Ao Prof. Mario Schenberg

Com os cumprimentos
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ENERGY STRATEGIES FOR DEVELOPED AND LESS DEVELOPED COUNTRIES

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I. The Nature of the Energy Crisis

The energy problems of the last decades of the 20th century will probably pass into history as the transitory problems of societies which coupled their growth and development to the consumption of irreplaceable fossil fuels.*

At the current growth rate of 2.1%[1] per year the world's population will reach 10 billion by year 2010; if at that time the "per capita" energy consumption were 12.8 TCE (tons of coal equivalent), the current level of the average U.S. citizen, the total energy consumption per year would be approximately 128×10^9 TCE (3500 Quads).

At this rate of consumption presently known deposits of coal, oil and natural gas would not last more than 60 years, with growing shortages and consequently rising prices occurring much before that. The world's energy problems resides therefore in the fact that the bulk of the energy being consumed comes from fossil fuels which are available in rather limited supplies (Table II).**

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*Table 1 shows the current levels of energy consumption for some selected countries and world regions.

**Of course even this enormous amount of energy (3500 Quads) could be provided, in principle, with renewable resources. This annual flow of energy corresponds to only the solar energy reaching 2.5% of the land on earth, utilized at 20% efficiency (Table III).

Actually the world's energy supply problems are not worse already precisely because of the extreme variations in energy consumption in different regions, as shown in Table I: yearly per capita consumption ranges from 0.18 TCE in the lower-income countries,[*] to 0.6 in India and to 12.8 in the U.S., with a world average of 2.23 TCE. Of the total world energy budget (8.9 x 10^9 TCE) 69% is consumed in the developed countries, which account for only 25% of the total population. The U.S., with 5.3% of the world's population, consumes over 30% of the world's energy.

It is very doubtful that these variations will persist for many decades due to social and political changes around the world. As LDC's develop, their share of the world energy budget tends to grow, which increases the competition for the fossil fuel resources that are not altogether very large. This tendency for an "equalization" of the levels of energy consumption is very strong and unless managed in a satisfactory way will certainly generate conflicts in the rush to gain access to and/or control over fossil fuels.

One can imagine two solutions to this problem, which are admittedly oversimplifications:

1. Try to preserve the privileged position of the developed countries relative to the less developed countries (LDC's), as far as energy consumption is concerned.

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[*] We used a classification of less developed countries as lower-income LDC's (annual per capita income under U.S. $200) and middle income LDC's (income over U.S. $200 and below U.S. $1,000). See Appendix I.

2. <u>Try to change in a rational way the course of evolution, as far as energy consumption is concerned, in all countries (developed and LDC's)</u>.

The first solution is the one presently in effect and corresponds to a "laissez-faire" type of policy. It is, however, condemned to failure because the spreading of modern energy intensive technology is stimulated by the large commercial and industrial enterprises of developed countries acting in the LDC's; as a consequence the acquisition of this energy intensive technology has become a strongly desired goal of the local leadership in many of the LDC's. The surging of the "advanced" LDC's which insist they must have access to <u>all</u> modern technology (including nuclear weapons in some cases) proves that a "paternalistic" society is not possible any more.

The second solution is a more realistic one and, as will be shown below, is basically equivalent to a shifting toward a "solar civilization,"[6] at least for some parts of the world.

Fortunately the "fossil fuel fix" and the associated profligate energy consumption habits of the industrialized nations can still be avoided in many LDC's without dashing hopes for development.

This can be seen quite clearly if one examines the evolution of the energy consumption profiles for the U.S.[7] (Figure 1) and Brazil[8] (Figure 2), taken as examples of developed and LDC's.

Fuel wood was the dominant source of energy in the U.S. until the end of the last century; wood was then replaced by coal, (which dominated the U.S. energy budget till the beginning of World War II; since then petroleum (and natural gas) have been dominant, accounting for nearly 80% of the total energy use in 1975.

Biomass (fuel wood, crop wastes, dung, etc.) was still dominant in Brazil up to 1950, but it's role was then superseded by the use of petroleum, most of which is imported. The absolute consumption of biomass has not changed much in Brazil in recent years (it has actually increased); what has changed is its relative importance with respect to other sources of energy. This can be seen clearly in Table IV which shows the commercial and non-commercial energy sources in Brazil over the last 10 years (see also Figure 3). While commercial sources (mainly petroleum) have tripled, the non-commercial ones have grown approximately 30%. This is an interesting point in itself. It means that the rural population, the main consumer of biomass, has neither changed its patterns of consumption nor increased much its per capita consumption. What has changed is that the urban centers have grown explosively. In these urban centers the population abandons the use of biomass and starts using other energy sources (mainly petroleum and electricity) in quantities (per capita) much larger than those consumed by rural populations.

This of course is reflected in the income per capita of people living in cities. On a worldwide scale this can be seen in Table V which shows the income per capita of typical cities around the world and the income per capita of the country to which the city belongs.[9] The per capita income in the large cities is 2 to 3 times larger than the average for the country.

The shift to petroleum consumption occurred in Brazil at least 25 years after the same thing happened in the U.S. The shift to petroleum was accompanied by the introduction of a sizable automobile industry and a fairly modern industrial park , bringing both advantages and well known unpleasant consequences: an emphasis on road transportation, deterioration of urban life and pollution problems. This is, however, a fairly recent development and has not led to the complete abandonment of biomass, a source of energy which still accounts for approximately 30% of the country's energy needs (and practically all the energy consumed by the rural population). Hydroelectric power has also kept it's share in Brazil and is slowly increasing in importance.

Many other LDC's have energy profiles similar to the one shown in Figure 2 but have not yet advanced so far into the "petroleum era" as Brazil has. A massive shift to petroleum is actually unthinkable at present because of the known problems with petroleum. While some countries might find petroleum (or coal) and therefore base their development on fossil fuels for the next decades, this will not be possible on a worldwide scale.

Non-commercial sources of energy are extremely important in the LDC's and dominant in many cases.[*] These sources are available and affordable by the population living out in the fields, small villages and outskirts of big cities. It is only when people move from rural areas to where non-commercial fuels are not readily available that the switch is made to commercial sources.

One of the most striking features of present day use of non-commercial fuels is that these fuels are used very inefficiently with rather primitive technology. Thus there are substantial opportunities for introducing more energy efficient technology not only in industrialized societies[10] but in rural areas of LDC's as well. Such improvements could substantially alleviate energy problems in these areas without introducing a dependency on external energy sources.

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[*] There are two questions of methodology relating to non-commercial energy sources which are not clearly settled and/or understood. The first is that little attention has been given to non-commercial sources of energy; because of their nature they are more difficult to measure than commercial sources. The existing data represent only rough estimates, as can be seen by a discussion of two examples, India and Brazil, for which the data relating to non-commercial energy consumption are more reliable than the corresponding data for other countries.

(Footnote continued on next page.)

In the case of India the method used for the estimates on non-commercial energy consumption is described by Henderson,[3] who used data from the Energy Survey of India Committee. Surveys were conducted in 1958 for urban areas in Delhi, Bombay and Calcutta and in 1962 for rural areas. From these it was possible to estimate average annual fuel consumption per head, measured in terms of coal replacement ratios, in urban and rural areas. The total consumption in the country was then estimated by using figures for the urban and rural populations. It was assumed that the total consumption per head changed only when there was a shift in the population from rural to urban areas.

In Brazil[2] (and in other LDC's to the best of this author's knowledge) no such survey has been conducted. Data on wood consumption is obtained from the transportation companies, which are controlled to some extent by reforestation authorities. Cane bagasse consumption is calculated on the basis of sugar production data and charcoal consumption is reported by the steel industry.

One can see in the case of Brazil that the numbers given must always be considered to be a lower estimate, because the individual gathering of wood and agricultural wastes for domestic use is really not included in the published figures. This is probably true of most estimates for non-commercial energy sources.

The second and more fundamental problem concerns the efficiency of using different types of non-commercial energy.

A problem of this type appears when one includes hydroelectric power in energy consumption calculations. What is usually done in this case is to divide the corresponding electrical energy generated divided by 0.35 to make it comparable to coal and oil as far as primary energy is concerned.

In the absence of better methods this is what's done with wood, agricultural wastes, dung, etc., which are transformed to equivalent tons of coal according to their energy content for unit mass. In the cases where animal and human work is appreciable (China and India among others) the same has been done in all the estimates. We followed this procedure.

This point deserves some elaboration. Humans and animals are quite inefficient converters of energy and it is estimated that only 5% of their primary energy (consumed in the form of food) is converted to work. Should one then divide by 0.05 the energy produced by them to get the primary energy consumed?

Just as one example one can mention here that to accomplish the work done by animals in China would require an equivalent of 31 million tons of coal/year and the work accomplished by humans 60 million tons of coal/year (as compared to a commercial consumption of 377 million tons of coal/year).[4] If relative efficiencies were taken into account the coal equivalent of animals and humans in China would be even higher.

As a solution to this problem Makhijani[11] suggests that one should consider separately the concepts of useful energy and energy input. He assumes that these are related by an efficiency of 5% for draft animals, humans, wood and agricultural wastes (the main sources of non-commercial) This method of accounting energies has not gained general acceptance.

(End of footnote.)

What seems clear from the discussion above is that it should be possible to formulate energy strategies capable of changing the energy consumption profiles of different countries in ways consistent with a better use of their renewable resources. This is also true (and desirable) in the U.S.,but it might be easier to achieve first in the LDC's, which are not totally committed to large centralized facilities for production (and consumption) of energy.

We will investigate here these possibilities often using the particular case of Brazil as an example and trying to formulate policy suggestions to that effect applicable to LDC's and developed countries in general.

As it will become evident there are no single universal solutions but small decentralized methods of energy use might help significantly to improve the quality of life in rural areas while the production of large quantities of hydro-electricity or ethanol might be essential to preserve the present life style of the urban type.

II. Basic Data on Energy Demand and Supply

In order to understand the differences (and similarities) between developed and LDC's it is useful to review some of the data available for demand and supply in selected countries.

Data for developed countries Canada, Denmark, Finland, France, Germany, Italy, Japan, Netherlands, Norway, Sweden, UK, US are available from a number of studies and we used here as a general reference the information given in the WAES study.[12] For this study information is basically given in tables in which the economy is divided in a set of separate sectors (transportation, industrial, residential, etc.) and the energy inputs classified as coal, petroleum, etc. (Appendix II). The flow of energy through a given economy can be constructed from such a table as shown in Figure 4.

Such dissaggregated data are not readily available for LDC's, except for Mexico which was included in the WAES study. It is important to stress here that usually only commercial sources of energy are estimated in studies comparing energy use in different countries and/or describing energy consumption in the different sectors of the economy. This is the case of the WAES study.

With this qualification Figures 5 and 6 show the supply and demand of energy for the developed and a few additional LDC's: India,[3] Brazil,[2] Bangladesh[5] and China.[4]

What is striking in these figures is that the supply and demand profiles do not differ much for all countries considered. It is noteworthy that oil is the dominant fuel (accounting for over 50% of energy use in all cases but China, where coal is dominant).

The situation does change however when one takes into account non-commercial sources of energy in the few cases where they are known (India,[3] Brazil,[2] China,[4] Bangladesh[5]), or have been estimated (East Africa[13] and Central American countries[14]) (Table VI).

Figure 7 shows the demand for energy by different sectors of the economy including commercial and non-commercial sources. We have introduced here a model developed country obtained by averaging the demand patterns of the developed countries given in Figure 6 (for which non-commercial sources are negligible) and lumped together here the residential, commercial, public, fishing and agriculture sectors. Although a weighted average (using as weights the total energy consumed by each country) might be better this would make the US role too dominant. A simple average takes more into account diversities of geography and lifestyles within the developed countries.

The major difference between the demand profiles of the developed countries and the LDC's is the much greater importance of the domestic sector in the LDC's, where it accounts for at least 60% of total energy use (90% for East Africa and 85% for Bangladesh), compared to approximately 40% in the developed countries. This reflects the demand profile one intuitively expects for LDC's but which is not apparent in Figure 6, which shows only commercial sources. Even Bangladesh, which is a fairly undeveloped country (with an income per capita of US $110) presents in Figure 6 a consumption profile similar to that of industrialized countries.

