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A SECURE ENERGY FUTURE: A CHALLENGE FOR DEVELOPMENT

by

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1. Introduction

The oil crisis of 1973 and the subsequent increase in the price of oil gave rise in a dramatic way to a public awareness of the global importance of energy and induced a series of developments oriented toward assuring a stable and economic supply of energy. The oil glut of 1985 and the resulting drop in oil price in the first quarter of 1986 followed by an increase by the middle of 1987 are bound to produce in the short and medium terms a series of events and decisions that unless carefully thought and implemented may have in the long term disastrous consequences. In particular, some of the problems that still persist in the energy sector may be seriously aggravated. But because energy is a commodity of global interest the solution of the problems related to energy require a global attention. And one way of paying this global attention is through effective global cooperation in energy research and development involving all countries regardless of their degree of technological capability or level of economic development. However, energy research and development cannot be done in isolation from other global concerns such as population growth, urbanization trends, environmental deterioration, and social inequities. This paper explores some of the challenges and the areas in which global cooperation is more urgently needed for assuring a secure energy future.

2. The Energy Problem.

It is well recognized that the uncertainties in energy supply and cost have had a profound worldwide economic impact. As a result the relation between economic growth and energy consumption has been subject to a close scrutiny. There is no doubt that economic output demands energy, which in turn implies a correlation between energy usage and economic performance, which gives an economic dimension to the energy problem. However, since we are comparing two very complex concepts which cannot be reduced to simple terms, the correlation cannot be expressed in simple mathematical terms. Economic growth implies increased production with everchanging technologies in a variety of industrial sectors, in a multitude of agricultural activities, and in a series of supporting areas such as transportation, household needs and style of living, each one having a different energy intensity. Also not all forms of energy are interchangeable and therefore the availability of adequate forms of energy to match the demand of the different economic sectors is crucial for sustained economic growth. In turn, the availability of energy in a country is determined by the existence of local resources and the capacity to import the energy resources required to supplement national production. Obviously, the price of energy also determines its availability.

In addition the response of the economic sectors to changes in price and availability of energy is not instantaneous and there is a time lag for adjustment which varies from one economic sector to another and from one country to another, adding a new dimension to energy planning.

This complex picture is aggravated by the existence of an extremely versatile but nonrenewable primary energy source, oil, that thanks to the petrochemical technology can be adapted to perform a great diversity of tasks and therefore has become the favorite energy source as well as the raw material for many products. However oil, which is still plentiful, eventually will be exhausted, and long before that it will become scarce and very expensive. On the other hand, the price of oil went up during the period from 1970 to 1980 by a factor of 20, it came down by a factor of four in early 1986 and has gone up again by a factor of two by the middle of 1987. Consequently it is impossible to predict with certitude the trend of oil prices, except that it is highly improbable that it will go down again in a significant amount and that most certainly it eventually will go up substantially. But in addition burning oil (as well as any fossil fuel) is a major source of environmental pollution, especially because of the release into the atmosphere of CO_2 and other chemicals.

Since currently oil constitutes about 40% of the primary energy used in the world (Table I), the energy problem in the short term is not lack of energy but really an oil problem which boils down to two considerations:

1. How is it possible to sustain steady economic growth in a situation of unpredictable and sudden changes in oil prices.
2. How is it possible to move away from an oil based economy as fast as possible?

In the longer term, the solution to the energy problem evidently consists in developing a stable global energy system based on inexhaustible and renewable energy sources capable of sustaining modern industrial societies and satisfy the growing needs of countries in process of development, while rationalizing the use of energy and minimizing the environmental impact. Although this is basically a technological problem, it involves many economic and social factors and requires appropriate policy decisions and strong international efforts. However, as it has been said many times, the world energy problem is not strictly technical or economic, but has a profound geopolitical content which presently is almost untractable. In fact, in spite of innumerable discussions it has not been possible yet to agree on a global energy strategy that would allow over a few decades a viable ordered transition into an oil-scarce new world. We may assume that the uncertainnty about how the energy transition should occur will remain with us for quite some time.

Disagreement on the course of action for managing all known and easily available and usable oil, at what prices and at what production schedule, is a natural consequence of the fact that all known and probable reserves are unevenly distributed (Table 2) not only in strictly geographical terms, abut also in terms of capriciously established political boundaries. This is reflected also in the oil production patterns. Those who have oil, obviously, tend to adopt views different from those who have no oil. But this is not the only difference, indeed. For example among the oil producers one finds countries with situations as diverse as the United States and Saudi Arabia, or as Mexico and Kuwait, or as the Soviet Union and Nigeria with quite different economic, social, cultural and political structures, so that oil does mean quite different things for each one resulting in a diversity of criteria for the management of their oil resources. The same holds for countries with no oil resources.

Even so the characteristic that perhaps serves better as a criterion for categorizing and identifying common positions is whether a country is a net oil exporter or a net oil importer, regardless of how large or small is its present oil production. Standard wisdom has maintained that the oil importing countries would like to keep oil prices down and production high, while oil exporting countries would like to boost oil prices and lower production output. However, this "standard wisdom" has not guided some recent OPEC decisions. This situation, of course, makes it difficult to adopt a global energy strategy.

