Appendix 6

Renewable Energy Technologies

I. THE SETTING

6.1 Energy derived from renewable sources such as wood, wind and water has assisted human activity and development for thousands of years. But following the invention of the steam engine and subsequently the internal combustion engine, fossil fuels (coal, petroleum and natural gas) have been increasingly used to meet the energy needs of the modern world. By 1980 they provided about three-quarters of the world's energy (commercial and non-commercial), with petroleum by far the most important of the three. However, steep rises in petroleum prices during 1973–74 and 1979–80 brought about a growing awareness that for reasons both of strategy (dependence) and of geology (depletion of resources), the world cannot continue to rely on this single source for the bulk of its growing energy requirements.

6.2 The transition from low to high cost energy during the past decade changed the pattern of energy usage. The developing countries, most of which possessed relatively unsophisticated energy technology and relied chiefly on imported fossil fuels for their commercial energy, generally missed the cheap and abundant petroleum that helped to fuel the rapid economic growth of the industrial countries. Further industrialisation and other aspects of economic development in the Third World are almost certain to be associated with a continuing marked increase in demand for commercial energy, and because of price (especially of petroleum) and ecological problems (associated notably with biomass and large-scale hydropower), the more efficient use and production of fossil fuels as well as the development of alternative energy sources will be of crucial importance. Each will depend on the development and application of new technologies.

6.3 New energy technologies cover a wide spectrum. They include improved techniques to convert primary energy into secondary energy (for example thermal electricity—where in some processes over half the primary energy is lost as waste heat); they also include techniques to increase end-use efficiency through new processes and products (for example heat pumps and fluidized-bed combustion), and in other ways to conserve energy (such as through a better organisation of the thermodynamic balance in industries). Their impact is thus felt not only directly within the energy sector itself—in the production, transportation and conversion of energy—but also indirectly, in the way in which energy can be used to produce goods and services or consumed as a final product. Here we concentrate on the new technologies associated with renewable sources of energy, especially those of particular interest to developing countries, although in the medium term technologies to improve the efficiency of production, conversion and use of fossil fuels may continue to be more important.

6.4 Renewable energy sources fall into six broad categories: bioenergy—in its traditional solid form as biomass (fuelwood; charcoal; animal, human and vegetable wastes and residues), or converted into liquids (ethanol and methanol) or gas (biogas/methane and producer gas); hydropower, including mini-hydro; solar power; wind power; geothermal energy; and ocean energy (tides, thermal gradient and waves). Nuclear energy is not considered, as although it is new, and in certain instances potentially renewable ('breeder reactors' and nuclear fusion), its capital requirements and potential environmental hazards do not make it *prima facie* attractive to most developing countries at present or in the near future. In the more distant future, however, it may become economic for the larger developing countries such as India, Brazil, Pakistan and Nigeria, some of which already generate electricity from nuclear fuel.

6.5 Renewable sources of energy are estimated to account for 20 to 25 per cent of all energy consumed in developing countries. In the poorer countries, they supply half to three-quarters of the total, and in individual cases the proportions can be even higher—between 70 and 90 per cent in some African countries. Traditional forms of bioenergy are particularly important in the rural areas and among the urban poor, even in middle-income developing countries. By comparison, renewable sources of energy (other than large-scale hydropower) are estimated to contribute only 15 per cent of world energy consumption and a mere one or two per cent of that in the developed countries. Biomass accounts for as much as 90 per cent of the renewable total (though less if human and animal draught power are included).

II. DEVELOPMENT AND APPLICATIONS

6.6 While some renewable energy technologies are commercialised, others are still at the research and development (R & D) stage. Relatively few are completely mature—large-scale hydropower is one exception—as even 'traditional' technologies can be upgraded. Some of the commercialised technologies are undergoing rapid development, with increasing technical effectiveness and declining costs. They include biomass thermo-conversion and bio-conversion technologies, wind turbines, and solar photovoltaic cells and arrays. Other technologies (including those to take advantage of ocean thermal gradients) still await full economic assessment although their technical viability has been demonstrated; yet others (including the photo-biological production of hydrogen) are not expected to become economic over the next 20–30 years.[1]

6.7 R & D on upgrading traditional sources of energy is taking place in both developing and developed countries; in the latter, private sector R & D is often supported by generous government incentives. R & D on the newest forms of energy is being undertaken largely by developed country enterprises, including those in the public sector (such as electricity utilities). But since many of the new products and processes are suitable for developing countries, location-specific factors favour some development in these countries themselves.