The reason for the smililarity of the profiles based on commercial energy is the following: most of middle-income (and some of the lower income) LDC's have a social structure that is dual in character: 80-90% of the population live in backward agricultural areas (or in shacks in the urban areas) and do not really participate in the economic life of the country; and 10-20% is quite affluent, living in big cities with cosmopolitan lifestyles, and accounts for most commercial energy consumption in the country.

The urban fraction of the population (and its leadership) determine the development policies which consist in general of pushing the leading industrial sectors and waiting for the results to "trickle down" to the people outside of the rapidly expanding economy.

This development model which is widespread in Latin America and Southeast Asia is often described as the "Belgium inside India model" for obvious reasons. There are effectively two-countries in one to deal with in most cases and average energy consumption and GNP/per capita have to be analyzed with great caution. Some population/energy data that help characterize the "Belgium inside India" model are given in Table VII, which shows that while the rural population accounts for 91%, 75%, and 52% of the total population in Africa, Asia, and Latin America, respectively, the rural share of commercial energy is only 4%, 23% and 23% respectively for these same regions.

The rural/urban population mix has been changing rapidly in LDC's. In general rural life and social organization in the fields is such that the peasant, owning no land, cannot expect, even working very hard, to improve his living conditions. Consequently many migrate to the large cities whenever possible living in shacks which might appear unbearable to the well established urban dwellers but nevertheless constitutes a progress of sorts for the migrants from rural areas; they can get in cities a few things such as medical aid, school for the children and some amenities such as lighting and TV and radio entertainment they can't have in the fields.

In Latin America this is a serious problem because the trend towards urban migration is very strong.[15] Figure 8 shows the evolution of the ratio of urban/rural population in Brazil and India in the last 25 years , indicating that in Brazil approximately 60% of the people now in cities[16] while in India the ratio is growing but is still only about 25%. India has at present 567,000 villages, 60% of which have less than 500 people.[13]

In Latin America as a whole population increases at about 3 per cent per year and the urban population already makes up 50 per cent of the total, so to absorb the whole natural increase the cities would have to grow at 6 per cent per year; this is just about the rate of growth of Latin American towns: the rural population is staying constant while virtually all the natural increase is accumulating in the towns. Asia and Africa have not reached this condition because although their population growth is about the same their urbanization level is smaller (approximately 25%) so towns cannot take all the natural increase of the population. (In order to do that they would have to grow at 10 per cent a year, an exceedingly high rate of growth.[17])

On a worldwide basis the problem of urbanization can be seen clearly in Figure 9; the rural population which was 80% in 1900 has decreased, to 65% in 1975, and will probably go down to 45% by the year 2000.[18]

In the developed countries less than 35% of the population lives in rural areas (down from 70% in 1900). The decrease of rural population has been rapid and accelerating for these countries.

In the LDC's approximately 90% of the population was rural in 1900 and this number has decreased slowly to 75% in 1975.

Looking at the problem in greater detail we show in Table VIII the population and energy consumption in the 5 regions of Brazil: north, northeast, west, south and southeast.

The southeast region with 42.4% of the population consumes 74% of the electrical energy, and within the southeast region the State of Sao Paulo (and in particular the city of Sao Paulo) per capita consumption is more than twice the average for this region.

One sees in this example why the commercial energy consumption profiles of the LDC's are rather similar to the profiles of developed countries: the data refers only to a small (but growing) fraction of the population. For this population living in large cities the industrial and transportation systems are practically identical to the ones in developed countries because essentially the same products are consumed (with, in many cases the same companies operating in all countries).

This imitative (or cosmopolitan) feature of LDC's is sometimes completely mismatched to the natural resources of the particular country involved as in the case of Brazil which has to import 80% of the petroleum it uses.[2]

Another way of looking at the problem, perhaps is to compare the ratio of commercial energy consumption/dollar of gross domestic product[19] (see Figure 10). The more efficient the use of energy in a society the lower this ratio. The use of inefficient machinery (such as gas guzzling autos, air conditioners, heat leaking houses, etc.) tends to increase it.

As one can see in Figure 10 there are no clear differences and pattern changes in this ratio between countries with small and large per capita GDP - which reflects again the fact that developed countries such as the U.S., Canada, U.K., Japan, France and middle income countries such as Argentina, Colombia, Thailand and India have similar energy consuming structures as far as the big cities are concerned (where most of the commercial energy is used).*

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*The case of Nigeria is interesting because it is a low income LDC, presumably with a more uniform income distribution than India and Colombia. In Nigeria commercial energy probably has no significance, so that its energy consumption/dollar of gross domestic product ratio is effectively much lower than that of other nations.

III. Characteristics of the Energy Systems of Developed and LDC's

As pointed out above the main difference between developed and LDC's countries lies in the fact that LDC's depend on non-commercial sources of energy to account for at least 30% (and generally much more than that) of their needs.

Table IX shows how energy use is distributed by energy consuming sector and by source in the U.S. This distribution is typical of developed countries.

At the other extreme we show in Table X the input-output energy matrix for a typical Indian village[21] (population ≤ 500). Data on villages in Bangladesh[22] and in villages in China, Tanzania, Northern Nigeria, Northern Mexico and Bolivia[23] confirm the picture suggested by these data. These patterns are probably characteristic of a total population of over 2 billion people in the LDC's.

In between one has "islands of prosperity" represented by 10 to 20% of the affluent part of the population of almost all countries outside the developed industrial countries.

What is outstanding in these two tables is not just the fact that an average U.S. citizen consumes 25 times as much energy as does a peasant in India but also the difference in the spending patterns.* A full 1/3 of the energy in the U.S. is spent in transportation and another 1/3 in industrial activities, items that are negligible in a village. In contrast agriculture and domestic activities account

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*There are no significant differences in the "per capita" energy consumption between the rural and urban population in the U.S.; actually the rural consumption seems to be 15% higher than urban consumption.[24]

for 85% of the energy spent in the village, items that account for only 25% of the energy used in the US (Table IX). Cooking by itself represents 61% of the total in the villages while in the US this item represents less than 1.5%, as can be seen in Table XI, which shows the distribution of energy consumption by end-uses in the U.S.

One has therefore quite different problems in different parts of the world and strategies to face them are bound to have many differences.

There is no question however that the energy problem not only on an international scale but inside many countries in the world is not more serious than it is already is because of the concentration of wealth (and energy spending) in a small fraction of the population. As the larger portion of the population abandons the use of noncommercial sources and enters into the use of commercial energy (as it is happening in Brazil) the situation might become very serious.

Since non-commercial sources are renewable and commercial ones in general are not, it appears desirable to reorient development so as to sustain the use of non-commercial sources (essentially biomass), enhance their importance and effectiveness. This can be done, coupled with an improvement of the quality of life, but it requires a decentralized social organization, as will be seen.

On the other hand while the developed countries (and the urban centers in the LDC's) should also strive to develop renewable energy resources the greatest emphasis in these areas should be on eliminating energy waste.

Since the level of urbanization is much smaller in Asia and Africa than in the more developed areas of the world the possible success of a decentralization strategy in these areas is much higher.

However the trend to urbanization could probably be stabilized and even reversed if rural areas could be made more pleasant than the present crowded and generally unhealthy urban slums.

Unfortunately, in developed countries there does not yet seem to be evident a sense of urgency in reducing present-day energy consumption. Only in a situation of crisis (such as the 1973 oil embargo) have significant efforts been made to save on fossil fuel consumption.

But recent research indicates that approximately 40% of the fuel spent in the U.S. could be saved by conservation measures based on presently available technology that would not affect life-styles - requiring only improvements in the efficiency of existing energy consuming systems.[10] This would lower the per capita consumption in the U.S. from 240,000 to 140,000 kcal/day.

Much less consideration has been given to understanding how far industrialized societies could shift their energy dependence to renewable energy resources (mainly solar energy and biomass).

In the LDC's energy conservation has to be taken with some caution because the urgency to increase energy consumption to improve the quality of life is very evident for a population living presently on the bare subsistance level (~ 7,000 kcal/capita).

The efforts to increase this level of consumption in general are linked to the use of fossil fuels (petroleum, coal and gas) either by introducing these sources in the villages or by populations migrating to urban areas.

A paradoxical situation exists here whereby both rich and poor populations increase the pressures on the limited fossil fuel supplies: the populations of developed countries (mainly the United States) do not show signs of changing their lifestyles to face the energy crisis (except maybe for some conservation measures); at the same time people in the LDC's have been quite willing to change their lifestyles only when it leads to an increase of petroleum consumption imitating the developed countries. They are not so willing for example to adopt other technologies such as solar cooking.

Clearly a compromise will have to be reached here: developed countries are becoming more dependant on oil imports with the unpleasant consequences on their balance of payments and inflation; less developed countries simply will not be able to afford oil at rising prices.

Consequently a reasonable course to expect is that the energy consumption "per capita" in the developed nations will decrease slowly due to a combination of conservation measures and slow changes to a less energy intensive lifestyle. At the same time the rural populations will increase their energy consumption by making full use of renewable resources.

Figure 11 gives a qualitative idea of the future as far as energy consumption is concerned.

It is reasonable to expect that the per capita consumption in the U.S. can be lowered to 80,000-100,000 kcal/day, both through an aggressive pursuit of energy efficiency improvements and through acceptable changes in lifestyle, such as the development of communities less dependent on the use of automobile and the elimination of much of the wasteful use of packaging. At the same time an increase in the per capita consumption of villagers to 40,000 kcal/day would represent an enormous progress and encourage them to stay in rural areas.

The minimum energy consumption needed for an acceptable standard of living is difficult to establish (and is bound to vary from country to country) but these numbers are indicative of desired levels to pursue simultaneously.

IV. Strategies to Face the Energy Crisis

What are needed therefore are ideas and/or methods to use renewable energy sources and/or adequate conservation measures acceptable to both developed and LDC's. Naturally differences in climate are rather considerable and no general prescription can be established. Regions with harsh winters will need heating in the cold months and similarly regions with hot summers will need air conditioning. Transportation problems however are rather similar everywhere and there is little difference in conserving energy in this sector in New York and Sao Paulo. The industrial sector of most countries is also rather similar and in many cases the same industries and the same technologies and energy consumption are found in Cleveland and Taiwan. Some countries however, such as Sweden, are already using modern equipment and lifestyles that lead to higher efficiency of energy use than in the United States. As is well known Sweden spends about a third less energy to produce the same products as does the United States.[25]

In the domestic sector energy strategies will differ markedly between developed countries and LDC's. In the case of cooking, for instance, it is difficult to improve significantly on the energy spent in the U.S. today where it is already very small (Table XI) but one can have a significant impact in the villages of the LDC's through a more efficient utilization of native fuels.

We will discuss in what follows the significanee of the following technologies and methods which we consider to be the most promising:[*]

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[*] Since this paper is not intended to cover all possible energy sources we left out of our discussion technologies that might become relevant to the problem such as photovoltaics. This represents a rather arbitrary choice: Nuclear reactors and specially "breeders"(that would extend the life of present uranium and thorium reserves) are not discussed because of the complex technology involved (and therefore less suited for LDC's) and because of political problems regarding proliferation of nuclear weapons. Most LDC's could probably do better without nuclear reactors altogether.

- A. Low temperature heat and the cogeneration of electricity
- B. Cooking stoves
- C. Biogas production
- D. Mini hydroelectric stations
- E. Long distance hydroelectric power transmission
- F. Improvements on transportation
- G. Ethanol production for internal combustion engines

A. Low temperature heat and the cogeneration of electricity

One interesting aspect of modern industry is the spectrum of temperatures in which heat (in particular process heat) is used.[25] Figure 12 shows this spectrum for the U.S., taken from a study that covered 48% of the total process heat used in the country. As can be seen 5% of the heat is used at temperatures below 100°C and 20% below 177°C. These fractions increase to 28 and 42% respectively if the heat required to preheat from ambient is also considered.[26]

One can estimate from Table XI and Figure 12 that 37% of the energy used in the U.S. is in the form of hot water, low temperature industrial process heat, or space conditioning. It is clear therefore that solar heat captured in simple flat collectors or in special flat collectors with selective surfaces can represent a large share of all the heat needed in developed countries.

