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ENERGY ISSUES AND POLICIES IN BRAZIL

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I - Introduction

Brazil is a modest energy consumer by United States standards: total energy consumption in 1980 was 5.1 Quads (as compared to 75 Quads for the United States); since its population (120 million), is half of that of the United States average per capita consumption in the United States was approximately 7.5 times greater than in Brazil.

This average however hides the fact that there are extremes of wealth and poverty in Brazil: many districts in the great industrial cities of the Southeast (São Paulo, Rio de Janeiro, and Belo Horizonte) are modern and prosperous, comparing favorably with many cities in the industrialized countries. At the same time there are large slums around these cities, and the rural population, mainly in the Northeast, is very poor. One could almost say that there are two countries, one within the other or "a Belgium inside an India" in which 20 million people have a standard of life comparable to urban dwellers in Belgium and the remaining 100 million have one comparable to the peasants in India.

One has in the same developing country a "modern sector", which consumes commercial sources of energy (hydroelectricity, coal, and petroleum) and a "traditional sector", which depends on noncommercial sources of energy (mainly fuelwood).

In the last 15 years economic growth has been very high in the urban centers, which have grown explosively, while most rural areas have remained relatively stagnant.

Brazil has meager petroleum resources; domestic production meets not more than 20% of liquid fuel consumption. Since 1973 this has become a fundamental problem in the development of the country; initially an attempt was made to solve this problem by heavy borrowing abroad, which paid for the petroleum needed for further expansion of internal consumption, as happened in many other developing countries. Hydroelectric resources are abundant in Brazil, so that electricity is plentiful; the "energy crisis" was a "liquid fuel crisis" right from the start.

When further borrowing to pay for petroleum became difficult - the foreign debt climbed to 50 billion dollars - attempts were made at conservation and substitution of petroleum derivatives.

The first policy was aimed at penalizing gasoline consumers (i.e private automobile owners) in order to save gasoline. Prices of petroleum derivatives and most other energy sources are administered by the Government in Brazil, which allows for strong regulatory actions. Although pricing policies led, to some extent, to more efficient use of gasoline in better cars, basically it merely altered the type of consumption, since the truck fleet converted to diesel. It is unfortunate that the "oil problem" was faced in 1974 with policies aiming at conservation of gasoline while the same did not happen in regard to diesel or fuel oil (residual oil). In fact, these fuels remained subsidized until recently.

The second policy was a determined effort to find substitutes for petroleum; the impressive increase in the production of ethanol (ethyl alcohol) from sugarcane and its use to replace gasoline has led the way for a series of other initiatives leading to the replacement of petroleum derivatives by fuels derived from biomass.

Such success was achieved because an unexpectedly strong coalition of government technocrats, energy analysts, and industrialists from various sectors was formed and was able to overcome opposition from more conservative sectors. The goal to achieve "energy autonomy" became a common denominator among many sectors in the country, with reasonable chances of success.

This paper analyzes such initiatives, most of which are applicable also to other developing countries. Our emphasis here is on the dynamics of the movement away from oil and the desire to base the development of the country on locally available resources such as hydroelectricity and biomass derived fuels.

II - Energy Resources

Table 1 gives a general view of the energy resources in Brazil by showing measured and inferred reserves of the most important energy sources (1). The units used are also given in this Table. Numbers in this report are updated from other information available in the literature. A discussion of the numbers for each of the energy sources of Table 1 is given below.

A- Petroleum and Natural Gas - The presently known reserves of petroleum and natural gas (2) are 1.28 x 10^9 barrels of petroleum and 47 x 10^9 m^3 of gas. Most of the country was surveyed by PETROBRAS, the state owned enterprise that has the monopoly for petroleum exploration. The most promising findings are on the continental platform in the southeast part of the country (Campos basin, near Rio de Janeiro).

The total number of operating wells is 2,142, of which 1,647 are inland and 495 offshore. The total number of wells drilled is 5,276, with a total of 7.95 million metters; the average amount of oil found is therefore 154 barrels/meter drilled, which compares favorably with the present yield of 60 barrels/meter in the United States. The rate of oil findings for each million of meters drilled (2) has been very irregular as shown in Figure 1.

Oil exploration is in its infancy in Brazil; the total number of meters drilled in the United States is approximately one billion meters, i.e. more than 100 times the amount drilled in Brazil, which has approximately the same territorial area. For the first 30 million meters drilled in the United States the average amount found was 700 barrels/meter (3).

B - Coal - Coal is not abundant in Brazil; it is found in significant quantities only in the southern states (Rio Grande do Sul and Santa Catarina). The most important deposits are in Candiota (Rio Grande do Sul) where more than half the existing reserves are located. Generally speaking, all the coal is of the bituminous type; prewashed coal has an ash content higher than 40% and can be used only for non metalurgical purposes such as

steam production. Information on reserves as of 1979 (4) is given in Table 2.

C - Shale - The known shale oil reserves (5) are given in Table 3; most of the deposits contain 4 - 8% oil. The recoverable oil is estimated to be approximately 500 x 10^6 tons of oil equivalent (TOE), several times higher than the petroleum reserves.

D - Hydro - The country is well endowed with hydroelectric resources (6), which are spread out over the country with a concentration in the North as shown in Table 4. This potential is evaluated in such a way as to produce an average power level that is guaranted, even under the worst climatic conditions ever recorded, at a 50% load factor. This corresponds to 932 terawatt hours(Twh)/year, equivalent to 271 x 10^6 TOE/year or 5.5 x 10^6 barrels of oil per day (11 Quads per year).

E - Nuclear - Important findings of U_3O_8 (7) have been made in the last few years as shown in Table 5. Most of the reserves are located in Poços de Caldas (Minas Gerais) and Itatira (Ceará).

Although the situation regarding uranium oxide reserves has improved, one should point out that half of the quoted reserves are inferred. The economic feasibility of exploiting most of them has not yet been assessed.

F - Biomass - Brazil is a large tropical country that has been heavily deforested except for the Amazonas forest. The distribution of land uses (8) is shown in Table 6. From this Table one can see that land for crops could be increased to 200 million hectares of which possibly 10% (20 million hectares) could be used for energy purposes in the form of woodfuel, charcoal, ethanol from sugarcane, ethanol or methanol from wood, and vegetable oils (as a possible substitute for diesel oil). This is a conservative estimate, because very extensive forested areas and marginal lands could be converted into energy forests.

Assuming a dry biomass yield of 10 ton/ha/year, from which 2 tons of oil equivalent fuels can be produced per hectare per year, we conclude that it is possible to obtain 40 x 10^6 TOE/year from this resource. This is approximately the current oil consumption in Brazil.

III - Energy Consumption

Energy consumption in Brazil has grown at a rate of 7.7%/year (1) since 1969, i.e. with a doubling time of 9 years; this is a very high growth rate. Even higher growth rates have been achieved in the hydroelectric sector where growth has reached 13.4%/year (Table 7). The absolute amounts of energy consumed in 1979 and percentages are also given in this Table.

It is of interest to analyse the evolution of primary energy consumption, i.e., the "dynamics" of energy consumption. The available data (9), starting in 1940, are shown in Figure 2. As one can see from this figure there was a very rapid shift from "traditional" to "modern" fuels in the period 1940 - 1979. Oil and gas represented 9.2% of total consumption in 1940; this fraction increased to 41.1% in 1979, while biomass represented 75% in 1940 and decreased to 24.7% in 1979. In absolute numbers the use of traditional fuels remained approximately constant. The modernization that took place in Brazil in this short period meant, in energy terms, the adoption of a "petroleum economy" and an abandonment of traditional fuels. However, the adoption of a petroleum economy was not matched by the production of petroleum: 81.5% of petroleum used in 1979 was imported and only 18.2% was produced from local fields (1).

IV - Issues and Policies

The consequences of the dependence on petroleum imports on the balance of payments have become disastrous since 1974, as can be seen from 8, which gives petroleum imports and the balance of payments (10).

Petroleum imports, which corresponded to less than 10% of

the value of exports before 1973, increased to more than 50% of total exports in 1980. Although a successful effort was made to increase exports, it was not enough to balance trade deficits, which rapidly plunged the country into a 50 billion dollar foreign debt.

The external trade deficit by itself was not unduly high, but the need to increase exports led to the influx of large amounts of foreign capital, which added to the foreign debt and therefore to the total amount of debt servicing. This created a vicious circle from which it became difficult to escape. The economic policies of the Brazilian Government have been entirely dominated by these concerns.

Since increased exports from the industrial sector require the increased use of petroleum derivatives (and imported machinery), a great effort has been directed in the past at exporting products of the extractive sector(iron, manganese, and other minerals) or agricultural products(coffee, soyabeans,etc), which are not very energy intensive as compared with manufactured goods. This is a very different policy from the one followed by Japan and West Germany; they also have to import their petroleum but are capable of exporting manufactured goods, and are therefore able to transfer to the purchasers the increased cost of petroleum.

It was not a lack of will that kept Brazilian exports at the present level (both qualitatively and quantitatively) but the lack of alternatives. What has been witnessed since 1974,in Brazil,is a modest effort in conservation and a greater effort in substitution of some petroleum derivatives, but little has been achieved in structural changes. Such changes would involve social readjustments, which are not attractive to the upper middle class that constitutes the "Belgium inside India" referred to in the Introduction.

Conservation was introduced mainly through pricing policies, which were followed later by substitution of gasoline by alcohol (ethanol). It was only in 1980 that the amount of alcohol produced reached 60,000 barrels per day, which is equivalent to 5% of the petroleum consumed in the country (although it corresponds to 20% of the total consumption of gasoline on a replacement basis).

A - Petroleum conservation through pricing policies

Pricing policies had a great impact on the consumption of gasoline in the period 1975-1979 before the production of alcohol became significant.

Starting in 1974 the Government increased the price of gasoline to a very high level but kept the price of diesel and fuel oil very low and in effect subsidized them (Figure 3). The reason for this policy was that individual automobile owners (who use cars for recreation) cannot transfer the aditional cost of gasoline to other sectors of society while diesel and fuel oil users (in transportation and industry) can, which increases the price of their services and products and thus contributes to inflation. As an example, Table 9 compares the present cost of gasoline and diesel oil in Brazil, the United States and France.

