fession and the country as a whole now face (5). In a society as poor as China, which has entered the era of the four modernizations, what kind of balance should ideally be struck between supporting the predominantly rural public health programs and primary care services created by Chairman Mao, and fostering the development of greater competence to apply the knowledge and skills of modern medicine to the treatment of patients in medical institutions, staffed by highly trained professionals, that will probably have to be located largely in cities?

At this juncture, the overall balance seems to be swinging in the direction of the latter alternative and the favoring of medical settings like the CCU of Tianjin's First Central Hospital.

References and Notes

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Alternative Energy Futures: The Case for Electricity

Umberto Colombo

Current estimates of the size of the energy systems required to carry the world's population through the next century differ by at least an order of magnitude. High-energy futures explored by Haefele and co-workers at the International Institute for Applied Systems Analysis (IIASA) involve a three- to fourfold increase in world primary energy consumption over the next 50 years (*1*, *2*). Analysis of low-energy futures by Lovins and co-workers (*3*, *4*) indicate that it will be possible to survive comfortably, and even with an improved standard of living 50 years hence, on as little as half of the energy consumed in the world today, notwithstanding a doubling of the population in the same period.

Summary. The energy trends of the past and their likely evolution in the next 50 years have been analyzed in the light of technological progress. It is concluded that society will tend to become less centralized than in the past and that it is possible to have future per capita values of energy consumption at the world level similar to those at present, with a substantial redistribution to allow for economic growth of the less developed countries. A condition for this is increasing penetration of electricity. The rationale for the suggested scenario is described, and prospects for electricity for both the industrialized and developing countries are discussed.

Both these visions of the future are possible and they may be considered internally consistent in all their major static equilibrium features. In real life, however, social and economic systems are highly dynamic and consist of independent decision-making elements aimed at different objectives, frequently unrelated to energy as such. Social, economic, and political factors, rather than enlightened choice, eventually dominate the actual course taken by nations in their quest for fulfillment of their basic needs.

Both the hard approach of Haefele and the soft approach of Lovins remind us that what is required is not energy itself, but the services that require energy. Lovins makes it clear that a great deal of energy is wasted today, while technologies are, or will soon be, available to substantially improve energy efficiency in end uses. The hard approach emphasizes the importance of functional efficiency of the energy systems to be favored in the future. The two approaches, taken together, indicate that energy is not necessarily required in large quantities, but needs to be available in forms with increasingly high quality.

It is safe to assume that the most likely future course of the world energy system will lie somewhere between the hard and soft extremes, which may be considered as boundary cases. Colombo and Bernardini (*5*, *6*) have suggested a different, more pragmatic approach to the study of energy futures; they predict in 50 years a doubling of the world population and energy consumption, and they assume a substantial redistribution of per capita energy consumption in the industrialized and developing countries.

Our scenario is based on a study of the energy trends of the past and an analysis of their likely evolution in the next 50 years, considering the progress of technology and the availability of capital for investment, and discarding unrealistic hypotheses concerning the structure of political power, and requiring tight coordination worldwide.

We do not assume that urbanization is inevitable. In the past, urbanization was favored by population pressure; the availability of centralized energy systems, which were far cheaper in urban areas than the decentralized energy systems they displaced; and the development of large-scale technologies, which have dominated the world scene. Prospects for the future appear quite different. In industrialized countries population is practically stationary and potentially declining; population pressure still exists in developing countries, but the context of energy and technology is quite different. The diseconomies of the very large scale—due to its excessive rigidity, environmental impacts, and other factors—need not be discussed in detail.

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The new waves of fundamental innovations have been in areas (such as microelectronics and biotechnology) that are suited to, and sometimes even favor, decentralization. The nature of energy systems and in particular the important role of electricity make it possible to conceive, for both the industrialized and the developing countries, a pattern of economic and social growth characterized by less centralization. This will also favor the exploitation of renewable energy sources.

In studying the historical relation between energy and gross domestic product (GDP) in industrialized countries, we have found a common pattern. In the initial stage of economic and industrial development, when base industries and infrastructures are built and society's demands are concentrated on material goods, the ratio of energy consumption to GDP increases dramatically. This continues until a country reaches industrial maturity. At this stage basic needs become saturated and demand shifts toward more sophisticated goods and services. Thus the energy intensiveness of GDP does not increase indefinitely but at a certain stage stabilizes and starts to decrease. In addition, the efficiency of the technologies of energy production and utilization keeps increasing, which contributes to a further drop in the energy intensiveness of GDP. Figure 1 illustrates this trend for different industrial countries.

