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11. The starting point for the calculation is an estimate made by C. J. Johnson and me that 1969 prices were in the range of 18 to 20 cents per million Btu's [C. J. Johnson, "Coal demand in the electric utility industry," thesis, Pennsylvania State University, University Park (1972); R. L. Gordon, *U.S. Coal and the Electric Power Industry* (Johns Hopkins Univ. Press, for Resources for the Future, Inc., Baltimore, Md., 1975)]. Comparisons were made on *Coal Week* listings of 1977 quotations for coal selling on long-term contracts, deflating by the implicit deflator for the gross national product.
12. U.S. House of Representatives, *Surface Mining Control and Reclamation Act of 1977 Conference Report*, 95th Congress, 1st session, 1977.
13. ICF, Inc., *Final Report Energy and Economic Impacts of H.R. 13950 (Surface Mining Control and Reclamation Act of 1976)* (ICF, Inc., Washington, D.C., 1977). For an alternative view on total costs, see Energy and Environmental Analysis, *Benefit/Cost Analyses of Laws and Regulations Affecting Coal* (Government Printing Office, Washington, D.C., 1977).
14. The numerous papers making the case were made available to me by the National Coal Association.
15. See W. E. Tyner, R. J. Kalter, J. P. Wold [*Western Coal: Promise or Problem?* (Department of Agricultural Economics, Cornell University, Ithaca, N.Y., 1977)] for a review of these problems, which suggests that ownership patterns and leasing policies hinder both ensuring maximum returns to the federal government and efficient industry development.
16. U.S. Congress, Public Law 94-377, *An Act to Amend the Mineral Leasing Act of 1920, and for Other Purposes*, 94th Congress, 2nd session, 1976.
17. U.S. Mountain Plains Federal Regional Council, "Preliminary draft of permitting procedure for surface mining of coal on federal lands or coal deposits" (Denver, Colo., 1977).
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22. I thank various government agencies that made reports available to me, ICF, Inc., and Robert Kalter who directly supplied their reports, coal industry sources who provided their material, and E. Welch who checked the manuscript for me.

# Brazil: Energy Options and Current Outlook

J. Goldemberg

*Summary.* Brazil's energy options and current outlook are examined, and a summary of known reserves of fossil and renewable energy resources is given. Brazil has abundant renewable energy resources but very modest reserves of fossil fuels. Consequently, the emphasis in the future will have to be on the utilization of solar energy, hydroelectric power, and biomass in a program designed to preserve local traditions and culture.

Brazil has an area of 8,511,965 square kilometers and a population of approximately 110 million people (*1, 2*). The country was kept dormant as a Portuguese colony for more than 300 years and, after gaining political independence in the last century, remained as a producer and exporter of agricultural products, mainly coffee and sugar, until World War II.

After World War II, Brazil entered a phase of accelerated industrialization which resulted in the growth of very large cities in the southern (and more temperate) part of the country and, consequently, in an exodus of rural populations to urban centers. The fraction of the population living in cities increased from 36 percent in 1950 to 45 percent in 1960 and 56 percent in 1970.

The energy consumption "per capita" of the average Brazilian therefore increased enormously in a brief span of time; in addition, the profile of consumption changed very significantly. Figure 1 indicates that by 1976 Brazil had reached a level of consumption comparable to some of the less developed European countries (approximately 10 megawatt-hours per year per capita) (*3*).

Energy consumption as a function of per capita income has increased in recent years in a manner similar to that in developed countries. Thus the country has entered a phase of modernization in which the energy-intensive consumption patterns of the great industrial countries have been adopted, without any critical assessment, through the transplantation of modern, foreign industries. As shown in Fig. 2, the relation between per capita energy consumption ($E$) and per capita income ($I$) is practically linear, a characteristic of highly developed countries (*4, 5*).

The ratio of total energy used to per capita income has also remained almost constant in the last 10 years at the level of $60 \times 10^3$ British thermal units (Btu) per dollar. This is approximately two-thirds of the value in the United States (*6*) and indicates that the efficiency of energy use has been slowly improving (Fig. 3); however, less energy is needed in Brazil to produce one dollar of income than in the United States, indicating a smaller use of energy-dissipating devices such as air conditioners and freezers.

The profile of consumption (*3*) changed in a somewhat predictable fashion in the era of cheap and abundant petroleum (Fig. 4). The relative importance of biomass in the balance of the energy consumed decreased dramatically from 1940 to 1975, with a corresponding growth of petroleum consumption.

Coal has had an insignificant role in energy consumption in Brazil, but hydroelectric power has increased its share to 20 percent of the total energy consumption in recent years. The balance is taken by petroleum; its contribution has grown from 9.2 percent in 1941 to 28.0 percent in 1952 and to 44.8 percent in 1972 (Fig. 5). Natural gas consumption has been negligible.

