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Renewable Energy Resources in the Developing Countries

World Bank

RENEWABLE ENERGY RESOURCES IN THE DEVELOPING COUNTRIES

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World Bank
1818 H Street, N.W.
Washington, D.C. 20433, U.S.A.

RENEWABLE ENERGY RESOURCES IN THE DEVELOPING COUNTRIES

GLOSSARY

The collective terms used to describe various energy groups are poorly defined, and several meanings for similar terms can be found in the literature on the subject. Collective terms used in this report are defined as follows:

Conventional Energy. Energy sources which have hitherto provided the bulk of the requirements for modern industrial society, i.e., coal (including lignite and peat); petroleum (including fuel oil, gasoline, kerosene, diesel fuel, natural gas and liquefied petroleum gas); and electricity generated by burning one or other of these fuels, or from hydro or nuclear power. Wood is not included in this category although it was extensively used in the past, and still is to some extent, for industrial purposes.

Commercial Energy. Any energy form sold in the course of commerce or provided by a public utility. The term is virtually synonymous with conventional energy. Wood and other traditional fuels (see below) are not included although they are widely traded.

Renewable Energy. An energy form, the supply of which is partly or wholly regenerated in the course of the annual solar cycle. Thus solar and wind energy, hydropower, and fuels of vegetable origin are regarded as renewable; mineral fuels and nuclear power are not.

Biomass Fuels. Combustible and/or fermentable material of vegetable origin, for example wood, charcoal, corn cobs, cotton stalks, rice husks, animal dung cakes.

Solar Energy. Technologies that use solar radiation to provide heat, which can be converted to mechanical or electrical power, or to directly generate electricity (i.e. photovoltaic cells).

Terms used in the report to describe particular forms of energy or procedures are defined as follows:

Solar Collectors. Devices which use solar radiation to heat air, water, or other fluids. Flat plate collectors are sufficient for low temperature applications; collectors which focus or concentrate the sun's rays and/or which track the sun across the sky are used to obtain higher temperatures.

Photovoltaic Cells. Solid state devices which usually employ silicon cells to convert solar energy directly into electricity.

Anaerobic Processes. Biological/chemical processes taking place in the absence of oxygen.

Biogas. A fuel gas of "medium" value, generally containing 55 percent to 65 percent methane, generated from the anaerobic decomposition of organic materials.

Producer Gas. A fuel gas of "low" value, obtained from the partial combustion of wood or certain other carbonaceous materials (e.g., straw, nut shells, rice hulls).

Gasohol. A blend of gasoline and alcohol containing up to 20% of alcohol.

Small Hydro. While there is no generally accepted definition of "small," the concept as used in the report refers to hydroelectric units with capacities not exceeding several hundred kilowatts and usually in the 5-50 kW range. Units of this size are frequently referred to as "mini" or "micro" hydro. They are usually located at low-head sites and serve individual consumers or villages.

ABBREVIATIONS

boe 1/	:	Barrel of oil equivalent
toe 1/	:	Ton of oil equivalent
kW	:	Kilowatt (1,000 watts)
mW	:	Megawatt (1,000 kW)
kWh	:	Kilowatt hour
Btu	:	British thermal unit
PV	:	Photovoltaic

1/ One ton of oil is equivalent to approximately 41 million Btu's or 10,500 teracalories. There are about 7.3 barrels of oil to a metric ton.

Chapter I: INTRODUCTION

1.01 Renewable energy resources occur in nature, in the form of energy flows of indefinite duration, as opposed to mineral deposits of finite amount. Thus solar and wind energy, hydroelectric power and fuels of vegetable origin are regarded as renewables while mineral fuels are not. Many of the technologies for exploiting renewable energy resources rely on scientific and engineering principles that have been understood for decades, if not centuries. But, in addition, recent advances in such fields as electronics and synthetic materials have opened up a variety of new approaches to the solution of old problems. The recent growth of interest in the exploration of renewable energy resources in developing countries has been prompted by two main factors: the increased international price of oil and gas, and the alarmingly rapid depletion of fuelwood supplies in these countries. By now most developing countries have renewable energy programs of some sort underway. Many of these are research and testing activities conducted on a small scale, *ad hoc* basis, often under university or foundation auspices. Several countries, such as Brazil, India, and the Philippines, have larger and more systematic programs. This paper examines the contributions that renewable resources can make to energy supplies in developing countries, and discusses the role of the World Bank in renewable energy development over the next five years. 1/

A. The Potential of Renewable Energy in the Modern Sector

1.02 Increasing oil prices have stimulated interest in alternative energy sources in developing countries as well as in the industrialized world. The impact of the higher prices on the balance of payments and economic growth of many developing countries has been severe, and the growing demand for energy associated with economic growth has emphasized the need to develop domestic energy alternatives. As in many developed countries, conservation and increased efficiency in energy use are regarded as helpful but not sufficient to meet growing needs.

1.03 Renewable energy can substitute for oil in a variety of modern sector uses in transport, industry, and the production of electric power. Quantifying the potential savings in oil, resulting from use of biomass, solar and other renewable energy resources is, however, difficult. The few studies which have attempted to do so suggest the possibility that renewable

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1/ This paper does not cover large-scale hydroelectric power, or geothermal power, since they involve "conventional" technology with a well established role in national electric power systems and in normal Bank operations. In order to concentrate on technologies of near- and medium- term interest to the largest number of countries, wave, ocean thermal and tidal power are not specifically referred to; neither are the prospects for increasing the supply of animal power, or for using human and animal power more efficiently.

energy may be able to substitute for some 5 to 15 percent of the oil consumed by the developing countries by the end of the century. Because of differences in coverage, methodology, and critical assumptions (for example, about world oil prices) these results can at best be regarded as indicative. However, they do point to the broad conclusion that renewable energy, while no panacea, can be expected to substitute for a small but significant share of oil consumption in the developing countries over the long run. An earlier and more substantial impact may be possible in regions and countries that are particularly well endowed with biomass.

B. Renewable Energy Needs in the Traditional Sector

1.04 Interest in renewable energy has also been stimulated by growing awareness of the existence of a "second energy crisis" brought on by the depletion of forests in many of the developing countries. In contrast to the rise in oil prices, a highly visible modern sector phenomenon, the crisis in traditional energy supplies is a quiet one, but it poses a clear danger in the lives of much of the population of the developing world. Traditional renewable energy resources such as firewood, charcoal, crop residues and animal dung account for virtually all of the fuel used in many rural areas, and may account for about 20 to 25 percent of the total energy consumption in the developing world. Africa is most dependent upon traditional renewable resources, Asia somewhat less, and Latin America is the least dependent upon these resources. About 75% of the population of the developing countries uses traditional fuels, largely within households and primarily for cooking. Most of these people have access to firewood, but roughly 1,000 million people use agricultural and animal wastes to fuel their cooking fires.