6.8 Comprehensive data of R & D expenditure on renewable energy technology by developed country enterprises are not available; but according to the United Nations,[2] bilateral assistance to developing countries for programmes and projects in this field amounted to some $1.15 billion during 1981–83, while international organisations provided a further $232 million. Large-scale hydropower accounted for $1.16 billion (five-sixths) of this assistance, while other sources of energy received relatively modest amounts, viz. geothermal, $68.6 million; fuelwood, $52.8 million; biomass, $13.1 million; mini-hydro, $4.1 million; and wind, $2.4 million; assistance to ocean energy and solar energy was negligible.

6.9 The technological development and applications of these six sources of renewable energy are summarised below, followed by a brief comment on integrated energy systems.

Biomass

6.10 Although assessment is difficult because of serious deficiencies in data, it has been estimated that biomass provides between 6 and 13 per cent of the world's energy,[3] and is by far the main source of renewable energy in the developing countries. Moreover, according to some experts, biomass in the form of alcohol (fermented from sugars and starch) and biogas (produced from animal and vegetable waste) provides the largest potential substitute for fossil fuels.[4]

6.11 Biomass consists of all combustible plant or animal matter, including wood (and charcoal), straw, husks and dung. It can be converted into energy by direct combustion to produce heat or steam; anaerobic digestion to produce biogas (methane and carbon dioxide); gasification to make 'producer gas'; and fermentation to produce alcohol. Organic materials have been used as a direct source of heat since time immemorial. Since they are likely to remain crucial to the energy needs of millions of people in both the rural and urban areas of developing countries, and because their rapid increase in use has important ecological implications, the technology involved merits serious consideration. The cutting of fuelwood in developing countries is estimated to claim 10 to 15 million hectares of forests each year. This causes soil impoverishment and erosion and in extreme cases, desertification; it thereby lowers agricultural productivity. The amount of fuelwood cut is enlarged by the low efficiency of relevant technologies in current general practice. As a result, large-scale afforestation is required, especially on non-arable or marginal lands, as is the upgrading of wood-burning/charcoal technology. The importance of the latter is apparent from the fact that improved wood-burning stoves can, in theory, approximately halve the energy requirements of the domestic sector; modern techniques of charcoal-making are also capable of effecting considerable savings.[5] In addition, wood and sugar-cane bagasse can be used directly as fuel to generate electricity. In countries such as Brazil and the Philippines, where adequate supplies can be assured, wood-fired electricity generating plants are competitive with diesel-fired ones, and can save valuable foreign exchange.

6.12 Significant developments are taking place in many of the technologies associated with biomass production and conversion. 'Traditional' biotechnology has been used to develop specific crops for energy purposes, and model tree-farms have been developed in a number of developing countries including Kenya, Nigeria and Sudan. But developments in genetic engineering and other areas of 'new biotechnology' are expected to make a greater contribution over the longer term. Higher-energy species can be engineered through recombinant DNA technology, and their supplies increased through molecular cloning. Existing tree-farms suggest that 1,500 hectares are needed to provide one MW of electricity per year. But this could be reduced if new biotechnology processes are used to maximise forestry output. Similar research is being carried out on other potential energy crops, such as sugar-cane, sweet sorghum, cassava, and certain oil-bearing plants, in order to select high-yielding, low cost varieties. Also being considered as an energy source are fresh and saltwater aquatic plants which have the advantage of not taking up valuable land.[6]