The energy profiles of Brazil and the United States are compared in Table 1. Petroleum represents approximately 44.8 percent of the total energy consumed in Brazil and only 20 percent of it is produced internally. The remaining 80 percent (700,000 barrels per day) is imported at a cost of more than $3 billion per year. To compensate for this deficit in the balance of trade, the country has to export large quantities of raw minerals, agricultural products, and semi-industrialized goods.

The future prospects for energy consumption are presented in Fig. 6, which shows the official projections for con-

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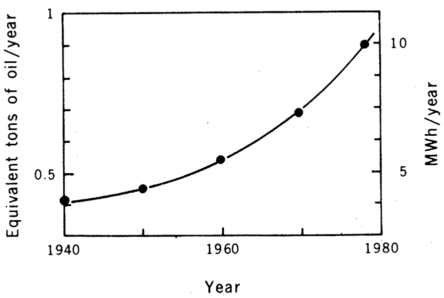


Fig. 1. Brazil's energy consumption per capita in the period 1940 to 1977.

sumption of different sources up to 1985: The contribution of biomass remains approximately constant, whereas hydroelectric production increases significantly but not enough to avoid a strong increase in the use of liquid combustibles (predominantly petroleum, although other sources such as alcohol and shale oil are also considered). Energy consumption is expected to grow at a rate of approximately 10 percent a year; the population growth rate per year is 2.9 percent, which, by itself, represents a great stress on the Brazilian economy.

In this article I review the known resources in Brazil and their possible utilization. As I will show, the prospects for a greatly increased petroleum production in Brazil are limited. Alternatives must therefore be found if an extremely serious situation is to be avoided in the next 10 to 15 years.

## Energy Resources in Brazil

The data given below are taken from the compilation made by the Brazilian National Committee of the World Energy Conference and published in (*2*). The data refer in all instances to 1972.

*Crude oil*. Sedimentary basins onshore extend over an area of 3,168,000 km², plus about 800,000 km² offshore on the continental shelf. The first basins to be explored were those in the northeastern region (state of Bahia) near the Todos-os-Santos Bay, and all locally produced oil has come from this region. Since 1939, more than 3900 wells have been drilled all over the country; 1985 of the wells produced oil, and 108 natural gas. The overall results have been disappointing, however; the recoverable oil reserves are only about $106 \times 10^6$ metric tons, and the annual production of $8.2 \times 10^6$ tons covers only one-fifth of the country's needs, the balance being imported (Table 2).

The remaining possibility for increased oil production in Brazil seems to be the offshore exploration that led to the discovery in 1976 of new fields off the shore of Rio de Janeiro. These reserves increased the figures shown in Table 2 by about 15 percent, and there are hopes for doubling the Brazilian production of oil by 1982.

*Natural gas reserves*. Natural gas reserves (Table 3) are usually associated with crude oil deposits. Although the production of natural gas was 1.2 km³ in 1972, only 18 percent was used for energy and industrial uses; the balance was either reinjected into the wells—to increase pressure or for storage—or flared locally. The principal reason for flaring is that the main producing centers are located in Bahia, which is not an industrial state. The recent establishment of a petrochemical industry near the crude oil and gas fields will encourage further use of gas.

*Shale oil*. Depending mainly on economic factors, the oil recovered from shales could complement conventional crude oil. The known shale oil reserves in the southern region of Brazil are given in Table 4. Most shale deposits contain 4 to 8 percent oil. The recoverable oil, considering only the formations in the southern region, is estimated at about $500 \times 10^9$ barrels, almost five times more than the known crude oil deposits.

Table 1. Energy resources in Brazil and the United States in 1972.

| Source | Brazil (%) | United States (%) |
|---|---|---|
| Coal | 3.6 | 17 |
| Petroleum | 44.8 | 46 |
| Gas | 0.3 | 32 |
| Hydroelectric power | 20.8 | 4 |
| Biomass* | 30.5 | 1 |
| Total | 100.0 | 100 |

*Including wood and sugarcane bagasse.

Table 2. Petroleum reserves (1972) in $10^6$ tons.

| Locality | Reserves | | Past cumulative production |
|---|---|---|---|
| | Total | Recoverable | |
| Bahia | 515.7 | 83.2 | 81.0 |
| Alagoas | 6.2 | 0.4 | 0.3 |
| Sergipe | 212.7 | 20.4 | 7.4 |
| Offshore | 14.9 | 2.6 | |
| Total | 749.5 | 106.5 | 88.7 |

Table 3. Gas reserves (1972) in $10^6$ cubic meters.

| Locality | Reserves | | Past cumulative production |
|---|---|---|---|
| | Total | Recoverable | |
| Bahia | 49.3 | 28.9 | 12.5 |
| Sergipe | 4.1 | 1.6 | 0.1 |
| Alagoas | 0.9 | 0.6 | |
| Offshore | 5.9 | 4.7 | |
| Total | 60.2 | 35.8 | 12.6 |

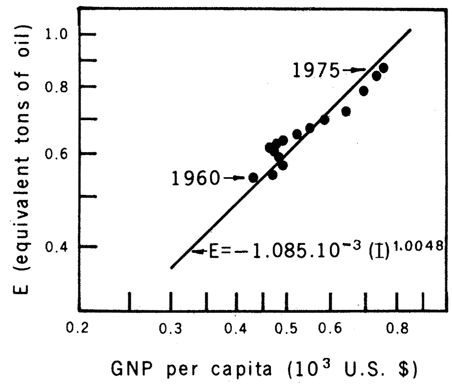


Fig. 2. Energy consumption (*E*) versus income (*I*). The data indicate elasticity *p* close to unity (*4*).