1.05 The rural energy crisis stems from the fact that the developing countries have been consuming their wood supplies far more rapidly than they are renewing them, with grave environmental, economic and human consequences. Fuelwood harvesting to meet the energy needs of rapidly growing populations, land clearing for agricultural purposes and increased lumbering, together, are consuming the developing countries' forests at a rate of some 1.3 percent or 10-15 million hectares a year. Deforestation, particularly on steep hill-sides, has contributed to soil erosion that has reduced upland water storage capacity and increased the siltation of reservoirs (shortening their lives), irrigation canals (raising maintenance costs) and river beds (increasing the danger of flooding). The search for fuelwood has also been an important factor in the destruction of covering vegetation in arid and semi-arid areas, thus contributing to desertification. As fuelwood supplies have dwindled, people have turned increasingly to burning dung and agricultural residues, depriving the soil of valuable nutrients and organic conditioning material. It is estimated that the current use of dung for fuel "costs" some 20 million tons of foregone food grain production annually.

1.06 The human cost of the rural energy crisis has also been high, both in terms of its immediate impact on the lives of the poor, and on the long-term prospects for alleviating poverty. The fuelwood shortages that have been felt severely in many parts of the developing world have put a heavy burden on the labor and cash flows of low income groups. Villagers, mainly women and children, who could previously collect fuelwood in the immediate vicinity of their homes, now find in many cases that they must search for it a half a day's walk, or more, away. For example, families in the upland areas of Nepal are spending the equivalent of 60-230 work-days per year on fuelwood collection while in some parts of Tanzania 250-300 work days are required to meet family needs. Nor is the impact limited to rural areas. A recent World Bank survey found poor families in Bujumbura, the capital of Burundi, to be spending upwards of 30 percent of their income for fuel (mainly charcoal).

1.07 The development of renewable energy will have its most important impact in helping developing countries meet this second energy crisis. This impact should be measured not only by the quantity of energy produced but also by the contribution made to welfare and development. Small hydroelectric units, wood burning power plants, wind pumps and other renewable sources of mechanical and electrical power, while perhaps not adding significantly to national energy supplies, can have a major impact on development and touch the lives of large numbers of the poorest people by providing power for agriculture and rural industries.

C. Advantages and Requirements for the Development of Renewable Energy

1.08 The developing countries are in some respects at an advantage in developing renewable resources of energy, since they are located in the latitudes that naturally receive the greatest amount of solar radiation. For example, India receives an average of 0.17 tons of oil equivalent (toe), or 1.2 barrels of oil equivalent (boe), per square meter per year, and the Sahelian countries 0.19 toe (1.4 boe), compared with average insolation levels of 0.15 toe (1.1 boe) in the United States and 0.09 toe (0.6 boe) in Western Europe. Where rainfall and soil conditions allow, the biomass produced by this abundance of solar energy gives many developing countries another major renewable energy resource. Unlike fossil fuel deposits, which yield energy in the relatively concentrated and portable forms suitable for large-scale industrial and urban use, solar radiation and biomass are most economically exploited on a small-scale, decentralized basis, and are, thus, well matched to the needs of dispersed rural populations. In addition, much of the equipment needed for many of the renewable energy technologies is suitable for domestic production in even the less industrially advanced of the developing countries.

1.09 The relatively high cost of energy from conventional sources in many rural areas of developing countries is likely to make the development of some types of renewable energy economically attractive there sooner than in the urban areas. In developing countries, electricity from large thermal or hydroelectric power stations supplying the national grid now generally costs 5-10 US cents per kWh. However, it is estimated that only about 35 percent of the total population of the developing countries, and about 15 percent of their rural population, is connected to the grid. Where the grid does not reach, the conventional alternative for meeting small-scale needs is usually gasoline- or diesel-generated power. Power from these sources costs, today, roughly 13 US cents per kWh from the units typically used to supply electricity to small towns, and 45 US cents per kWh from the smallest (1 kW) unit used by individual consumers. These estimates are based on an assumed crude oil price of US$30/barrel and "normal" refining and distribution costs; power generated from conventional sources may be much more costly in remote inland locations where high transport charges make fuel substantially more expensive.

1.10 While many developing countries have favorable conditions to develop and use renewable energy, the pace at which the full potential of this resource can be developed will be determined by the ability to of the countries to:

-- develop adequate data on sources and uses of renewable energy;

-- enhance their technical capabilities;

-- design systems that can deliver renewable technologies in socially and culturally acceptable forms to large numbers of energy users; and

-- strengthen institutions for energy planning and programming.

1.11 Most developing countries lack the data for a realistic assessment of the present and future role of renewable energy in their economies. Hard information on existing resources, uses, and costs of renewable energy is available from only a limited number of case studies, and there have been few efforts to take careful stock of the availability and distribution of national resources for the production of energy from biomass, solar radiation, the wind or small hydro sites. In most countries, systematic efforts to fill the most serious data gaps are a prerequisite for moving beyond pilot projects and isolated investments to the stage of rational selection of development priorities and sound program planning.

1.12 As regards technical capabilities, the technologies involved in exploiting renewable energy require varying degrees of scientific and engineering sophistication. A few cases (for example, photovoltaic cells to produce

electricity) involve new developments falling in the realm of high technology; others (for example, solar collectors), while also relatively new, demand more in the way of careful engineering than scientific innovations. Developing countries should attempt to build up the capacity to keep abreast of relevant technical developments, to adapt technologies to local conditions, and to apply them successfully. While local capability clearly extends far beyond these areas in some countries, notably Brazil, India, and the Republic of Korea, many countries currently do not have enough trained manpower or material resources to deal with even the less sophisticated renewable energy technologies.

1.13 The third major area of concern is the weakness of existing extension services and other delivery systems capable of reaching the rural and urban poor with knowledge about renewable energy and providing them with the technical and other assistance necessary for its application. Popular acceptance is a particularly important and sensitive area. Because households account for the bulk of energy consumption in poor communities, the impact of the renewable technologies will to a large extent depend on the developing countries' ability to make them available in forms compatible with the needs and life styles of their people.