3. The Case of the LDC.

Although, no country is totally devoid of energy resources, either renewable or nonrenewable, in a good number of situations they are not adequate to provide the energy mix required by the economic structure and the industrial base of the country as well as the distribution of the population. However, lack of oil is more critical than lack of any other energy sources, given the present structure of energy use and the limited flexibility for substitution of energy sources, particularly in the transport sector. This is exemplified by the trend in the use of oil in the OECD region (Fig. 1) which shows that while it is possible to reduce the use of oil for power generation, particularly by using more coal and nuclear power, and for domestic and commercial needs, through conservation and efficiency measures, it seems difficult to do so in the transport sector, as long as it continues to depend on internal combustion engines (alcohol has limited possibilities).

There are also certain important differences between the industrialized countries (IC) and the relatively less developed countries (LDC) regarding the energy use. One is the large importance of traditional or non commercial fuels in many LDC, which accounted roughly for 30% of the energy used in 1980, and which in some instances is close to 90%, as in Haiti and some African countries; even in relatively industrialized developing countries such as India and Brazil, it may be as high as 48% and 20% respectively. On the other hand the use of these fuels is negligible in IC. Non commercial fuels are basically immune to oil price changes and to the worldwide energy situation. However, traditional non commercial fuels are mostly used for household purposes and have very limited effect in the economic sectors, but their use has several undesirable effects,

with clear economic implications such as deforestation and soil erosion,[2] of which Haiti and the Sahel are dramatic examples. It is important to note that on the average the role of the traditional non commercial fuels is rapidly declining in LDC due to a multitude of well known circumstances, particularly industrialization and urbanization, and are being replaced by oil based fuels. Economic development has given rise to a shift from low energy intensity agriculture and cottage industries to high energy intensity agricultural and industrial production, and urbanization results in increasing demand for centrally produced energy for services and transportation, for which non commercial energy is not suitable. This places a severe strain on the financial situation of the oil importing LDC resulting in a steady increase in their external debt.

Another difference between IC and LDC is the relatively higher dependence on oil as a primary commercial energy source in LDC.[3] For example in Latin America it is of the order of 70% but reaches in some cases more than 90%, such as in Barbados and Panama, while in the IC it is on the average of the order of 48%. Even so the LDC consume only 30% of the world's oil production, while the IC consume about 70%. This situation is basically the result of the late industrialization of the LDC, which tended to incorporate in a higher proportion oil intensive production methods developed in the IC, although the total industrial production in LDC is smaller than in IC. However, most IC have available broad energy options as well as financial resources, have continued using coal to a great extent and many have adopted strong nuclear energy programs. In fact, OECD countries plan to increase their present use of coal three times and of nuclear energy five times by the year 2030 while simultaneously decreasing their overall energy intensity through convervation, improved efficiency, and structural changes in energy use. However, this is not the case of the LDC which have much less flexibility for changing patterns of energy use (Fig. 2). Coal is used in a relatively small amount in LDC, except in a few countries such as India, and nuclear power makes an insignificant contribution, except in Korea, Taiwan and Argentina. This circumstance combined with a production structure in LDC highly dependent on external parameters introduces an undesirable rigidity in the energy situation of most LDC, while it is much less pronounced in the IC.

A third and important difference between the IC and LDC is the energy consumption per capita which in the former is of the order of a few kW/cap, while in the latter it is on the average well below one kW/cap, with great variations from country to country, and among the different population sectors within the same country. In fact the poorer people in LDC may consume 40 times less energy per capita than the world average. This situation among other things, leaves very little room for conservation and puts great pressure for more energy use as the standard of living improves, particularly that of the poorer people. In fact, in many LDC commercial energy use has increased lately at a rate of the order of 6% to 10% per year, much larger than the rate of population growth, while in the IC the rate of growth of energy demand has remained on the average at less than 2%.

The present world energy consumption is of the order of 10 TWy/y,or simply 10 TW (amounting to about 300 Q/y or 140 MBOE/D) resulting in an average per capita consumption of 1.9 kW/cap. However, the consumption of energy is very unevenly distributed all over the world. In 1985 North America (U.S. & Canada), with about 290 x 10^6 habitants, or 6% of the world population, used about one third of the world energy, 3.0 TW (or 93 Q/y) while, for example, Latin America, with a larger population of about 390 x 10^6 persons used almost eight times less energy, 0.40 TW (or 12 Q/y) resulting respectively in about 10 kW/cap and 1 kW/cap, although more than half of the population in Latin America used about one tenth or less of that amount. As a matter of fact, about 72% of the world's population (3.6 x 10^9 persons) is located in LDC and PROC but consume only 20% of all energy produced in the world (about 2 TW) with an average energy consumption per capita of about 0.6 kW/cap (Fig. 3).

Therefore, the first inescapable conclusion is that just increasing in a short term the energy consumption in LDC to approach the world average of 1.9 kW/cap with a more equitable distribution among all population groups in order to improve in a short period of time the quality of life of the majority of the population to a reasonable minimum, requires an enormous additional production of energy. This, in turn implies that the LDC will have to make considerable investments for which the resources are simply not available. The answer might be in finding less energy intensive ways to improve the conditions of LDC combined with a reduction in the rate of growth of their populations, a task in which the IC must make a special contribution, jointly with the LDC efforts.

The question then is not just whether the world in general and the LDC in particular can sustain large increases in energy consumption but whether the LDC countries have at their disposal the capital, resources and technologies required so that they can afford increases in energy consumption of the magnitude that might be needed. Another way of asking this question is whether it is possible to improve the conditions of living in the LDC, which comprise the majority of the world population, without requiring enormous additional energy consumption and the consequent capital investment, and without increasing the level of environmental degradation.