Studies are under way for the commercial exploitation of shale deposits in Paraná. Operation of the oil-producing facilities is expected to begin in 1978 with a daily production of about 10,000 tons of oil, 900 tons of sulfur, 400 tons of liquefied petroleum gas, and 1.7 million cubic meters of light heating gas. Environmental problems associated with these plans have yet to be solved. For the oil to be recovered, large quantities of rock have to be removed (200,000 to 400,000 tons) daily, and material remaining after extraction is highly acidic and presents a disposal problem.

*Coal*. Coal deposits are scarce in Brazil and all those that have been discovered are in the southern region (Table 5). The total known reserves are $3256 \times 10^6$ tons of which $2014 \times 10^6$ tons are of the subbituminous type, $1240 \times 10^6$ tons bituminous, and only about $2 \times 10^6$ tons anthracite. Coal of a metallurgical grade suitable for coking can only be obtained after complex processing. Prewashed coal has an ash content of up to about 30 percent. The subbituminous coals of the states of Rio Grande do Sul and Paraná are also of poor quality and produce only steam coal for local use. Fluidized bed combustion of poor-quality coal might be used to advantage in Brazil.

*Uranium and thorium*. Only very recently did prospecting for the so-called fissile fuels begin in Brazil. Coastal monazite-sand deposits containing both thorium and uranium are known to exist, but the cost of exploiting them commercially has not been evaluated.

The only known uranium deposits (Table 6) are in the southeastern region, in the State of Minas Gerais (Pocos de Caldas). They occur in an intrusive pipe

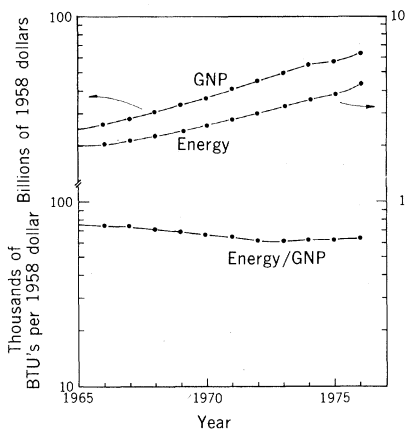


Fig. 3. Energy and gross national product (*GNP*) in the period 1965 to 1975. The ratio of energy to gross national product is approximately constant over the period and somewhat smaller than the equivalent value for the United States.

of alkaline rocks covering an area of about 900 km². The economic thorium reserves (Table 7) come from monazitic beach sand deposits. The monazite occurs in association with zircon and rutile, and the deposits are located along the eastern and northeastern Atlantic Coast. A total of only 408 tons of thorium was produced in 1972.

Other possible sources of fissile fuels, not yet sufficiently known in terms of economic exploitation, occur in the State of Minas Gerais. These include thorite and thorogummite, in connection with highly decomposed alkalic rocks. In the Araxá niobium deposits, thorium appears associated with monazite. Still other sources could be fluvial monazite-sand deposits and monazite-bearing pegmatites in the states of Minas Gerais, Goiás, and Rio Grande do Norte.

*Hydroelectric energy*. The geomorphology of Brazil is such that water resources are spread over the whole country, with a certain predominance in the northern region where the world's biggest basin—the Amazon—is located.

Table 8 shows the main characteristics of the local hydroelectric potentials. Figures are presented by geographic region. Of the overall installable hydropower capacity of 118,980 megawatts, approximately 17,000 MW are being used and this number should increase to 35,000 MW by 1985 with the completion of the huge Itaipu central dam, with a capacity in excess of 10,000 MW, on the Paraná River, and a few other dams. At present, only 14 percent of the total hydroelectric power of the country is being used, although in the most populous southeastern region this fraction is 27 percent (Table 8). There remains a potential of almost 50,000 MW mainly in the tributaries of the Amazon River in the northern region (Tocantins, Araguaia, Xingu, Tapajós, Cotinga, and Trombetas).

A serious transportation problem may develop because these sources are located at least 2000 km from the great population centers (Rio de Janeiro and Saõ Paulo) in the southeastern part of the country that has a total population of 40 million people.

*Biomass*. Wood accounts for approximately 30 percent of Brazil's present energy needs; this represents approximately 170 million cubic meters, most of it used as fuel. These numbers probably represent a lower limit.

The utilization of wood for charcoal is important in the steel industry and it is estimated that 40 percent of the needs of this industrial sector are supplied from this source (approximately 2 million tons yearly).