The problems here are not typical of developed or LDC's but common to them: any break through in the U.S., for possible utilization in its southwestern region could work even better in tropical countries where the insolation is usually higher.

In some of the LDC's it is quite common for the government to finance (in general with low interest loans) housing complexes for workers and middle-income people. It might be quite reasonable to introduce into the design of such housing complexes solar central heating which will add little to the initial investment and will be paid off along the years by the resultant economy of fuel or electricity.[27] To encourage key industries to use solar heated or preheated water for steam production might also be very promising to the more widespread use of sola energy.

In the energy balance of the United States industrial boilers generating steam for processing and other low temperature heat uses represents 33% of all industrial energy consumption or 14% of total U.S. energy requirements. The steam is produced generally at approximately 200°C from the combustion of oil, gas or coal which burn with flame temperatures of ~ 2000°C. This is an exceedingly wasteful process. It makes sense therefore to first generate electricity in a heat engine using the high temperature heat available in combustion and to recover "waste heat" for low temperature process steam applications.

Several different technologies could be used for the "cogeneration" of electricity and process steam. In general the fuel savings ranges from 20 to 30%.* It has been estimated that net fuel savings from cogeneration in the U.S. could be on the order of 2-3 million barrels of oil equivalent energy per day by the year 2000.[28]

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*If all the savings are allocated to electricity generation then only about half as much fuel would be needed to produce a kwh as in a conventional steam electric plant.

The most widely used method involves the steam Rankine cycle with a back pressure turbine. However, cogeneration can also be carried out using waste heat boilers with gas turbines or Diesels. Perhaps the most interesting new technology on the horizon for cogeneration is the pressurized fluidized bed combustor, which would allow the clean burning of coal or other low quality fuel to generate electricity with low cost gas turbines. Fluidized bed combustors can operate on any grade of coal, liquid or gaseous fuels organic wastes including urban refuse.

The interest of this technology for LDC's is evident because many of them have only low-grade coal or biomass that could be burned in a fluidized bed combustor with much higher efficiency than with existing technology. The technology for this device will be available in 5 to 10 years. An industrial consortium (Stal-Laval of Sweden, Babcock and Wilcox of the U.K. and the American Electric Power Corporation) is conducting a feasibility study to construct a 170 Mw gas turbine/steam turbine central power station fired with a coal burning pressurized fluidized bed combustor.[28]

In Brazil for example it has been estimated that approximately 2,000 Mw of electricity could be cogenerated using commercially available boilers from excess bagasse at sugar distilleries producing alcohol for automotive purposes.[29] This is being already done in a small scale in Hawaii.[30]

B. Cooking Stoves

In most undeveloped areas of the world more than half of the energy consumed by people goes into cooking. This applies to the rural areas and some slum areas around large cities. As can be seen in Table X the rural population of India spends 4,000 kcal/day/capita (16,000 Btu/day/capita) in this particular activity. The same is true for a population of approximately 2 billion people around the world. As will be shown this is due to the use of quite inefficient and wasteful cooking stoves. Surprising as it might seem there is room in very primitive villages for "conservation measures."

Traditionally cooking is done in primitive stoves using wood as the main fuel. This has had serious consequences in devastating forests and in some sub-Sahara African countries long trips ($\sim$50 kilometers) have to be taken by families to gather wood for domestic uses. It is estimated that 200-300 man-days of work are spent per family in India in the process of collecting wood.[11] Sometimes children are engaged in this work, diverting them from educational activities.

Manure (and crop residues) are sometimes used for cooking, thus consuming one of the important land fertilizers available in poor areas.

The efficiency of existing primitive stoves is very low. Estimates indicate that it is in the range 5-10%.[31] Figure 13 shows schematically a traditional Indian cooking stove. More energy is spent in cooking in undeveloped areas than in the United States, where the average consumption is 2,000 kcal/day/capita in gas stoves and ranges that have efficiencies of 15-60%.

The overall efficiency of gas ranges is 15%; of the total energy input in a typical unit (2.5 x 10^6 kcal/year) 41% is spent on the pilot lamps 30% on miscellaneous losses and the remaining is used effectively in cooking; the surface burners are 48% efficient.[32]

The overall efficiency of electric ranges is much higher (59%) so the total energy input is accordingly smaller (0.6×10^6 kcal/year at the input to the stove or 2×10^6 kcal of primary energy at the power plant); the reason is that the losses are smaller (21%) and more significantly the surface heaters are 74% efficient due to the close proximity of heater elements and the cooking parts.[32]

It appears that the principal defects of cooking stoves using wood or dung are the lack of an adequate air supply and draught control; this results in a smoky low temperature flame which is both inefficient and unhealthy.[31] In addition to that fires are kept going all day long which is wasteful.

One ton of wood costs in India from U.S. $4 to U.S. $10 and prices have been going up constantly; the very poor cannot afford to buy it and some members of each family have to walk many kilometers per day to gather it in some regions.

To alleviate this load would mean an improvement in the quality of life in villages; more time and energy could then be spent in more useful activities and in education of the children who are usually engaged in the demanding job of gathering wood for cooking.

Interestingly enough little progress has been made in designing and building better stoves even in India and only recently the Hyderabad Engineering Research Laboratories developed a cooking stove (with a water heater) for which a 25% fuel economy improvement is claimed.[31] The availability of warm water is of course a very welcome additional commodity in a house.

It is estimated that the cost of xtoves of this type might be of the order of U.S. $10 which can still be excessive in some backward areas. U.S. $10 would be the replacement cost for picking up wood during 1 year.[11]

The need for advanced research in a problem that looks so pedestrian as a cooking stove is clear. This is an area where developed countries might help contribute to the needed research efforts. Research is needed not only on hardware but on cultural factors as well.

As is well known cookers based on solar energy were a failure in India not only because of high price but because its use was not compatible to Indian cultural practices. (Cooking is done mainly in private and in the evenings.)

C. Biogas production

The production of gas by anaerobic conversion is one of the most promising methods for the solution of the energy problem of villages of the undeveloped world.

The process is quite simple in principle[4, 11, 23, 33,34] (Figure 14): animal dung, pieces of vegetation (crop stalks, straw, grass clippings and leaves), garbage and waste water are sealed up in insulated containers (digesters) and left to decompose. Digestible organic materials (liquids, proteins and most starches) are broken down by acid-producing bacteria and the resulting volatile acids are in turn converted by anaerobic methanogenic bacteria into a gas that is typically composed of 55 to 70% methane (CH_4), 30 to 45% of carbon dioxide (CO_2) and a trace of hydrogen sulfide and nitrogen. Besides the versatile low-pressure, medium-caloric gas (between 5,300 and 6,300 kcal per cubic meter) the process yields an organic fertilizer of outstanding quality and improves sanitation conditions in rural areas.[*]

Small scale production of biogas was researched in the late 30's but it has received serious attention only since the 60's. With the help of minor modifications the biogas can be used to power internal combustion engines and to substitute for diesel oil in small electricity generators for lighting and irrigation. It is a clean and convenient fuel for household cooking which is exactly the sector where most energy is needed in rural areas.

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[*] Different combinations of human and animal excrements, crop wastes (including grass) and water have been tried and some proved more successful than others.[34] Typical combinations are: 10% human waste, 30% animal waste, 10% crop waste and 50% water or 10% human water, 10% animal waste, 30% crop waste and 50% water.

The burning of biogas for cooking is clearly advantageous when compared to the burning of animal manure. Typically the efficiency of biogas digesters[11] is 60%, which means that 1 kg of dry manure produces 400 liters of gas with an energy content of 2,200 kcal; the cooking efficiency of this gas as seen above is 48%, delivering 1,050 kcal to the cooking pan.

If 1 kg of dry manure having an energy content of 4,000 kcal/kg (which is probably an overestimate) is burned directly for cooking the amount of heat delivered to the cooking pan will be 400 kcal in a cooking stove that is 10% efficient. Biogas is therefore 2.5 times more efficient than manure for cooking purposes.

The method was introduced in China some years ago but picked up momentum only in the last 5 years with 410,000 digesters in use in Szechwan province alone and another 80,000 in Mien-yang country in 1975. Hundreds of thousands of households benefitted from them.[4] It is reported that in the first 6 months of 1976 another 1.3 million digesters were built in China.[34]

The main problem of biogas conversion is that it does not work in cold regions because of the thermal requirements of the fermentation process. In addition to that the pH of the mixture has to be watched and a minimum of maintenance given to the pits.

An estimate made of the potential for biogas generation in China[4] (based on the residues of cattle, horses, pigs, chickens and man) is the energy equivalent of 48 million tons of coal per year (more than 15% of the total consumption of energy in that country). A similar estimate for India[3] gave 60 million tons of coal-enough to satisfy all the rural domestic requirement of energy for the country.

The widespread introduction of biogas generation seems therefore to be feasible in many undeveloped areas of the world.

As mentioned above biogas can be used either for cooking (solving thereby one of the more important energy problems of villages) or for electricity generation, or both.

Electricity has of course many advantages because it would allow irrigation, lighting and communications (radio and TV) which would mean important improvements in the conforts of village life.

Detailed cost studies have been made for the centralized production of methane for typical villages[23] and have been recently compared with costs for rural electrification in India.[35] The digestors to be used would have to be big ones (~ 400 m^3 per day capacity) as compared with the family site units in widespread use in China[4] which are built for 10-50 dollars and produce 2-3 m^3 of gas/day using local materials. In India these prices are reported as being much higher (200-300 dollars). Despite the much higher expected costs Indian plans call for installing 100,000 of these units per year over the next 10 years.[31]

The capital costs for community biogas schemes[31] are appreciable (∿U.S. $ 10,000) and the cost of electricity produced from the biogas is comparable to the cost of centrally produced electricity from coal or nuclear power stations (the distribution lines included).

According to Tyner and Adams,[35] 46 mils/kwh is the upper limit cost for conventional electricity in the average Indian village while 51 mills/kwh seems to be the lower limit for electricity produced from community biogas plants.

Although this might be true in a narrow accounting sense it is not entirely relevant in discussing the problems of poor villages in LDC's. The total foreign exchange requirements will be much smaller in the case of the biogas alternative, which will also create 10 to 100 times as many jobs.[11,31] In addition much of capital cost is direct labor cost. Local manufacture may substantially change capital costs, as suggested by China's example.

The problem of rural electrification from central generating stations versus community size biogas generation of electricity seems to be developing into a major issue in India and presumably in other LDC's.

According to World Bank estimates,[36] 23% of the rural population of Latin America has been reached by rural electrification programs, 15% in Asia (and a few scattered countries in the Middle East and North Africa) and 4% in the South of Sahara's Africa. Roughly this corresponds to 400 million people in a total population of 2.4 billion. By 1985 it is estimated that an additional 300 million people will be reached by rural electrification (of which only about half will be able to afford it).

Just as an example one can give some numbers for India[13]; only 11% of the 350,000 villages with a population under 500 people have been electrified (or will be electrified in the next decade); the daily consumption of electricity is very low in these villages (~100 kwh), corresponding to about 10% of the total energy demand.* This energy is mainly consumed by the more affluent 10% of the people in the village, which means that 1% of the energy demand in electrified Indian villages is supplied from central stations.

By the end of the century only 25% of the Indian rural population will have electricity in their homes. Clearly the "centralized approach" (generating electricity at large stations and distributing it with a grid) has severe limitations: not only are the government and World Bank resources going into it limited (although quite large) but in addition the resources of the potential buyers of this centrally-generated electricity are so low they might not be able to afford it even if it passes through the fields in which they live.

Makhijani[11] has argued strongly for the use of community biogas plants to generate electricity to supply the villages; he pointed out the family units (for cooking and lighting) could only benefit a small fraction of the population.

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*As is well known the average utilization factor of centralized electric power generation is very low in rural areas, ranging from 8-10% as compared to a total utilization factor of 48-55% in India. This is a major factor (in addition to expensive transmission lines) in increasing electricity costs for rural areas.