4. Global Energy Scenario.

Taking for granted that it might be very difficult to agree on a global strategy, the need for regional and country energy strategies is thus evident. However, as it was said earlier, the energy strategy for a country or even a region is not an isolated element of decision making. It is coupled to many other factors, some of them external to the energy sector itself, such as the rate of population growth and its distribution between urban and rural areas, the structure of the productive sectors, the nature of the country's natural resources required for the expansion of the economy, and the social goals for a more equitable economic base, and others more directly related to the energy sector such as the energy required by present technologies to produce basic goods and products, the financial resources available to expand the energy systems, and last but not least the technologies for energy generation and distribution.

Based on the previous considerations it is possible to define a worldwide energy scenario for the short (year 2000) and medium (year 2030) terms. This energy scenario can be defined in part as follows:

i. Population:

The World population (5 GP or 5 x 10^9 persons in 1987) is increasing at the rate of 1.7% or 85 MP/y, reaching a total of about 6.2 GP by 2000. (Table 3) However, excluding the PROC the population of the less developed world (about 52% or 2.6 GP in 1987) increases at 2.3% approximately (60 MP/y), while in the IC (28% of world population or 1.4 GP) the rate of increase of population is on the average less than 1% (14 MP/y). In China the population (about 1GP in 1987) is increasing at about 1% or 10 MP/y. By the year 2000 the population of LDC will have increased by 27% or 1 GP, while in the IC the increase will have been 200 MP which is five times less than in LDÇ. In China the increase will be 13% or about 140 MP, seven times less than in the LDC. By the year 2030 the world population may have reached 10 GP with the largest increase in the LDÇ (about 6 GP). (Fig. 4) Therefore, population growth in LDC has more serious implications for energy than in the IC.

ii. Total Energy:

As indicated earlier , the World energy consumption (10 TWy/y in 1987) is increasing at a rate of about 2% or 0.2 TWy/y. (Table 4). The IC, with 28% of the world population, use more than 80% of the energy produced in the world , while the LDC, with 52% of the world population, use 10%, or about 1 TW, and PROC with 20% of the world population, uses 10% of the energy or 1 TW. By the year 2000 the total energy consumption most probably will be of the order of 13TW or an increase of 40% over 1987. The IC, because of conservation efforts and improved energy efficience, will increase its energy consumption up to 10 TW , or about 20%. However PROC will increase its total energy consumption by 40%, up to 1.5 TW mostly due to the increase in industrial output, and the LDC supposedly will double their energy consumption up to 2 TW because population increase, general improvement in the quality of life, and overall economic and social development. This increase, of course, is subject to many other conditions such as political stability, sound development plans and availability of capital. The projections for the year 2030 are more uncertain because the great variety of factors involved. If energy consumption continues to increase at 2% per year it should reach 23 TW by 2030, but even if the rate of increase of energy consumption is reduced to only 1% per year after 2,000 it will mean a total energy consumption of about 16 TW by 2030 or 60% more energy than at present. The general implications of this large amount of energy are difficult to assess in detail at present but one conclusion is obvious: efforts must be made to restrain the overall energy consumption without constraining the development of the LDC, and the IC must become the leaders in this effort.

iii. Energy per capita.

Current energy consumption per capita is about 2 kW/cap (Table 5) but with great differences among the different regions of the world. The IC use 5 kW/cap, PROC uses 1 kW/cap, and LDC use 0.4 kW/cap on the average.

While the world average energy consumpption might remain at about 2 kW per capita, until the year 2000 and the more advanced countries will use 5.0 kW/cap, the LDC and PROC will use only about 1 kW/cap, and in some instances still much less than that amount. The estimates for 2030 are rather uncertain but most probably an appreciable difference in energy consumption per capita between IC and LDC will still exist at that time. Reducing this energy gap in a judicious way is one of the most serious challenges of development that must be met jointly by the IC and the LDC.

IV. Energy and Urbanization:

The trend toward urbanization will continue unabatedly but will have more serious implications for the LDC. Currently 42% of world population or 2 GP live in urban centers, split almost evenly between the IC and the LDC/PROC, but by the year 2000 the urban population will be 60% or 3.7 GP of which 1.2 GP will be in the IC and 2.5 GP in the LDC/PROC, resulting in a larger increase in absolute numbers in LDC and PROC (about 1.5 GP). (Fig. 5)

It is to be expected a steady increase in the energy requirements of urban populations, which already are much larger than those of rural areas, and have an average density of about 5 W/m^2 or 25 times larger than the world average solar radiation (0.2 W/m^2), or 250 times the amount usable at 10% efficiency of collection. The consequence is that urban centers will continue to depend on highly concentrated energy sources and efficient energy supply lines. This applies both to LDC and IC. Therefore urbanization will pose a more acute energy problem in LDC. Current technologies for renewable energy sources are inadequate to fully supply the needs of large urban centers. Also urban planning must consider explicitly all aspects related to energy supply and use.