The trend toward a lower energy contribution to the increase of GDP is likely to continue in the next decades in the industrialized world, and this will mitigate the general growth in energy demand due to continuing population growth in developing countries and to their industrialization.

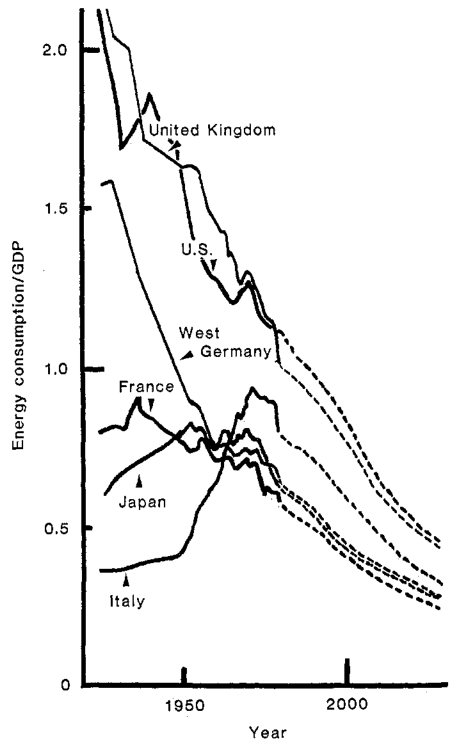

Fig. 1. Energy consumption/GDP ratios in several industrialized countries. Ratios are computed as kilograms of oil equivalent (koe) per U.S. dollar (1973 value). [Source: (5)]

Role of Electricity in the Energy System

The electricity intensiveness of GDP has been increasing in all countries since the beginning of electrification, despite the attainment of relatively advanced industrial development. Even during the early stages of growth, represented today by the less developed countries and yesterday by the present industrial countries, the increase in electricity consumption has, with very few exceptions due to local circumstances, been considerably greater than the increase in energy consumption in general. In the industrialized countries 50 years ago electricity represented only 4 percent of consumption in terms of primary sources, and it has now risen to 27 percent. In 1980 in the Third World countries 25 percent of commercial primary energy was transformed into electricity; this fraction is expected to rise to 31 percent in 1990 (*7*).

The relation of electricity to energy as a whole is further emphasized by developments after the energy crisis of the 1970's. Despite the fact that all energy prices rose substantially, electricity consumption continued to grow faster than GDP in almost all countries, while overall energy consumption remained steady or even declined. Moreover, the price of electricity in most countries will tend to decline compared with the present price.

The economic convenience of electricity compared with other forms of energy is likely to improve with time, since all sources of energy can, in principle, be converted to electricity. Thus investments to build up the electric system will be based on what seems the most convenient mix of sources. This factor should further increase the penetration of electricity in the energy systems of the next two decades. In practically all industrial countries there has been a substantial decoupling of the growth of GDP and the consumption of energy since 1973, but the relation between GDP growth and electricity consumption has remained close. Figure 2 illustrates these trends in the United States, Japan, and France. The per capita index of electricity consumption is particularly high in France (Fig. 2C), a country with a policy of strong electronuclear development.

Figure 3 shows the average per capita indices of growth relative to GDP for total energy, electricity, and nonelectric energy consumption for the periods 1960 to 1973 and 1973 to 1980. The United Kingdom is the only country for which the electricity/GDP ratio is lower than 1 in the second period. However, the large difference between the indices for total energy and electricity should be noted.

Among the most important features of electricity on the demand side are its versatility, easily controllable nature, relative safety in end uses, and unique ability to satisfy certain essential requirements. Electricity growth and industrial productivity increases have been closely correlated in all countries and are likely to remain so in the future as societies develop from the material to the information-intensive stage of growth (Fig. 4) (*8*).

On the supply side, electricity is attractive because it can be produced from many different sources: hydropower, geothermal steam, fossil fuels, and nuclear power. This is a factor of strategic significance, considering the possibility of geopolitical diversification of energy supplies. The development of new technologies, stimulated by the energy crisis, has added other sources to the potential suppliers of electricity: urban and agricultural wastes, biomass, wind power, solar energy, ocean thermal gradients, and so on. These new technologies are in general compatible with small, decentralized conversion systems, although some may also be suitable for large-scale production [for instance, photovoltaics with reference to the solar power satellite project (*9*)].