6.13 Biogas technology has recaptured the attention of many developing countries in recent years as a relatively simple and cheap way of producing energy, although its contribution is likely to remain marginal. The gas is used basically as fuel for cooking and lighting, and special purpose-built stoves are already in use in China, India[7] and some other developing countries. It can also be used to power engines for processing crops, pumping water or generating electricity. The gas is environmentally sound, as by reducing the demand for firewood, it improves forestry conservation and reduces soil degradation and desertification. In addition the by-product 'sludge' produced in the fermentation process can, after treatment, be utilised as a fertilizer, as animal feed or for fish farming. The technology is also of particular importance in rural areas which lack adequate organic waste disposal systems, and can lead to improvements in public health. Such integrated bio-systems can be installed and operated in rural areas by few persons at low cost and with only routine maintenance. The main problem is that the cost of the equipment and quantity of raw material (waste from, say, four or five animals) may be beyond the means of the average family in most developing countries. Increasing use of biogas technology in rural areas has also the drawback of making the landless poor still poorer by reducing their supply of free fuel (wood and dung). In addition, as the organic substitute used must be mixed with water (up to a maximum solids content of about one-sixth), the availability of water could be a constraint in certain locations.

6.14 Producer gas can be used to generate shaft-power and heat. One of its major attractions is that it can be consumed in virtually any type of internal combustion engine: with relatively simple adjustment, gasoline engines can be converted to run entirely on producer gas. It can also supply heat for glass-making, brick-making, brewing, fertilizer production, etc. Countries with large forest resources are obviously well endowed for making producer gas, although it is highly toxic, needs careful handling and has the added disadvantage of producing a tarry, corrosive by-product when more efficient conversion techniques are employed. New technology is being developed, however, which could make it safer and more efficient.

6.15 The supply of alcohol fuel (methanol and ethanol) is limited by the large amount of wood or crop surpluses needed for its production. And since at present micro-organisms are relatively inefficient in converting the feedstock to alcohol, the ratio of energy produced by the process to that consumed in it may be as little as 1:1 (especially if the energy cost of planting and harvesting the feedstock is taken into account); it is possible, however, to reach a ratio of 8:1 by using sugar-cane residues and by-products. Production of ethanol from sugar, molasses and starches, for use as a substitute for petrol in transport and as a feedstock in the chemical industry, is the most important recent application of alcohol. Cars with engines adapted to burn fuel containing 15–20 per cent ethanol have for some time been common in Brazil (where by 1984 ethanol production had reached 100,000 barrels per day, costing US$40 per barrel[8]), and engines have now been designed to use pure ethanol. It had been planned that by the year 2000 all cars in Brazil would be run on alcohol, but falling real prices of petroleum mean those targets may have to be adjusted. Several other countries, including the United States, Costa Rica, Malawi, Kenya and Zimbabwe, have also embarked on alcohol production for use as a petrol substitute or chemical feedstock.

6.16 Although alcohol increases fuel efficiency by raising the octane-rating, corrosion had been a problem for ethanol-fuelled engines: this has been largely solved by nickel-plating the carburettors. A further difficulty is that ethanol has only a single flash-point and must therefore reach the car engine's combustion chamber at precisely the right temperature. Methanol is difficult to integrate with petrol for use in vehicles, and is more expensive to produce than ethanol.

6.17 Research in genetic engineering aims (*inter alia*) to increase the efficiency of microbial breakdown of cellulose in order to facilitate the direct conversion of cellulose waste into methane.[9] This may provide a more efficient route to methane and methanol production, and Canada's National Research Council has been engaged in identifying suitable micro-organisms to convert forestry wastes into methane.[10] It has also been suggested that an exchange of genes between yeast and organisms that degrade cellulose could lead to the production of ethanol from plant wastes.[11] These approaches remain at the R & D stage, however, and are not expected to have any commercial application this decade.