Another investigator,[13] however, has estimated, that 12 million households in India own enough animals to provide dung for the current individual digesters; probably 90 million people could satisfy most of their requirements of energy from them. At current prices this can be done in India only with government subsidies.*

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*It is intriguing to observe that biogasefiers have become quite popular in China and are facing many institutional difficulties in India. This is not due to political inducement in China, as one might think. According to Vaclav Smil (private communication) the Chinese farmers use the dung of their domestic animals (pigs and chickens) in their private lots to run the digesters. Community plants on the commune level are rare in China.

In India the cultural habits are such that cattle roam around the country making it difficult to collect their dung.

D. Minihydroelectric Stations

The technology for generation of hydroelectric power from small stations has been available for many years but its use has always been dwarfed by the construction of gigantic dams and huge hydroelectric power projects.

A massive effort to build mini hydrostations was made in China[4] and Table XII shows that by the end of 1975 over 40,000 of these stations (with an average capacity of 50 kw) were in operation. Since China doesn't have a very large installed hydropower capacity (~10,000 Mw in 1975) the contribution of ministations to the total hydropower is appreciable.

Actually several existing minihydro stations were closed in the U.S. as the national distribution network extended over the country.[37] This is a type of evolution that cannot be repeated by many countries. It is quite questionable also if other countries should depend completely on centralized electric power stations (fired quite often on coal or uranium) when abundant hydropower in many small streams might be available in the countryside.

A 100 kw minihydroelectric plant, enough to supply the needs of at least 100 houses, can be installed in a small waterfall with a flow of 1.5 m^3/sec and a 6 meter head. If smaller heads are available but the streams are swift moving, one can still operate small turbines with good efficiency. Since the available mechanical energy in a flow of water is $gh + 1/2\ v^2$ per kilogram (h is the head, v the velocity and g the gravity acceleration, 9.8 m/sec^2), a stream with velocity of 10m/sec is equivalent to a 6 m head waterfall.

In recent reviews[38] of the worldwide situation regarding minihydropower it is notable that Germany has at least 11, Austria 2, Finland 2, France 56, England 1, Japan 5 and Luxembourg 3. These stations range in size from 10 kw to 10,000 kw.

The price per kilowatt of installed capacity is competitive with large conventional hydroelectric stations.[39]

Measurements (or even good estimates) of the hydroelectric potential for small rivers and streams do not exist. Rough estimates can be made on the basis of precipitation over a given region, and the region's average altitude above sea level. The product of these two numbers is a crude measure of the total hydroelectric power available.

Using this relationship the total hydropower potential of a country like Brazil can be estimated from knowledge of the potential in a region like Europe, where the potential has been more carefully measured. The area of Brazil is 8,500,000 km^2, the annual precipitation of water 2000 mm (which corresponds to 15×10^{12} m^3 of water) and the average altitude of the country 400 m. The product of these two numbers is 800,000 while the corresponding product for Europe is 240,000. Since the hydroelectric potential of Europe is known to be 158,000 Mw, the potential in Brazil should be on the order of 500,000 Mw, of which 1/3 is concentrated in well known large rivers where waterfalls do exist or where conventional large hydroelectric plants can be built. The remaining 2/3 should then be distributed in thousands of streams where minihydrostations could conceivably be installed.

It should be stressed here that in the usual tabulations of hydroelectric potentials,[40, 41, 42] such as the one given in Table XIII the small streams are ignored; it is difficult to find out where the line is drawn in different countries but probably most resources below 1,000 kw per site are not included in these estimates.

E. Long distance hydroelectric power transmission

Untapped hydroelectric power resources are still very great in many LDC's. Table XIII, shows the hydroelectric potential of several regions of the world and indicates that Africa, South America and Southeast Asia have large untapped reserves.

It is in a way difficult to understand why the economic development strategy followed in hydro rich LDC's has not been based much more on hydropower, following, say, the Norway model.

One of the reasons of course might be the lack of capital for the initial investments needed in the construction of large hydroelectric generating stations. However larger expenditures have been made by some countries in the purchase of nuclear reactors to produce electricity.

One of the most serious problems involved in a larger utilization of these potentials is that the convenient locations for hydropower are sometimes far away from consuming centers.

In the case of Brazil the situation is very clear in this respect: all the major water resources in the more populated Southeast Region will have been used up by 1985 when the installed capacity will reach 35,000 Mw (including the 10,000 Mw Itaipu Central). There is in Brazil at least another 60,000 Mw available in the tributaries of the Amazon.[20] But this power is located at approximately 2,000 km from the main consuming centers.

The suggestion has been made[43] that "captive" hydropower generating stations located in these areas could be used to produce energy intensive products such as aluminum. Thus the hydropower could be transported to demand centers from remote regions in the form of high value products. There is one 4,500 Mw station being considered in the Tucurui River in Brazil precisely with this in mind.

In general the problems posed by the long distance transmission of the electricity itself from these remote areas was considered a technological problem not completely solved some years ago.

There is however a new technology to reduce losses in the lines using high voltage direct current (HVDC) transmission; this is the most attractive solution for lines longer than 1000 km. Table XIV shows the main facilities using this new technology in the world today[44]; some of them have been operating for years including,the Pacific Intertie in the Western U.S. One should notice in this table the Cabora-Bassa line which will supply South Africa (Pretoria and Johannesburg) with power from Mozambique. Upon completion this line will carry 3,600 Mw.

HVDC is such a promising technology that renewed efforts should be made to encourage LDC's to make better use of their hydroelectric potential before engaging in costly and many times controversial nuclear power projects.

A very significant decision was taken in this regard in the case of the 10,000 Mw Itaipu Central in Brazil mentioned above. Half of the power will be generated at 60 cycles and half at 50 cycles, for political reasons. The Central is owned by a binational company of which Brazil and Paraguay are partners in equal footing. Almost all of the power will be consumed by the large urban centers of Brazil which use 60 cycles in all of their industrial installations. Parguay uses 50 cycles (as does most of

Latin America) and does not want to change to 60 cycles. The solution adopted was to convert the Paraguaian share (5,000 Mw) to DC current for sale to Brazil and to transmit this power to the Southeast part of Brazil where it will be reconverted to 60 cycles.

This will be the first HVDC line in Latin America. The introduction of this technology will probably encourage other lines of the same type.

F. Improvements on transportation

What is striking in many LDC's is that the transportation system is either oversized or inadequate for the geographical features of the country. The tendency to use automobiles and road transportation, which is quite recent in some of these countries, has led them to patterns that are sometimes worse (as far as energy is concerned) than in the industrial countries from which they were copied.

Table XV shows, for example, that most of the merchandise in Brazil is transported by road. This is very unusual compared to other territorially large countries such as the U.S.S.R. or the U.S. For the nations shown in Table XV the dominance of freight in Brazil is comparable only to the importance of road transportation in Italy, which is a much smaller country.

This reliance on road transportation is a relatively recent development in Brazil. Table XVI shows that road traffic (which was twice as large as the rail traffic in 1952) increased six-fold in 20 years while rail traffic tripled. This of course has a lot to do with the deliberate policy of subsidies to road construction and the gradual abandonment of obsolete rail rolling stock, aggravating the transport situation and reinforcing the justification to subsidize road traffic as the only efficient means.[45]

Because of the present high price of world oil and Brazil's strong dependence on oil imports, Brazil's road intensive and therefore petroleum intensive development strategy is no longer viable.

Fortunately transportation can be rationalized from the point of view of energy. This is certainly true for the U.S. and other developed countries, as well. Western Europe has gone a long way towards using less energy than the U.S. for the same transport activities (e.g. the use of smaller cars for personal transportation, emphasis on rail transportation, etc.).

As a matter of policy mass transportation,[*] particularly electric buses running on exclusive lanes should be encouraged. The added average speed of these vehicles constitutes by itself a significant gain and would discourage individual car driving.[9] Also zoning of new urban areas should be carried out so as to discourage a dependence on the automobile.

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[*] The building of expensive subway systems is a much more controversial solution due to the very high capital costs of these systems.

G. Ethanol Production for Internal Combustion Engines*

Ethyl alcohol (ethanol) can be used as a substitute for gasoline in modified automotive engines (the required modifications are minor, involving mainly a change in the compression ratio) as is done sometimes in racing cars. Unmodified engines can run on a mixture of up to 20% alcohol + 80% gasoline and the performance as far as fuel consumption and power delivered at the shaft is very satisfactory.[46, 47]

Ethyl alcohol is therefore a strong candidate as a renewable fuel that could replace gasoline in cars and eventually diesel motors in trucks. It can be produced from a variety of crops such as sugar cane, cassava and sweet sorghum but sugar cane is clearly the best choice from the point of view of the net energy balance. It can be shown that the energy gain is 2.40 in the case of sugar cane as compared to 1.45 for cassava. Typical production rates are 3,500 liters/ hectare/year.[47]

The price of a liter of alcohol (which is produced in large quantities in Brazil) is approximately US$ 0.20, which makes alcohol economically competitive with gasoline (sold at present for US$ 0.40 per liter due to high government taxes).

At such high prices alcohol has been considered a solution for the petroleum shortage in Brazil and a full experiment is being conducted at present in the city of Sao Paulo with 1,000,000 cars running on a mixture of 20% alcohol and 80% gasoline. Some especially modified test cars are running with 100% alcohol.

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*The more conventional method of switching road transport to efficient Diesels will not be discussed here although so doing could generate considerable savings in petroleum consumption. The petroleum savings would arise two ways. First the fuel required to operate a diesel car is much less than that needed to operate a comparable gasoline driven car, and second, there are less refinery losses in producing diesel fuel than in producing gasoline.

If these experiments are successful, (and so far no technological problems have shown up), Brazil plans to produce 4 billion liters of alcohol in 1980 on 1,000,000 hectares of land (approximately 1.5% of the total fertile land of the country).

The Brazilian alcohol program represents an important step toward reversing the trend away from biomass energy sources. Similar programs could be carried out in a number of other tropical countries.

A technological problem that deserves some attention is the improvement of the alcohol distilleries. At present their capital cost is rather large (approximately 10 million dollars for a plant of 500 barrels capacity per day). A petroleum refinery that handles 100 times that amount does not cost more than 100 million dollars. The large capital cost for alcohol distilleries is due to the fact that sugar cane syrup from which the alcohol is distilled contains 93% water which has to go through distillation columns.

One solution to this problem is to use solar heating to concentrate the syrup to some extent. The distillation columns could also operate at low temperatures (little above the boiling point of water) to gain more efficiency.

V. Conclusions

The most significant point that emerges from this report is that non-commercial sources of energy play a fundamental role in the economy and development of LDC's. At least 30%, often 50% and quite generally more than 80% of the energy consumed in these countries is non-commercial (typically fuelwood, agricultural wastes and dung).

The failure to recognize the importance of non-commercial energy sources leads to gross misinterpretations of the nature of the energy problems of LDC's and to false projections of their energy needs, which are based on commercial sources only.

It must be realized that good or even adequate data on non-commercial sources in most LDC's is non-existent and the numbers we gathered in Table VI seem to exhaust the presently available information. Only in the case of India was it ascertained that non-commercial energy consumption was based on an actual sample (in rural and urban areas). Clearly more of this work for other countries would be extremely valuable. In most cases indirect measures or estimates were used.

Almost all energy sources used in rural areas are non-commercial. (Villages depend on fossil fuels mainly through their use of fossil fuel derived chemical fertilizers imported from industrial centers into the villages). This contrasts strongly with the fact that the energy sources of the urban sector are all commercial. This "modern" sector of the economy is approximately the same in all countries and benefits only 25% of the world's population, although it is responsible for the consumption of more than 80% of the commercial energy produced. Almost all of this energy consists of non-renewable fossil fuels (mainly gas and oil) which will be exhausted in the near future.

The efforts to conserve energy in the more affluent part of the world (which consists of approximately 1 billion people) and, if possible, to convert some of its consumption to renewable sources (basically solar energy) have to be coupled with efforts to improve the well being of the part of the world's population (approximately 3 billion) which already is surviving on renewable energy sources.

If this is not done in the near future the increasing number of fossil fuel consumers will exacerbate the serious economic and environmental problems caused by the overdependence on petroleum.