1.14 Weaknesses in planning and programming present a formidable obstacle to the realization of the renewable energy potential of the developing countries. While, again, the situation varies widely among developing countries, most of them (like most developed ones) lack coherent national energy plans that can provide a framework for defining the role of renewable energy in the economy, for determining priorities among the various technologies and for assigning resources accordingly. In the first stages of a renewable energy development program, a general sense of priorities may suffice to shape surveys, technical research and development, and work on extension techniques. Lack of energy planning capacity may not be a major obstacle so long as investment is mainly concentrated on demonstration and pilot projects, but is likely to become more important at a later stage, when renewable energy programs begin to require important budgetary or policy commitments. Many countries lack suitable institutions that can serve as focal points for planning strategies on renewable energy, devising and supporting research and development programs, and promoting commercial applications.

D. The Role of the World Bank 1/

1.15 The World Bank's involvement in renewable energy has largely been limited to lending for hydroelectric power and for fuelwood and forestry projects. Chapter III of this paper discusses an approach to renewable

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1/ For details about the World Bank's lending program for renewable energy for the period fiscal 1981-85, see Energy in the Developing Countries, (Washington: World Bank, August 1980).

energy development over the next five years. It suggests concentrating on projects based on fuelwood and alcohol production, which address the most urgent needs of developing countries and for which the Bank is presently best equipped on the basis of experience and expertise. Incorporating other technologies in suitable projects is a way for the Bank to gain experience with them and promote their development. Through sector work, institution building, coordination with other international agencies, and support for research the World Bank can both assist developing countries directly and lay the foundations for expanded lending in the future.

Lending Program, FY1981-85 1/

1.16 A country-by-country review of the supply/demand outlook concluded that a five-fold increase over current levels of fuelwood planting is needed in the developing countries to satisfy their needs for household cooking and heating through the year 2000. To respond to this need, a lending program that would support the planting of trees on one million hectares over five years in some fifty countries is considered a desirable objective. Such a program would involve more than double the amount of lending now planned for FY81-85.

1.17 Alcohol production is a second major area in which Bank lending could contribute to the development of biomass-based renewable energy. The recent Bank study of this subject 2/ will be followed up by investigations of the potential for alcohol production in individual countries, along the lines of the review of the Brazilian alcohol program carried out in FY80. Five countries, in addition to Brazil, with potential for producing biomass raw materials for alcohol at low cost, and over 20 countries with a potential for producing alcohol based on surplus molasses have been tentatively identified.

1.18 The Bank's approach to other types of renewable energy production will emphasize (a) gaining operational experience with the most promising technologies and applications and (b) building local capacity to plan, design and implement energy programs in the future. There are presently plans for incorporating "other" renewable technologies in only a small number of Bank projects, but a broad range of opportunities for doing so exists, considering the types of projects in the lending program and the countries' renewable energy needs and resources. Power projects, particularly rural electrification, can in some cases include wood-fueled and small hydro plants. Agriculture, industry, education, health and other projects can draw their energy requirements from a variety of renewable sources. Rural and urban development projects can include stove improvement, biogas, solar water heating and wind pumping components. Small industry projects can promote the local manufacture of renewable energy equipment. Since the technologies in question are all quite new, a "demonstration" approach may sometimes be in order.

1/ The World Bank's fiscal year (FY) runs from July 1 to June 30.

2/ Alcohol Production from Biomass in the Developing Countries, (Washington: World Bank, September 1980).

Sector Studies

1.19 More energy sector studies and more emphasis on renewables by energy sector missions are essential to an effective and expanding Bank role in lending, technical assistance and other areas of renewable energy development. The appropriate focus of renewable energy sector work will vary considerably from country to country. Where little or no organized national attention has been given to renewables, the initial focus will be largely on assessing the needs and potential for renewable energy development, and on advising governments on the improvement of their renewable energy information base and analytical capabilities. Where governments have taken an active interest in renewable energy and made progress in developing appropriate activities, sector work can be investment-oriented.

Institution Building

1.20 The development and use of renewable energy sources on a large scale in developing countries will depend heavily on the quality of the institutions responsible for planning and implementing projects and programs. Technical assistance will need heavy emphasis in the Bank's approach to renewable energy; it is most needed for planning and policy formulation, preinvestment studies, delivery systems and support for the building of research and technological capabilities.

Research

1.21 Developing countries, by no means unique, are short of the expertise needed to evaluate and exploit renewable energy resources; they need assistance to select from, and adapt to their own needs technologies that are being developed in the industrialized countries. They also need assistance in research on technologies that have greatest potential in the developing countries. The Bank will try to assist its developing member countries in filling these needs both by directly supporting national research programs through technical assistance components/projects and by helping to organize an international program of support for research and development in renewable energy.

Aid Coordination

1.22 Many of the major bilateral aid agencies have made renewable energy a priority area and have undertaken studies to assist them in defining priorities and developing expanded assistance programs. The Organisation of Economic Cooperation and Development (OECD) reported in 1969,.that its members already had more than 300 projects underway in 60 countries. The United States Agency for International Development (USAID), in particular, has a strong legislative mandate to assist in developing renewable energy. Ways in which the Bank can further coordination include sector and energy planning missions that can provide donors with a common framework to select projects for support, consultative group discussions of support for national programs and, if appropriate, assistance in the formulation of joint approaches by aid donors and recipients to specific problems.

Chapter II: RENEWABLE ENERGY TECHNOLOGIES AND NEEDS OF THE DEVELOPING COUNTRIES

2.01 This chapter briefly surveys the renewable energy technologies that seem to hold the greatest potential for meeting developing countries' energy needs in the near and medium term. The technologies are grouped according to the type of demand they seem best able to serve. The first section covers technologies whose principal potential use is to provide (or conserve) cooking fuel for the urban and rural poor, thereby helping to stem the shift that has been underway in much of the developing world to environmentally unsound practices and/or greater use of commercial fuels to meet household needs for energy. The technologies in the second group can meet the need for small, decentralized power sources for agriculture and rural industry. The third and last section covers technologies primarily of interest as potential substitutes for oil in the modern sector. The categories are not fully exclusive but the classification is used to facilitate comparisons among alternatives for meeting a specific need.