The high price of gasoline dramatically effected its consumption, as shown in Figure 4. The consumption levelled off in 1974 because the large gasoline truck fleet shifted to diesel through engine replacement. In addition, the average consumption per vehicle was reduced by almost a factor of two between 1974 and 1979 because of improvements in fuel economy, better roads, better traffic systems, changes in driving habits encouraged by the high cost of gasoline, and the increase in two car families. The production of derivatives from the refineries of PETROBRÁS did not follow the changes in consumption. In 1979 these products were: gasoline 23.1%, diesel oil 29.66%, fuel oil 31.76%, liquefied petroleum gas (LPG) 6.26%, and others 9.22%. This profile has changed little since 1975 except that the gasoline fractions have decreased from 30% to 23%, while use of naphtha for petrochemical purpose has increased to 6%.

Probably one of the weakest points of the pricing policies has been their failure to bring about changes in the refining profile from the cracking operations; PETROBRAS has been unwilling to make such changes, on the grounds that they would require high investments and that the company has been able to market its present profile by selling excess gasoline abroad and purchasing heavy oils in return. It has argued also that total consumption of light components of petroleum (e.g., naphtha) will surely grow because of petrochemical projects already in progress and that a new cracking profile could inhibit these projects (11).

An important development in early 1981 was the dramatic increase in diesel and fuel oil prices (Figure 3). Diesel oil is now selling at above international price levels, but it is unclear yet how this will affect diesel consumption, since there are no options for its substitution. Fuel oil is being substituted by other fuels.

It was realized early that pricing policies in an expanding economy could shift the use of petroleum derivatives but not reduce total petroleum consumption. In the period 1975-1980 petroleum consumption did not in fact decrease, and this is expected to happen only when the alcohol program begins to produce very significant amounts of fuel in the next few years.

Since the present refining profile seems unalterable at present a broad range of other conservation measures has been effected to reduce consumption of the three main petroleum derivatives (gasoline, fuel, and diesel oil). However these measures have not been highly successful.

B - Petroleum conservation by other means - The climate in the southeastern part of Brazil, where most of the population and industrial activities are concentrated, is rather mild, which means that neither heating nor air conditioning affects total energy consumption very much.

Most industrial equipment is either imported or copied from similar equipment in industrial countries; as a consequence the patterns of Brazilian industrial consumption of energy are similar to those of more highly industrialized countries. This can be seen in Figure 5, which shows the embodied energy per unit of industrial output (in kcal/cruzeiro) for the United States and Brazil. The data for the United States includes 92 sectors of the economy evaluated for 1967 (12); the data for Brazil are from the 1970 census (13).

The Brazilian economy as a whole is less energy intensive than that of the United States, but the distribution among sectors is very similar for the two countries: the average embodied energy for the United States is 22,500 kcal/dollar and for Brazil 15,750 kcal/dollar (in 1970 dollars). This means that conservation policies in transportation and industry cannot be very different in Brazil and the United States.

Conservation of Gasoline (6) - 59% of gasoline supplies are consumed in intermunicipal driving and 41% in city driving, all in automobiles. Although most cars in Brazil are of the compact and subcompact type with reasonable but improvable, fuel economy (around 10 km/liter) the Government felt that savings were achievable in other ways, such as improving the flow of city traffic, limiting highway speeds to 80 km/hour, closing service stations or weekends, and encouraging the use of buses. It is difficult to estimate the savings from these initiatives, but they are probably small.

Conservation of fuel oil (6) - 88% of fuel oil is consumed by industry, 6% is used for electric generation, and 6% in transportation. Industry is therefore the sector for significant economies. Since Brazilian industry is modern it should be possible to model these economies on those in industrialized countries. A recent study made by industry (1) indicates the possibility of conservation of 46,000 barrels per day in 1985, relative to the amount extrapolated to that year without conservation measures. Investments to achieve these savings have been estimated on the basis of return on investment by the oil saved; assuming an average payback period

of 15 - 36 months, conservation requires investments of US$ 5,250 for every bbl/d saved (11).

Conservation of diesel oil (6) - The consumption of diesel oil is distributed in the following way: 75% for transport, 13% for industry, and 12% for others. The transport share is distributed between intermunicipal transport (buses and trucks, 55%) and urban transport (mainly buses, 45%).

Possible savings of diesel oil in the urban areas are more closely related to improvements in the flow of traffic than to technical improvements of the vehicles themselves. This is being done in various degrees around the country, but clear success is visible only in the city of Curitiba (Paraná), where lanes exclusively for the use of buses and rescheduling of work shifts have led to economies of 30-40% in fuel consumption. In road transport, the only significant measure enacted so far is a shift to heavy diesel trucks, which represents appreciable savings in fuel.

The savings of petroleum arising from strict conservation measures, excluding alcohol substitution are estimated to be 140,000 bbl/d in 1985 relative to the consumption expected in that year without such conservation measures (6).

C - The Alcohol Program The rationale - In 1975, Brazilian production of alcohol from sugarcane was 903 million liters per year, used mainly for indutrial purposes. It was therefore necessary to launch a large program for financing new cultures of sugarcane and associated equipment to increase alcohol production for fuel (14,15).

A deficit of 8 billion US dollars in two years (Table 8) in 1974 and 1975 led the Government to swift action. The future prospects for energy were considered bleak in 1975, with rising prices of petroleum, and there was also a strong preoccupation with the increased dependence on oil from Middle East countries on which little pressure could be applied: as a consequence security of supply became an important consideration.

In addition, in 1974 the price of sugar in the international market was very low (approximately 200 US dollars per ton). Therefore, to divert some sugar to alcohol production was considered to be a method of increasing the value of this commodity and using a considerable idle capacity in the sugar refineries. Although the price of sugar went up to 608 US dollars per ton in 1975 it went down again in 1979 to $120 per ton. (1 kg of sugar is approximately equivalent to 0.7 liters of alcohol.)

Benefiting from Government subsidies, the program picked up speed, and all gasoline used in the country was rapidly converted to "Brazilian gasohol", a mixture of up to 20% alcohol and 80% gasoline.

In 1979, the Iraq-Iran war threatened the stability of oil supplies from the Middle East, and the automobile manufacturers, encouraged by the Government, took the bold position of producing cars with new motors adapted for pure alcohol consumption. The Alcohol Program thus entered a new phase from which there was no return.

Brazilian production of alcohol reached a total of 4.08 billion liters in 1981, out of which 1.88 billions were consumed as hydrated alcohol (91-93% alcohol plus water) in more than 300,000 automobiles and the remainder of the fleet used 2.2 billion liters of anhydrous alcohol mixed with gasoline in the proportion 10-20%. There are presently close to 8 million cars in Brazil.

Distribution of (hydrated) alcohol benefited from the infrastructure previously used for high octane gasoline; in December 1980 there were 3,587 service stations in the 22 States offering alcohol (in addition to gasohol), which had already replaced all regular gas.

The Executive Committee of the National Alcohol Commission (CENAL), which oversees the implementation of the program approved 100 projects in 1980 with a total capacity of 2.4 billion liters/year . As a result, the cumulative

number of projects approved so far has reached 321, with a total capacity of 6.4 billion liters/year. Adding this to the previously existing capacity for alcohol production (0.9 billion liters in 1975) one has a potential of 7.3 billion liters for projects already approved (about 110,000 bbl/d).

Annex and autonomous distilleries are being installed for alcohol production and over time new capacity has shifted from the former to the latter. Annex distilleries have the advantages of requiring smaller investments and yielding results in a shorter time; the disadvantages are the limited capacity of the industrial units already in place and available land. Autonomous distilleries offer more freedom, but the investments are larger and more time is required for the projects to reach maturity. Both strategies are being followed in Brazil. It is estimated that the traditional sector could produce an additional 3.2 billion liters in annex destilleries in 4-5 years. The establishment of new autonomous distilleries could produce another 3.5 billion liters, 3 years after approval by CENAL.

The initial goal set in 1975 of production of 10.7 billion liters of alcohol per year in 1985 will probably be reached, although a 10-20% shortfall in this goal would not be surprising. Out of this amount 9.2 billion liters will be used as fuel and 1.5 billion in industry.

Many questions have been raised as to the meaning of the Alcohol Program in strictly economic terms; is the price of alcohol real or subsidized ? Is the program feeding the already high inflation rate in Brazil ?. What complicates the evaluation of the real cost of ethanol from sugarcane is the complex system of subsidies of the Brazilian economy. Initially 90% of the investments (except land) were financed by the government at very favorable terms (interest of approximately 25%, well below inflation rates of roughly 100%). The program thus became inflationary although it was justified by security of supply considerations and the interest in saving the automobile industry. Starting in January 1981, however, interest rates were raised to approximately 50%, still well below the inflation rate.

Although still subsidized, the program is approaching a situation in which it can be justified in economic terms (16). The cost of production of alcohol from sugarcane is approximately 27 cents/liter i.e. 43 US dollars per barrel or 58 US dollars per barrel equivalent to gasoline. This equivalence takes into account both the heating values and the higher efficiency of ethanol in motors (see next section). In Brazil one barrel of gasoline from petroleum(at 35 US dollars per barrel)costs approximately 52 US dollars to produce,which indicates that alcohol is close to becoming economically competitive

Concerns regarding the competition between land uses for food production versus fuel production are discussed in the section on patterns of land utilization.

D - Technical Aspects - Before 1975 extensive experimentation at the Aerospace Technological Center of the Air Force, in São José dos Campos, demonstrated the technical viability of using alcohol either in existing or in retrofitted engines. Figure 6 shows the measured power of Otto engines using either gasoline or ethanol for motors with different compression ratios and fuel/air mixtures (16, 17). For example, for an Otto engine with a compression ratio of 6 and regulated for a 0.07 fuel/air ratio, the resulting power was 9.5 HP (point A in Figure 6). With use of ethanol in this engine modified for a compression ratio of 10 and the chemically correct value for the fuel/air ratio (0.11), the power increases to 12 HP (point B in Figure 6) and the specific consumption remains about the same as for gasoline. In general the efficiency for Otto engines using ethanol is about 38%, while for gasoline it is only about 28%. Engines specially designed for the use of ethanol also show superior performance. Automobiles in Brazil use Otto engines with a compression ratio of approximatelu 6 - 7, which is suited to the low octane gasoline in use (62 octane); alcohol, which is 98 octane, allows the use of a higher compression ratio (approximately 10) and therefore

produces higher engine efficiency. This means that the use of pure alcohol in the United States were automobile engines already have higher compression ratios (approximately 9), would not have spectacular effects.