Different technologies for electricity production and transmission have many elements in common, and this is another advantage of electricity for the industrial and economic system as a whole, as it leads to greater simplicity through similarity of supply infrastructures.

But perhaps the most important factor determining the level of penetration of electricity is the convenience of transporting and distributing it to consumers. The consumer gives high priority to bulk quality and ease of use of energy forms, and these factors frequently outweigh price considerations. Solids, which must be moved in trucks, carried in buckets, and fed with shovels, are clearly inferior to liquids, which still must be delivered by trucks within city boundaries but can be piped to their final use. Gases represent a real jump in quality, since they can be delivered entirely through a pipe network. Once the structures are laid down they can last for many decades with only minor repairs or changes in layout, and this is clearly an asset to urban societies. Finally, electric systems represent the greatest convenience in distribution, at least from the consumer's point of view. They involve the least physical effort, are cleaner and less noisy than other systems, and are versatile in satisfying end-use requirements.

Prospects for Electricity in Industrial Countries

In industrial countries, despite the advantages of electricity, it is not likely that in the next 50 years electricity consumption will achieve the long-term rates of growth experienced in the past. Electricity growth in industry has traditionally been related to the expansion of heavy industrial sectors such as steel and other basic materials. Although there is still considerable room for substitution of electricity for other fuels in many energy-intensive sectors of industry, substitution may be reduced if the price of competing fuels becomes low enough. Furthermore, although major growth areas such as electronics, fine chemicals, and synthetic materials have relatively high electricity requirements, they generally have a much lower energy intensity of value added, so that increased electricity requirements in these areas are more likely to affect electricity penetration than the overall level of energy consumption.

Whatever the prospects for electricity in industrial countries may be during the next decades, there appears to be little doubt that they will be considerably better than those for alternative fuels. In particular, as income rises it becomes easier to accommodate the price differential between electricity and other forms of energy. The trend to increased electricity growth is therefore expected to persist, justifying relatively higher levels of investment in this energy sector than in others. Moreover, in some countries which are not plentifully endowed with alternative sources of energy, electricity may represent a strategic element of energy policy, and this may increase its growth potential relative to that for the industrial countries as a whole.

Expansion of electronics and robotics, will also favor the use of electricity. Decentralization, which in the past has been hindered by lack of opportunities and infrastructures in the periphery comparable to those of the center, will be aided by flexible and widespread automation and by an energy system largely based on electricity.

Prospects for Electricity in Developing Countries

Forecasts for electricity use in the developing countries are difficult to make because of the extreme variability of relevant parameters such as stage of development, social and political structures, pattern of industrialization, and resource endowment. It is clear, however, that if adequate supplies are available, electricity consumption will grow in these countries at rates well above those of economic growth and energy consumption as a whole, and probably at rates higher in absolute terms than those characteristic of the industrial countries at comparable stages of development.