To counteract the tendency for an increased flow of population to urban areas requires that efforts be made to significantly improve the quality of life for present rural populations.

The major recommendations of this report are for new research, economic and political initiatives in the following areas:

A. Low temperature heat and the cogeneration of electricity

Solar heaters for providing low temperature heat for residential (and some industrial) applications could be commercialized without substantial developmental work. Considerable progress will be made in this area (if economic incentives are applied) in the near future. These initiatives would be beneficial mainly for the urban sector. Cogeneration of steam and electricity could represent a very efficient use of coal and biomass.

B. Cooking stoves

The development of an acceptable efficient cooker seems to be the most significant single need for rural areas and could have an enormous impact in improving the quality of life of villages. A sophisticated design might be necessary to solve this seemingly mundane problem, though it is essential that costs be kept low for rural areas.

C. Biogas production

The use of biogas could solve the problem of supplying energy for domestic uses in many LDC's including some urban areas, improving sanitation conditions in the process. Low construction costs for these systems have been achieved in China, but not in India or other countries. Financing biogas systems on the community level with cogeneration of electricity should be considered very seriously by the World Bank and other organizations of this type.

D. Minihydroelectric stations

These stations are not a novelty in a technical sense. The technology is proven and available at competitive prices. Its widespread use will require more awareness on the part of governments and some financing. Intensive surveys of potential supplies are needed in most countries. The U.S. Army Corps of Engineers completed recently such a survey for the United States.

E. Long distance hydroelectric power transmission

Little emphasis has been given to this very important technology; a more intensive use of the abundant untapped resources of hydropower in LDC's would be possible through use of DC transmission. International cooperation will be needed between the developed countries possessing the technology (U.S., Canada, U.S.S.R. among others) and the LDC's. Regional projects might be essential to justify the construction of large hydroelectric stations with enough capacity to supply several countries.

F. G. Improvements on transportation and the use of ethanol as a substitute for gasoline

These are techniques that could alleviate (but not solve) urban problems. Ethanol is a renewable fuel that could replace petroleum in some areas around the world. There is room for technological improvement here.

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As an overall conclusion it is probably fair to say that in very few countries have integrated studies of total energy demand and supply been conducted. This is an area in which international cooperation might prove extremely useful and productive since the understanding of how both commercial and non-commercial sources are used today and how this usage could be improved would be very helpful in finding solutions to many of our present energy problems.

One should realize of course that while finding an adequate energy supply is an important problem for LDC's, it is certainly not the only one. Effective land reform is probably more urgent in many LDC's than harnessing the sun's energy. Therefore the proper perspective should be kept in analyzing the contribution of technology in solving a countries' problems.

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VII. Figure Captions

Fig. 1 Historical evolution of energy sources in the U.S. 1850-2000

Fig. 2 Historical evolution of energy sources in Brazil 1940-1980
Fig. 3 Historical evolution of energy consumption and population increase in Brazil 1940-1980.
Fig. 4 Approximate flow of energy through the U.S.
Fig. 5 Energy supply for developed and LDC's - commercial sources

[1] Natural gas and coal are each 2%

[2] Other is 2%

[3] Other is 1%

Fig. 6 Energy demand for developed and LDC's - commercial sources

[1] Fishing, agriculture, mining and construction are aggregated into other sectors.
[2] Only three sectors are shown: domestic (including residential and commercial), transportation and industry
[3] Transportation includes bunkers.
[4] FAMC is 1% - FAMC: fishing, agriculture, mining and construction
[5] Commercial and public also includes fishing and agriculture.
[6] Commercial public, residential, fishing, agriculture lumped together as residential.

Fig. 7 Energy demand for developed and LDC's - all sources (commercial and non-commercial

Fig. 8 Ratio of urban/rural population in Brazil and India since 1950

Fig. 9 Evolution of the world population in rural and urban areas.

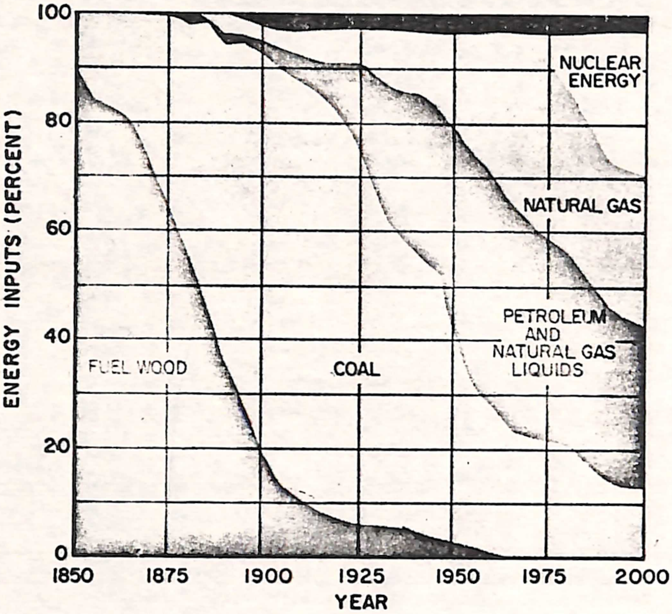
Fig. 10 Energy consumption (TCE) per dollar per million dollars of gross domestic product for a number of countries (commercial sources only).

Fig. 11 Evolution of energy consumption/capita in the world

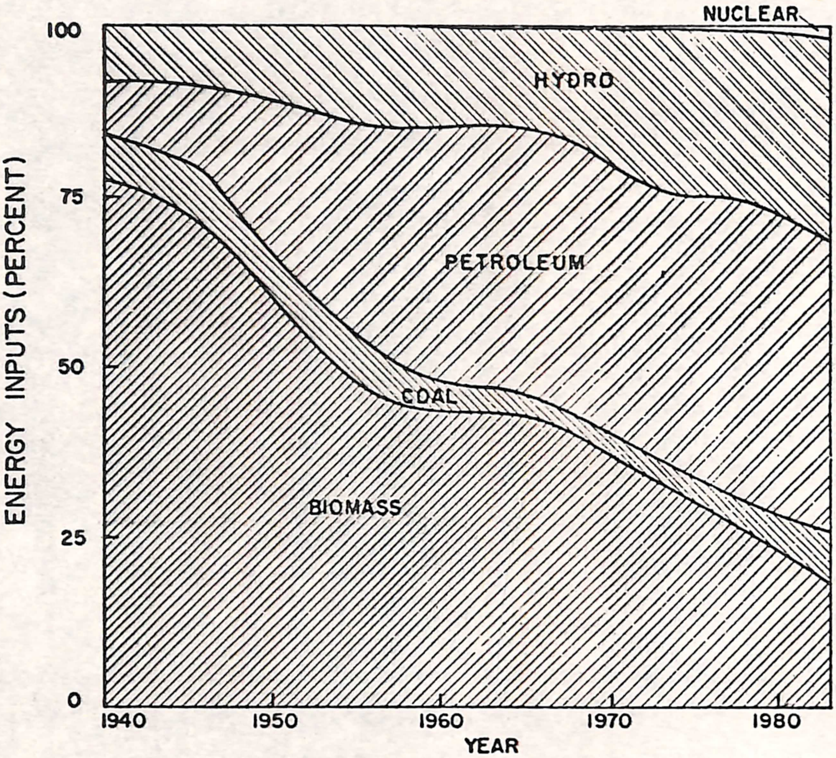
Fig. 12 Temperature spectrum of process heat used by the U.S. industry in 1972