V. Energy and Food:

Although food production, and agriculture in general, depends primarily on solar energy for at least 80% of their energy requirements, they are becoming increasingly dependent on additional energy sources, either directly or indirectly [4]. This is due to several factors such as depletion of soils, artificial irrigation, chemical fertilizers, pesticides, mechanization, processing, conservation, and transportation. For example the U.S. uses 17% of its total energy in the food system, of which about 6%

is for production, 6% for processing and packaging and 5% for distribution and preparation [5]. Currently an average of 1.14 BOE are required to produce one ton of grain (or 6.8 GJ/ton) which is more than twice the amount required in 1960. [6] If the energy used by the agriculture sector, which at present is about 0.5 TW or 5% of global energy, continues increasing at a rate close to 4% or twice the global rate of energy demand, it will reach 0 .8 TW by 2000 or 7% of the global energy. This poses a challenge for feeding the people in the poorer countries, especially at a time when the food production per capita is decreasing in many of those countries. Improving the energy intensity of the food sector demands priority consideration. On the other hand it must be recognized that in many LDC agricultural wastes account for a large fraction of household energy. In PROC it is about 44%. [7] This is an indirect (but not optimum) way of recovering part of the agricultural energy input.

vii. Oil and Environment:

As we have indicated earlier, of all fossil fuels oil is the most versatile and preferred primary energy source. It is currently used at the rate of about 20×10^9 barrels per year, as compared with coal, 16×10^9 BOE/yr, and gas, 10×10^9 BOE/yr. Current estimates of oil reserves (Table 2) indicate that the ultimate depletion of world oil will probably occur by the end of the next century unless additional reserves are discovered, oil consumption drops dramatically, and oil recovery (secondary and terciary) is enhanced. The gradual depletion of oil reserves and the increase in the cost of oil production will eventually make oil a rather expensive and difficult to get energy source. Unfortunately, this is an area in which the information available is rather insufficent for predicting even the immediate future because other factors affecting oil supply. But even if oil were to remain available for a few more centuries, its ever increasing use in the transportation sector will pose a severe environmental problem. In fact it has been estimated that the fuel used in the transportation sector releases about 700 million tons of carbon into the atmosphere annually or about 14% of total carbon release, which presently is about 5×10^9 ton/y. This release of carbon, mostly in the form of CO_2, may induce effects such as forests and soils degradation, change in the quality of ground water, overall earth warming, etc, whose economic and environmental impact may be extremely serious and in some instances irreversible.

These seven points conform the scenario which must be kept in mind in formulating international cooperative programs for the next two or three decades in order to chart a sustainable energy course.

4. The Technology factor:

In the last 25 years considerable research has been carried out worldwide to develop new and better energy technologies. Although substantial progress has been done in some areas, we are still far from achieving the "final solution," among other reasons because besides technology we must keep in mind the economic and social factors that influence whether an energy source is usable or not. We shall review briefly some of the technological aspects of energy supply and use. In broad terms the technological challenges are better efficiency in the use of oil coupled with energy conservation, and appropriate oil substitution.

a. Energy conservation and efficiency. In the IC and in many LDC strong conservation efforts and a shift toward better energy efficiency are clearly under way although the efforts are still insufficient. A methodology called "least-cost planning" allows to make a cost-benefit analysis by comparing the investment in expanding energy supply vs. investment in conservation and efficiency. Use of these methodologies might help to plan for a more energy efficient future.

Buildings, which generally are very energy-inefficient, must be prime targets for conservation. Among the most appropriate technologies are superinsulation, window technology, thermal storage, condensing furnaces, new heat pumps, improved lighting, etc. The so-called "smart buildings" allow to optimize the environmental conditions inside buildings by sensing temperatures, light, people, etc. Electricity use in households can be reduced by using more efficient appliances, already available, and new types of light bulbs such as the compact screw-in fluorescent light bulb coupled with solid-state ballasts. But all these innovations are sometimes restricted by cost or require further development.

An area where improved efficiency is badly needed is the transport sector. In the last ten years the average fuel efficiency of passengers cars has improved appreciably reaching about 30 m.p.g. (12 km/l) on the average as a result of engine improvements and reduction in weight. Just in the United States, as a result of strong government regulations the average consumption of gasoline in automobiles has changed from about 5 km/l in 1970 to about 10.5 km/l in 1986. Some new production cars have reached about 50 m.p.g. (20 km/l), and prototypes under development can reach about 80 m.p.g. (32 km/l). But even if the efficiency of automobiles improved further, it is still critical to rationalize the methods of moving people and goods around in cities and between cities.

Energy intensive industries (steel, aluminum, electrolysis, etc.) have also improved. But the problem with energy efficiency is that it takes time and money to replace old equipments and processes by new ones, and this is more critical in the LDC than in the IC.

An interesting concept for energy conservation is that of cogeneration for producing simultaneously electricity and process heat. It can be used both with steam turbines and with diesel engines. This should be an attractive option for LDC.

The apparent irreversible trend toward increasing urbanization, particularly in LDC, is a common ground where population planners, social workers and energy technologists must work together in defining a strategy for more efficient energy use which will permit to avoid reaching an unmanageable situation. This consideration is most important for regulating the expansion of existing urban areas and planning new ones.

b. <u>Oil Substitution:</u>

As it can be seen from Fig. 6, the oil component of total world energy consumption has decreased from the peak of 65 MBOD or 4.6 TW around 1980 to about 50 MBOD or 4 TW in 1987 while the total energy demand increased by more than 20%. This dramatic change in oil consumption in relative terms is reflected also in the trend in world production of oil (Figs. 7) and is a consequence of oil substitution and conservation efforts.

Thus oil substitution coupled with energy conservation is an important goal of the energy strategy for all countries. But as it was said earlier, oil substitution is relatively easier in the IC than in the LDC, as Fig. 2 shows. The two major energy users of oil products are the transportation sector and the electric sector. Oil substitution is different in these sectors. The transport sector depends primarily on liquid fuels such as gasoline and diesel oil, while the electric sector uses also fuel oil as well as solid fuels, hydro energy and nuclear energy. Oil substitution in the transport sector has not yet been appreciable worldwide. So far the most promising liquid fuel substitute for oil in the transport sector is alcohol.