As indicated in Table 9, forests originally covered 55 percent of the Brazilian territory. The Atlantic and Brazilian pine (*Araucária braziliensis*) forests have now been almost completely decimated, but the Amazon forest remains almost intact (*7*).

*Total reserves*. The proved recoverable energy reserves of the country for 1972 are summarized in Table 10.

## The Nature of the Problems

In the southern part of Brazil the patterns of energy consumption are not very different from those of the great industrial nations. This part of Brazil suffers from crowded cities, roads clogged with automobiles, and air pollution, and there is a general deterioration of the quality of life in the urban centers.

Table 4. Shale oil reserves (1973).

| Locality | Deposit area (km²) | Oil content (kilograms of oil per 1000 kg of shale) | Total recoverable oil ($10^6$ tons) |
|---|---|---|---|
| São Paulo | 200 | 40 to 130 | 288 |
| Paraná (Iratí) | 82 | 70 | 95 |
| Rio Grande do Sul | 350 | 20 to 80 | 114 |
| Total | 632 | | 497 |

Table 5. Coal reserves (1972). The total recoverable quantity is 688 × $10^6$ tons.

| Locality | Total reserves ($10^6$ tons) | Annual production ($10^3$ tons) |
|---|---|---|
| São Paulo | 1 | |
| Paraná | 35 | 346 |
| Santa Catarina | 1200 | 4536 |
| Rio Grande do Sul | 2020 | 978 |
| Total | 3256 | 5860 |

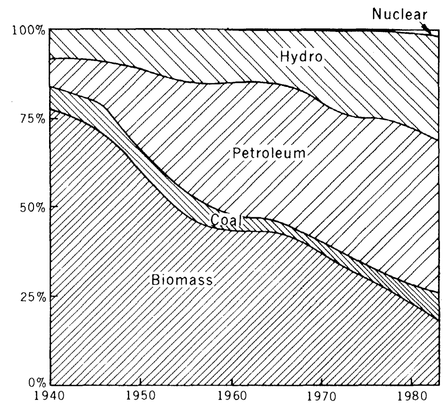


Fig. 4. The energy consumption profile of Brazil indicating the rapid decline of biomass consumption.

The number of automobiles in Brazil has grown from a few thousand 30 years ago to about 5 million in 1975. For the transportation of goods and services, road transportation has been emphasized, often because of the availability of subsidies for road construction, with the result that the energy spent in road transportation is approximately 83 percent of the total transport energy (*8*).

In addition to the gasoline consumed in cars there is an industrial energy-intensive sector that uses large quantities of petroleum derivatives and electricity. The transportation of electricity to these urban centers from distant locations in the Amazon basin poses a serious technological problem, and for this reason the construction of nuclear reactors was considered as a solution to the energy problem. The Brazilian government has now begun an ambitious program of installing several nuclear reactors, mainly in the southeastern part of the country. This program could alleviate the energy shortage in the urban and industrial southeast, but would have little effect on the automobile and the automotive industry, which is the leading industrial sector in Brazil.

Since most of the petroleum consumed in Brazil is imported, the price of gasoline is now among the highest in the world: U.S. $1.80 per gallon (approximately three times the current price in the United States).

Because of strong pressure to reduce consumption of gasoline (and other oil products), the government has made a determined effort to promote the use of ethyl alcohol (ethanol) as a partial (or total) substitute for gasoline in automobiles.

Even if the programs to produce nuclear energy and to substitute alcohol for gasoline succeed, the problem remains that the development patterns which "modernized" the southern part of Brazil—in the sense of introducing the latest gadgets and products of industrialized countries—have benefited only approximately 20 percent of the population concentrated in large cities. Thus a situation has arisen in which there are, in effect, two countries in one: a reasonably well-developed section that includes 20 percent of the population, and an underdeveloped section that includes the remaining 80 percent of the population living either in the northeast under conditions of poverty or in slums in the big cities.

Although the total population growth rate in Brazil is 2.9 percent per year, the growth rate for the rural population is 2.3 percent whereas that for the urban population is 6.13 percent per year. Thus, in addition to meeting the requirements of the high general rate of growth, energy production must meet the requirements of the even higher rate of urban population growth. Up to now, the high rates of growth of energy production (approximately 10 percent per year for all sources; 12.5 percent per year for hydroelectric power) (Fig. 6) have been able to keep pace with population growth, but how long this rapid growth rate can be sustained is a fundamental question because, in developed countries, such growth rates in general are not higher than 5 percent per year.

The possible utilization of wind energy, thermal gradient of oceans, tidal power, and other new sources of energy has been discussed in Brazil, but the work being conducted on these techniques can be generally regarded as following the "state of the art."

### Possible Solutions

There are several possible solutions to Brazil's energy problems. Here I will discuss biomass and the alcohol program, hydroelectric power, solar energy, nuclear energy, and conservation measures.

*Biomass and the alcohol program.* The average intensity of solar radiation over most of Brazil is approximately twice the intensity in the United States, and this, together with other conditions, such as humidity, permits rapid growth of most types of vegetation.