In practice, although the energy content of alcohol is only about 60% of the energy content of gasoline, the mileage per liter decreases only 25% when Brazilian automobiles are converted to the use of hydrated alcohol. Since alcohol is sold at a price up to 65% that of gasoline (per liter) the conversion to alcohol allows a net benefit of about 20%.

The energy balance in ethanol production from sugarcane is clearly favorable (16); this is due to the fact that for each liter of alcohol approximately 4 kg of bagasse are produced; 70% part of this bagasse is burned to produce the heat needed in the ethanol distillation,the remaining being returned to the land to improve the texture of the soil.

A considerable amount of stillage(vinasse) is a by product of ethanol production in a proportion of 13 liters of stillage per liter of alcohol ; initially this was considered a threat to the environment but it was soon realized that stillage can be used as a fertilizer in the majority of the soils; in addition a modest amount of chemical fertilizers and irrigation is needed in many areas to allow the use of the land for sugarcane production in a sustainable way.

E - New Initiatives - The success of alcohol produced from sugarcane as a substitute for gasoline, although limited in solving the overall energy problem of Brazil, has spurred a number of other approaches to the problem of fossil fuel substitution.

The simple fact that alcohol is a renewable energy source that can be produced domestically has had a powerful effect on the whole approach of the Government; as a result it has come to take other initiatives in this area far more seriously. Most of these initiatives are geared to finding substitutes for diesel oil, since fuel oil can be replaced by coal or woodfuel with existing technologies. The most important programs in this area are the use of vegetable oils and methanol (from biomass).

E.1 - The Oil Seeds Program - The program was established in 1980 and its original goals were to substitute 16% of the diesel oil with vegetable oils by 1985 and 30% by 1990 (18). For this purpose an additional 1.5 x 10^6 tons of oil for energy purposes will have to be produced in 1985 which is double the normal amount expected in that year for food purposes (1.5×10^6 tons). Production of this oil will be based on soyabeans and peanuts starting in 1981, colza and sunflower starting in 1982, and palm oil starting in 1986.

It is hoped that this program will emulate the alcohol program and provide increasing amounts of oils to substitute for diesel. From a strategic point of view this is attractive because of the flexibility in the vegetable oil plus diesel mixture. More or less vegetable oil may be added to diesel depending on the availability of vegetable oil, withouth the need for irreversible commitments. No changes in existing diesel motors are contemplated and the new oils would have to be adapted to them. There are technical, agricultural, and economic problems to be solved before such a program can succeed.

From a technical point of view (19) vegetable oils can be mixed with diesel or used in pure form, but engine performance is affected; not enough long-term experiments have yet been done to allow firm recommendations. At present the following situation prevails:

(a) Diesel motors with precombustion chambers accept either pure vegetable oil or mixtures with diesel oil. The performance of the motors is very good for some models; in others, carbonization and excessive wear are at unacceptable levels.

(b) diesel motors with direct injection do not accept vegetable oils even if mixed with small amounts of diesel oil. Most engines in use in Brazil use direct injection.

(c) The use untreated vegetable oils containing glycerol presents problems from high viscosity, strong odors, and undesirable exhaust gases and particulates.

It seems highly advisable to process vegetable oils before using them in diesel motors; this processing might be less expensive than present processes of preparation of edible

oils. This is particularly true in the case of glycerin-carrying oils, which applies to most of the oils under consideration. A simple chemical process called "trans-sterification" breaks the molecules in the oils to produce hydrocarbons very similar to diesel oil with the advantage of permitting the recovery of the glycerin fraction. The hydrocarbons can then be used in direct injection diesel motors.

Questions of cost are still unclear, since no large-scale experiments have been conducted. However vegetable oils in the international market are worth at least 500 US dollars per ton (close to \$700/ton presently), at least twice present diesel oil costs. In terms of balance of payments considerations it might therefore make more sense to export vegetable oils and import petroleum. However, using vegetables oils as a diesel substitute may still be desirable for security of supply reasons.

Oils from some agricultural products may be less expensive than others and there may also be regional reasons to produce them. Table 10 gives the characteristics of the oilseeds being considered at present (20). Palm oil seems to be the most interesting option because of its high productivity and lower production costs, although it takes at least five years to establish extensive new cultures.

E.2 - Methanol from biomass - Methanol production from natural gas or coal is a well-mastered technology, and this fuel is favored in some North European countries as the best replacement for gasoline. Most probably this will not be the route followed in Brazil, which has already adopted ethanol as the substitute for gasoline. It is unlikely that ethanol and methanol will be both used for automobiles in the near future. The use of ethanol for automobiles and methanol for diesel motors is most likely until such time as broad-fuel tolerance motors are developed.

Burning of pure methanol in present-day diesel motors can be achieved with small modifications in the motor, mainly the introduction of a glow-type spark plug; extensive testing of this is taking place with encouraging results. In addition, use of methanol in stationary motors in locomotive or industry offers great opportunities.

For this reason an experimental program has been established by the Energy Company of the State of São Paulo to produce methanol from eucalyptus in some areas of southeast Brazil (21). This requires setting up gasifiers for the production of synthesis gas from biomass; once obtained, the synthesis gas can be converted to methanol by existing technologies.

The cost of methanol should be low compared to ethanol from sugarcane, although initial investments are higher.

Three large size (200 dry tons of wood/day) gasifiers of different types are being installed to test technologies that have previously only been tested on a laboratory scale: one of the gasifiers uses a fluidized bed at atmospheric pressure, another, a fluidized bed at high pressure, and a third, a newly developed electric arc gasifier. Results should be available within two years.

E.3 - Ethanol plus Additives (22) - Since the Alcohol Program (ethanol) seems well entrenched in Brazil, a number of experiments have been made to use ethanol in diesel motors; to do that it is necessary to add an explosive to it such as 12% of hexile nitrate or 4 - 5% trietileneglicol. Very good results have been reported with these fuels, although questions of price remain to be solved. The additives being seriously considered at present can be produced from sugarcane bagasse.

The possibility of using a mixture of diesel oil and pure alcohol in dual injection engines is also being investigated.

E.4 - Ethanol from Wood (23) - In addition to ethanol produced from sugarcane, it will probably be produced in the future from wood through the acid hydrolysis method; the use of wood will allow the use of marginal lands through reforestation.

A state-owned company named COALBRA was established by

the Government in 1980 to build and operate the first pioneer plants based on this technology. The first one, a 30,000 liter/day plant is being installed in Uberlandia, Minas Gerais and should begin operation at the end of 1982. In this plant, hydrolysis of eucalyptus will be performed by a modified version of the Madison-Schoeller process in which diluted sulfhuric acid separates the lignin and saccharifies the cellulose portion of the wood which leads to a fermented wine containing ~1.5% of ethanol. This wine is distilled to produce pure ethanol; byproducts are CO_2, proteins, and lignin, which can be made into coke after briqueting and carbonization.

Expected yields per ton of dry wood are 160 liters of ethanol, 75 kg of proteins (from the pentoses), 9.5 kg of furfural, 96 kg of CO_2, and 338 kg of lignin (or 135 kg of coke).

Investments for this plant are estimated to be approximately 15 million US dollars, and the final price of the alcohol approximately $0.30/liter.

E.5 - Woodfuel; Charcoal and Bagasse - Wood was the dominant fuel in Brazil until 1954 and its use has remained approximately constant since then, although, in percentage terms, it's contribution has been decreasing rapidly. Consumption in 1979 was 20.5×10^6 TOE or 87.5×10^6 tons (220×10^6 m^3 of wood with 10% humidity).

On this matter an interesting methodological question was raised by Brown (24), who analyzed the calorific content of wood as defined in Brazil. Brown pointed out that the calorific content used in government documents (1) was in error because when dry, the density of wood is 0.4 ton/m^3 and when wet (with 25% humidity) it is 0.53 ton/m^3. The calorific content for wet wood (2.5 Mcal/ton) should be used. The effect of correcting for this error is an 35% increase in the amount of energy per ton of wood. The real amount of energy in TOE from fuelwood should therefore be increased from 20.5×10^6 TOE (consumption in 1979) to approximately 27×10^6 TOE.

A breakdown of the uses of wood as an energy source (24) is given in Table 11.

Charcoal consumption in 1979 was 2.976 x 10^6 TOE, which corresponds to 16.7 x 10^6 m^3; charcoal is an important ingredient in the preparation of pig iron in Brazil, and about 40% of Brazil's steel production uses charcoal instead of imported coke (25).

Taditionally, charcoal has been produced by the cutting of natural forests, which has contributed to deforestation in many areas, especially in the State of Minas Gerais. In addition to detrimental environmental effects, this has led to scarcities in the supply of woodfuel and increases in price, since woodfuel and charcoal have to be transported farther.

As a consequence, the Government has encouraged reforestation projects through subsidies; in the period 1965 - 1980 approximately three million hectares of land were reforested using pinus and eucalyptus, both of which grow rapidly in the favorable climate of Brazil; yields of wood corresponding to 6 - 8 ton/ha/year or higher are commonplace. Not all reforestation trees are destined to become charcoal; some are used fo fuelwood, pulp, and paper products.

The energy conversion efficiency from wood to charcoal is approximately 40 -50% using primitive methods; this efficiency can be raised to about 60% by improvements in basic kiln type (at low cost), and to 65 - 70% by recovery of tars with the same kiln type.

Enormous quantities of bagasse will result from the large alcohol program which is based on sugarcane. As is well known, even if all energy needs of the alcohol distilleries were to be obtained from bagasse as a source of heat, a large surplus would be still available. The production of 1 liter of alcohol produces approximately 2 kg of dry bagasse, of which only 1 kg is needed in the process in the form of heat and electricity if modern technologies are used in the processing plant.