Oil substitution in transportation requires easily accessible liquid fuels in relatively large quantities. For that reason the potential of traditional biomass solid fuels, such as wood and charcoal, as oil substitutes is practically nil. However, biomass liquid fuels, such as ethanol and methanol, show a great potential for displacing liquid fuels derived from oil. Ethanol is obtained from three major types of biomass material: a) sugar bearing material (sugarcane), b) starches (cassava, corn, etc.), c) cellulose rich materials (wood, agricultural wastes). Methanol is basically derived from the last type of material. We shall not elaborate on the technology for production of alcohol from biomass, except to say that sugarcane and cassava are perhaps the most important biomass raw materials for bulk production of ethanol. Also ethanol is more attractive than methanol as a liquid fuel substitute for both technical reasons and raw material supply.

Alcohol can be used in principle as a substitute of gasoline, diesel oil and fuel oil. However, its use to displace fuel oil does not fully utilize its potential as a superior liquid fuel. Ethanol in anhydrous form can be aded to gasoline up to 20%, a blend called "gasohol," without any major change in the automobile engines, and it can be used pure (4% water), but this requires appreciable changes in the engines. In Fig. 8 the substitution of oil by ethanol and methanol in terms of volume of each substance is shown. From the figure we see that 1 liter of ethanol replaces 0.83 l of gasoline, 0.58 l of diesel oil or 0.49 l of fuel oil, while the displacements for 1 liter of methanol are respectively 0.63 l of gasoline, 0.43 l of diesel oil and

0.36 l of fuel oil.

An element which is critical for extensive use of alcohol is land requirements, thus competing with land for food. In Brazil, for example, to produce 10^6 m^3 (or 10^9 l) of ethanol it is necessary to plant about 2800 km^2 of sugarcane or of cassava, amounting to about 0.6 Ha per automobile. Because ethanol production is land intensive, its production is limited to countries that have land to spare without conflicting with food production. This is one of the reasons why only a few countries in the world have established national programs for ethanol production as a liquid fuel. Without question Brazil is the country that has the most ambitious alcohol program in the world. Other countries with significant programs are United States, South Africa, New Zealand and Australia.

Brazil has vast biomass resources and a long tradition for its use for energy purposes. For example, in 1980 about 30% of Brazil's energy supply came from firewood, sugarcane bagasse, charcoal and ethanol. During the 1967-77 decade the demand for crude oil in Brazil increased at the rate of 9.5%/yr, while the total energy demand increased at the rate of 7.2%/yr. In addition Brazil is a net oil importer with an annual oil bill in 1980 of the order of \$8 x 10^9, which was responsible for a trade deficit of about \$2 x 10^9/yr. These facts served as incentives to organize a national alcohol program, which was launched in 1975. The major component of the program was the production of ethanol using sugarcane and cassava. As a result alcohol production has increased dramatically (Table 5), being close to 10 x 10^9 l in 1985. Table 6 also shows the amount of automobile fuel that has been displaced by alcohol. Brazil has planted about 30,000 km^2 (4% of Brazil's crop area) with sugarcane for fuel alone, more than all the sugarcane planted in the rest of the world.

Besides achieving a substantial automobile fuel substitution, the alcohol program has created new jobs, hopefully helping to reduce the migration of rural population toward urban areas. This is particularly relevant in relation to alcohol from cassava that can be produced from small processing plants with capacity of up to 50×10^6 l/yr that can operate independently. Presently, there are about 300 alcohol distilleries operating in Brazil.

However, the success of the program depends on three factors. One is public acceptance; there have been its ups and downs, but presently it appears that public acceptance is growing in Brazil. The second is the adaptation of the automobile fleet to alcohol, both in terms of new vehicles and retrofitting of vehicles in use. Brazil produces more than one million vehicles per year. The automobile industry has agreed to cooperate with the government in this effort and by 1982 the total number of ethanol fueled vehicles in operation in Brazil was 1,200,000. Finally the success of the program depends on the degree of total oil substitution. Although alcohol can basically displace gasoline, this is only one of the three fractions resulting from crude oil distillation, and therefore alcohol cannot fully balance the integral substitution of oil.

In conclusion alcohol from biomass although a good gasoline substitute, offers only a limited option for total oil displacement for transportation in the majority of LDC, and is not expected to play an important role in IC for the time being.

Another fuel derived from biomass is biogas, a mixture containing about 55-65% methane and which can be obtained from the decomposition of human, animal and plant waste. However, the potential contribution of biogas to the overall energy supply equation is marginal except in some rural areas of LDÇ where it is used as household energy, particularly in

China and India. On the other hand biogas contributes positively to the eco-agriculture system since the slug from the gas digestors constitute a good fertilizer.

A potential oil substitution in the transport sector is the electric powered automobile. The use of small electric powered vehicles for certain specific purposes is well proven. However , a lot more R & D is required before the electric automobile becomes competitive with automobiles powered by internal combustion engines. On the other hand electric trains and urban transport systems that draw their electric power from a central grid are widely used. They are efficient and economic when electric power is available at reasonable cost, such as hydropower

The electric sector is where oil substitution is being pursued more actively in the world. Three reasons support this effort:

i. the demand for electricity is growing worldwide more rapidly than the demand for total energy.

ii. The resources of the world for oil substitution in the generation of electric power are readily available,

iii. the technologies for such substitution are well known.