Hydropower

6.18 Hydropower is by far the largest commercial source of renewable energy. It is used mainly for generating electricity, of which it accounts for almost one-quarter of the world's total, although its associated dams are also used for irrigation, flood control and water supply. Its limitations include site specificity, heavy capital outlay and long lead times, while variations in water-flow can cause fluctuations in energy supply. Moreover, large reservoirs can harm the environment, resulting in loss of human habitats, fisheries, farm and wood lands, as well as wild-life; they can also cause soil erosion.

6.19 Despite these problems, the growth of hydropower continues. The potential is huge and according to estimates by the World Bank, only about one-sixth of the world's reserve is being utilised. Developing countries possess about half this resource base and only one-tenth had been developed by 1980. Forecasts suggest that hydro-electricity generation could be at least doubled by the year 2000. In the last quarter of this century, developing countries (excluding China) are expected to increase their hydro-electricity output fourfold, and to raise it a further two and a half times by the year 2020.[12] Large projects planned, underway or in operation in developing countries include the Guri project in Venezuela, Yangtze Gorge in China, Itaipu scheme in Brazil, Qattara Depression in Egypt and Mahaveli scheme in Sri Lanka.

6.20 Indigenous technology for hydro-electricity generation exists in only a few developing countries, including China, India, Brazil and South Korea. Mainly because of low operating and maintenance costs, electricity from large and medium sized hydroplants is cheaper than that from coal, petroleum or nuclear-fired stations. Small turbines are still generally less efficient than large ones, but technical developments have raised their efficiency and new designs for low 'heads' are being developed. When electricity from thermal plants is already available, mini-hydro stations (under one MW) can supplement supplies, reduce average costs and enhance self-sufficiency. Mini-hydro projects are estimated to comprise 5 to 10 per cent of the world's currently harnessed hydro resources; with the advantage of relatively low capital costs and a non-pollutant nature, and given likely further improvements in the efficiency of turbines, mini-hydropower is expected to grow in popularity in developing countries.

Solar energy

6.21 Technology for producing solar energy can be divided into two main categories: solar thermal technology, which traps sunlight in collectors and transforms it into heat or electricity through solar engines; and photovoltaic (PV) energy conversion technology, which harnesses solar rays directly to generate electricity using solar cells.

6.22 The technology embodied in solar collectors is fairly simple and costs have been reduced markedly although they are still high for mechanisms such as sun tracking devices which increase the collector's efficiency. The efficiency of solar collectors is expected to increase considerably in future, especially with the use of chemical salts instead of water for storing solar heat. Plant for solar thermal electricity generation ranges in capacity from 10 kW to several MW, but the efficiency of small-scale plant is low and such devices have not met with widespread acceptance in developing countries. Solar energy is increasingly being applied for space heating, water heating and air-conditioning in developed countries, and for drying wood and agricultural crops in developing countries. Other devices which are currently available include solar cookers (not yet widely used because of technology problems), solar stills for water desalination, solar ponds for domestic space heating and electricity generation, and solar water pumps for irrigation; solar furnaces (heliostats) for electricity generation are being developed in a few industrial countries.

6.23 PV technology is mainly in the hands of large multinational companies and has benefited from development grants by industrial country governments. The PV systems they have developed can operate over a wide range of capacities and have several important applications. Their portability and freedom from utility linkages make them specially valuable where remote power requirements need to be met, as in communications (power telephones and repeater stations, radio transmitters on mountain tops), navigation (power warning beacons on oil drilling platforms), and geological surveys (in remote-sensing equipment). The PV systems can also generate electricity for use in isolated villages and power irrigation pumps, although in general they have not yet proved cost-effective in these applications. Although the cost of PV systems, currently estimated at about US$7 per peak watt, is still prohibitively high and has not fallen as sharply as anticipated, these systems could become competitive with oil-fired or nuclear-fuelled electricity generation plants in developed countries by around the year 2000, when solar power could meet about 5 per cent of the world's energy needs. This, however, depends on increasing the conversion efficiency of solar cells (possibly by the use of germanium) and improving the crystallisation process.