Fig. 13 A traditional Indian cooking stove

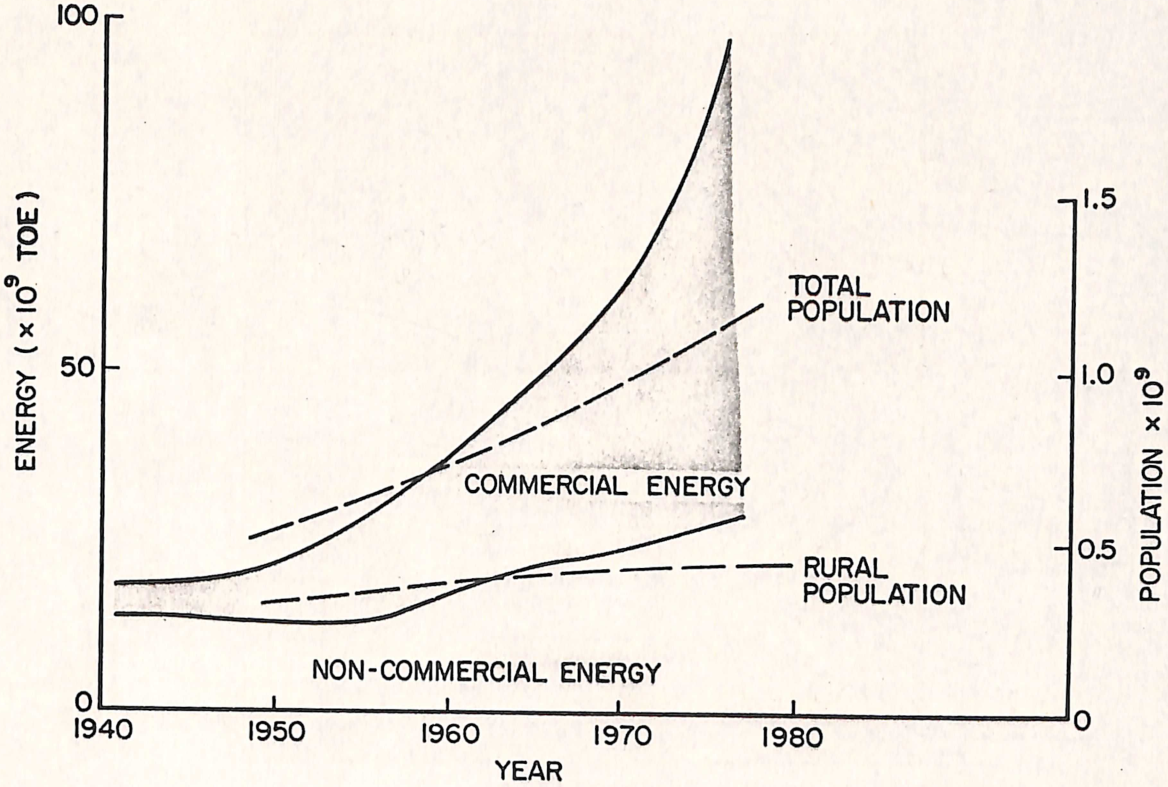
Fig. 14 Gobar gas plant schematics



ENERGY SOURCES IN THE US

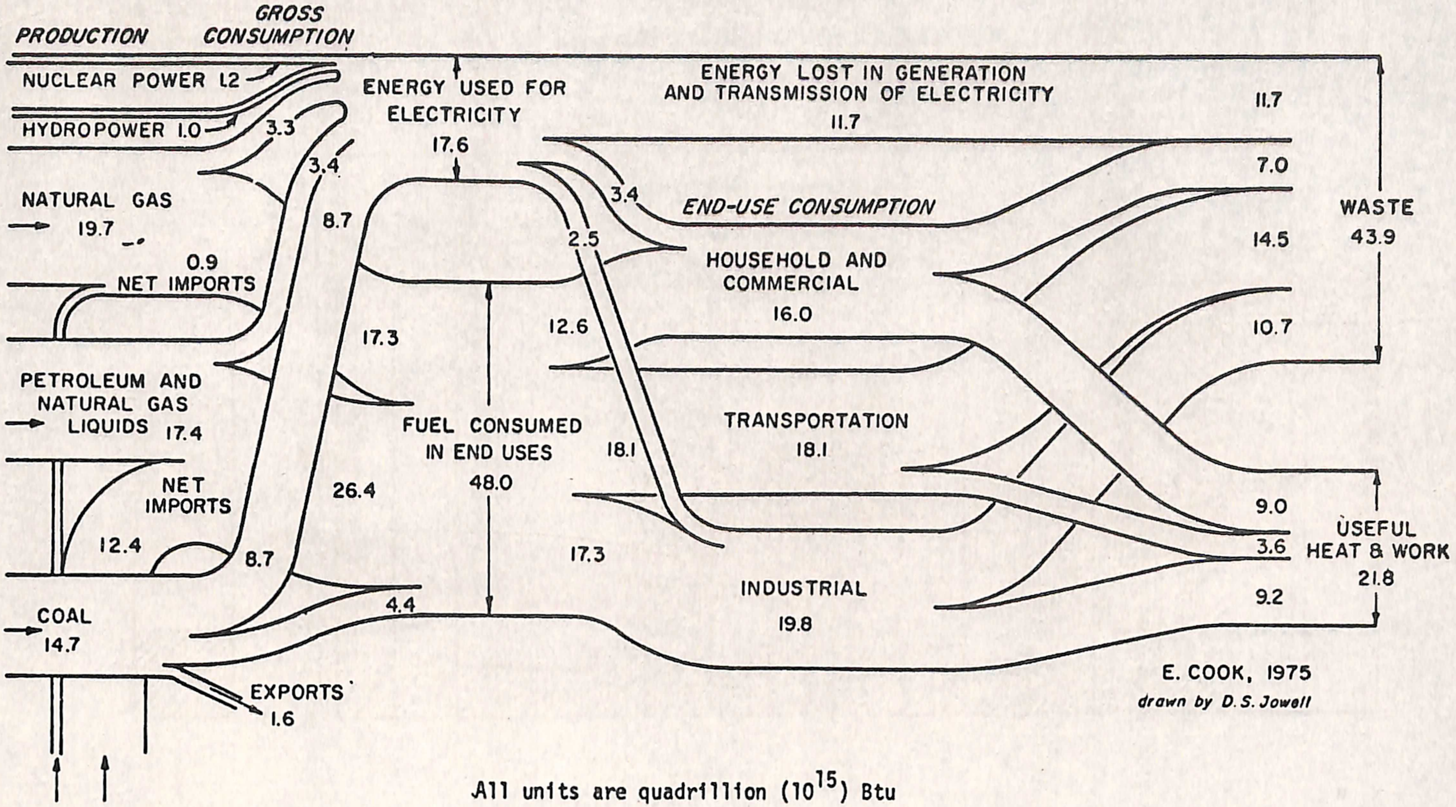


ENERGY SOURCES IN BRAZIL



ENERGY CONSUMPTION AND POPULATION IN BRAZIL

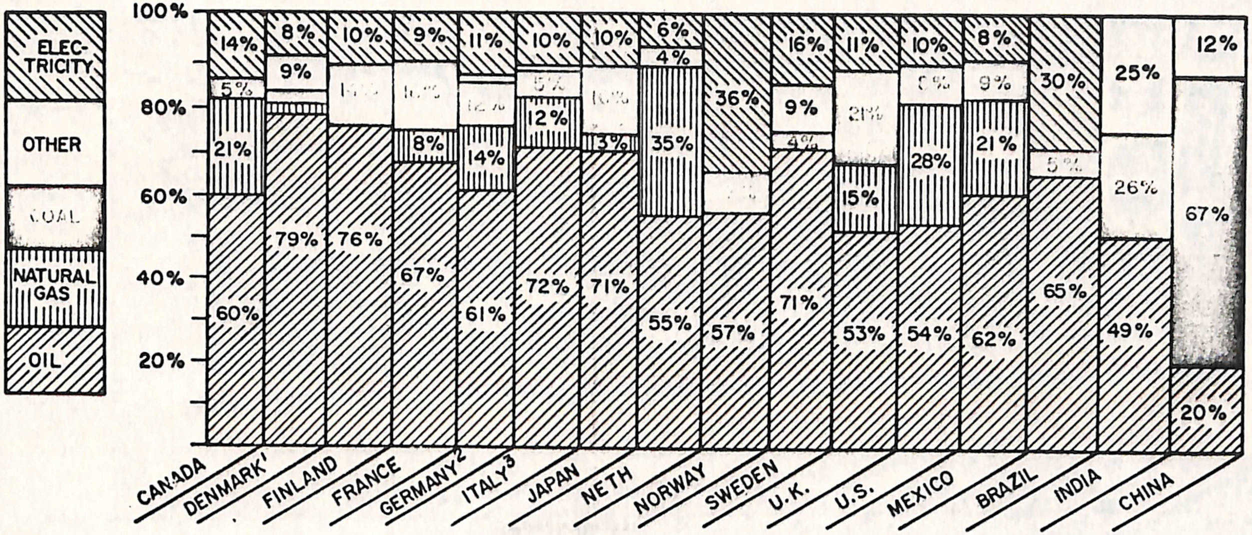
APPROXIMATE FLOW OF ENERGY THROUGH THE UNITED STATES ECONOMY, 1974



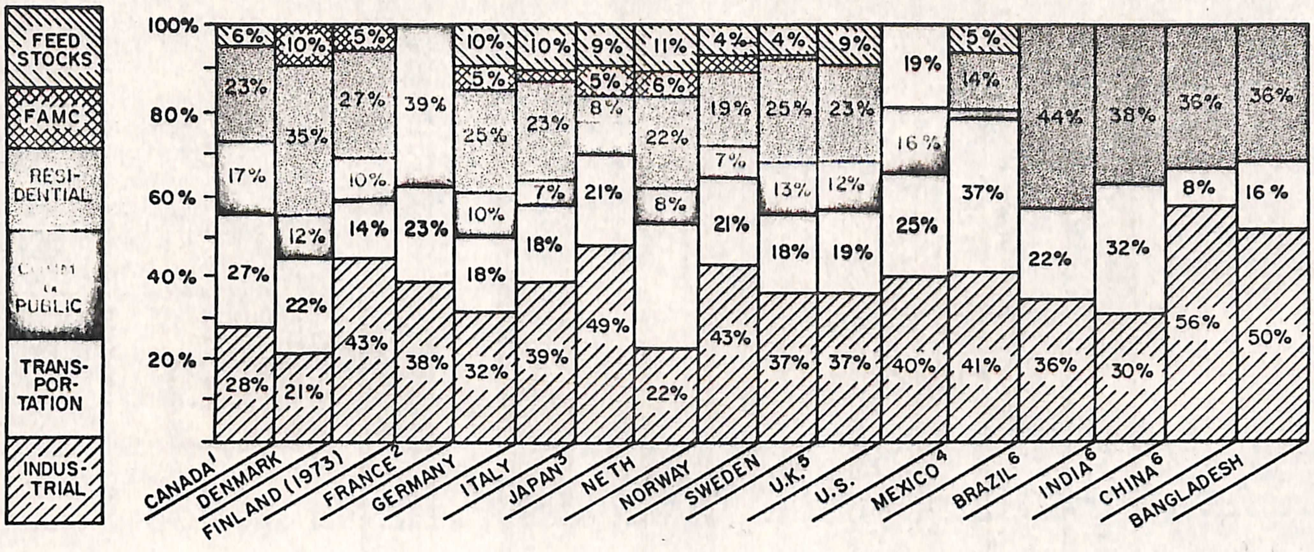
E. COOK, 1975
drawn by D.S. Jowell

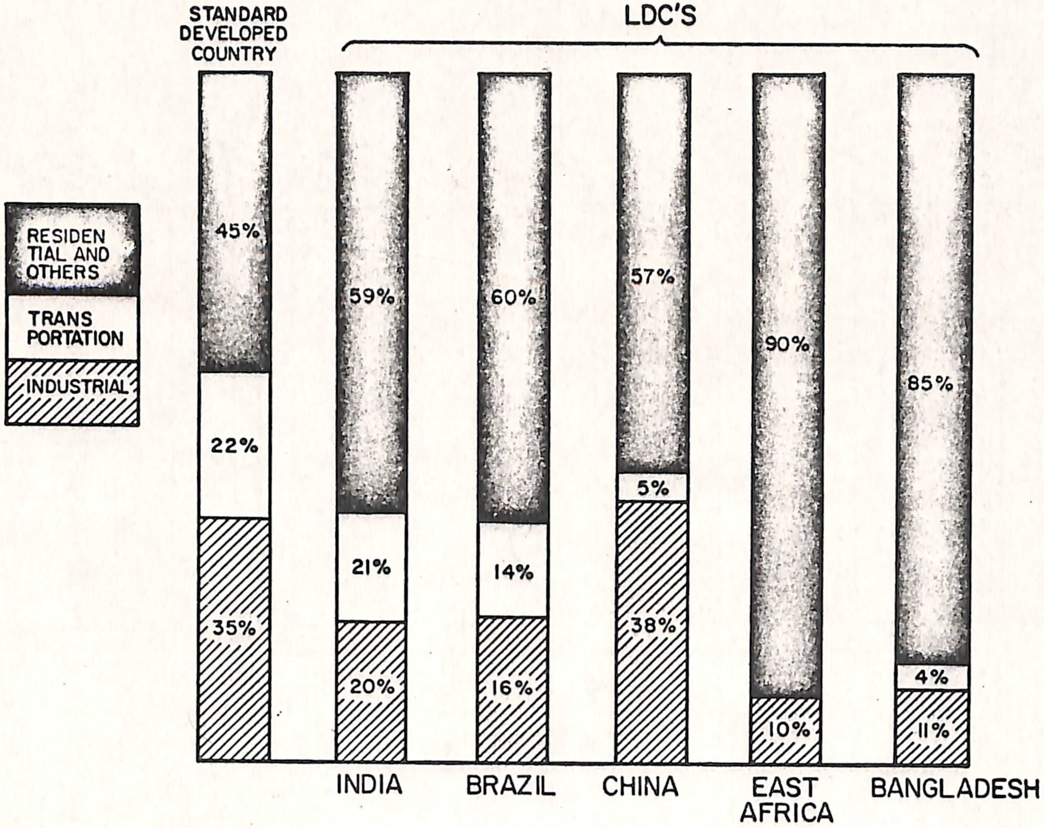
All units are quadrillion (10^{15}) Btu

ENERGY SUPPLY

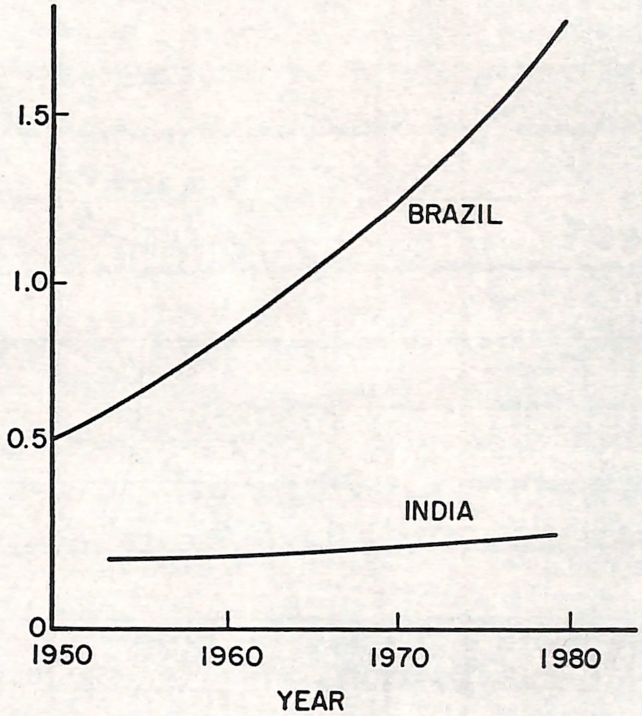


ENERGY DEMAND

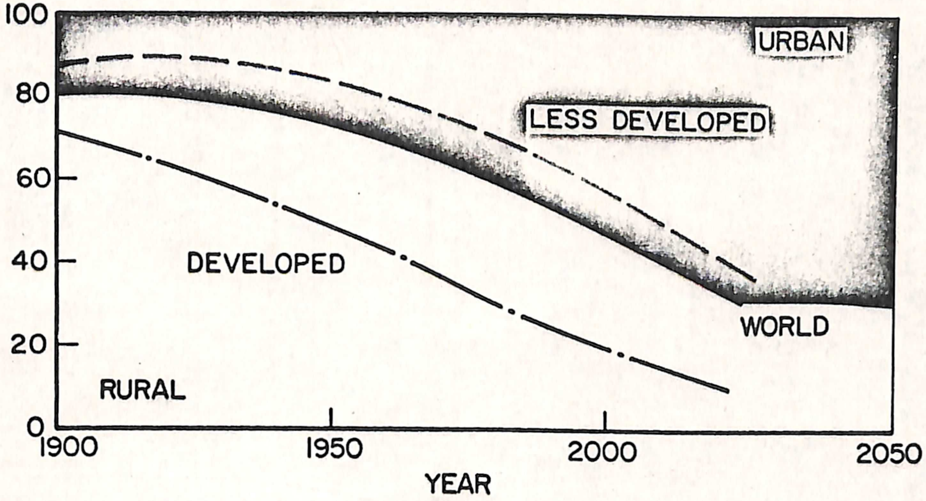


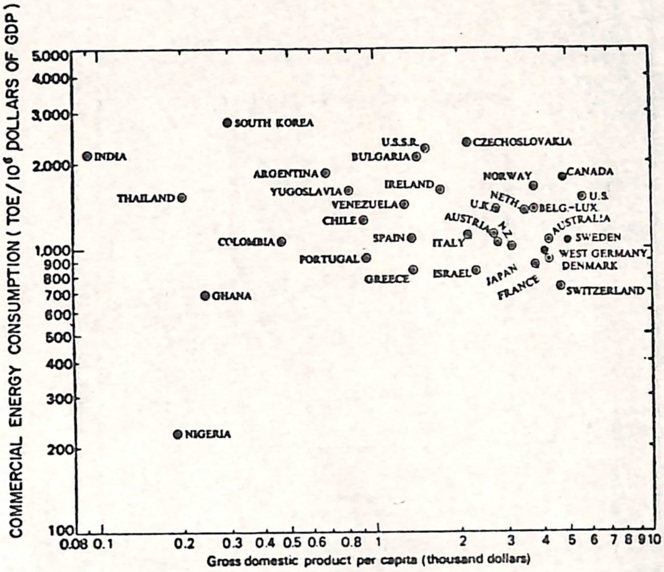


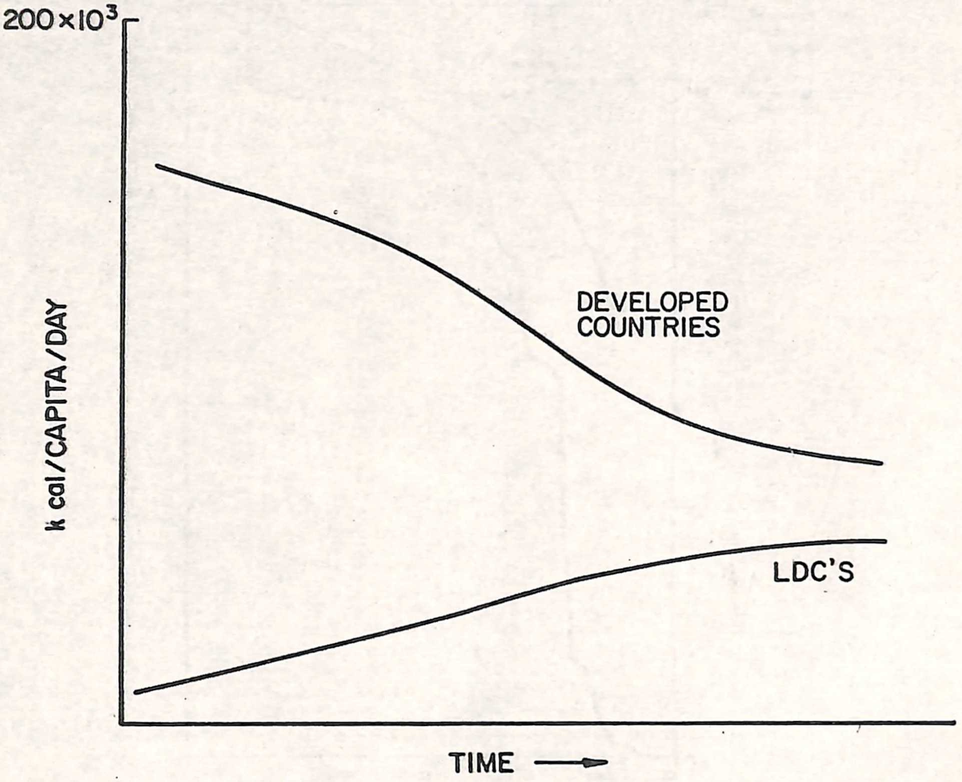
ENERGY DEMAND - NONCOMMERCIAL SOURCES INCLUDED



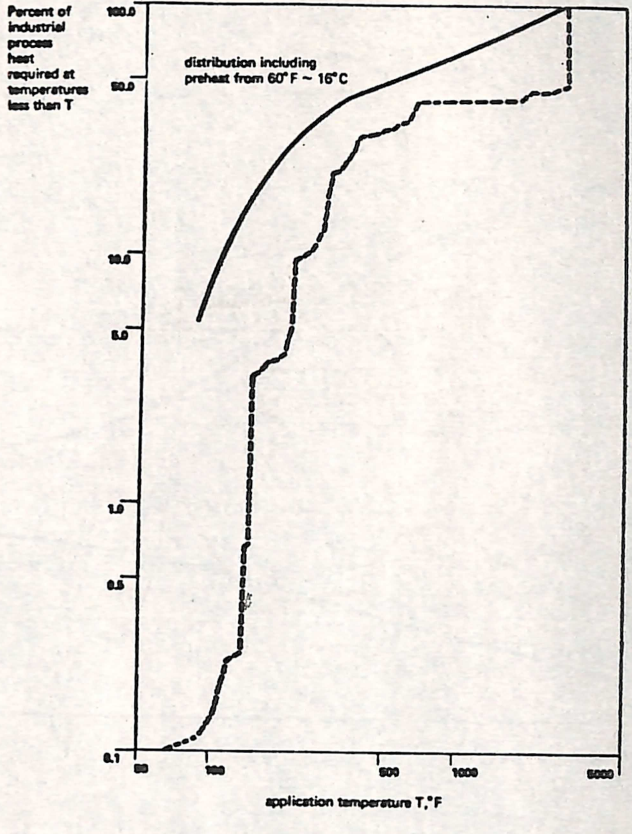
RATIO URBAN / RURAL POPULATION

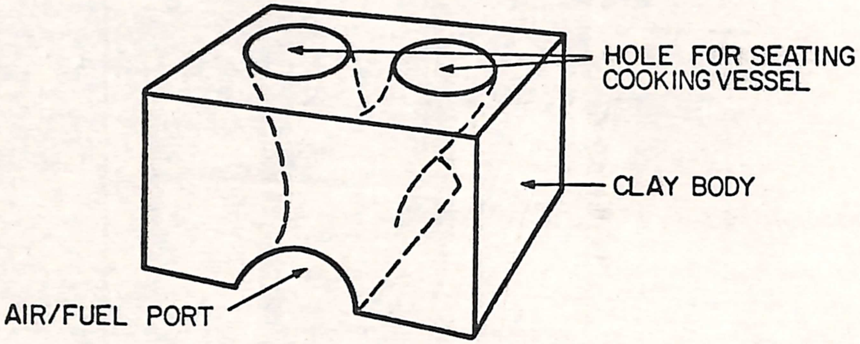

100
80
60
40
20
0
1900
1950
2000
2050
YEAR
URBAN
LESS DEVELOPED
DEVELOPED
WORLD
RURAL

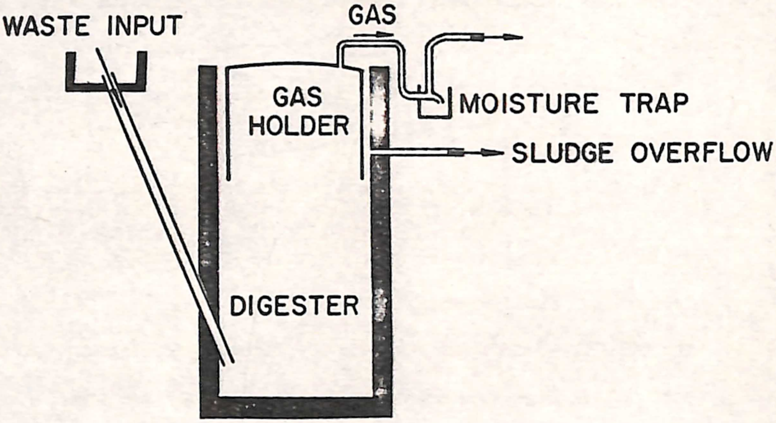

COMMERCIAL ENERGY CONSUMPTION (TOE/10⁶ DOLLARS OF GDP)
5,000
4,000
3,000
2,000
1,000
900
800
700
600
500
400
300
200
100
0.08 0.1
0.2
0.3 0.4 0.5 0.6 0.8 1
2
3 4 5 6 7 8 9 10
Gross domestic product per capita (thousand dollars)
SOUTH KOREA
INDIA
THAILAND
ARGENTINA
YUGOSLAVIA
VENEZUELA
CHILE
COLOMBIA
PORTUGAL
SPAIN
GREECE
GHANA
NIGERIA
U.S.S.R.
BULGARIA