It is expected that the demand of electricity will increase from 1.0 TWe in 1980 to about 1.9 TWe in 2000, requiring for its generation about 2.5 TW and 4.8 TW respectively, or 27% and 38% of all primary energy used in the world. However, about 50% of the population in LDC has no access to centrally produced electricity; this places a great pressure on electricity demand in LDÇ.

In the foreseeable future the main alternatives for oil substitution in electric power generation in central power stations are coal, hydro, nuclear and gas. Coal is not expected to replace a significant additional amount of oil to generate electricity in the LDC with the possible exception of PROC. Also a shift from oil to coal is environmentally less desirable because it will exacerbate the release of carbon into the atmosphere. Thus its share of the primary energy used in generating electricity will probably remain the same for the next decades. Presently coal accounts only for about 25% of the total primary energy produced in the world and 40% of the total electricity generated. The same applies to gas which most probably will remain at its present level of 18% of total primary energy.

However, it is important to recognize that there are strong forces working for the "clean use of coal." This is particularly true in Europe and in the United States. There are already technologies to make coal a less harmful fuel, such as new flue gas cleaning methods, fluidized bed combustion and fuel beneficiation. Thus the use of pre-combustion processed coal manufactured in "coal refineries" is an option to make coal a more attractive fuel as oil displacer. One key issue is of course the value added to the pre-processed coal.

While for most IC the incremental contribution of hydroenergy is limited (Fig. 2), hydroenergy is the most promising substitute for oil in electricity generation in LDC. For example the hydro potential of Latin America is vast, of the order of 328,000 MWe, and more or less well distributed among all the countries, but only 15% of the total resource has been developed, and in some countries it is even less than 3%. Hydroenergy accounted in 1980 for 14% of the total primary energy used in Latin America, and for about 58% of the total electric energy generated, with an installed capacity of 49,600 MWe. In 1990 it is expected to generate 64%, with an installed capacity as high as 98,000 MW. Thus, hydroenergy is bound to play an important part in the expansion of energy production in most LDC, both in terms of large and small units, but its incremental contribution will still be small compared with that of other sources. One of the largest hydroelectric projects in the world, Itaipu, a joint Brazil and Paraquay project, with a capacity of 12,600 MWe, is near completion on the Parana River, which serves as a boundary between those two countries. Another large hydroelectric station is Guri, in Venezuela with 10,000 MWe. China has under consideration the Three Gorges project, with about 13,000MWe, and in India it is planned to build 3000 hydropower units in the Narmada valley.

Small hydroelectric units (less than one MWe) that can be manufactured locally are becoming increasingly popular and a lot of R & D has been done to improve their efficiency and reduce their cost. They are particularly suitable for remote rural areas and in mountainous regions. [8]

Another energy source that can contribute substantially to displace oil in central electric power generation is nuclear fission, although on a worldwide basis it will remain much smaller than coal, oil, and hydro for a few decades. The availability of fissile materials is not expected to be a critical factor in the short term since uranium and thorium are relatively abundant in terms of prospective needs. [9] Although the contribution of nuclear energy to the total primary energy consumption in the world is still small, it is nevertheless significant within the electric sector since, according to a recent report by IAEA, nuclear energy provided about 0.16 TWe or 15% of the electricity generated in the world in 1985, displacing about 5.6 MBOED or 10% of the oil production that year, assuming a 40% efficiency in the transformation of primary energy into electricity. When all nuclear plants under construction are completed with a total capacity of about 0.45 TWe, NE will produce the equivalent of about 8% of the total primary energy displacing about 14 MBOE/D. For that reason it is very difficult to ignore NE as a major oil displacer.

The main critical factor for the use of nuclear energy is the size of the electric grids of many countries, particularly in the LDC, making it difficult for such countries to consider nuclear plants in the range of 500 MWe to 1000 MWe, which roughly is the size of nuclear power plants commercially available at present in the IC. It is possible that nuclear power plants in the range of 100 MW to 400 MW may become commercially available in the near future, but even so, those plants are too big for a good many LDC countries. A potential solution will be the deployment of safer, more economic and modular types of nuclear reactors; several designs are available (PIUS, HTGC, PRISM, etc.) but none has been build yet.[10] It is most desirable that demonstration units of these new nuclear concepts be built as early as possible if NP is to play a more important role in the generation of electricity. Unfortunately many factors, particularly public acceptance, conspire against this desirable goal.

Among the LDC only about 25 countries have grids sufficiently large as to justify a comprehensive nuclear program, which might include the construction of several nuclear power plants in the next few years, as well as some of the facilities related to the nuclear fuel cycle (uranium mining, uranium enrichment, fuel production, fuel reprocessing and heavy water production). In fact seven of those countries have adopted quite serious nuclear programs, which are in different stages of development and suffering various vicisitudes, and three or four more have NP under consideration (Table 6).

For those LDC that can only justify a small NP program with the construction of perhaps one nuclear plant each in the next decade, it is not justified to consider facilities for the nuclear fuel cycle. Thus in such countries the assurance of fuel supply and other nuclear services is most important. For those countries it is also most relevant to receive the cooperation of the IC to make acceptable and feasible the use of nuclear power. In particular the United States should reconsider its nuclear policy, as stated in the Nuclear Non-Proliferation Act (NNPA) of 1978, and be more flexible and reliable in terms of the provision of nuclear services to those countries.