Wood is not being extensively utilized in Brazil for the production of ethanol and methanol. Recently, however, with the alcohol program becoming an important government priority, much research is being conducted on the possibility of growing various plant crops for alcohol production.

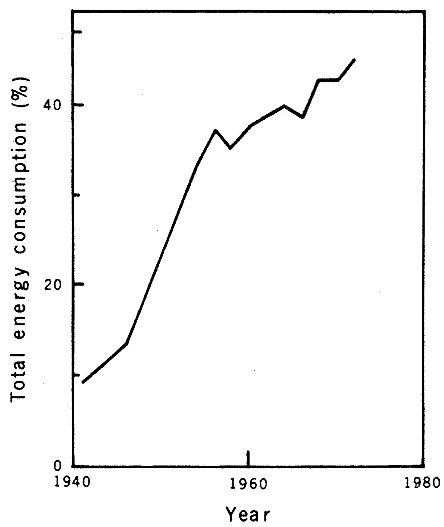

Fig. 5. The rapid rise of petroleum consumption in the period 1940 to 1977.

Technically, the idea of using alcohol as a gasoline substitute is feasible: present internal combustion engines can use or be converted to run on ethanol, and the huge amounts needed could be produced, mainly from sugarcane, in Brazil (*9*). Alcohol can be mixed with gasoline without any changes in present-day internal combustion engines in any amount up to 20 percent. Although ethyl alcohol has a calorific content that is 39 percent lower per liter than gasoline, there are other compensating factors: ethanol has a higher density than gasoline, and the power of a motor running on alcohol is 18 percent higher than a motor running on gasoline. The overall result is that only 1.4 percent more alcohol is consumed than gasoline. Motors running on 100 percent alcohol can be produced with minor modifications of the present ones (*10*).

Typical goals of the Brazilian alcohol program are given in Table 11 (*11*). The amounts of land that would be needed for some of these scenarios are very large (*12*). Of Brazil's total area of 850 × $10^6$ hectares, approximately 70 × $10^6$ ha are fertile lands. If one assumes that by the year 2000 the total amount of fertile land will increase to 14 percent (120 × $10^6$ ha), approximately 20 percent of that land would be necessary to produce all the alcohol needed by then (almost twice the amount for scenario 4 in Table 11). This would correspond to 3 percent of the Brazilian territory being covered by

Table 6. Uranium reserves (1972). Costs are in U.S. dollars. New findings, raising these numbers to perhaps 10,000 to 20,000 tons, have recently been reported.

| Locality or deposit | Range of maximum recovery cost ($/kg) | Quantity recoverable (tons) | Average grade of ore (% of $U_3O_8$) | Estimated additional resources (tons) |
|---|---|---|---|---|
| Minas Gerais | Up to 33.0 | 3195 | 0.15 to 0.19 | 4250 |
| Monazite sands | Up to 22.0 | 49 | 0.18 | 37 |
| Total | | 3244 | | 4287 |

Table 7. Thorium reserves (1972). Costs are in U.S. dollars.

| Locality or deposit | Range of maximum recovery cost ($/kg) | Quantity recoverable (tons) | Average grade of ore (%) | Estimated additional resources (tons) |
|---|---|---|---|---|
| Minas Gerais | Not available | 65,000 | 0.09 to 1.0 | 1,200,000 |
| Monazite sands | Up to 20 | 1,350 | 5.0 | 1,000 |
| Total | | 66,350 | | 1,201,000 |

Table 8. Hydroelectric potential in Brazil.

| Region | Installable capacity (MW) | Potential annual generation* (GWh) | Power generated in 1975 (GWh) | Fraction utilized (%) |
|---|---|---|---|---|
| North | 46,200 | 202,400 | 1,020 | 0.5 |
| Northeast | 13,349 | 58,500 | 8,800 | 15 |
| Southeast | 39,577 | 183,700 | 51,570 | 27 |
| Central-West | 1,164 | 5,100 | 1,730 | 34 |
| South | 18,690 | 67,200 | 8,390 | 12.5 |
| Total | 118,980 | 516,900 | 71,510 | 14 |

*Available 95 percent of the time.

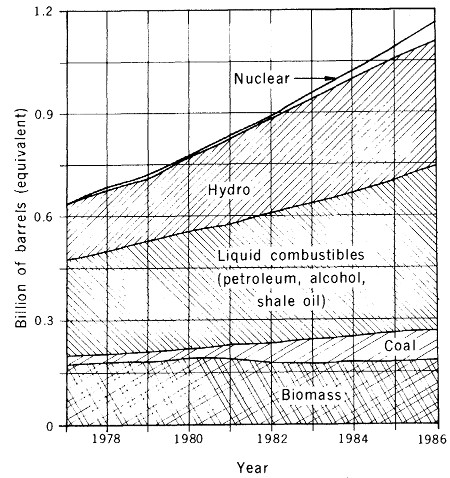


Fig. 6. Projections of energy consumption of different sources in the period 1977 to 1986. All sources converted to oil equivalent.

sugarcane—a difficult goal to achieve and probably an undesirable one.