Wind energy

6.24 Windmills are highly site-specific and, as an energy source, generally unreliable. Their use has therefore been concentrated in those activities, such as pumping water, where discontinuity is least critical. Though of great antiquity, their widespread use in developing countries has been inhibited by high cost (in comparison, say, with diesel pumps) and design unsuitability for small-scale manufacture. As a result, present production is probably only about a tenth of the potential world market of 50,000 units per year. But considerable R & D is taking place and some results appear promising. For example, a three ton wind-pump capable of lifting water from 200 metres has been developed which is claimed to last five times as long as a diesel engine and to cost half as much. Ninety of these pumps are presently in use, mainly in Kenya and Pakistan.[13] In Peru, some 2,000 locally-designed and manufactured wind-pumps have been installed in one region to raise irrigation water,[14] while new types of sail windmills have been designed in India, Colombia and Ethiopia. Yet, although wind energy may seem attractive in certain rural areas and small islands, the lack of mechanisms to demonstrate these technologies and of expertise to evaluate and exploit them means that the large-scale use of wind pumps and power units in the developing countries still appears remote.

6.25 The use of onshore winds to generate electricity for grid linkages is being actively developed in the industrial countries. Most of the countries have wind-power programmes, and progress has been such that systems (mainly between 50–100 kW) are often regarded as economically attractive in remote locations, especially when fiscal and financial incentives are taken into account. Possibly the largest installed capacity is in the United States where, in California alone, the capacity of wind farms was 600 MW in 1984 and was expected to reach 1,000 MW in 1985. Many of these are subsidised, however, and their commercial viability is still to be demonstrated. American attempts to make giant commercial wind turbines (over two MW capacity) have so far been unsuccessful, although a British consortium is on course for completing a three MW turbine in Scotland by 1986.

6.26 There are a number of problems relating to large-scale wind turbines. Their installation and maintenance are expensive while fluctuating wind speed, as well as often strong seasonal dependence, is a further complication. But perhaps the major drawback, in industrial countries at least, is their lack of environmental acceptability on grounds of noise and visual intrusion. Even so, wind energy is environmentally safer and cleaner than nuclear or fossil-fuelled electricity plants.

Geothermal energy

6.27 Geothermal energy is contained in the natural heat under the earth's surface; technologies have been developed for tapping three of the six systems (dry-steam fields, hot-water fields, and low-enthalpy fields) and are at the R & D stage for the others (magma energy, geopressurised zones and hot dry rocks). Hot-water fields are the most commonly exploited, but dry-steam fields have the advantage that steam can be used directly in generating electric power.[15] The actual production technologies are relatively mature, being akin to the petroleum industry. Among the problems encountered is the production of hydrogen sulphide.

6.28 Although geothermal resources are widely distributed, relatively few sites have been exploited, both because alternative sources of energy have been cheaper and because the energy can often be used only in close proximity to where it is being tapped. The main economically recoverable resources are to be found in the western part of the American continent, a band from South-east Europe to the East African Rift Valley, and an area from South-east Asia to the Pacific islands.[16]

6.29 Geothermal energy can be used for space heating for residential, commercial or agricultural purposes, hot water supply, process heat, and electricity generation. With the rising price of fuel oil in the 1970s, geothermal electricity generation became increasingly economical in several countries. Although the capital costs of geothermal electricity generating plants are high (in 1980, the World Bank estimated them at $1,000–2,400 per kW, compared to $400–1,200 for coal or diesel-fired plant), operating costs are lower than for most nuclear and oil-fired plant.

6.30 In the Third World, geothermal electricity generating plants have been established in China, El Salvador, Indonesia, Kenya, Mexico and the Philippines. In the industrial countries, they exist in France, Hungary, Iceland, Italy, Japan, New Zealand, USA and USSR. Worldwide, installed capacity was estimated at 1,800 MW in 1980.

Ocean energy

6.31 The only technology which has been commercialised to exploit ocean energy is that to harness the tides.[17] A tidal plant of 240 MW has been operating in France since 1966. Capital costs of this type of plant were estimated in 1980 at $1,500 per kW (compared with $400–1,200 for coal or diesel-fired) and generating costs at about $0.08 per kW. Small-scale tidal plants have been built in China and the Soviet Union, while a few other countries are undertaking feasibility studies. However, it is believed that, worldwide, there are no more than 40 sites which might eventually be used for generating electricity through this means.