Congeneration schemes could be used to produce electricity (in addition to the heat needed for industrial

purposes in the distilleries) and the excess sold to outside consumers(26). Government regulations have been changed recently to allow this.

F - The Food versus Fuel Controversy - Considering the size of Brazil and the possibilities of expansion of the agricultural frontier is it possible in the long run to produce all the alcohol needed for fuel in addition to having sufficient land available for food production ?

In the short run, fuel production will have to be done at the expense of other agricultural products, unless the agricultural frontier is expanded (27). Out of the 45.9 million ha of agricultural land in use in Brazil in 1977, approximately 60% were used to grow products for domestic consumption (rice, blackbeans, cassava, corn, onions, tomatoes, etc), 38% for exports (cotton, soybeans, sugar, coffee, etc), and only 2% for fuel.

The share of land needed for fuel purposes (including oilseeds for substitution of diesel) will increase to 7.3 million ha in 1985 (4.3 million ha for sugarcane, 1.8 for energy forests, and 1.2 for oilseeds); the present amount of land covered by sugarcane for alcohol purposes is 1 million ha. In the last 40 years land for all agricultural uses has been growing at a rate of 3.5%; in the future this growth rate will need to be higher (Table 12).

Significant expansions of Brazil's agricultural frontier have occured in short spans of time in the recent past; for example, soybeans became, in a few years, the dominant export crop using presently 8.7 million of ha of land.

Although the rate of growth of land needed for fuel production is high, the absolute amount of land needed is not, and steps are being taken by a number of private groups to produce crops for fuel in regions that are at present unproductive. This is the case of many developments in Bahia, Mato Grosso do Sul, and Goiás which do not require further deforestation but the use of low quality soils and even rich soils which require irrigation.

However, in some regions of the country, such as São Paulo, sugarcane is rapidly displacing other crops. To compensate for this, marginal land can be recovered; the effect of crop displacement on prices of agricultural products is as yet unclear, and it will probably vary from one region to another.

To keep things in perspective one should realize that the agricultural area of the United States is 20.5% of its total and corn covers only 3.1% of the total area. The idea that sugarcane plantations will convert Brazil into a monoculture and lead to an ecological disaster seems unwarranted.

G - Nuclear Energy (14, 28) - Large scale use of nuclear energy in Brazil is controversial: a 624 MW pressurized water reactor (PWR) was purchased in 1969 from Westinghouse after long hesitation. With this reactor, fueled with enriched uranium, no significant transfer of technology was contemplated, and participation of Brazilian industry was restricted to the civil works and some low technology equipment. For this reason, the decision to purchase this reactor was strongly criticized by many scientists and by industry spokesmen.

In the 1950's many Brazilians were trained in nuclear technology and Brazil was one of first developing countries to receive a research reactor (5 MW) under the "Atoms for Peace" program; considerable interest developed in the use of nuclear energy both as a source of energy and as a frontier technology that could spur developments in other areas such as metallurgy and electronics. At the time strong similarities existed between the type of nuclear program developed by India and Brazil. In Brazil a strong feeling developed among scientists that the country should be involved in the full domain of nuclear power technology including all phases of the construction and operation of the reactors.

Sensitive to that criticism, the Government, in 1974, embarked on an ambitious nuclear program in cooperation with

West Germany that in principle would lead Brazil to complete autonomy in the nuclear field within 15 years (14). Eight PWR's (1,300 MW each) were scheduled to be installed in Brazil with an increasing index of nationalization that would approach 100% in 1990. A semiindustrial uranium enrichment plant was to be built based on the "jet-nozzle" method. In addition a spent fuel reprocessing plant was to be built by German enterprises. In all cases joint companies were to be formed. This program was believed to be the minimum capable of justifying the setting up in Brazil of all phases of the nuclear industry, including the complete fuel cycle (mining, enrichment, and reprocessing) and the construction of the nuclear reactors themselves. Technology transfer was to be part of the Program.

Although there was initial enthusiasm for such a comprehensive nuclear program, difficulties soon became apparent.

First, the feasibility of uranium enrichment (which is essential if any real autonomy is to be achieved) was viewed with strong skepticism by many scientists, because the Becker jet-nozzle method was not proven. For many years, therefore, enriched uranium would possibly have to be purchased, which would frustrate the dream of nuclear independence. Although enriched uranium is easier to stockpile than fossil fuels, Brazilian authorities faced serious problems in securing a steady supply from abroad. This is what led to the great interest in enriching uranium in natural facilities.

Second, the transfer of technology was unsuccessful from the very start; with disagreements on the role to be played by Brazilian local industry and German suppliers it became apparent that the program was heavily biased in favor of the suppliers.

Third, the role of Brazilian scientific and technological institutes was neither properly defined nor given much attention, which strengthened suspicions that no real transfer of technology would occur.

Finally, the planned installation of a spent fuel reprocessing plant raised strong objections in the United States because such a plant could contribute to the danger of nuclear weapons proliferation.

In addition to these issues, the question was raised of whether there is a real need for nuclear power in a country such as Brazil which is well endowed with hydroelectric resources. Since 1974, reassessment of hydroelectric resources by ELETROBRAS, the state enterprise for electricity, has almost doubled the known potential (29).

The question of the economics of nuclear power has also become important. In 1974 nuclear was seen as a cheap source of energy. By contrast, today, dramatic cost increases have cast doubt upon the economics of nuclear power , more so in less-developed than in developed countries, and especially in competition with hydropower, where the latter is available.

As a consequence of all these factor, a reassessment of the program is presently under way: out of the eight reactors scheduled for operation in 1990 only two will be operating, according to the most optimistic forecasts. It is expected that the remaining six reactors will not operate until the year 2000, postponing until that time all the questions raised above on enrichment and reprocessing.

Most Brazilian scientists and industrialists believe that it would have been preferable for Brazil to have adopted a more modest program in which they could play a dominant role and acquire progressively the necessary technology and skills for the development of nuclear power.

V - Energy Projections

Most of the investments in infrastructure in Brazil are made by state-owned enterprises, which have a monopoly in given sectors of the economy, such as PETROBRAS for petroleum, ELETROBRAS for electricity, and NUCLEBRÁS for nuclear energy. For this reason it is possible to formulate goals for a full presidential period, such as the present one, which lasts until 1985 (Table 13). These goals are given in the "Brazilian Energy Model" of the Ministry of Mines and Energy (30).

Plans have been made for important expansions in the industrial sectors, that will increase energy needs, as outlined below. In the period 1969 - 1979 the GDP of Brazil increased 8.9%/year and it is expected to continue to grow between 6 and 7%/year in the period 1979 - 1985. Hydroelectricity consumption is expected to grow at even higher rates: 12.0% in the period 1979 - 1985; 8.2% in the period 1985 - 1990, and 7.4% in the period 1990 - 1995. (The electric sector is the only one in which projections are made with a 15-year lead time).

The assumptions and rationale behind the projections in the Brazilian Energy Model are worth probing,and we do that in what follows. Being an official Government document, it contains elements of propaganda and wishful thinking, but it also incorporates the better structured programs such as the alcohol program, which represents the most successful attempt to replace petroleum derivatives, and the hydroelectric program.

A - Petroleum and Natural Gas - The goal of the present program of domestic petroleum production is to reach 500,000 bbl/d, up from the 170,000 bbl/d produced in 1979. The important new discoveries made in the Campos basin in 1976 are already producing minor amounts of oil, but should reach full production before 1985. The 500,000 bbl/d in 1985 are to be reached in the following way: 231,000 bbl/d production from wells presently in operation; 127,000 bbl/d production from wells due to operate in the next few years; and 142,000 bbl/d production from newly discovered wells. The goals are speculative; presently existing wells, mainly in Bahia, are operating at full capacity and it is doubtful that their production can be increased without seriously compromising future extraction. The Campos basin,for which there were great expectations a few years ago when it was discovered, has developed a number of problems, and its production (around 30,000 bbl/d in 1980) is well below projections. Finally to count on production from "newly discovered wells" is a dubious proposition.

The desire of the Government to increase oil production has been considerable, and therefore in 1977 it changed existing regulations to allow foreign oil companies to prospect on the Brazilian continental shelf under "risk contracts" in which companies get returns only if oil is found. This was a hotly debated decision that required considerable determination by the Government in the face of criticism from the more nationalistic elements of the Army and PETROBRAS; the fact that it was taken shows both the seriousness of the oil situation and the influence of foreign capital in Brazil. The foreign companies have thus far had little success in finding oil.

Natural gas is always associated with petroleum in Brazil but has not been used very widely for energy purposes: in 1979 total use was 498 x 10^3 TOE (547 x 10^6 m^3); in addition, an unspecified amount has been used for reinjection in wells and as raw material for the production of fertilizers and as feedstock for the petrochemical industry in the State of Bahia. Projections for consumption in 1985 in well-defined uses are presently 1.186 x 10^3 TOE (1.303 x 10^6 m^3).

B - Coal - Coal traditionally represented a small contribution to the energy profile of Brazil, never amounting to more than 5% of total primary energy consumption. In 1979, consumption was 8.6 x 10^6 tons of which 4.2 x 10^6 tons were imported (mostly metallurgical coke) and 4.4 x 10^3 tons were produced domestically (mostly for non metallurgical purposes such as steam production, because of the high ash content of Brazilian coal).

Projections for coal consumption in 1985 reflect the evolution of pig-iron production in the Government plans. In addition, coal for steam production will become more important because it will be used as a substitute for fuel oil in many industries (mainly cement, ceramics, and paper and pulp). By 1985, therefore there will be almost a tripling of imports of metallurgical coke and an increase by a factor of 5 in the production of local coal, which should reach 27.5 x 10^6 tons

in 1985. (At the beginning of 1981 this goal was already reduced to 17 million tons.)

C - Shale - The only project for the production of oil from shale presently under way is by PETROBRAS in São Mateus do Sul, Paraná, where some of the most important shale reserves are located; this is a 50,000 bbl/d plant to be built with technology developed in Brazil and already tested in a 5,000 bbl/d pilot plant in the same location (5). Environmental problems associated with such a plant have yet to be solved, mainly those arising from the disposal of the huge quantities of rock that remain after the removal of the oil from the rock shale. The first stage of the plant (25,000 bbl/d) is to be completed in 1984 and the second stage (reaching 50,000 bbl/d) in 1986. In full operation 900 tons of sulfhur and 400 tons of liquefied petroleum gas will also be obtained as byproducts.