In addition the international instruments have to be reinforced to assure that nuclear weapons are not produced or introduced in countries using nuclear fuel cycle facilities as an umbrella. To this avail the IAEA and its international non-proliferation instrument, the NPT, play a key role, but there are still concerns about the effectiveness of such mechanisms for the promotion of NP, as the recent review of the NPT (Geneva, September 1985) has shown.

Eventually nuclear fusion will be developed. An attractive possibility is the fusion of ^3He and ^2H, which has the advantages of not producing radioactive products and having a better energy/mass ratio than nuclear fission. One limiting factor is that ^3He is not available on earth in significant amounts and must be brought from the moon, where it is relatively abundant.[11] In any case it is not to be expected that nuclear fusion will become a significant energy source in the time horizon of this paper, but it is critical for a secure energy future.

Renewable energy sources can also play in the long term an important role as oil displacer in the electric sector, but in the short term their prospects are very limited because of cost and availability in the amounts required, unless some breakthroughs occur in the near future.

Geothermal energy is an adequate and established energy source for electricity generation but because its critical dependence on geographical localization, it will remain an insignificant oil displacer in relative worldwide terms, although it may be of great importance for some countries. For example in Nicaragua geothermal energy may produce about 30% of the electricity, or 200 MWe, by 1990.

The same applies to OTEC and tidal power except that there are even fewer locations where the conditions are appropriate for these technologies and the cost may be much higher than geothermal.

Many ideas have been explored for the direct utilization of solar energy but only two or three seem to be promising. One, of course, is wind power which together with fire, is one of the oldest energy sources used by mankind. Many pilot projects all over the world are testing several designs for wind electric generation. Just to mention one case of particular interest, in the United States by the end of 1985 there were installed in windfarms in California 13189 wind turbines with a total peak capacity of 1,100 MWe. The average capacity of the turbines was 97 kWe and the total energy generated was 632 x 10^6 kWh, resulting in a low capacity factor of only 6%. This represents a dramatic increase relative to 1984, where the number of wind turbines was 8200, with a combined capacity of 613 MWe and an average capacity of 81 kWe; the electric energy generated was 183 x 10^6 kWh, corresponding to a 3.3% capacity factor. In 1986 the combined output of windfarms in California reached 10^9 kWh. Wind energy however, depends on seasonal and daily variations in wind velocity and the cost of electricity generated by wind energy is still very high, over 200 mills /kw hr, while the amount of energy extracted is very low. Windpower development in California has been possible because strong subsidies and tax incentives, and its future growth is not very certain at the moment.

An interesting concept developed in Israel is the "solar pond", based on a temperature differential between the bottom and the surface in a pond in which there is a salt concentration gradient. A` low vapor pressure fluid is used to extract the thermal energy and drive a turbine. A 48 MWe system is under construction in California.

Photovoltaics is perhaps the most attractive and advanced way of using solar energy for electricity production, and substantial progress has been made in the last decade to improve the efficiency and reliability and decrease the cost of manufacture, which unfortunately still remains high at about $5/Wp. The estimated cost of the electricity generated is of the order of 400 to 500 mills/kWhr. Very active research and development is being carried out in many countries to improve the performance of PV technology. In the United States a National Photovoltaic Program Research Plan was adopted in 1984 which is being carried out as a joint government-industry effort. Several technological advances have already been achieved (increase in efficiency over 15%, extension up to 20-30 years of the life of the modules, new materials (such as GaAs) and new production methods). Several PV projects have been built in the United States, and many electric utilities are building pilot PV installations of sizes ranging from 1 MW down to a few kW. An interesting one is a 300 kW system at Georgetown University in Washington D.C. which began operation in 1984. Also 58 small PV demonstration systems have been built by NASA in 27 LDC with a total capacity of 77 kWp. Thus it is reasonable to expect that PV will play in the future an important role in electricity generation.

Solar based systems for electric generation can either stand alone or be connected to an existing grid. Stand-alone systems require some sort of energy storage such as water reservoirs, deep discharge lead-acid batteries or even chemical and hydrogen systems using advanced electrochemical concepts. A substantial R & D is being conducted in the United States in these areas. For grid-connected systems the grid acts as an infinite electric storage system. However, in the case of PV it is necessary to convert the dc-power into ac-power using a power inverter, also designated as power conditioner. The fluctuation in power generation inherent of solar systems has been one reason by which utilities in the United States have had some reluctance to consider seriously this source of energy for their electric grids.

5. The Economic Impact of the Energy Crisis

We said at the beginning that the energy crisis which began in 1973 with the oil embargo and the subsequent increase of oil price that suddenly quadrupled, has had a profound global economic impact. This is particularly true of the oil importing LDÇ (NO LDC). The economic impact has short and long term components, which of course are not the same for all countries. In the short term demand for oil is inelastic and the steady increase in energy prices during 1974 - 1984 has produced a disruption in the balance of payments and in the current accounts of all countries. For example in 1980 the oil exporting countries had a surplus of \$115 x 10^9, the oil importing IC experienced a deficit of about \$50 x 10^9 and the NO LDC, which imported oil at a rate of about 5 x 10^6 Bbl/day, had a deficit estimated to be \$70 x 10^9. This deficit exceeded by more than 30% the total revenues from their export accounts and was about three times the total external assistance aid received by the NO LDC. How was then possible for the LDC to sustain economic growth under such conditions? On one hand some countries, such as Korea, were able to increase their production output through increases in their exports, which in some instances were doubled in value. In most cases however, as in Latin America, economic growth has been achieved by borrowing money for financing the energy the countries had to import. This, of course, has deteriorated the current accounts of those countries and serioously increased the debt service, particularly because many of the loans are short term, but allowed them for the time being to finance the energy required by their development plans. Curiously some oil exporting countries, such as Mexico and Venezuela, have increased their external debt in a proportion even larger than the oil importing countries. Of course, those countries that could not do either one thing or the other suffered the most. This is one reason why the WB has established a fund to help finance the external debt of NO LDC resulting from higher oil prices.