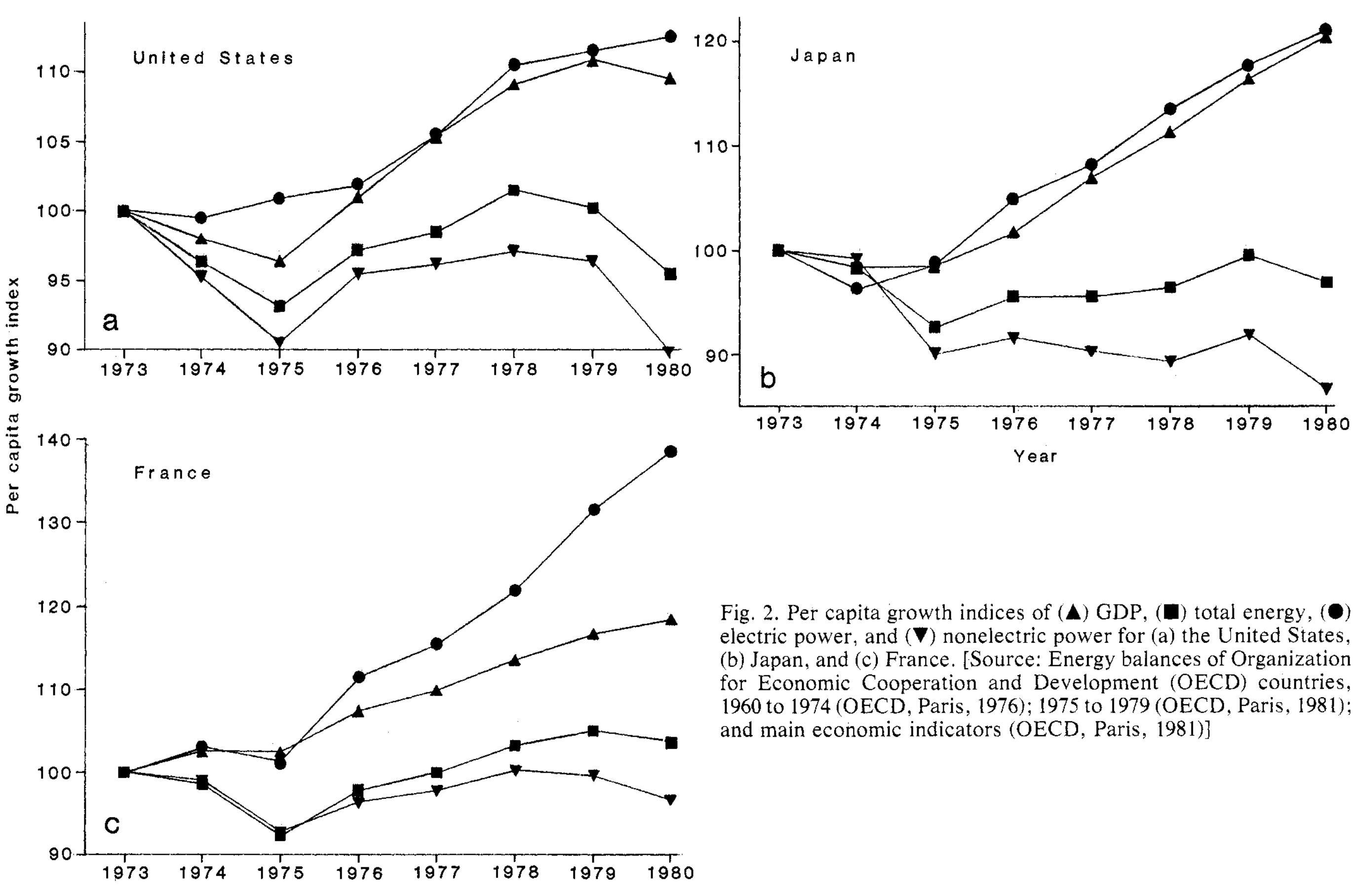

Fig. 2. Per capita growth indices of (▲) GDP, (■) total energy, (●) electric power, and (▼) nonelectric power for (a) the United States, (b) Japan, and (c) France. [Source: Energy balances of Organization for Economic Cooperation and Development (OECD) countries, 1960 to 1974 (OECD, Paris, 1976); 1975 to 1979 (OECD, Paris, 1981); and main economic indicators (OECD, Paris, 1981)]