A. Technologies for Cooking in Low-Income Households

2.02 The technologies discussed in this section are those with potential in meeting the need for cooking fuel: fuelwood production, improved stoves, charcoal, and biogas. Village fuelwood projects provide the most direct response to cooking fuel shortages; they also provide building materials, help control erosion, and offer other benefits as well. Two of the other technologies discussed are conservation measures: stoves that burn less fuel to cook a given meal and charcoal production techniques that use less wood to produce a bag of charcoal. Biogas is a fuel produced from dung, usable for lamps and stationary engines as well as for cooking. Its potential is probably the greatest in areas where dung is already collected for use as a cooking fuel. Biogas is not only a more convenient fuel to use, but it allows the dung to be "used twice," since the residues remain rich in nitrogen and can be used as fertilizer.

2.03 Most of these technologies have potential applications outside the household. Fuelwood can be used in power plants. Charcoal also has industrial uses, notably as an alternative to coke in steel production, and the gaseous and liquid byproducts of charcoal may be collected and used as an industrial fuel. Biogas can be produced on a large scale where there is a sufficient concentration of raw material (e.g., commercial livestock operations) and used for industrial or other purposes rather than as a household fuel.

Fuelwood Production

2.04 The majority of the developing world's poor depend for cooking fuel on wood, a "renewable" resource that is, in fact, being depleted rapidly. High priority clearly must be given to increasing the supply of fuelwood. Recognizing this, the Bank launched in 1978 launched an expanded social forestry

program under which loans and credits for forestry totaling over US$200 million and a number of forestry components in agriculture and rural development projects have already been approved. These projects will help finance the planting of about 400,000 hectares of fuelwood. After a maturation period of 5-10 years, this area can be expected to yield roughly 6 million cubic meters of wood with an energy value of about 1.5 million toe per year (30,000 boe per day).

2.05 Fuelwood production is being financed as part of national forestry programs and also through agriculture and rural development projects that include a wide variety of components. Some fuelwood projects include the establishment and management of plantations by a national forest service. Others emphasize the establishment of woodlots by villagers and/or individual farmers. Nurseries to provide seedlings and extension agents to provide technical assistance are typical of these projects.

2.06 Fuelwood projects are innovations for many of the borrowers as well as for the Bank. Some of the initial projects are not designed to meet total estimated fuelwood requirements but to build the institutions, train the manpower, and test the technical packages and extension techniques that can form the basis for larger projects later on. Many projects include components to provide the information needed to design larger-scale projects such as the demand and supply of fuelwood, land availability, the merits of alternative tree species, the consequences and costs of deforestation, and the potential for conserving wood through more efficient use.

2.07 Fuelwood projects require effective local participation in planning and management. Strong local support for fuelwood production is generally needed to get the land and labor required to establish a woodlot and to assure it is maintained and protected from grazing and fire while it is growing to maturity. Fuelwood is apt to be scarcest where the pressure of population on land resources is high and land that can be used for raising food cannot be spared for wood production. However, fuelwood species do not require land of as high a quality as is required for crop production. Most projects use lands of marginal quality, or land bordering cultivated areas, such as, for example, roadsides and boundaries between fields. While a tree species appropriate for a given area can often be identified without extensive trials, the best species and subspecies and the best combination of planting, fertilizing, and disease protection techniques--the "technical package"--generally cannot be determined without local trials.

Stoves

2.08 At least as important as increasing the supply of firewood is improving the efficiency with which it is used. The poor in the developing countries actually use more fuel for cooking than people in industrialized countries, because they effectively use only a small fraction of the energy in the fuels that they burn. Most of the stoves for traditional fuels accomplish

little more than holding the cooking vessel at an appropriate height above an essentially open fire. Many improvements are possible in this system. Generally, they involve enclosing the fire, regulating the flow of air into the stove, and adding a chimney. These measures can increase efficiency by a factor of 4 to 5 in laboratory tests; a halving of fuel requirements in household use has been claimed for a variety of designs. In some designs, the stove is given a large thermal mass, so that much of the heat that is lost for cooking is released gradually afterwards and thus provides space heat at high altitudes and in other areas where this is needed.

2.09 Two general types of improved stoves have been developed. The first is sometimes referred to as a "mud" stove, but is actually made from a mixture of sand and clay with enough sand to prevent excessive cracking and enough clay to hold the stove together. The clay should harden after a few uses, producing a durable surface in the firebox and flues. The chimney may be made from metal stovepipe, bamboo, or lengths of ceramic pipe or it may be built up with bricks of stove material. These stoves cannot be transported, but must be built where they are to be used. The technique can be taught to artisans and the stoves are estimated to cost no more than US$10-20, including labor. They thus appear to be an extremely low-cost approach to increasing the effective supplies of fuel and are affordable by the majority of the poor without the need for subsidy or special credit programs.

2.10 The second type of improved stove is made with a shell, usually a metal can of five gallon capacity or larger. A liner of ceramic or other material may be used to keep the fire away from the shell, reducing heat losses and prolonging the shell's life. The cooking vessel and food may be placed on top of the shell for frying or inside it for stewing and higher efficiency. Some stoves of this type are designed to be packed with sawdust, rice hulls, or other loose fuels rather than wood.

2.11 Improved stoves have been developed in many countries but successful efforts to get them into widespread use are few. The best documented case is in Guatemala. The key elements in the program there appear to be (a) feedback from users that allowed the stove designers to incorporate features that may have little or nothing to do with fuel efficiency but greatly influence the stoves' acceptability--such as waist-level working surfaces, safety for children, or resemblance to stoves sold in stores--and (b) an extension system based on artisans with a direct interest in selling their services as stove builders.

Charcoal

2.12 Charcoal can be transported and handled much more economically than an equivalent amount of wood. In many countries, charcoal is the most widely used household fuel in urban areas whereas firewood is used by the rural population that is closer to the source of supply. While much of the energy in wood is lost in the conversion to charcoal, this is largely compensated for by the higher efficiency of charcoal stoves compared with wood fires. Charcoal is also used in some steel plants, for manufacturing lime and cement, for drying hops, tobacco, and fish, and for smelting metals.

2.13 Charcoal is produced by pyrolysis, the application of heat with insufficient oxygen to support combustion. When wood is heated to about 250°C (480°F), moisture and volatile materials in the wood evaporate, leaving carbon and inert materials in the form of charcoal. A substantial fraction of the raw material is usually burned to provide the heat required for the process. Modern kilns produce a ton of charcoal from about six cubic meters of wood, while traditional earthen kilns require as much as twice that amount. The conversion from wood to charcoal has an energy efficiency of about 40 percent with modern equipment or 20 percent with traditional kilns. Utilization of the gaseous and liquid products of pyrolysis as well as the charcoal can increase the overall energy efficiency to about 80 percent.