CZECHOSLOVAKIA
IRELAND
NORWAY
CANADA
U.S.
NETH.
U.K.
BELG.-LUX.
AUSTRIA
N.Z.
AUSTRALIA
ITALY
SWEDEN
WEST GERMANY
DENMARK
ISRAEL
JAPAN
FRANCE
SWITZERLAND



EVOLUTION OF ENERGY CONSUMPTION/CAPITA IN THE WORLD


Percent of industrial process heat required at temperatures less than T
100.0
50.0
10.0
5.0
1.0
0.5
0.1
distribution including preheat from 60° F ~ 16° C
50
100
500
1000
5000
application temperature T, °F


HOLE FOR SEATING COOKING VESSEL
CLAY BODY
AIR/FUEL PORT


WASTE INPUT
GAS
GAS HOLDER
MOISTURE TRAP
SLUDGE OVERFLOW
DIGESTER

VIII. <u>Tables</u>

TABLE I

ENERGY CONSUMPTION OF WORLD REGIONS AND SOME SELECTED COUNTRIES

	Population (billions)	Billions of TCE/year			Energy/capita		Source
					TCE/cap.	kcal/day	
		Commercial	Non-Commercial*	Total			
World	4.0	7.4	1.5	8.9	2.23	42,500	Ref. 1
Developed Countries	1.05	6.1	---	6.1	5.8	110,000	"
Developing Countries	2.95	1.3	1.5	2.8	0.95	18,000	"
Middle-Income** Countries	0.55	0.37	?	0.37	0.67	12,700	"
Lower-Income** Countries	0.89	0.16	?	0.16	0.18	3,400	"
Brazil	0.11	0.10	0.03	0.13	1.2	22,800	Ref. 2
India	0.6	0.16	0.2	0.36	0.6	11,000	" 3
China	0.878	0.377	?	0.377	0.384	7,100	" 4
Bangladesh	0.08	0.002	0.007	0.009	0.12	2,300	" 5
US	0.214	2.7	---	2.7	12.8	243,000	" 1

---

[*] Non-commercial sources are mainly fuel, wood, crop wastes and dung.

[**] Middle and lower income countries are listed in Appendix I.