D - Hydropower - In 1979, only 12.5% of the estimated hydroelectric potential was in use; the average growth in the 1979 - 1985 period is expected to be 14.2%/yr reaching 227,566 GWh in 1985, or 24.4% of the potential. Many believe that such high rates of growth will not be maintained. Most of the activities leading to the production of this amount of electricity are under way: the first stage of the great hydropower station of Itaipu (final capacity 12,000 MW) will be producing electricity in 1983, which will be transported to São Paulo through two transmission lines, one AC and another DC. The latter represents a newly introduced technology in Brazil, which will be very important for the future utilization of the large hydropower potential of the Amazonas basin. In addition, Tucuruí (4,500 MW), first large hydropower station in the Amazonas basin, will start operation, as well as Foz de Areia and Salto Santiago in the Southern region. An important priority of ELETROBRAS is the interconnection of the North and Northeast regions.

E - Nuclear Energy - The most obvious progress made in this area in recent years is the increase in the uranium reserves (215,300 tons of U_3O_8 in 1980). Production of yellow cake was due to start in 1981 in the Poços de Caldas plant with 150 tons/yr, which will increase to 1,100 tons/yr in 1985. The only nuclear power plant in operation in 1985 will be a 624 MW reactor purchased from Westinghouse on a "turn key" basis; it is scheduled to begin operation in early 1982, with initial fueling with imported enriched uranium. Later refueling will be made with locally produced U_3O_8, enriched abroad. The rest of the ambitious nuclear program is seriously delayed, as indicated earlier.

F - Biomass

F.1 - Fuelwood - Since Brazil is going through a process of rapid urbanization the consumption of wood for domestic purposes (mainly cooking) has been declining and is being replaced by LPG and electricity. To compensate for this the substitution of fuel oil in boilers has increased wood consumption for industrial purposes. Projections for consumption in 1985 are 82.3×10^6 tons, slightly below the consumption level in 1979.

F.2 - Charcoal - A projection of the needs of the steel industry indicates that charcoal production should increase to 9.1×10^6 TOE (14.5×10^6 tons) in 1985, a threefold increase from production in 1979. Approximately one million hectares of reforested areas will be needed to supply this amount of charcoal in a sustainable basis. This activity will generate 47,000 direct jobs (4.7 jobs/100 ha).

F.3 Bagasse - If the alcohol program's goal of 10.7 billion liters/yr is reached by 1985 there will be a surplus of 10.7×10^3 metric tons of bagasse(above the bagasse required for alcohol distillation)in addition to the bagasse obtained from sugar production.

Consumption of bagasse was 5.5×10^6 TOE in 1979, and the projection to 1985 is 9.6×10^6 TOE (46.1×10^6 tons of bagasse with 50% water content).

G - Solar Energy - A very small number of solar units are

in use in Brazil presently; projections for 1985 are that 0.43% of the total energy used at that time will come from solar devices; this corresponds to 15,000 bbl/d (1,000 from direct solar and wind energy, 4,000 from biogas, and 10,000 from other forms).

An independent assessment (31) indicates that residential water heating, water preheating in industry, agricultural drying, and water distillation are the main opportunities for solar direct energy, and irrigation the main opportunity for wind machines. The data are shown in Table 14. Roughly speaking 1.4 - 2.5 $\times 10^6$ TOE of energy could be generated from solar and wind energy. This corresponds to 1.2% to 2.1% of all energy consumed in the country in 1979.

H - Overview of Projections - Table 15 summarizes the figures for energy consumption projected for 1985 according to government goals (1, 6, 30). In this table all numbers are converted to barrels equivalent of petroleum per day (BEP/day); to obtain consumption in TOE it is necessary to divide the numbers by 20.5. In the same table are given the values for energy consumption in 1979 and the increments in energy consumption expected in the period 1979 - 1985. Also included are figures for conservation taken from the section on petroleum conservation by means other than pricing.

The investments needed to reach these goals have been estimated (32) and are given in Table 16. The availability of capital for such high investments seems problematic at present.

VI - Social Issues - It is implicit in the Government projections that no important changes in the social status quo will occur in the near future and therefore no changes in the structural composition of energy consumption. The expectation is for conservation and substitution of some fuels by others. A comprehensive discussion of a country's energy needs cannot ignore, however, who consumes, how income is distributed, and related social questions such as land use and ownership. We examine these questions in what follows.

A - The Structure of Energy Expenditures (33, 34) - Income distribution in Brazil is asymmetric, with most of the income concentrated in 10 - 20% of the population. This can be seen clearly in Figure 7, which shows in detail the income distribution of the population of the State of São Paulo, the country's wealthiest. It is obvious that,at present,rural and urban nonmetropolitan areas have more poor people than rich people(in relative terms)than metropolitan areas, and consequently they consume less energy per person.

Surveys of monetary and non monetary expenditures of households with different incomes are available. Figure 8 shows, for the year 1970, calculated energy expenditures associated with these expenditures, grouped into four brackets:0-2, 2-5, 5-10 and more than 10 minimum montly wage units (one wage unit corresponded to approximately 41 US dollars in 1970). Total energy consumption in the highest income group is fifteen times greater than in the lowest income group; 66% of the population is in this low income group while 4% is in the highest income group, which is responsible for one quarter of the total energy consumption of the country (mostly petroleum products). Low income groups consume less petroleum products (38%) than higher income groups, where petroleum products account for 66% of the total energy consumption.

The structure of energy expenditures for the whole country in 1970 is the following: food (27.0%), transportation (19.3%), household (11.5%), civil construction (15.7%), distribution (5.0%), and others (21.5%), which shows that food production consumes as much energy as the transport sector.

B - Urban versus Rural Energy Consumption - The low energy consumption per capita in rural areas of India (35) is frequently cited to indicate that there is a large increase in energy consumption associated with urbanization. A detailed study of this question in rural, urban non metropolitan, and metropolitan areas in the State of São Paulo, Brazil (36) leds to the conclusion that primary energy consumption per capita is solely

determined by income: the low primary energy consumption of the rural areas merely reflects the fact that the personal incomes of people in those areas are very low. The results of this work are shown in Figure 9, which gives the direct and total (direct plus indirect) energy expenses for the three areas mentioned above. As can be seen in this figure the data for the three areas falls roughly along the same line and are thus indistinguishable.Notice that up to 10 wage units, energy expenditures are proportional to income and that the non linear portion of this curve (above 10 WU) involves only 9% of the families which consume however roughly 26% of the energy.

Although there are few rural households with large incomes in Brazil presently, it seems inescapable that they will fall into the general pattern of consumption found in urban areas: as their incomes increase they will demand more energy services, and also will use more-energy-efficient systems.

If one multiplies the distribution of population as a function of income (as given in Figure 7) by the primary energy consumption as a function of income (Figure 9) one obtains the total energy consumption as a function of income. The area under this curve is the total energy consumed by the population (approximately 1.16×10^{17} cal).

If a radical redistribution of income were to take place, as indicated by the dotted line in Figure 7, the total energy consumption of the population would correspond to of 1.35×10^{17} cal. This means an increase in primary energy consumption of 15%, i.e. the country's total energy requirements would not be very different from the current ones. Thus redistribution of income would not lead to an inordinate increase in primary energy consumption. This is due to the fact that the great majority of the families lie in a portion of the curve of figure 9 that is linear and the saturating part of the curve has not large a effect on energy consumption. This surprising results runs counter to conventional wisdom, i.e., that a redistribution of income would lead to a large increase in the purchase of energy-intensive goods and therefore to a further worsening of the energy crisis.

It is not entirely clear however if the income redistribution would not lead to an inordinate increase in petroleum derivatives. Since most of the families (66%) are bellow 2 WU (Figure 8) any improvement in income will be used initially for food purchases and not automobiles and other energy-intensive amenities;this might lead to a greater fuelwood consumption in some areas of the country and also to greater use of petroleum derivatives as liquefied petroleum gas used for cooking. This point is being under further investigation.

C - Patterns of Land Utilization (37) - As a result of the alcohol program large sugarcane plantations are being established in regions where previously many small farms existed; this Government policy is favored by the fact that sugarcane production is well suited to mechanized techniques. As a consequence, the subsistence crops that the small farms used to produce (corn, vegetable, blackbeans, etc) are being eradicated, which forces the importation of food from distant regions. This has had the negative social consequence of forcing the exodus of small farmers and field laborers to cities where it is difficult for them to get jobs. Thus they become seasonal laborers for the large plantations, since sugarcane is a six months per year activity.

This encouragement of large farms for technical reasons and by the availability of Government subsidized credits for alcohol production has generated a few large companies that hold most of the land in many regions of Brazil. This has had a negative effect on income distribution by concentrating resources in the hands of a few enterpreneurs. This is clearly a consequence of the policies followed ; the Government could instead have encouraged a system of cooperatives in which individual farmers could grow sugarcane and process it in a collectively owned refinery, which is the method used in Australia.

VII - Conclusions

The stage of development reached by Brazil is typical of a number of developing countries. The lack of abundant fossil fuels, the abundance of land and forests, a highly developed urban sector, a skewed income distribution, and a mounting external debt are common characteristics of many Latin-American and some African and Southeast Asian countries.

The emphasis put on the use of biomass as an energy source, mainly through the production of ethanol, is however unique to Brazil. This strategy can be usefully adopted in a number of other countries (37). The production of large quantities of ethanol from sugarcane is possible in India, Cuba, China, Mexico, and Pakistan; the use of forests for the production of charcoal, methanol, or ethanol is very promising in Indonesia, China, Zaire, Australia, and Colombia.

It has been estimated (38) that the participation of biomass in the energy budget of all developing countries, which was 4.2% of the world's total energy consumption in 1976, (and 17% of the total energy consummed in these countries) could be increased to 11% by 1995 (1,550 million tons of coal equivalent). This amount of renewable energy would correspond to an important fraction of the energy consumed in developing countries but represents probably the upper limit of the contribution to be expected from the developing nations to attenuate the fossil fuels crisis.