2.14 Charcoal is traditionally produced with such simple tools as an axe and a shovel in earthen kilns made by covering a pile of wood with a layer of dirt. With these kilns it is difficult to restrict combustion to only that fraction of the wood required to generate the heat needed to char the remainder; neither can the byproducts be captured. Moreover, the charcoal can be separated only imperfectly from the dirt and the process also produces fines that are not generally useable as fuel.

2.15 Charcoal making can be improved in several ways. Brazil has developed an earth kiln that significantly reduces the production of fines and from which volatile liquids can be recovered. Portable steel kilns or large masonry kilns can be used, or an externally heated retort can be substituted for the internally heated kiln.

Biogas

2.16 A mixture of gases containing 55-65 percent methane is obtained from the anaerobic decomposition of organic materials. This process occurs in nature (yielding swamp gas for example) and gas has been produced in controlled environments for many years in certain types of sewage treatment plants. When produced for use as a fuel, it is often referred to as biogas. There is currently considerable interest in many countries in the potential use of biogas plants by individual families or by villages to provide fuel, improve sanitation, and increase the fertilizer and soil-conditioning value of animal dung and other organic wastes.

2.17 A biogas digester consists basically of a sealed container filled with water and the material to be digested. Gas produced rises to the top of the container and is extracted through a tube or pipe. In most designs, an upper portion of the container is reserved for gas storage. Raw materials are generally added through an inlet at one end of the digester and the digested "sludge" withdrawn via an outlet at the opposite end. A wide variety of designs is under development. The process by which biogas is produced is complex and not fully understood but involves at least two types of bacteria. Production is sensitive to temperature, acidity or alkalinity, and to the type of feedstock used.

2.18 Biogas is usually produced under low pressures, so distribution is generally limited to a restricted area. Biogas also generally contains small amounts of hydrogen sulfide that may corrode metal parts with which it comes in contact. However, with suitable adjustments to the burners, most appliances made for natural gas or bottled gas can be adapted for use with biogas, and suitable clay burners have been developed. Biogas can also be used to run internal combustion engines.

2.19 China and India both have large-scale biogas programs. The Indian program involved technical assistance and subsidies on construction costs and reportedly resulted in the construction of some 37,000 plants. The program was criticized on the grounds that the benefits from the units initially promoted went to the relatively wealthy families who had the cattle, land, and credit needed to build and use them. These units cost Rs. 2,000-3,000 (US$240-360) several times the average annual income per capita in rural areas and reduced the availability of free dung, so that the program had a negative impact on the real income of the poorest groups. The program is now giving greater emphasis to community-sized plants.

2.20 Biogas was one of the technologies promoted in the Chinese "Great Leap Forward" program of 1958-60, but reportedly was not used on a widespread basis until the 1970s. Now, it is reported that over seven million biogas digesters have been built in China. Most of these are said to be family-sized units. The Chinese designs are simple and well adapted to do-it-yourself construction and reportedly require a cash outlay equivalent in Chinese prices to roughly one quarter or one third the average annual per capita rural income. A large part of the credit for the Chinese success with biogas is also due to an intensive extension effort.

2.21 Most of the other Asian developing countries have from ten to a few hundred biogas plants in operation. They appear to be very successful in the Republic of Korea (where they are not operated during the winter). There, as in China, the main feedstock is pig manure, which has technical advantages over cow dung.

2.22 Although there has been no dearth of studies on the economics of biogas, no consensus has emerged. Cost-benefit analyses of the comparatively well-documented Indian experience have yielded various conclusions, reflecting the widely different assumptions made about the economic cost of dung, the quantity and value of the labor required to operate the digester and the value of the gas and sludge as fuel and fertilizer. The only points that seem to clearly emerge from these studies, taken together, are that the economic assessment of the biogas digester requires more definitive work on the methodology and values, and that careful study of the specific socioeconomic context is essential to the proper evaluation of individual projects. There is also clearly a need to broaden the base of experience on which economic analysis has been based and, in particular, to assess the implications for biogas economics of the apparently less costly Chinese designs.

B. Rural Power Technologies

2.23 The technologies discussed in this section are solar driers, photovoltaic cells, windmills, and small hydroelectric units. Solar driers, depending on the circumstances, would replace either fuelwood or commercial fuels previously used to dry crops or certain other products such as fish, in order to reduce spoilage and improve the product. The other technologies in this group are all primarily of interest as potentially cheap sources of small amounts of mechanical or electrical power in remote or isolated areas that have a suitable resource base. In some cases, these technologies would be used for traditional tasks such as grinding grain and pumping water and thereby liberate human and animal power resources for other activities. In others, they would be used to provide modern services such as lighting, refrigeration, and telecommunications.

Solar Drying

2.24 The term "solar drying" includes techniques as simple as laying or hanging the material to be dried outdoors. Open air drying is appropriate for many uses, but has disadvantages that are important in some cases: it is difficult to control temperatures, the material to be dried cannot easily be protected from rain, wind, or animals, and large areas are often required. Controlled drying in an enclosed space avoids these problems and may be worth the cost for delicate, high-value products such as fruit, tobacco, or fish, where space is a limitation, or where there is too little sun.

2.25 The use of solar equipment for controlled drying has been demonstrated for meats, fruit, vegetables, grain, tobacco, and timber in a number of countries (e.g., Australia, Brazil, Colombia, India, Syria and the United States). In some cases, the solar drier has a transparent roof and functions as a greenhouse. In others, air is heated in a solar collector and moves by convection to the drying area.

Photovoltaics

2.26 Photovoltaic (PV) cells convert solar energy directly into electricity. They appear technically well suited for application in many developing countries because they hold promise of long life and of being relatively free of trouble in operation. The cost of photovoltaic electricity is falling, but is still at levels (on the order of US$2/kWh) that makes it commercially viable only where relatively small amounts of power are needed in remote locations, as in telecommunications repeater stations, navigational buoys and beacons, or remote monitoring equipment. The use of photovoltaics to meet larger-scale power needs is being demonstrated by aid agencies in a number of village electrification and irrigation projects.