The overall efficiency of alcohol production from different crops is indicated in Table 12 (*13*). In the case of sugarcane, the energy gain is 2.40 with a total production of 3564 tons per hectare. This corresponds to an efficiency of solar energy utilization of a few tenths of a percent (0.3 to 0.4 percent). It is assumed that the bagasse is used as a combustible in the alcohol distillation plants. There is, however, a surplus of bagasse that could be used to generate electricity as a byproduct in a "cogeneration" process.

*Hydroelectric power*. The average annual growth of Brazilian hydroelectric consumption in the last 15 years has been 12.5 percent. By 1985 all the reserves of the southeastern part of the country will have been used up and it will be necessary for the southern region to consume electricity generated in the Amazon tributaries.

Long distance lines will therefore be needed, and possibly the use of direct-current high voltage transmission to minimize losses that are inevitable with the usual methods of transmission. The construction of a 4.5 million-kilowatt hydroelectric power plant located on the Tucurui River in the Amazon Basin is being considered; the electricity produced would be consumed locally in the production of aluminum from bauxite instead of being transported long distances. Ideas of this type have been studied in some detail by Strout (*14*) and probably deserve further consideration.

Some smaller hydroelectric power plants remain to be built in the State of São Paulo such as Porto Primavera and Ilha Grande on the Paraná River. Water resources might also be used more economically; for example, reversible stations could be constructed on the Serra do Mar where water could be pumped uphill during off-peak hours (*15*). Another 10,000 MW could be made available through this method.

A new idea receiving much discussion involves the use of "bulb type" generators that can work efficiently in small waterfalls (2 to 20 meters) or in fast-moving streams (*16*). Costs of these turbines compete favorably with the conventional ones, and they produce from 10 kW to 10 MW of electricity. Such "mini" hydroelectric generating stations are adequate for decentralized electricity-dispensing with expensive transmission lines. They are economically competitive and have been used for at least 15 years in France, Germany, Japan, England, and a few other countries, but have been used in only a few locations in the United States.

*Solar energy*. The most significant projects for the use of solar energy in Brazil are those for drying agricultural products and for heating water for industrial or hospital use. In one such project, 1000 $m^2$ of flat plate collectors are being installed in the roof of the University Hospital at São Paulo (400 beds). The water heated by the collectors will be used to provide steam and for other purposes. The total energy consumption of this hospital is approximately 1800 tons of fuel oil per year, and it is expected that 15 to 20 percent of this fuel oil will be saved by solar energy utilization. The same method will be used in some textile and food industries; it has been estimated that the total energy consumption in the industrial sector in Brazil could be reduced by 5 percent by this method (*17*).

The project for grain drying is being developed at the University of Campinas (*18*) where it has been shown that 10 tons of sorghum per day can be successfully dried under economically competitive conditions.

*Nuclear energy*. The strong pressure to guarantee the supply and prosperity of the large cities in the São Paulo–Rio de Janeiro area has encouraged the inclusion of nuclear reactors in plans to provide alternative energy sources in Brazil, although paradoxically there are enormous hydroelectric reserves in other parts of the country. After a long period of hesitation, a 624-MW nuclear reactor was purchased in 1969 from Westinghouse for construction in Angra dos Reis, Rio de Janeiro. This pressurized water reactor (PWR), which is due to start operation in 1979, is fueled with enriched uranium, and it was almost totally constructed by U.S. technicians. No transfer of technology was contemplated and participation of Brazilian industry was restricted to the civil works and some low technology equipment. The decision to purchase this reactor was strongly criticized by many scientists and by industry spokesmen because it increased Brazil's dependence on foreign imports. Sensitive to that criticism, the

Table 9. Brazilian vegetation. All numbers represent percentages of total territory.

| Forest | Primitive | Present |
|---|---|---|
| Amazon | 40 | 36 |
| Atlantic | 10 | 1 |
| *Araucaria** | 5 | 0.5 |
| Total | 55 | 37.5 |

*Brazilian pine.

Table 10. Brazil's energy resources.

| Resource | Proved reserves (× $10^6$ ton) | Total energy content ($10^{15}$ joules) | Percentage of total |
|---|---|---|---|
| | *Nonrenewable* | | |
| Crude oil | 106.53 | 4,687 | 11.1 |
| Natural gas* | 35.8 | 1,468 | 3.5 |
| Shale oil | 497.0 | 21,868 | 52.0 |
| Mineral coal | 688.0 | 13,760 | 32.7 |
| Uranium† | 0.0032 | 309 | 0.7 |
| Total | | 49,092 | 100.0 |
| | *Renewable* | | |
| Hydroelectric power (present) | | 649 | |
| Biomass (present) | | 954 | |
| Hydroelectric power‡ (potential) | | 3,023 | |

*Proved reserves are in cubic kilometers. †Figures are for pressurized water reactor without plutonium recycling. ‡Annual generation based on potential of 119 GW and on historical average hydrological conditions, converted at substitution basis (1 KWh = 12.75 × $10^6$ joules).