Thus in many countries, there is the possibility for a sustained economic development based on locally produced liquid fuels derived from biomass, which avoids undesirable dependence on the use of imported fossil fuels. The cost of these fuels might be high and drain resources needed for other purposes so a balance must be found between security of supply from local sources and vulnerability and dependence on imports. Perhaps the unique experience with biomass in Brazil will be an example to other countries to attempt its large scale utilization.

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Figure Legends

Figure 1 - Oil findings (in barrels/meter drilled) for each million of meters drilled in Brazil.

Figure 2 - Evolution of the primary energy consumption profile from 1940-1980 in Brazil.

Figure 3 - Evolution of prices of petroleum by products relative to 1970 (in constant currency).

Figure 4 - Evolution of the automobile and truck fleets (left side scale) and fuel consumption (right side scale). Also shows the projected consumption of alcohol (ethanol) up to 1985.

Figure 5 - Frequency plots of embodied energy (in kcal/cruzeiro) by sector for the United States (1961 data base) and Brazil (1970 data base) [1 1970 US dollar = 4.59 cruzeiros (Brazilian currency)]

Figure 6 - Engine power versus fuel to air mixture for regular low octane gasoline and anhydrous alcohol. A, chemically correct mixture for gasoline; B, chemically correct mixture for ethanol.

Figure 7 - Household expenditures in the State of São Paulo in 1974 as a function of the income [in wage units (WU)]. One WU corresponds to 52 1974 US dollars.

Figure 8 - Distribution of the number of families and total daily energy consumption per family for different incomes in Brazil in 1970. One WU corresponds to approximately 41 1970 US dollars.

Figure 9 - Energy expenditures (direct and total) for metropolitan, urban nonmetropolitan, and rural areas of the State of São Paulo in 1974 as a function of household expenditures. 1 WU ≅ 52 1974 US dollars.

Table 1 Energy resources in Brazil (December 1979)

Source	Unit	Measured	Estimated and Inferred	Total
FOSSIL FUELS				
Petroleum	(in millions of cubic meters)	198	-	198
Natural gas	(in billions of cubic meters)	47	-	47
Coal	(in millions of tons)	4,836	17,938	22,734
Shale oil	(in millions of cubic meters)	465	207	672
Nuclear[b]	(in metric tons of U_3O_8)	126,000	89,300	215,300
RENEWABLE SOURCES				
Hydro[c]	Gw	67.0	39.5	106.5
Biomass[d]	x 10^6 tons/yr	-	-	200

[a] For fossil fuels the total resources are given; for renewable sources the energy available per year on a continuing basis.

[b] At costs no higher than 95 US dollars/kg.

[c] To electricity is attributed the calorific content of oil needed to produce electricity with an efficiency of 27.5% 1 kwh = 3150 kcal (1 Mwh = 0.29 TOE).

[d] Estimated on the basis of 10 tons of dry biomass fuel per hectare/yr.

1 metric ton = 1000 kg.

Table 2 Coal reserves in millions of tons (1979)

State	Measured	Indicated	Inferred
Rio Grande do Sul	947.5	2,597.8	9,397.9
Santa Catarina	369.3	859.0	712.8
Paraná	32.0	27.7	5.0
São Paulo	2.0	1.0	7.0
Total	1,350.8	3,485.5	10,122.7

Table 3 Shale oil reserves (1980)

State	Area (km^2)	Average oil content (%)	Total resources of oil in millions of barrels (measured and inferred)
São Paulo (Vale do Paraíba)	191	4	2204[a]
Paraná (São Mateus do Sul)	64.5	7.4	560
Rio Grande do Sul (São Gabriel)	84.0	7.0	240
Rio Grande do Sul (Upacarai)	191.0	6.8	463

[a] 60% of this amount is inferred.

Table 4 Hydroelectric resources in gigawatts of installed or installable capacity (1980).

Region	In use or under construction	Still available (measured)[a]	Still available (estimated)[b]	Total
North	4.073	40.697	53.023	97.793
Northeast	8.217	6.011	1.194	15.422
Southeast	25.095	18.012	13.518	56.625
South	13.400	16.495	13.640	42.935
Total	50.705	81.215	81.375	213.375

a Based on topographical surveying in the prospective sites and minimal flows in the last 40 years.

b Based on aerophotogrammetric surveys and minimal flows in the last 40 years.

Table 5 Uranium reserves in tons

Year	Measured and indicated	Inferred	Total
1970	700	-	700
1971	1,730	3,300	5,030
1972	3,080	3,000	6,080
1973	3,580	4,500	8,080
1974	3,940	7,100	11,040
1975	3,940	7,100	11,040
1976	16,900	9,480	26,380
1977	32,300	34,500	66,800
1979	126,000	89,300	215,300

Table 6 Land utilization in Brazil (1977)

Type of land	x 10^3 hectares
Arable land and permanent crops[a]	40,720
Permanent meadows and pastures[b]	166,000
Forest and woodland[c]	509,000
Other land[d]	129,931
Land area[e]	845,651
Total area[f]	851,197

[a] Land under temporary crops (double cropped areas are counted only once); permanent crops include crops that occupy the land for long periods such as tea and coffee.

[b] Land used permanently for herbaceous forage crops, either cultivated or growing wild.

[c] Land under planted and natural forest and bushes.

[d] Unused but potentially productive land, built-on areas, wasteland, parks, roads, lanes, etc.

[e] Total area, excluding area under inland water bodies, i.e. lakes and rivers.

[f] Total area of the country, including area under inland water bodies.

Table 7 Primary energy consumed (1979)

Energy Source	Tons of petroleum equivalent (x 10^3)	Percentage	Average yearly rate of growth 1969-1979 (%)
oil	47,974	40.7	8.3%
Gas	498	0.4	17.9%
Alcohol	1,876	1.6	52.8%
Hydro	33,379	28.3	13.4%
Coal	5,123	4.3	8.1%
Bagasse	5,489	4.7	8.1%
Charcoal	2,976	2.6	9.6%
Woodfuel	20,469	17.4	0.7%
Total	117,785	100.0	7.7%

Table 8 Petroleum imports and balance of payments in billions of dollars (1971-80)

Year	Exports	Imports	Balance	External debt accumulated	Petroleum imports	Petroleum imports (Percentage share of total exports)
1971	2.904	- 3.245	0.341		0.280	9.6
1972	3.991	- 4.235	- 0.244	9.521	0.376	9.4
1973	6.199	- 6.192	+ 0.007	12.571	0.718	11.7
1974	7.951	-12.641	- 4.690	17.165	2.812	35.2
1975	8.670	-12.210	- 3.589	21.171	2.747	31.6
1976	10.130	-12.277	- 2.147	25.985	3.460	34.0
1977	12.120	-12.024	+ 0.006	32.837	3.664	30.1
1978	12.659	-13.683	- 1.024	43.510	4.089	32.3
1979	15.244	-17.961	- 2.717	49.904	6.189	40.5
1980[a]	20.132	-23.100	- 2.868	-	10.300	51.2

[a] Estimated.

Table 9 Prices of petroleum derivatives in US dollars per liter (April 1981)

Derivative	Brazil	United States	France
Gasoline	0.81	0.30	0.63
Diesel oil	0.39	0.21	0.50

Table 10 Vegetable oils in Brazil

Source	Productivity (tons/hectare/year)	Fraction of oil(%)	Amount of oil (kg/hectare)
Palm	20 - 25	17 - 20	3,400 - 5,000
Coconut	23 - 29	5 - 7	1,115 - 2,100
Babaçu	2,0 - 3,0	3 - 4	60 - 120
Sunflower	1,8 - 2,5	30 - 55	480 - 1,375
Colza	1,2 - 2,0	40 - 55	480 - 900
Peanuts	1,2 - 3,0	30 - 40	360 - 1200
Soybeans	1,3 - 2,0	16 - 22	240 - 660
Cottonseeds	1,3 - 2,0	14 - 16	170 - 320

Table 11 Use of fuelwood in Brazil (1976)

End use	x 10^6 tons
Domestic (rural)	40 ± 12
Domestic (urban)	12 ± 4
Agriculture	14 ± 6
Industry	13 ± 2
Commerce, Transportation	1 ± ?
Government, Public Services	0 - ?
Total	80 ± 14

Table 12 Agricultural areas in Brazil in millions of hectares

Use of land	1977	1985	Increment	%/yr
Products for internal consumption	29.9	42.1	12.2	5.1
Products for export	15.0	24.3	9.3	5.5
Energy purposes	-	8.3	8.3	- 40
Total	44.9	74.7	29.8	6.7

Table 13 Annual rate of growth of energy consumption (1979 - 85)

Energy source	Rate of growth (%/yr)
Petroleum	2.7
Gas	15.6
Alcohol	24.7
Hydro	12.0
Coal	23.0
Fuelwood	1.0
Bagasse	9.9
Charcoal	20.5
Primary energy consumption	6.7

Table 14 Potential savings for solar energy ($x\ 10^3$ TOE)

Sector	Savings		
Residential water heating		670	
Water preheating in industry	250		1240
Agricultural drying	80		260
Irrigation		280	
Water distillation		120	
Total	1,400	-	2,500

Table 15 Primary energy consumption

Primary energy	BEP/day		
	1979	1985	Increment
1 Fossil	1,090,000	1,277,000	+ 187,000
Imported petroleum	920,000	420,000	- 500,000
Local production	170,000	420,000	+ 250,000
Gas	10,000	25,000	+ 15,000
Coal	100,000	364,000	+ 264,000
Shale	-	25,000	+ 25,000
Nuclear	-	23,000	+ 23,000
2 Renewables	1,310,000	2,293,000	+ 983,000
Alcohol	38,000	145,000	+ 107,000
Bagasse	111,000	198,000	+ 87,000
Fuelwood	410,000	394,000	- 16,000
Charcoal	61,000	187,000	+ 126,000
Hydro	690,000	1,354,000	+ 664,000
Other	-	15,000	+ 15,000
3 Conservation	-	140,000	+ 140,000
Total	2,400,000	3,710,000	+ 1,310,000