6.32 The exploitation of ocean thermal energy conversion has only reached the pilot stage. The system used is related to the solar pond concept, although the smaller differences in temperature (around 20°C) lead to low efficiencies and the need to pump very large quantities of sea-water. While the technology has been demonstrated technically, its economic viability has yet to be proven.

6.33 Despite the large number of designs for harnessing wave-power, no breakthrough has yet occurred, though some developed countries are continuing R & D.

Integrated energy systems

6.34 The use of a single source of renewable energy may not provide a reliable and continuous supply or, on its own, be technically efficient and cost-effective. A combination of several of them may, however, rectify these deficiencies. Countries are therefore beginning to adopt integrated approaches to energy. Demonstration projects already exist.

For example, at a UNEP-assisted project in a Bangladesh village, animal waste, solar radiation and wind power are being utilised to provide energy in various forms: biogas for cooking, solar power for pumping (drinking water and irrigation), and wind power for generating electricity.

III. ECONOMIC AND SOCIAL IMPACT

Economic aspects

6.35 The relationship of increases in energy consumption to economic growth varies substantially, from one country and time to another, but it remains generally true that increasing supplies of energy are a prerequisite for an expanding economy. This is especially true of developing countries, whose growth of commercial energy consumption has significantly outstripped that of GDP.[18] The reason is to be found partly in the substitution of 'commercial' for 'non-commercial' energy but mainly in the growth of the industrial sector, particularly of 'heavy' industry.

6.36 Although economic development requires the balanced growth of all sectors, the key to economic growth has generally been found in industry, especially manufacturing. Industrial development requires the ready availability of heat, mechanical energy and electrical energy. High-grade heat, especially important for the operation of process plant, notably in metal smelting, is not readily obtainable direct from renewable sources of energy, except in the case of some sources of geothermal energy. Lower-grade heat, suitable for some industrial applications, can be obtained from sunlight (through the use of solar thermal technology, as in solar engines), from biomass (through direct combustion or anaerobic digestion/gasification or alcohol fermentation) and from fuelwood/charcoal.

6.37 Mechanical energy can be readily obtained from wind, water and draught animals. In this form it is generally more suitable for small-scale 'light' industry, such as processing agricultural products, than for 'heavy' manufacturing. Electrical energy is a key input, not merely for manufacturing but for mining, services and even agriculture. To date by far the most important renewable source of electricity generation has been water (to drive turbines); though other sources, including the sun (through solar thermal technology and PV energy conversion technology) and the wind (through aerogenerators), are being increasingly employed, their contribution is still only marginal.

6.38 Apart from well-known large-scale hydroelectric projects, the main impact of renewable energy in developing countries has so far been felt in the agricultural and household sectors, especially in the rural areas. In some instances relatively simple improvements to the technology can make big differences to the welfare of the users. Examples include more efficient wood-burning stoves, biogas converters, and windmills and watermills. As far as transport is concerned, one of the most notable recent developments has been in the use of alcohol as an additive to motor spirit in Brazil.

6.39 The greater use of energy—including that from renewable sources—will clearly have a positive (if unquantifiable) impact on overall employment. In so far as many renewable sources are widely available, the energy they produce can help to stimulate decentralised activities, and thus encourage rural development and generally facilitate the implementation of regional policies. The ability to generate electricity on a small-scale, local, yet economic basis, through the greater use of, say, solar, wind or biomass energy, rather than to bring it into a region through expensive long-distance transmission lines, should be particularly helpful in this respect.

Social aspects

6.40 Acquisition of technologies to produce renewable energy has social as well as economic effects. In the medical field, for example, reliable supplies of potable water are basic to improved health: solar stills to desalinate water are already being used in a few countries and are likely to be introduced into others. The installation of biogas digesters can improve nutritional standards and therefore health, through the enhanced crop and animal yields which result from using the fertilizer or animal feed produced from the by-product 'sludge' created in the fermentation process.