One positive thing is that as a result of the oil crisis, after a period of adjustment of about five or six years, oil demand in the IC has begun to decrease dramatically without seriously affecting their economic growth. In the case of the United States the total energy consumption slightly dropped from 2.35 TW in 1984 to 2.33 TW in 1985 while the GNP increased by 31%, resulting in a decrease of the US energy intensity by 24%. This has been mostly a consequence of structural changes in manufacturing combined with more efficient technologies.

The situation has reversed with the decrease in the price of oil from $30/Bbl in November 1985 to about $10/Bbl in April 1986, followed by an increase to about $20/Bbl in 1987, with the aggravation that it is impossible to predict how the price will change in the immediate future, especially since one country, Saudi Arabia, holds the key to the situation. One benefit for the oil importing LDC has been an aleviation of their current account situation, while the oil exporting LDC have suffered severe deterioriation of their current accounts (Table 8). For the United States the cost of oil imports declined from $\$51 \times 10^9$ in 1985 to about $\$44 \times 10^9$ in 1986, or savings of 14%, while for the Soviet Union, which is the world largest oil producer, its oil production has been reduced by 7% and as a result its exports to the West have decreased by about $\$2 \times 10^9$. However, the situation of the United States is rather mixed since while some sectors have benefitted in different degrees from cheap oil, the oil industry in Texas and Oklahoma has gone through a severe crisis, with extensive economic ramifications, of which it is beginning to recover. The lesson to be derived from the experience in the last 15 years is the absolute need to create a stable and fair world energy system, but unfortunately nobody knows yet how.

6. An Agenda for International Energy R & D cooperation.

To achieve what might be called a "sustainable energy course" the challenges identified in previous sections must be met by appropriate actions and programs based on vigorous international cooperation. Some of these programs could be the following:

1. Improve the understanding of the role of energy in economic performance. Specifically the energy intensity of key economic sectors (manufacturing, transportation, agriculture, etc) must be improved. The energy efficiency of food production demands special attention.

2. Develop more energy efficient styles of living without sacrificing the quality of life. This is of particular importance for LDC which need to improve the quality of life of large sectors of their population with minimum increase in energy consumption.

3. Design of more energy efficient systems for urban areas, which presently are the most energy wasteful. This program must comprise:

a. buildings including designs, materials, appliances and land use.

b. urban transportation, including more efficient automobiles and public transportation as well as innovative planning of urban areas to reduce and rationalize the mobilization of people and goods.

c. development of new energy-efficient methods for supplying energy and other energy related inputs to urban areas.

d. recycling of urban wastes in economic and energy efficient ways.

4. Active cooperative research on new energy systems such as:

a) advanced fission reactors, b) fusion reactors,

c) magnetohydrodynamics, d) superconductivity, e) materials,

f) renewables, particularly biomass direct solar energy conversion (PVC) and wind.

5. Improve the acceptability of nuclear energy which at present is the only adequate and feasible substitute of fossil fuels for electric power generation. This requires:

a. a worldwide public information program.

b. international standards for the design, construction and operation of nuclear power plants.

c. design and testing of new more economic and reliable nuclear power systems.

6. Develop methods to reduce pollution of the biosphere resulting from conventional energy systems (particulates, CO2, S, and N oxides, radiation, etc.). This requires:

   a. a better understanding of the flow of pollutants in the biosphere and of their biological effects.

   b. adoption of universal criteria for determining acceptable levels of pollution.

   c. design of more efficient and clean energy systems.

   d. international monitoring arrangements for assessing the levels of pollution of the biosphere and prompt alerting of potentially dangerous situations.

The above list is obviously not exhaustive, but points out some critical areas in which truly international cooperation and multidisciplinary efforts are more urgently needed. Of course many cooperative programs are presently under way under the sponsorship of several national and international agencies, but they are insufficient or inadequate, and in many cases lack appropriate funding and/or coordination and political support. What is required are more innovative ideas and better means of diffusion of the results as well as the political will to support them. Unfortunately geopolitical factors might make it very difficult to achieve a truly meaningful cooperation in the field of energy. This is why it might be desirable to establish an international cadre of energy experts to look regularly into these issues and formulate specific cooperative programs for consideration by governments and appropriate agencies.

<u>NOTE:</u> For the purpose of this paper the following equivalencies have been used:

$1\ Q = 10^{18} J = 1.7 \times 10^{2}$ MBOE = 24 MTOE

$1\ TW = 10^{9}$ kW = 31.6 Q/y = 14 MBOE/day = 5.1×10^{3} MBOE/y

1 kW = $3.2 \times 10\ H^{10}$ J/y = 1.4×10^{-8} MBOE/day = 8.889×10^{3} kWh/y

1 MBOE/day = 2.2 Q/y = 7×10^{7}P kW = 7×10^{7} kW = 7×10^{-2} TW

1 MBOE = 0.6×10^{-2} Q = 0.6×10^{16}

1 MTOE = 4.23×10^{-2} Q = 4.23×10^{16} J = 7.05 MBOE

1 MTCE = 2.50×10^{-2} Q = 2.50×10^{16} J

1 TOE/y =9 1.34 kW

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