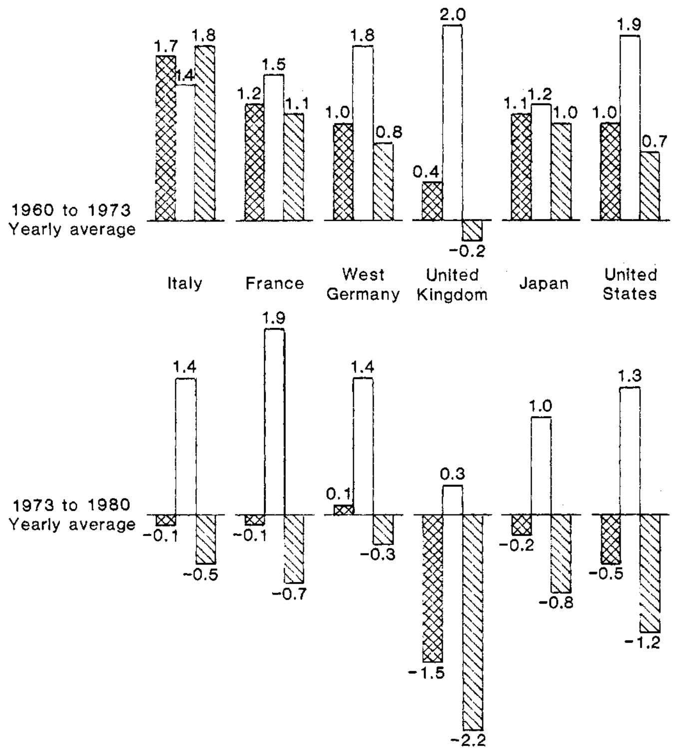

Fig. 3. Per capita growth indices relative to GDP of total energy (cross hatching), electricity (open bars), and nonelectric energy consumption (hatching) in the periods 1960 to 1973 and 1973 to 1980. [Source: Same as Fig. 2]

Many developing countries have ample hydropower potential and sometimes also geothermal energy. These indigenous resources are likely to lead to higher rates of electricity growth than will be experienced in countries unendowed with geothermal and water power. The assumption here is that these countries will be able to secure the financial and technical assistance necessary to develop such resources, and above all that the economic climate will improve in the world as a whole.

In developing countries with a large rural sector, attention should be given to improving local living conditions through energy resource development. Despite its high development costs in rural areas, electricity may become a major strategic element in promoting the creation of local economic opportunities and helping to satisfy basic needs. Through substitution for traditional sources of energy, it would help to allay the pressure toward urbanization and its high energy requirements, as well as impacts on land resources and the environment.

Many developing countries, in fact, face a double energy crises. Decreasing availability and increasing costs of wood fuel and other local renewable resources, caused by growing population pressure and inappropriate land-use management, create hardships for the rural sector. Combined with decreasing opportunities for survival on the land, this contributes to urbanization. On the other hand, the growth of the urban sector increases the demand for conventional energy sources, particularly oil, which many countries can no longer afford to import in sufficient quantities. Unless coal and nuclear resources are developed, which is difficult in the short term because of problems of financing and frequently because of the small size of energy systems, these countries face a real energy resource gap, which has implications for both economic development and social stability. These problems may be alleviated by rural electrification. Although at present the connection of villages and towns to the central electricity grid frequently represents a very costly option, it may in the long run prove the least expensive alternative, considering the very high cost of the urban expansion necessary to accommodate the exodus from the country.

Rural electrification need not be considered in terms of connecting villages, towns, and other localities to the central electricity grid. The versatility of present and potential future electricity supply systems in terms of both technology and size means that electricity use can grow from the bottom up as well as from the top down. In rural areas of developing countries it would seem most appropriate to develop electric systems with the most suitable local inputs and technologies. Today, local electricity grids are based largely on expensive diesel generation. However, technologies exist or are being developed for electricity generation from renewable resources—these range from biogas systems and gas from agricultural wastes, through wind turbines and microhydro converters, to more complex systems based on solar energy conversion, including photovoltaics. In the longer term, local electric systems based on renewable energy resources would be connected to the central electricity grid, resulting in a unified and resilient structure having the advantages of both centralization and decentralization: a degree of local self-sufficiency as well as the benefits of centrally coordinated load management.

The potential for reliability of such a mixed structure should be emphasized. Present electric systems in many developing countries are highly centralized and vulnerable. Partial reliance on local renewable electric systems could reduce the likelihood of malfunctions and should be considered in resource development. However, it would require the creation of a local capacity for electric system planning and management, which may be a problematic aspect of this strategy in developing countries and one that needs to be tackled urgently.

A case for increasing the linkage between centralized and decentralized technologies can, of course, be made for energy types other than electricity: gas production and distribution, for example. However, electricity in particular is of sufficiently high quality in local as well as in centralized production and is amenable to transport and capillary distribution over the distances involved in most countries. Thus electricity is also a crucial element of energy strategy in the developing countries.