6.41 Renewable energy technologies can also have considerable environmental and ecological effects. For example, in the generation of electricity, the substitution of solar cells or panels in place of fossil fuels reduces pollution, while that of solar or wind energy in place of wood reduces deforestation and therefore soil erosion and the risk of desertification. On the other hand, the use of aerogenerators is visually and acoustically intrusive, while the construction of large reservoirs for hydro-electric generation can cause losses of human and animal habitats, climatic changes and soil erosion. Perhaps most important of all are the effects of the still fast increasing use of fuelwood. In developing countries this is estimated to claim 10-15 million hectares of forest every year. It has caused widespread soil impoverishment and erosion, and in extreme cases, even desertification; it has also reduced agricultural productivity. Rectifying the damage needs not only large-scale reafforestation but a further upgrading of wood-burning and charcoal-making technology (particularly of stoves in the household sector).

6.42 The greater utilisation of renewable energy technologies also has effects—actual and potential—on the structure of societies. To the extent that these technologies can be economic at low levels of energy output, and in so far as they depend on elements which are widely available—for example biogas digesters at present and perhaps PV systems in future—they can help societies to decentralise and curtail the drift from rural to urban areas.

IV. PROBLEMS AND POTENTIALS FOR DEVELOPING COUNTRIES

6.43 Some developing countries are comparatively well supplied with renewable energy resources, especially solar and biomass, although many countries do not have the space to make great use of them. These resources are particularly suited to meeting the needs of dispersed populations in rural areas for decentralised sources of energy in small amounts, and may prove much more cost-effective than in the industrial countries. Nevertheless, because of a number of constraints, some of which are outlined below, it is unlikely that most renewable energy technologies will be sufficiently developed and diffused to make a major contribution to the energy supplies of developing countries this century. In the meantime, however, individual countries may still benefit significantly, while the impact of renewable sources of energy on particular locations and ways of life can be substantial.

6.44 The ability of developing countries to exploit their renewable energy resources depends largely on their own capacities. Mastering the different technologies requires varying degrees of scientific knowledge and skill, but a basic requirement is an ability to undertake energy planning and assessment. Here the major stumbling-block is the inadequate data base on such factors as wind velocity and variation, water flow and seasonality, and insolation and cloud cover, to which these energy sources are highly sensitive. Regarding the operational technology, most newly industrialising countries can produce small hydro units, biogas digesters, bio-fuels (ethanol) and windmills; they can also assess, acquire, instal and operate the more sophisticated technologies for PV systems, large hydro-plant, aerogenerators and geothermal equipment. But many other developing countries lack the knowledge, skills and other resources to instal and operate even some of the less sophisticated renewable energy technologies. These countries need more help from the international community to strengthen their national capabilities to select and adapt existing technologies. In particular help is needed with R & D programmes undertaken either on a national or, where possible, regional or wider collaborative basis, as well as in the diffusion of the resultant products and processes.

6.45 Cost and other factors continue to inhibit both the development and the use of renewable energy technologies, including in certain regions even the more mature ones. For example, a major factor in determining the viability of biomass conversion projects is the net energy ratio,[19] which for some feedstocks has been found to be less than or approaching 1:1. The cost of producing biomass feedstocks is equally crucial. Such feedstocks have many competing uses; for example, instead of being used to produce energy, sugar and starch crops can be eaten, wood can be used for construction or paper-making, and dung for fertilizer or brick-making. The energy, food and raw material potential of biomass has therefore to be considered in an integrated way, in line with the particular needs and resources of individual countries.[20]

6.46 Reliable information on the comparative costs of different renewable energy technologies is difficult to obtain, and generalisations have to be made with caution, since location-specific factors affect development and operating costs considerably. However, a broad estimate of the costs of energy from different sources, made by the World Bank in 1980, indicated that a number of sources of renewable energy were then at or near the cost of imported crude oil.[21] If their production technologies were given adequate financial and other support, they could be used more extensively, contributing to the development of the countries concerned and saving some of their scarce foreign exchange. Provided the technologies for producing, transporting and utilising renewable energy are readily available at competitive costs, the potential for these energy sources seems to be bright.

