to the total amount of energy needed for its production.

Table IV shows our most recent results for four cultures : sugar cane, cassava, plant sorghum and ratoon sorghum (including labor in energy units, machinery, fertilizers, etc.) (Gomes da Silva, Serra, Moreira, Gonçalves and Goldemberg, 1977).

They all have a positive balance: sugar cane has a net energy gain of 21,345 Mcal/ha/year and cassava only 6,032 Mcal/ha/year (if the stems are utilized for steam production) and only 1,315 Mcal/ha/year if they are not used. The superiority of sugar cane from the energetic point of view is evident here but there are hopes of increasing the agricultural productivity of cassava.

TABLE IV - ENERGY BALANCE OF ETHYL ALCOOL PRODUCTION

CULTURE	Agricultural yield		Alcohol production			ENERGY - Mcal/ha/year						
						Produced			Expended			BALANCE
	t/ha	t/ha/year	L/t	L/ha	L/ha/year	Alcool	Residue	Total	Agriculture	Industry	Total	
Sugar cane	72	54	66	4,752	3,564	18,747	17,550	36,297	4,138	10,814	14,952	21,345
Cassava (1)	29	14.5	174	5,046	2,523	13,271	-	13,271	2,573	8,883	11,456	1,815
(2)	29	14,5	174	5,046	2,523	13,271	5,512	18,783	3,868	8,883	12,751	6,032
Sweet sorghum (stems and grains)												
Plant sorghum	(3)	-		3,775	3,775	19,856	11,830	31,686	4,671	11,883	16,554	15,132
Ratton sorghum	(4)	-		2,383	2,383	12,535	7,280	19,815	3,350	7,501	10,851	8,964
TOTAL	-	-		6,158	6,158	32,391	19,110	51,501	8,021	19,384	27,405	24,096
Sweet sorghum (stems)												
Plant sorghum	32.5	32.5		2,600	2,600	13,676	11,830	25,505	4,671	7,722	12,393	13,113
Ratoon sorghum	20.0	20.0		1,600	1,600	8,416	7,280	15,696	3,350	4,752	8,102	7,594
TOTAL	52.5	52.5		4,200	4,200	22,092	22,092	41,202	8,021	12,474	20,495	20,707

(1) No utilization of stems for steam production.
(2) Utilization of stems for steam production.
(3) 32.5 t of stems and 3.0 t of grains per ha.
(4) 20.0 t of stems and 2.0 t of grains per ha.

Another problem in the industrial production of alcohol from sugar cane is the handling of very large amounts of liquid ("caldo de cana") of which only about 7% are ethanol. The remaining 93% (13 times the volume of alcohol) still have to be destilled which means that, for the same size, an alcohol destillery produces 13 times less alcohol than a refinery (in which 100% of the petroleum is destilled into useful oils or combustibles). Typical capacity of a petroleum refinery is 50.000 barrels a day (8.000.000 liters a day) against 100.000 liters of alcohol per day in an alcohol refinery.

Finally the "vinhoto" left in alcohol destilleries is a pollutant, usually thrown in rivers, but which could be used as a fertilizer. The handling of the very large volumes of "vinhoto" is however a difficult problem.

VI. CONCLUSIONS

With these qualifications the brazilian alcohol program is going ahead and already the city of São Paulo (with its 1.5 million automobiles) is being used as a giant laboratory in which alcohol is being added to the gasoline in the proportion of 20%, with no important problems so far. A fleet of 200 vehicles was also converted to pure alcohol propulsion and these vehicles are being tested in operation with good results.

If all goes well the program will expand enormously and Brazil might be the first country to run on non-fossil renewable combustibles.

This will constitute a major utilization of photossynthesis (and ultimately of solar energy) which is well suited for the tropical climate of Brazil; the experience could possibly be extended to other countries.

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FIGURE CAPTIONS

Fig. 1 - Petroleum consumption in Brazil

Fig. 2 - The Brazilian Energetic Balance

Fig. 3 - Consumption of alcohol mixtures in combustibles

Fig. 4 - Cultivable areas in Brazil