Table 11. Goals of the alcohol program in Brazil. The scenarios are as follows: 1, 20 percent alcohol added to gasoline plus $10^9$ liters for industry; 2, 100 percent alcohol plus $10^9$ liters for industry; 3, 100 percent alcohol plus 50 percent of the diesel oil consumption; 4, 100 percent alcohol plus 100 percent diesel oil consumption.

| Scenario | Production (liters/year × $10^9$) | Cultivated area needed in 1000 ha of sugar cane* |
|---|---|---|
| 1 | 4 | 1000 |
| 2 | 16 | 4400 |
| 3 | 22 | 6000 |
| 4 | 33 | 9000 |

*The average agricultural productivity was taken as 60 tons per hectare and industrial output as 70 liters per ton. One hectare is equivalent to 10,000 $m^2$ or 2.47 acres.

government in 1974 embarked on an ambitious nuclear program in cooperation with West Germany whereby Brazil would achieve complete autonomy in the nuclear field over a period of 15 years.

Eight PWR's (1300 MW each) were scheduled to be installed in Brazil with an increasing index of nationalization that should come close to 100 percent in 1990. A semi-industrial uranium enrichment plant (250 tons per year) was to be built in Brazil based on the jet-nozzle method. In addition, a plutonium-reprocessing plant was to be built by German enterprises. In all cases companies were to be formed in which the Brazilian government would be dominant but there would be German associates (and in some cases private Brazilian capital).

Although there was some initial enthusiasm for such a comprehensive nuclear program, the difficulties soon became apparent. First, the feasibility of uranium enrichment (which is essential if any real autonomy is sought) was viewed with strong skepticism by many scientists because the Becker jet-nozzle method to be used was not considered a proved method; for many years to come, therefore, enriched uranium would have had to be purchased from other suppliers. The achievement of "nuclear independence" was therefore in the far distant future.

Second, the transfer of technology was not successful from the very start; disagreements on the role to be played by Brazilian local industry and German industries surfaced and it became apparent that the program would benefit the German nuclear industry in Germany and not in Brazil.

Third, the role of Brazilian scientists and technological institutes was neither properly defined nor given much attention; this strengthened the suspicions that no real transfer of technology was to occur.

Finally, the planned installation of a plutonium-reprocessing plant raised strong objections in the United States because such a plant would constitute an added danger to nuclear proliferation.

These problems caused the program to be delayed, and the urgency of nuclear energy in Brazil is now being reassessed. Most Brazilian scientists and industrialists would probably prefer a more modest program in which they could play a dominant role and acquire the necessary technology. The construction of a prototype nuclear reactor—preferably working on the thorium cycle—would probably be the most appropriate choice from the point of view of Brazilians familiar with nuclear problems.

Table 12. Annual energy balance in alcohol production.

| Crop | Agricultural yield (tons/ha) | Alcohol production (liters/ha) | Energy (Mcal/ha) | | |
|---|---|---|---|---|---|
| | | | Required | Produced | Gain |
| Sugarcane | 54 | 3,564 | 14,952 | 36,297 | 2.40 |
| Cassava | 14.5 | 2,523 | 12,751 | 18,783 | 1.45 |
| Sorghum | 32.5 | 3,775 | 16,554 | 31,689 | 1.92 |

*Conservation measures.* Although a number of energy-saving methods have been suggested, the only practical actions taken by the government have been in the direction of reducing gasoline consumption in private automobiles and in trucks. To this effect the following measures were adopted about 1 year ago: (i) limitation of the maximum speed on roads to 50 miles per hour; (ii) gradual banning of cars from the center of large cities to discourage people from driving their own cars to work or to go shopping; (iii) improvement of the bus system with the introduction of "executive" buses and exclusive bus lanes; (iv) closing of gasoline stations in the evenings and weekends; (v) gradual price increases for gasoline; (vi) the addition of up to 20 percent ethyl alcohol to the gasoline used by cars in some cities.

A precise evaluation of these measures has not been made, but a modest decrease (7 percent) in gasoline consumption occurred in 1977 which is encouraging if one considers that the number of cars increased by about 10 percent. Some of the more drastic suggestions made were not adopted, such as allowing the use of cars only on alternate days according to the last digit in their license plates (odd digit, odd days; even digit, even days), or rationing gasoline according to quotas. The suggestion to limit the power of cars produced by manufacturers (which is a better gasoline-saving measure than velocity limitation) was also refused. Many industries and bus and truck companies, however, are shifting away from gasoline to diesel oil, which is cheaper by a factor of 2.

Cars are generally smaller in Brazil than in the United States, but they are not very efficient; this upsets the gain due to the smaller weight. Although detailed data are not available for comparison, the average consumption seems to be 20 to 30 percent higher for cars of corresponding sizes in the United States; this may be related to the lower quality of the gasoline used in Brazil and to less efficient motors. Important improvements could be made on these two counts as in other countries.