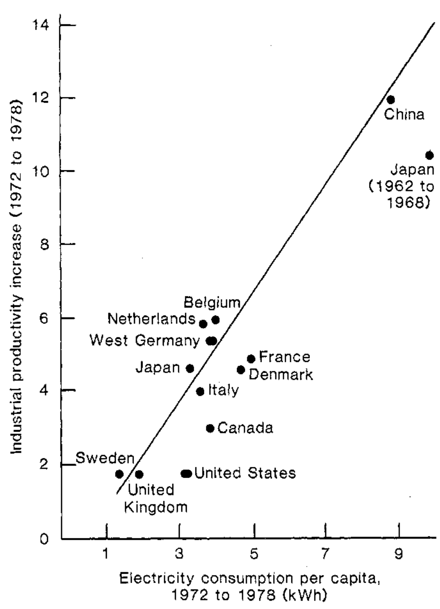

Fig. 4. Industrial productivity versus electricity consumption. [Source: (8)]

Penetration and Supply

In our current work on the Colombo-Bernardini energy scenario, we have been focusing on the dynamics of evolution of the energy system and the penetration of electricity up to the year 2000. Our preliminary results indicate values of electricity penetration on the order of 40 to 45 percent in the industrial countries and 30 to 35 percent in the developing countries (disregarding noncommercial energy, which is difficult to account for). These high projections are due to such factors as the potential for conservation of thermal uses of energy and the gradual shift of modern society toward new industrial sectors, a different mix of products, and the automation of factories and offices.

This increase in electricity demand will have to be matched by an adequate supply, and the problem to be dealt with is one of choice of primary sources. Fuel oil was, until the energy crisis of 1973, the most convenient source for conversion into electricity. Now it is too expensive and the supply is vulnerable; only under exceptional conditions can it constitute the basis for new power plants. For base load supply nuclear power and coal are now the most convenient sources in practically all countries, once any local hydropower potential has been exploited. The choice between coal and nuclear is not easy and depends on several factors, such as availability of coal deposits, perception of environmental and safety problems, and considerations of strategic and balance of payments implications.

Each country has defined, more or less explicitly, a strategy for solving its electricity supply problem based on a mix of fuels. France, for example, has made a clear-cut choice of nuclear, while Denmark is shifting from oil to coal for electricity production. But it should be noted that small countries like Denmark may find it expensive to set up a system of authorization, licensing, and safety controls for what would amount to a very limited number of nuclear power plants. The problem of electricity supply in the developing countries has a somewhat different connotation, because the availability of electricity is a precondition of economic and social development. Electrification of rural areas requires policy actions and is not brought about by market forces alone.

As far as sources are concerned, coal is becoming the fuel of choice for new power plants. Whether existing oil-fired plants should be converted to coal is a complex question, since the choice depends on factors such as the available infrastructure, the shape of the load curve, and the number and size of existing plants. Construction of nuclear power plants, which are now commercially available only in relatively large capacities (above 600 megawatts), is convenient only in countries with power systems of 5000 megawatts or more, considering the need for reliable and stable base load supply (*7*).

Connected with the problem of electricity supply is the question of load management. While coal-generated and nuclear-generated electricity are most convenient for base load, peak load can be met with a variety of sources and technologies. Nontechnical measures, such as differential time-of-day pricing (which might also stimulate new uses of off-peak electricity), are also elements of a load management policy aimed at reducing the need for peak power generation by gas or diesel turbines.

Short-Term Problems

Recently, several industrialized countries have experienced reduced rates of growth in electricity demand as a consequence of economic recession. In some cases this has resulted in excess generating capacity, even in countries where there is little need to replace oil-fired plants. Additions to capacity during the second half of the 1970's reflected the optimistic anticipation of electricity growth of the late 1960's or early 1970's.

In other countries, public opinion and pressures from environmental groups have held back the development of large electric systems based on nuclear power and, to some extent, those based on coal. Increasing lead times for development of these large systems have contributed to escalation of costs at a time when the size and distribution of electricity loads required increasing contributions from reliable, inexpensive base load power.

From a strategic point of view, both coal and nuclear power are essential for the transition to future energy systems and, in the medium term, their exploitation must rely largely on conversion into electricity. The problems that have arisen produce a very uncertain climate for electric power development in both countries with excess capacity and those without it. In the face of these problems utilities have become increasingly indecisive, while the situation calls for immediate action.

In planning for the future we must remember that there are two fundamental objectives: achieving the maximum in energy conservation through rational use of energy, and providing the electricity supply. In pursuing the latter objective, utilities in many countries will have to cope with an enduring situation of shortages in capital markets and high interest rates. It is essential that governments and policy-makers closely consider the risks involved. It is their primary role to ensure that conditions are reestablished in their countries to facilitate the proper functioning of the market in relation to utilities, industries, and financial institutions as they move to satisfy the growing demand for electricity, which is an essential ingredient for the wealth and progress of the economy and of society.

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