2.27 Most PV cells manufactured today are made from extremely thin slices of high-purity silicon crystals, but cells made with other materials or with amorphous (non-crystalline) silicon may come into wider use in the future. Solar cells are generally rated in terms of "peak" power--the number of watts

that can be produced under nearly optimal terrestrial conditions. Cells in good sites produce four to six watt-hours per day per peak watt. In such sites it takes an array of about two square meters of photovoltaic cells to produce one kilowatt hour a day, so sizable arrays are needed to produce even modest amounts of power.

2.28 The price of PV equipment is falling. Prices for arrays of PV cells are quoted today in the US$10 per peak watt range, depending on quantity, quality and the source of supply. This is about ten percent of the 1970 price range, and it is generally assumed that the PV array costs will continue to drop in the next few years. As the price of arrays themselves drops, the costs of the other elements of PV power systems--items such as structural supports, electrical controls, wiring, and batteries--become increasingly important. In a recent PV demonstration project funded by USAID in Africa, the cost estimate for the auxiliary hardware and for installation of the system came to over US$10 per peak watt. Such "balance-of-system" costs can be expected to fall as PV cells themselves become cheap enough for system designers to concentrate on reducing these costs.

2.29 However, the scope for reductions in balance-of-system costs is more limited than that for reducing the cost of the arrays themselves, so that in the next five years total system costs are unlikely to fall below about US$10 per peak watt (e.g., US$3 for arrays and US$7 for balance-of-system costs). At this level, PV power would still cost 55 US cents/kWh (assuming 10 percent per year capital recovery) in a location providing five peak hour equivalents per day. This might make photovoltaic power competitive for low-lift, small farm irrigation and village water supply pumping requirements in some cases since small conventional generators produce electricity at an estimated cost of 45 US cents/kWh. 1/ However, it appears that PV power is unlikely, at least in the medium term, to be competitive with either conventionally-generated power or other renewable sources for village electrification and large-scale irrigation pumping. Diesel generators can today supply electricity to small towns at an estimated cost of 13 US cents/kWh while small hydroelectric plants may be able to do so at 18 US cents/kWh or less (see para. 2.38). As costs are reduced, an expanded role for photovoltaics can be foreseen in specialized low power applications (such as refrigerators in clinics and educational television in village schools) in remote areas.

Windmills

2.30 Windmills have been widely used in rural areas and interest in them is reviving. The best established applications historically have been water pumping and grain-grinding, but windmills have also powered sawmills, paper mills, and oil presses. It is estimated that in 1850 there were over six million windmills in the US alone. The old Dutch windmills reached the mechanical equivalent of 35 kW in unit size. Traditional windmills continue to be used in large numbers in parts of Crete and Thailand.

1/ The Bank is executing agent for a global project financed by the United Nations Development Programme; that project is testing and demonstrating photovoltaic and solar-thermal powered small irrigation pumps.

2.31 Windmills exist and are proposed in a wide variety of configurations, sizes, and materials. The wide diversity in designs appears to reflect both the need for different approaches to deal with different wind regimes, fabrication techniques, and applications and the fact that experience has not yet sorted out all the advantages and disadvantages of competing designs. Some approaches to windmill designs emphasize minimization of cash costs, and keeping materials, fabrication, and maintenance requirements within the capabilities of local artisans. The resulting "appropriate technology" designs appear to provide least-cost solutions in many cases, at least where low pumping heads permit low unit sizes and where modest windspeeds permit light weight designs.

2.32 The cost of harnessing wind energy has been estimated at 20 US cents/kWh assuming a 5.5 hour/day operation with winds of 5 meters/second (11 mph) using locally-manufactured or artisan-built windmills. If these cost estimates are correct, this type of windmill can compete with conventionally-powered pumps in the same areas if connections to a central electrical grid are not available and pumping heads are low. Winds are not generally as strong in the tropics as they are at higher latitudes, but there are areas where the trade winds or geographic features such as mountains and coast lines produce average windspeeds over 5 meters/second. Among the most interesting areas for wind-powered water pumps would appear to be parts of northern Argentina, Chile, Mexico, Peru, northeast Brazil, coastal areas of Africa northward from about Senegal in the west and Somalia in the east, India, Pakistan and People's Democratic Republic of Yemen. Windmill-powered pumping is generally more competitive for relatively shallow water sources that require relatively small pumping capacity.

2.33 Wind-driven electric generators are available commercially in unit sizes up to at least 15 kilowatts rated capacity. Some of these can produce power at costs of 25 to 50 US cents/kWh at low load factors and 5 to 15 US cents/kWh at high load factors in locations with average windspeeds in excess of 5 meters/second. The World Bank has financed one wind-power feasibility study as a component of a power project in Costa Rica. Similar studies may be taken up in other countries with small, isolated load centers in coastal or other areas with favorable wind regimes.

Small Hydro

2.34 Waterwheels have been used for thousands of years, primarily to grind grain and lift water. It is estimated that in the year 1800 there were about half a million waterwheels in Europe. Waterwheels are in fairly wide use today in mountainous areas in Afghanistan, Nepal and Turkey, constructed by skilled traditional artisans using well-known and reliable technologies. Waterwheels have recently attracted some commercial interest in industrial countries and are reportedly available in kit form for roughly US$200 per kilowatt. Where appropriate sites can be found, these cost levels and the simplicity and ruggedness of the technology would make waterwheels a power source to be considered for energy requirements that can be served by a stationary, low-speed power source of 5-10 revolutions per minute.

2.35 Turbines are generally preferred to waterwheels for electricity production because turbines spin at the much higher rates required by electric generators. "Small hydro" refers to those hydro power units with capacities of no more than several hundred kilowatts, most often 5-50 kW, used to provide electricity to a few users or to individual villages. Turbine systems with capacities of less than 50 kW have been installed in over two dozen developing countries, and there are reportedly over 80,000 small-scale hydro power systems operating in China.

2.36 Small hydro power projects require substantial hydraulic resources. To provide a household with 1.5 kWh/day from a site that provides five meters of vertical drop or "head" requires a flow of water sufficient to cover 6.6 hectares to a depth of one meter over the course of a year. The larger the drop the smaller the volume required.

2.37 Unit costs of small hydro power projects can be expected to vary widely, depending on the characteristics of the site, the water available, and the distance to, magnitude, and time pattern of the electricity demand. The lowest cost sites are those that can provide large volumes of water and high heads without much investment in civil works. Transmission losses over even a few hundred meters can be substantial if investment costs are kept down by using low voltages and light wiring, so proximity to demand is an important consideration in evaluating small hydro power projects. Electric systems designed to meet demands that are concentrated in a few hours each evening will generally have higher costs per kWh than systems whose loads are more evenly spread.