It is interesting to point out, however, that price increases alone were not very successful in Brazil in discouraging people to drive cars. This indicates that the class of people owning cars has enough money—and a strong adherence to the established habit of driving—to afford price increases; or, perhaps, they give up other goods so that they can continue to drive their cars. People with lower incomes are discriminated against by high prices: the number of prospective car owners is reduced, and this creates a situation that ultimately will affect the economic health of the automobile industry.

## Conclusions

It is evident that Brazil has plenty of renewable energy resources but very modest reserves of fossil fuels. The present energy problems of the country are the consequence of industralization having been based largely on imported fossil fuels in an era of cheap and abundant petroleum.

In order to utilize Brazil's renewable energy sources—mainly hydroelectric power and biomass—the people will have to make considerable social adjustments. These adjustments will probably include the relocation of some of the producing centers so that they are closer to the hydroelectric plants, and a general decentralization of the urban centers. This does not mean a return "to the fields" or to a more primitive type of civilization, but a redistribution of the amenities of modern life in a way more compatible with nature. The pollution in the air and waters of the city of São Paulo has already reached such proportions that there is strong political support for decentralization.

To reduce energy consumption, restrictions on the use of automobiles will probably have to be imposed, and there will have to be a stronger emphasis on mass transportation. The use of rail and hydro transportation will have to be encouraged. Solar energy will probably be used directly in water heating, mainly for industrial purposes, and solar dryers may well be used in agriculture. Innovation is very fast in this area and the direct use of solar energy could become important in the future.

Biomass, for the production of alcohol as well as charcoal, will have an enormous role in the future. The historical association of the use of wood with underdevelopment will have to be counteracted by pilot projects and demonstrations of the utility of biomass. The reorientation of the steel industry toward the use of charcoal instead of mineral coal has been done to some extent and should be encouraged, together with a coordinated program of reforestation.

Nuclear energy will have only a secondary role in energy production in Brazil; efforts to promote a widespread use of this form of fossil energy cannot be justified. High-grade uranium resources are small in Brazil, and serious risks would be associated with a new dependence on imports of nuclear fuel.

Although oil shale is abundant, the extraction of the oil poses serious technical and environmental problems, and this resource should probably be used only in the chemical and pharmaceutical industries. Recovery in situ might eventually prove to be an attractive technology.

In the overall picture, Brazil seems to be capable of finding within its own frontiers most of the energy needed to sustain its population.

New patterns of energy consumption will have to be adopted in Brazil. The construction of completely enclosed buildings—requiring constant air conditioning—in Brasilia and other cities in the temperate regions of the country indicated a total disregard for efficient energy use. The Portuguese colonizers some 200 years ago constructed simple but functional buildings and with some effort it should be possible for Brazilians today to design a new type of "tropical civilization" that is appropriate to the environment.

### References and Notes


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19. I thank R. H. Williams of the Center for Environmental Studies for a complete revision of the manuscript and for useful discussions.


# Energy Options and Strategies for Western Europe


Wolf Häfele and Wolfgang Sassin


The present world energy situation is characterized by total consumption at an average rate of about 7.5 terawatts (1 TW = $10^{12}$ watts) of thermal energy; this is roughly equivalent to 8 billion tons of coal equivalent per year. As much as 5.5 of this 7.5 TW is supplied today by oil and gas, and this high proportion has built up through the last 30 years. Oil systems as we know them today have a low capital cost investment [~ \$50 per kilowatt thermal (kWt)]; they are clean, easy to handle, and can easily adjust to market and end-user requirements. Not exactly but essentially the same is true for natural gas. It is therefore quite natural that the energy situation of Western Europe is mostly reflected by the supply of oil and gas. For the member nations of the Organisation for Economic Cooperation and Development (OECD), the *World Energy Outlook* (*1*) expects a total energy requirement in 1980 of 1400 million tons of oil equivalent, which is practically 2 TW. Of this, about 0.9 TW is expected to be supplied by oil, which amounts to roughly 12 million barrels per day (MBD). Reasonable estimates of the expected oil imports of the United States and Japan are 10 and 7 MBD, respectively, giving a total for these countries and Western Europe of about 30 MBD for 1980. Under present circumstances oil production by OPEC (the Organization of the Petroleum Exporting Countries) might be between 33 and 45 MBD. A recent study by the Workshop on Alternative Energy Strategies (WAES) (*2*) indicates that a ceiling of 45 MBD for OPEC production might lead to a gap between supply and inherent demand by 1990, and a ceiling of 33 MBD might lead to such a gap as early as 1982.


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### Competition for Buying Energy

If and when world oil demand outstrips supply, who gets the OPEC oil? The answer is, those who can pay. In the WAES study oil prices up to \$24 a barrel are considered; three questions follow from it.

1) Which countries will maintain a strong enough balance of payments to pay for the high-cost oil, and what will be the effect of such high oil prices on the world trade pattern?

2) How much oil will be added to world reserves at a price of \$24 a barrel, and what are the lead times for producing from these additional resources?

3) What is the domestic resource base