TABLE II

WORLD NON-RENEWABLE ENERGY RESOURCES

	Potential Resource (Billions T C E)
Coal	7,000
Oil	400
Natural Gas	400

Source: Ref. 1

TABLE III

WORLD RENEWABLE ENERGY RESOURCES

	Annual Potentially Extractable Energy (Billions T C E)
1) Direct Solar	
a) 2.5% of Land, 20% efficiency, Non-Photosynthetic	125
b) Open Field Plants; 10% of Land; 1% photosynthetic efficiency Greenhouse Plants 2% of Land; 5% photosynthetic efficiency	25
2) Hydroelectric	3
3) Wind	3-15
4) Ocean Thermal	~ 10
5) Tidal	<.01

Source: Ref. 1

TABLE IV

ENERGY SOURCES IN BRAZIL

($\times 10^6$ Tons of Petroleum Equivalent - TOE)

	Commercial	Non-Commercial	% of Total	Total
1966	26,527	22,583	46	49,110
1967	28,327	23,119	45	51,446
1968	31,699	21,706	41	53,405
1969	33,937	22,952	39	56,889
1970	37,512	23,649	38	61,161
1971	41,506	24,076	36	65,582
1972	46,623	23,473	34	70,096
1973	54,210	23,785	31	77,995
1974	58,916	25,438	30	84,354
1975	64,159	26,257	29	90,316
1976	70,448	28,614	28	99,062

1 TOE = 1.3 TCE.

Source: Ref. 2

Table V. Income per capita in cities and countries (1970)

in US dollars

City	Income/per capita	Country	Income/per capita	Ratio income city/country
Seoul	440	Korea	210	2.1
Djakarta	325	Indonesia	110	3.0
Bangkok	524	Thailand	160	3.3
Calculta	270	India	110	2.5
Teheran	950	Iran	350	2.7
Istanbul	810	Turkey	350	2.3
Caracus	1,600	Venezuella	1,000	1.6
Bogota	450	Columbia	290	1.6
Sao Paulo	784	Brazil	270	2.9
Mexico City	1,274	Mexico	580	2.2
Buenos Ayres	1,800	Argentina	1,060	1.7
Taipeh	555	Taiwan	300	1.8
Singapore	800	Malaysia	340	2.4

Source: Ref. 9.

TABLE VI

COMMERCIAL AND NON COMMERCIAL ENERGY CONSUMPTION IN LDC'S

	Commercial	Non Commercial	Total	Source
India	48%	52%	100%	Ref. 3
Brazil	70%	30%	100%	" 2
China	70%	30%	100%	" 4
East Africa	10%	90%	100%	" 13
Bangladesh	26%	74%	100%	" 5
Costa Rica	69%	31%	100%	" 14
El Salvador	54%	46%	100%	" 14
Guatemala	52%	48%	100%	" 14
Honduras	52%	48%	100%	" 14
Nicaragua	66%	36%	100%	" 14
Panama	81%	19%	100%	" 14

TABLE VII

RURAL POPULATION AND ENERGY CONSUMPTION FOR SMALL WORLD AREAS

	Asia	Africa	Latin America
Rural share of commercial energy	23%	4%	23%
Rural populations	75%	91%	52%

Source: Ref. 13.

TABLE VIII

POPULATION AND ENERGY CONSUMPTION IN BRAZIL

(1975)

Region	Population	Electrical Energy Consumption (Mwh/year)x10^6	Consumption per capita	
			Electricity (Mwh/year)	Petroleum (liters/year)
North	4,120,000 (3.9%)	1 (1%)	0.242	304
Northeast	31,490,000 (30.0%)	7.6 (11%)	0.241	139
West	6,027,000 (5.8%)	1.53 (2%)	0.253	229
South	18,857,000 (17.9%)	7.85 (12%)	0.417	359
Southeast	44,848,000 (42.4%)	50.20 (74%)	1,120	559
TOTAL	105,342,000	68.18		

Source: Ref. 20

TABLE IX

Energy input-output matrix for the US (1972)

Energy Source	Energy Consuming Activity (kcal/capita/day)[*]					
	Agriculture Mining and Others	Commercial	Residential	Transport	Industrial	Total
Oil	5,500	3,300	13,000	59,000	17,000	97,000
Coal	----	700	-----	-----	14,000	15,000
Nat. Gas	1,000	6,000	20,000	-----	26,000	53,000
Electricity	500	5,000	6,000	-----	7,000	17,000
Total	7,000	15,000	39,000	59,000	64,000	184,000

[*] 20,000 kcal/capita/day corresponds to an available power of 1kw.

Source: Reference 12. Not included in this table is the amount of energy lost in the production of electricity from coal, oil and synthetic gas which is approximately 60,000 kcal/capita/day (25% of the total energy consumption). See Appendix II.

Table X

Energy input-output matrix for typical Indian village

Energy Source	Energy consuming activity (kcal/capita/day)					
	Agriculture	Domestic Activities	Lighting	Transport	Manufacturing	Total
Human Labor	370	250	---	60	10	690
Animal work	840	---	---	160	---	1,000
Non-commercial energy (wood, dung, crop residues)	---	4,200	---	---	460	4,660
Oil	270	---	260	---	---	530
Coal	---	100	---	---	---	100
Electricity	90	---	40	---	---	130
Total	1,570	4,500	300	220	470	7,110

Source: Ref. 21.

TABLE XI

US PRIMARY ENERGY CONSUMPTION

(1973)

End Use	Percentage of Total	
Transportation	25	
Miscellaneous Electric	19.5	
Feedstock and Other Nonfuel Uses	7	
		51.5
Heat		
Water Heating	4	
Space Conditioning	19	
Industrial Process Heat	24	
Cooking and Clothes Drying	1.5	
		48.5
TOTAL		100.0

Source: Reference 10.

TABLE XII

SMALL HYDRO STATIONS IN CHINA

Province or Region	Number	Installed Capacity (Mw)	Average Capacity (kw)
Kwangtung	11,740	688.0	58.60
Szechwan	6,000	300.0	50.00
Hunan	5,200	-	-
Yunnan	5,000	-	-
Fukien	4,600	155.0	33.69
Kweichow	4,290	-	-
Kwangsi	4,000	114.9	28.72
Chekiang	3,600	-	-
Liaoning	278	16.8	60.43
Tsinghai	146	22.8	156.16
Tibet	100	-	-
TOTAL	44,954	1,297.5	

Source: Reference 4.

TABLE XIII

WORLD POTENTIAL AND DEVELOPED HYDROELECTRIC CAPACITY

Region	Potential (10^3 Mw)	Developed Capacity (10^3 Mw)	Percent Developed
North America	313	90	28.5
South America	577	30	5.2
Western Europe	158	90	56
Africa	780	10	1.3
Middle East	21	1	0.5
Southeast Asia	455	6	1.3
Far East	42	20	48
Australia	45	5	11
USSR, China	466	45	9.5
TOTAL	2,857	277	9.7

Source: Refs. 40, 41, and 42.

TABLE XIV

HIGH VOLTAGE DIRECT CURRENT (HVDC) SYSTEMS

	Transmission Distance (km)	Rated Voltage (kv)	Rated Power (Mw)	Commissioning
In Service				
Volgograd-Donbass (USSR)	470	±400	720	1962-65
New Zeland	570	±250	600	1965
Pacific Intertie (USA)	1362	±400	1440	1970
Nelson River, Bipol 1 (Canada)	895	±300	1080	1973
Inga-Shaba (Zaire)	1700	±500	560	1976
In Construction				
Cabora Bassa (Mozambique -South Africa)	1414	±533	1920	1979
Nelson River, Bipol 2 (Canada)	895	±500	1800	1981-82
Under Active Consideration				
Gull Island (Canada)	750/1080	±400	1600	1985
Nelson River, Bipol 3 (Canada)	900	±500	1800	1983-85
Ekibastus Centre (USSR)	2400	±750	6000	?

Source: Ref. 44.

TABLE XV

INTERNAL TRANSPORTATION OF MERCHANDISE IN SEVERAL COUNTRIES (1960)

(all numbers in %)

	France	Italy	USSR	US	West Germany	Brazil
Rail	58	29	86	38	50	19
Hydro	11	1	6	44	27	9*
Road	31	70	6	18	23	72
Total	100	100	100	100	100	100

*Coastal transportation.

Source: Reference 45.

TABLE XVI

EVOLUTION OF THE TRANSPORTATION OF MERCHANDISE IN BRAZIL

(in billion ton-kilometer .

	1952	1960	1970
Rail	9.1	13.7	30.3
Hydro*	10.1	14.5	21.4
Road	20.6	420	124.5

*Includes coastal transportation.

Source: Reference 45.

IX. Appendices

Appendix I.	Classification of Less Developed Countries
Appendix II.	National input worksheet for supply/demand Integration (United States 1972)
Appendix III.	Units

APPENDIX I

CLASSIFICATION OF LESS DEVELOPED COUNTRIES

Lower-Income Countries [annual per capita income under $200] 1972 dollars

South Asia

Afghanistan
Bangladesh
Burma
India
Nepal
Pakistan
Sri Lanka

Lower-Income Sub-Sahara Africa

Burundi
Central African Republic
Chad
Cahomey
Ethiopia
Guinea
Kenya
Madagascar
Malawi
Mali
Niger
Rwanda
Sierra Leone
Somalia
Sudan
Tanzania
Togo
Uganda
Upper Volta
Zaire

Middle-Income Countries [annual per capita income over $200 and under $1000] in 1972 dollars

East Asia

Fiji
Hong Kong
Korea (South)
Malaysia
Papua New Guinea
Phillippines
Singapore
Taiwan
Thailand

Middle-Income Sub-Sahara Africa and West Asia

Angola
Bahrein
Cameroon
Congo P.R.

Cyprus
Egypt
Ghana
Israel
Ivory Coast
Jordon
Lebanon
Liberia
Mauritania
Morocco
Mozambique
Oman
Rhodesia
Senegal
Syria
Tunisia
Turkey
Yemen AR, DM
Zambia

Caribbean, Central and South America

Argentina
Barbados
Bolivia
Brazil

Chile
Colombia
Costa Rica
Dominican Republic
El Salvador
Guatamala
Guyana
Haiti
Honduras
Jamaica
Mexico
Nicaragua
Panama
Paraguay
Peru
Trinidad and Tobago
Uruguay

Source: Reference 9.

APPENDIX II

United States

NATIONAL INPUT WORKSHEET FOR SUPPLY/DEMAND INTEGRATION

Country: U.S.A.

Year:

Case: 1972

Units: 10^{15} Btu

	(a) Coal	(b) Petroleum	(c) (Syn. Liquids)	(d) Nat. Gas	(e) (Syn. Gas)	(f) (Heat)	(g) (Electricity)††	(h) Hydro Energy	(i) Nuclear Energy	(j) Geothermal energy and other	(k) Total
(1) Transport	0	16.98		0			0.01				16.99
(2) Industry	3.93	1.56		6.96			1.81				14.26
(3) Agric., Mining, Construction	0	1.60		.30			.13				2.03
(4) Commercial)	.19	.90		1.67			1.42				4.17
(5) Public											
(6) Residential	0	3.77		5.70			1.88				11.35
(7) Non-energy Uses	.12	3.40		.67			0				4.19
(8) Final Energy Demand*	4.23	28.21		15.30			5.25				52.99
(9) Electricity**	7.68	3.25		4.10			-6.04	2.66	0.53		12.18
(10) Syn. Gas											
(11) Syn. Liquids											
(12) Heat											
(13) Energy Sector Self Consumption & conversion losses	.67	2.36		3.72			0.79				7.76
(14) Primary Energy Input	12.60	33.82		23.12			–	2.66	0.53		72.73
(15) Indigenous Supply	14.05	23.71		22.12			–	2.66	0.53		63.07
(16 Imports***		10.11		1.00							11.11
(17) Exports	1.45										1.45

*Includes non-energy uses.

**Blocks 9g, 10e 11c, and 12f must be negative to avoid double counting of energy from primary fuels.

***Includes imported products.

††Includes only electricity to be purchased by each sector

Source: Reference 9.

APPENDIX III

UNITS

Unit		kwh kilowatt-hour	j joules	cal (calorie)	Btu
kilowatt-hour (kwh)	equals	1	3.60×10^6	8.60×10^5	3,410
joule (j)	"	2.78×10^{-7}	1	0.239	9.48×10^{-4}
calorie (cal)	"	1.16×10^{-6}	4.18	1	3.97×10^{-3}
British thermal unit (Btu)	"	2.93×10^{-4}	1.054	252	1

Energetic content of	kwh	cal
1 kg of coal	8.6	7.4×10^6
1 liter of oil	10.5	9.0×10^6

k - kilo = 10^3 = 1,000

M - Mega = 10^6 = 1,000,000

G - Giga = 10^9 = 1,000,000,000

T - Tera = 10^{12} = 1,000,000,000,000

Q - Quad = 10^{15} = 1,000,000,000,000,000