2.38 The Intermediate Technology Development Group (UK) has compiled cost estimates for a "model" 40-kW project based on six existing and planned projects in Nepal. The estimated total capital cost is US$1600/kW. While this can be a least-cost solution for village electrification, the cost to consumers per kWh would be very high (18 US cents/kWh) if the electricity is used principally for domestic lighting and the plant is operated at a load factor of only 20 percent. Daytime demand that could appreciably raise the load factor and consequently reduce unit costs might be for commercial, small industry, or agricultural uses. At 55 percent load factor the cost would be about 7 US cents/kWh.

C. Technologies for the Modern Sector

2.39 The renewable energy technologies with greatest potential applications in the modern sector include alcohol production from biomass, combustion and pyrolitic gasification of biomass, and solar water heating. These technologies would fit into the energy economy in different ways. Alcohol would replace or partially replace gasoline in motor vehicle use and a variety of petrochemical feedstocks in chemical industries. Producing alcohol may be an economically attractive option for countries where the agricultural raw materials can be made available at low cost. In industry, "producer gas" generated by pyrolysis of processing plant residues such as sawdust, rice husks, or nut shells can serve as a fuel to provide energy for process heat,

motive power, and electricity generation. Producer gas can be used in internal combustion engines and appears to be a less expensive alternative to steam plants in some circumstances, especially in small unit sizes. In rural areas with ample wood supplies, small power plants burning wood either directly or in gasified form might produce electricity more cheaply than diesel plants. Residential, institutional, and some industrial water heating needs can be met with solar collectors that would in some cases substitute for electricity (and, indirectly, power plant fuels), and in other cases for bottled gas or other commercial fuels.

Alcohol

2.40 Alcohol is the only well established alternative vehicle fuel based on a widely available renewable resource. For this reason, it has attracted a great deal of interest, most notably in Brazil where, as a result of a massive government program, the majority of automobiles use a "gasohol" blend of up to 20 percent alcohol. Vehicles that operate on 100 percent alcohol are now being introduced to the general public.

2.41 Two types of alcohol are of interest as vehicle fuels. Ethanol (ethyl alcohol or "grain alcohol") is currently produced on a commercial scale from saccharine materials such as sugarcane, sugar beets and molasses, and from some tuber and grain starches; it has also been produced commercially from other starches, notably maize. Efforts are also underway to produce ethanol from cellulosic materials including wood, agricultural residues and solid wastes. Methanol ("methyl alcohol" or "wood alcohol") can be produced by distillation of wood or synthesized from carbon monoxide and hydrogen, which in turn may be obtained from natural gas or coal. Methanol produced from renewable sources is not considered to have much potential as a vehicle fuel in the immediate future, because it is generally more expensive than methanol produced from natural gas and coal, and because methanol-gasoline blends present considerably greater technical and environmental problems than ethanol blends.

2.42 While ethanol has approximately only 60 percent of the energy content of gasoline by unit weight, it is 5 percent denser and appreciably improves the octane rating when blended with gasoline. Studies comparing fuel economies obtained with alcohol blends and regular gasoline have obtained a range of results. For ethanol used in blends, they seem to indicate that its greater density, octane-boosting effect, and other physical/chemical properties, compensate for its lower energy content. At most, only very minor engine modifications are required. Ethanol blends are not dangerous to handle and store but can separate when water is present. When ethanol is used by itself, alterations in the design of gasoline engines (particularly in carburation) are required.

2.43 Though it appears technically feasible to replace substantial volumes of petroleum with ethanol, the economics of doing so vary considerably according to circumstances. The recent Bank study concluded that alcohol production may be economically justified at present in two kinds of cases: where large amounts of sugarcane or other biomass can be produced at low economic cost, and where

surplus molasses is available from existing sugar production in mills in remote areas where, owing to high transport costs, sugar has a low value. Assuming the economic cost of gasoline, from a local refinery, to be about US$1/gallon (US$42 per barrel or US$365 per metric ton) rising by 2.5 percent a year in real terms, and a 10 percent rate of return per year on capital, ethanol can be produced economically in "medium capital cost" countries where the value of sugarcane is below US$14 per ton. Sugarcane production costs in many relatively efficient sugar producing countries are considered to be below this level; the opportunity value based on the Bank's average sugar price projection through 1985 of 16 US cents per pound is about US$17 per ton (in constant late 1979 dollars).

2.44 Intensive research and development is being done on several approaches to reduce costs, but it is still too early to assess the prospects for significant innovations. Success in producing ethanol from feedstocks such as cassava that can be grown efficiently on marginal land by smallholders would be particularly welcome, since this would help to lessen the potential conflict in the use of land between food and fuel, broaden the scope for ethanol production in the developing world and enhance the employment benefits of producing energy domestically.

Combustion and Pyrolytic Gasification of Biomass

2.45 Direct combustion and pyrolytic gasification are related technologies that can be used to convert biomass into energy forms such as heat, mechanical power, and electricity. For the near future, the most promising among them are those that use solid biomass such as wood, bagasse, rice hulls, and nut shells in industrial and small central power station applications. Most of these materials are byproducts of agro- and forest industries. Some have alternative uses that make them too valuable to use as fuel, but others have a very low value or present a disposal problem. Where processing plant residues are used as fuel, they are most often employed to provide the energy required to operate the processing plant itself. Three types of processing plants for which the use of residues as fuel is widespread are rice mills, sugar mills, and sawmills. 1/

2.46 Green plant material such as fresh leaves may be 95 percent water by weight. This water increases the weight that must be handled and transported and absorbs heat as it evaporates when the fuel is burned. Mechanical drying (e.g., by compression), sun-drying and air-drying are useful techniques in some cases. In others, it is possible to use low-temperature exhaust heat that would otherwise be wasted to dry the material.

2.47 Wood-fired power plants independent of sawmills or other sources of wood waste appear to be viable competitors to diesel plants in areas where

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1/ At least a dozen countries have rice mills that use the husk as fuel. In India, about 45 percent of the rice crop is processed in such plants. Cane sugar mills that do not utilize bagasse as fuel are exceptional. A high proportion of developing country sawmills use residues as fuel.

adequate wood fuel supplies can be assured for the life of a plant at delivered costs of up to US$15 per ton (US$75 per toe or US$10 per boe). 1/ This cost appears realistic for at least some sparsely settled, humid tropical areas where land is not suitable for agriculture. A broad comparison yields the following unit costs:

	Costs in US cents per kWh of Capacity		
	Capital	Fuel	Total
Diesel	3.0	7.2	10.2
Wood	6.0	3.0	9.0

In this simple comparison, while the wood-fired plant costs 3 US cents/kWh more to build, it saves 4.2 US cents/kWh in fuel costs and thus its operation is 1.2 US cents/kWh cheaper than the diesel alternative. This calculation does not include nonfuel operating or maintenance costs and the investment and operating cost estimates can vary widely depending on circumstances.