Table 16 Overview of energy projections for 1985

	Additional BEP/day 1980-85	Investments in billions of US dollars (1980-85)	Dollars BEP/day
Oil (local production)	250,000	8.0	32,000
Coal	221,000	5.8	26,300
Shale	25,000	1.5	60,000
Alcohol	107,000	5.2	48,500
Charcoal	126,000	0.4	3,150
Hydro	674,000	28.0	41,000
Conservation	140,000	1.0	7,100
Total	1,542,000	51.9	

FIGURE 1

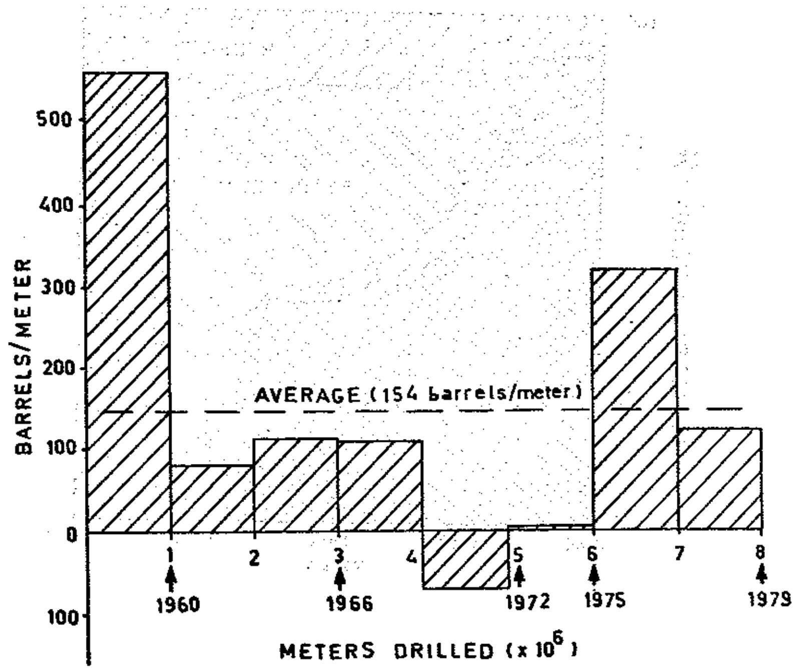
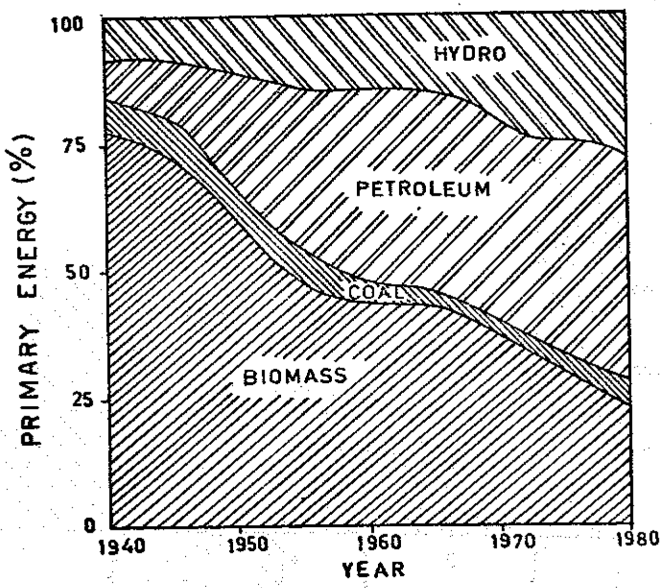


FIGURE 2



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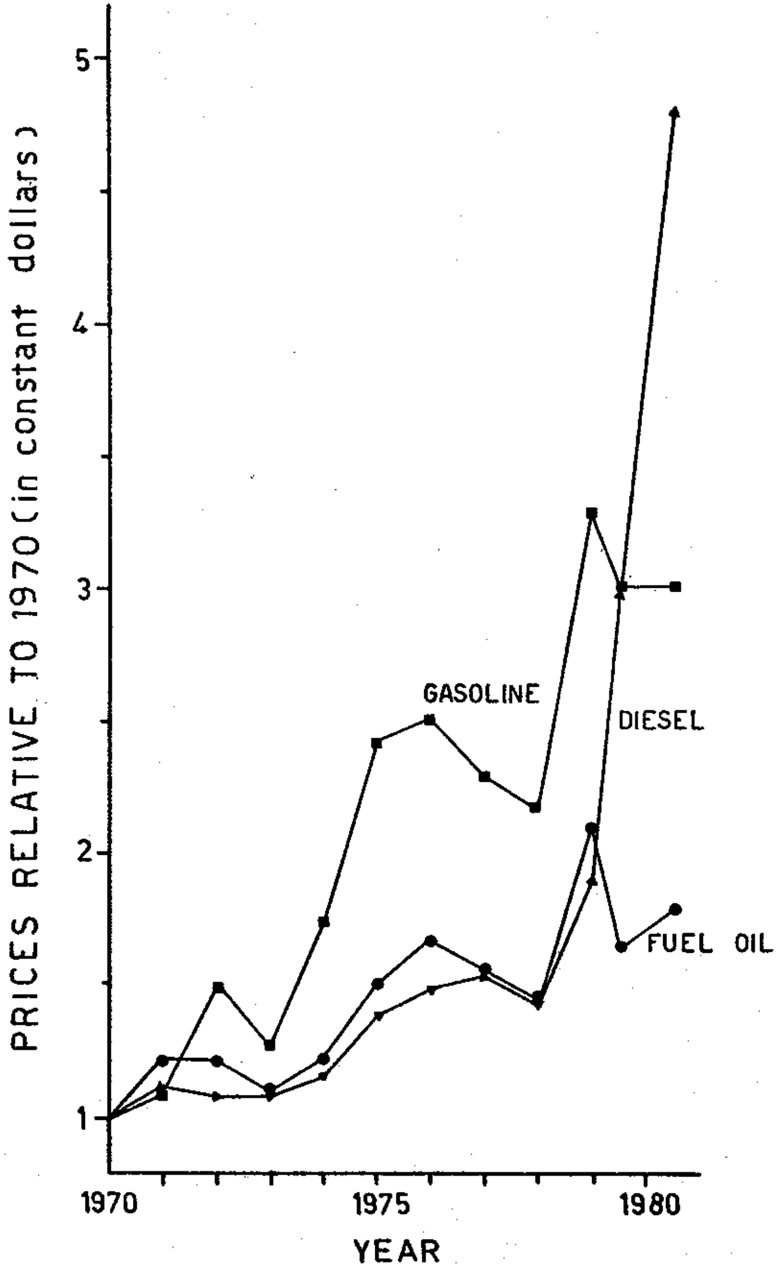

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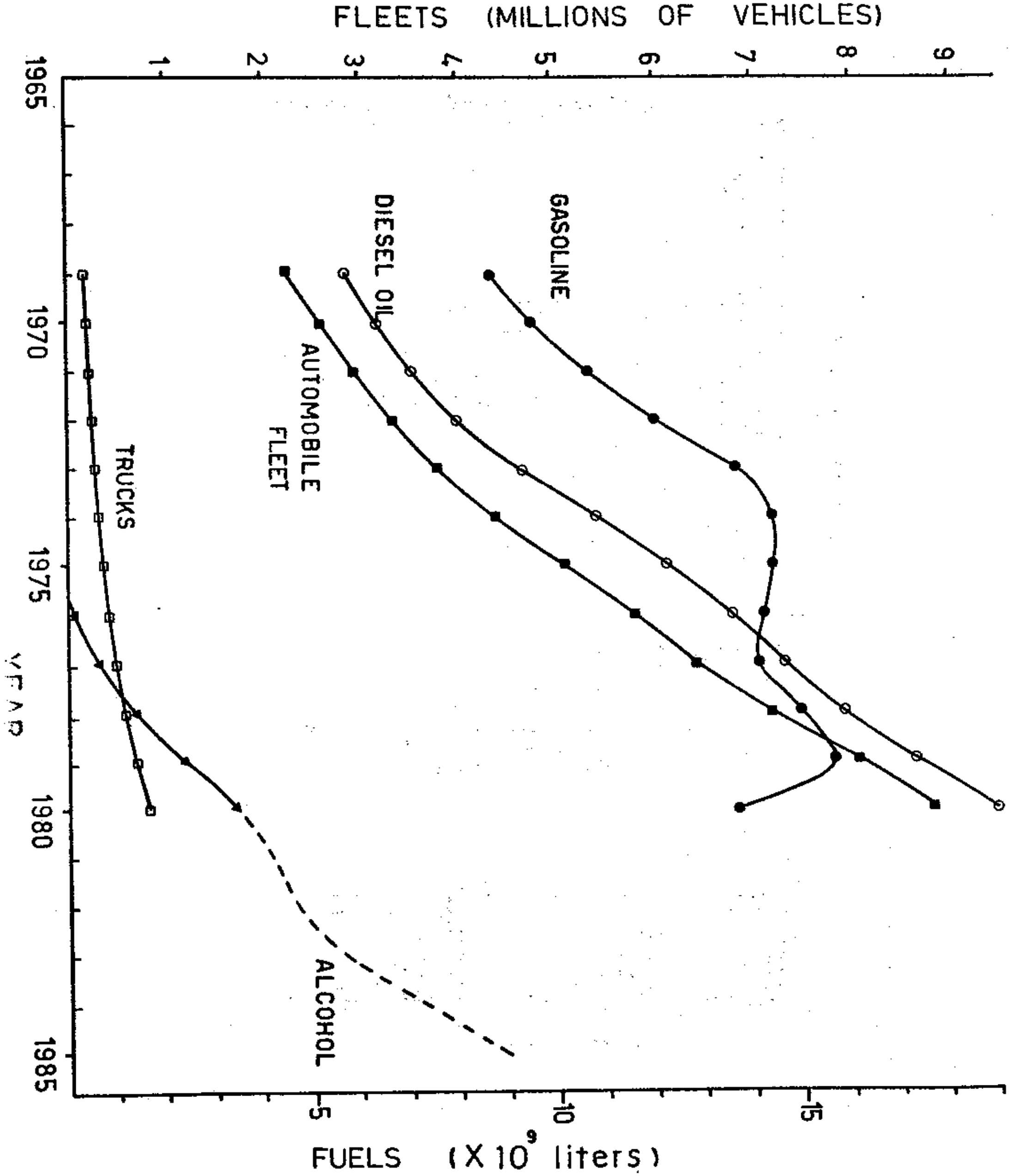