6.47 How appropriate they are to the development efforts of the countries concerned, depends on the nature and objectives of the countries themselves, at least as much as on the technical characteristics of the energy source. In countries with small and dispersed populations, mini-hydro schemes, small-scale biogas digesters, solar crop driers, solar waterheating/pumping systems, and more efficient wood-burning stoves usually contribute more to improving the quality of life than do large-scale hydro projects, which often are economical only if the surplus electricity can be exported. In small island economies, wind, and sometimes geothermal resources, offers scope for supplementing energy produced from biomass and solar technologies, while eventually ocean thermal energy conversion technologies might conceivably become applicable. Large developing countries can often benefit from a greater mix of renewable energy sources, including large-scale hydro and, in a few cases, the generation of electricity from biomass.

6.48 The great variations in developing countries' natural characteristics (topography, climate etc.), technical capabilities and financial resources, mean that considerable thought has to be given to deciding the most appropriate mix of policies to optimise the use of energy supplies. This will often require assistance from the more technically advanced countries. Opportunities for technicians, technologists and policy-makers to see, at firsthand, how other countries seek to overcome their energy problems would doubtless be instructive and should be encouraged.

NOTES*

1. UN, Preparatory Committee for the Conference on New and Renewable Sources of Energy, Third Session, *Synthesis of Technical Panel Reports,* New York: March 1981 (A/CONF. 100/PC/42).
2. UN, Report of Secretary-General, *Activites and Financial Flows in the Implementation of the Nairobi Programme of Action,* Committee on Development and Utilisation of New and Renewable Sources of Energy, Second Session, New York: April 1984 (A/AC. 218/5, Table 5).
3. UNIDO (1982) ID/WG. 384/6/Rev.1.
4. Heden (1981).
5. In India, 132 million tons of wood, 41 million tons of agricultural waste and 70 million tons of dung were reportedly used as fuel in 1978. With new stove designs, it has been estimated that no more than 85 million tons might be needed to meet current requirements. (K. Prasad, *Wood-burning Stoves: their technology, economics and develoment,* ILO Working Paper, 1983.)
6. UNIDO (1982) ID/WG. 384/6 Rev.1.
7. In one province of China alone there are reportedly over seven million gas digesters in operation. In India it was planned to bring in 150,000 digesters in fiscal 1984–85, with a 50 per cent subsidy of costs up to Rs. 3,000.
8. *OPEC Bulletin*, June 1984.
9. Narang (1981), para. 63.
10. Heden (1981), p. 21.
11. Narang (1981), para. 64.
12. World Energy Conference, *Annual Report,* 1980.
13. *The Economist,* 16–22 February 1984.
14. *Vita News,* July 1982.

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* In those cases where only abbreviated references are given here to the works cited, complete references will be found in Appendix 10, Selected Bibliography.

15. *Energy for Development: an International Challenge,* North-South Roundtable of the Society for International Development, New York: Praeger, 1981, p. 48.
16. M. Fritz, *Future Energy Consumption of the Third World,* London: Pergamon Press, 1981, p. 88.
17. This section is based on UN (1981) A/CONF. 100/PC/42.
18. Between 1960 and 1980 the average annual rates of growth of commercial energy consumption and of GDP were 6.5 per cent and 5.5 per cent, respectively, in developing countries. By contrast, they were 3.3 per cent and 4.2 per cent, respectively, in developed market economy countries.
19. The net energy ratio is the energy output of useful products divided by the energy costs of agricultural processing and of inputs (such as fertilizers or pesticides).
20. UNIDO (1982) ID/WG. 384/6/Rev.1.
21. World Bank, *Energy in the Developing Countries,* August 1980, Table III.1.