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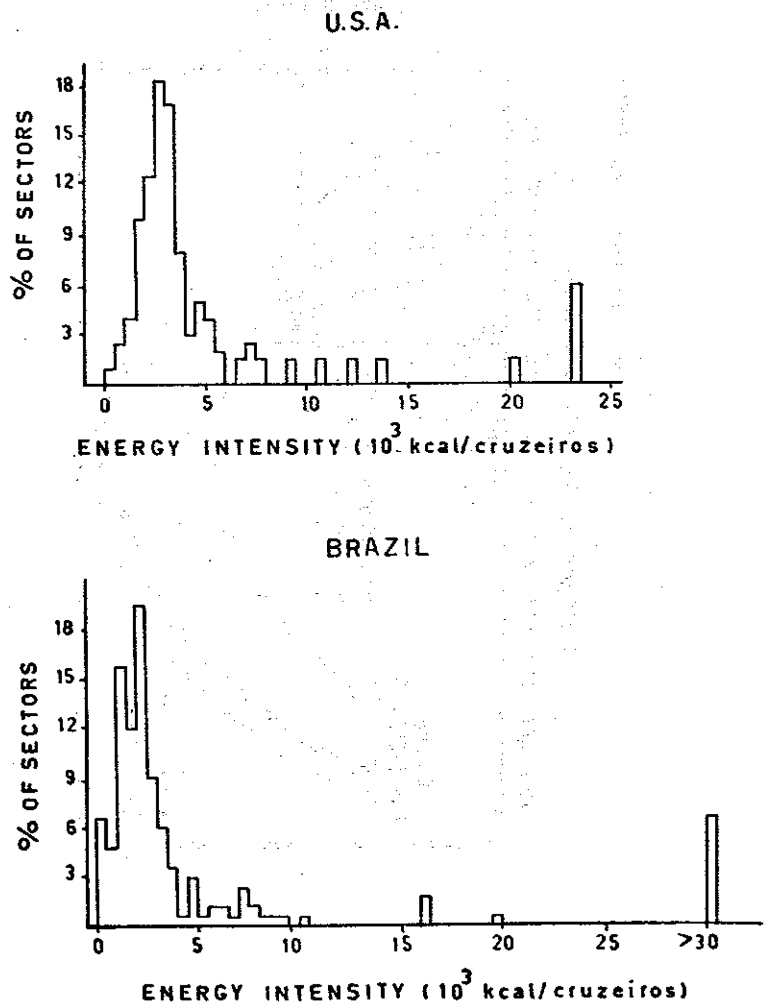


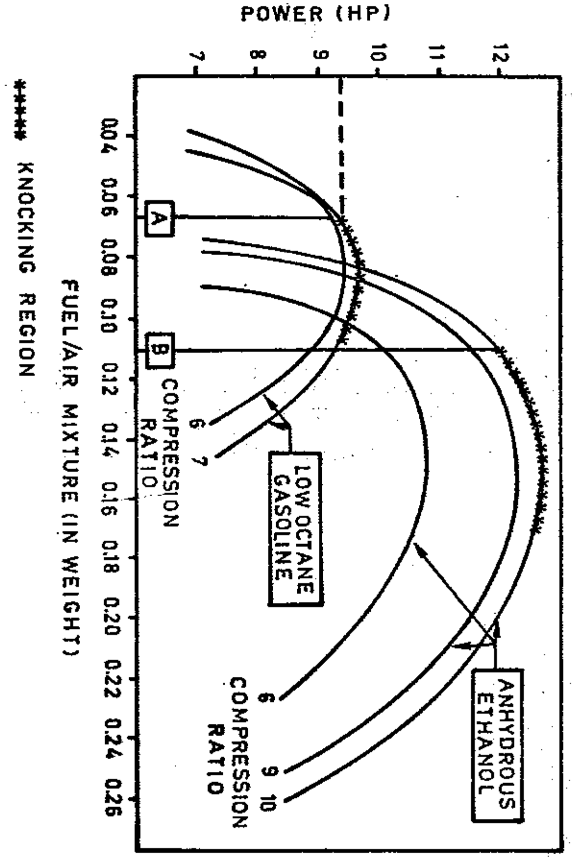
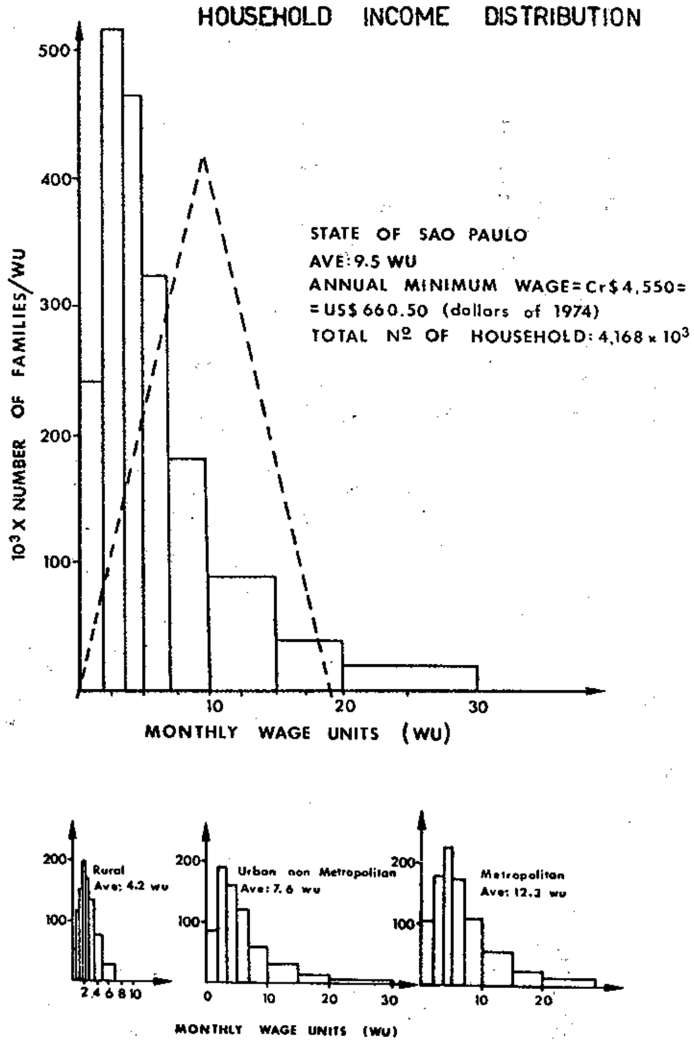


FIGURE 6

FIGURE 7



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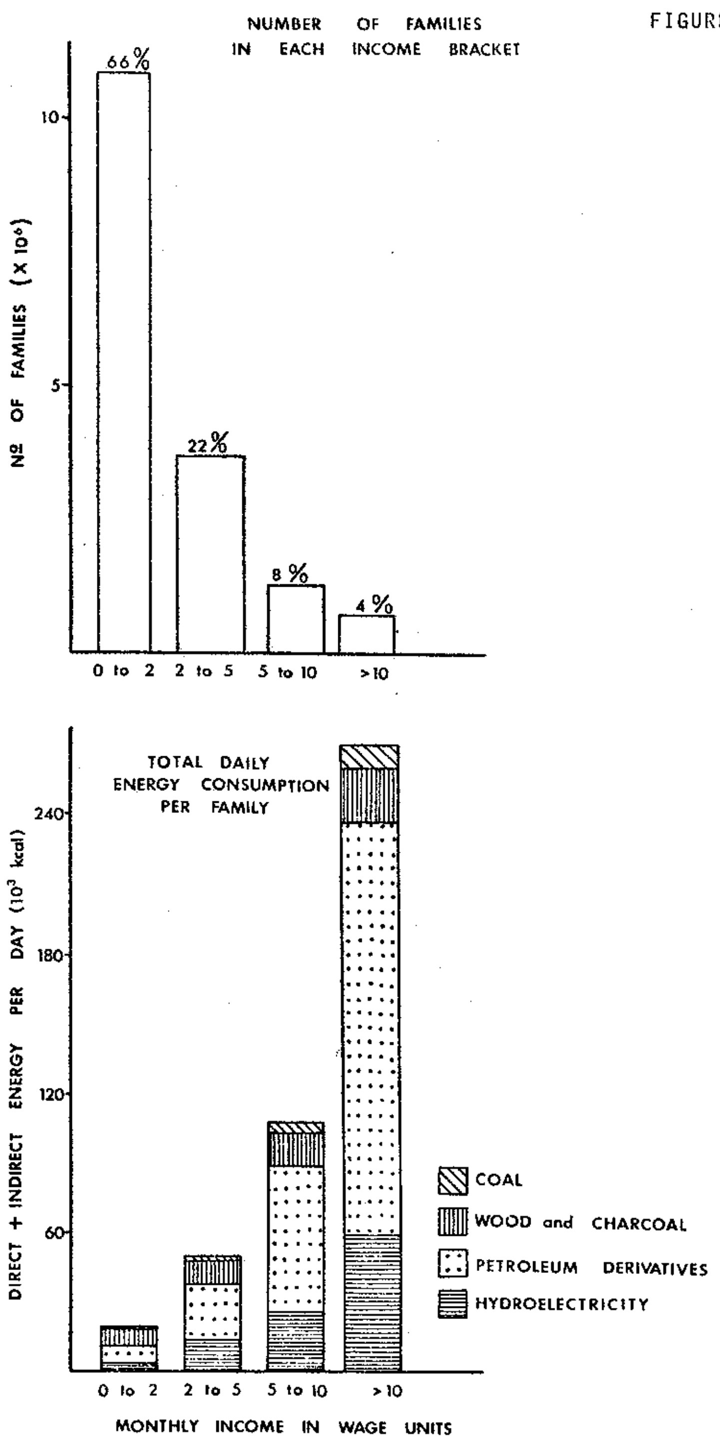

FIGURE 9