2.48 Wood-fired power plants would generally be most competitive in relatively small sizes. As plant size increases, conventional alternatives become cheaper, the transport costs associated with the wood-fired plants rise disproportionately and the amount of land necessary to supply the plant becomes very large. For instance, with an average yield of 7 tons of wood per hectare annually, almost 1,500 hectares would be required to produce one mW of power per year.

2.49 The relatively high unit cost and low efficiency of small, solid-fuel boilers encourage the use of pyrolytic gasification to meet power requirements of below 5-10 mW where process steam is not needed. Pyrolytic gasification involves the partial combustion of wood or certain other carbonaceous materials. 2/ Carbon monoxide and hydrogen are formed and drawn

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1/ The estimate is based on the following assumptions: plant costs: US$750/kW diesel, US$1,500/kW wood; 3,000 hr/yr load factor; 12 percent a year interest and amortization; 2,500 kcal/kWh diesel and 3,500 kcal/kWh wood heat rates; 10.4 million kcal per ton diesel; 1.75 million kcal per ton wood (50 percent moisture); US$300/ton or US$40/barrel diesel fuel; US$15/ton or US$20/cubic meter wood delivered to the plant. A Bank project in the Philippines financed a 4,000 hectare tree farm to produce wood to be delivered to a particle board plant at a cost of US$15/ton.

2/ Straw, nut shells, peat, bark, cotton gin trash, rice hulls and even dried seaweed have all been used successfully. The principal constraints appear to be moisture and ash content.

off in a combustible, gaseous mixture known as "producer gas." Producer gas typically contains about 25 percent carbon monoxide and 15 percent hydrogen, giving it a fuel value about one-sixth that of natural gas.

2.50 Producer gas can be burned under boilers designed for oil and gas. When filtered, it is also a serviceable fuel for internal combustion engines, and it is in fact produced for this purpose on a commercial basis. It can be used to fuel vehicles by using a portable generator; tens of thousands of vehicles in Europe and the Far East used producer gas during World War II.

2.51 The Bank has made at least two loans for projects involving the generation and use of producer gas, but neither project is yet operational. A rice mill in Cameroon will obtain its electricity from engines running on gas produced from rice husks, and a lumber mill and an associated township in Guyana are to get their electric power from a similar system operating with saw mill wastes. Equipment costs are estimated at US$1,500/kW fob Europe for the Cameroon project. This is about twice the capital cost of a conventionally fueled diesel plant but, since producer gas was judged to be the cheapest fuel, its use was calculated to be the least-cost alternative over the life of the project.

Solar Water Heaters

2.52 Water heating by means of the flat-plate collector is the solar technology that is most ready--technically, economically and commercially--for widespread application. Water heating is not a major item in any country's energy budget, but it does account for significant amounts of energy in middle-income countries. In the Latin American and Caribbean region as a whole, it has been estimated that about 2.3 percent of commercial energy is used for domestic water heating. Solar water heaters have been widely used for some time in Australia, Israel and Japan, where 2.5 million units are in service. Such heaters are now being used on a growing scale in the US, where an estimated 30,000 units were installed in 1978. In developing countries, actual use still seems limited and scattered, from the available data, but interest in solar heaters is now growing rapidly.

2.53 Domestic solar water heaters are being installed in the US at costs of about US$500 per square meter of collector, including back-up heaters for sunless days, protection against freezing, internal tubing needed if the unit is to be set at an angle, and other refinements not always needed closer to the equator. Solar hot water systems can be made much more simply and cheaply than the US models. Water can be both heated and stored in wide, long, clear plastic tubes under a glass cover in units yielding between 80-200 liters of warm water per day and costing about US$100-150. Even though such modestly built collectors are likely to be relatively shortlived, annual capital charges should not exceed US$25 per year. Then, if 150 liters of hot water are produced daily with a 40°C temperature gain, the cost of doing so would be about US$125 per ton of oil equivalent (US$17/boe)--considerably less than with conventional systems.

2.54 Solar water heaters can be made in developing countries. The capital costs of manufacturing facilities are relatively low and the manufacturing processes themselves quite straightforward. Local manufacture has already begun in a considerable number of countries despite the fact that the market largely consists of commercial enterprises such as hotels, certain public facilities such as hospitals, and relatively affluent households.

2.55 Solar collectors may also offer an economic means of meeting the need for low and medium temperature process heat in industry. Flat-plate collectors of sophisticated design using specialized materials can produce temperatures in the 90°C range that are sufficient for a variety of industrial processes. Focusing or concentrating collectors are used to obtain temperatures above about 100°C. The need for a "tracking" system, to keep the collectors aimed at the sun, makes for economies of scale in concentrating collector systems, so they are usually considered as most appropriate for industrial and commercial applications. "Trough" systems, which focus along a line rather than a point, need to be moved only along one axis over the course of a day and appear to be the most practical types for providing process heat in the 180°C range. Solar industrial process heat systems of both the flat-plate and concentrating types are being developed, tested and demonstrated in the US and other countries, but are not yet considered economic. A 1978 study suggests that "early commercial" systems, to become available in about 1984, may be capable of producing process heat of over 100°C at a cost of about US$540 per toe (US$75 per boe).

Chapter III. THE ROLE OF THE WORLD BANK

3.01 The World Bank's role in assisting developing countries in the renewable energy field must be considered in the light of:

- the potential of renewable energy for meeting the energy requirements of the developing countries in the traditional and modern sectors;

- the "readiness" of the various renewable energy technologies for practical application in developing countries; and

- the need to strengthen the ability of the developing countries to plan and manage renewable energy programs.

A. General Approach

3.02 Taking into account resource potential, available technology and economic feasibility, it seems clear that efforts to develop renewable energy in the developing countries must concentrate on biomass. Although the fuelwood crisis has already reached serious proportions in many areas, technically and economically sound means are available for stemming the deforestation. A technical basis also exists for the introduction of fuel-efficient stoves and improved techniques for the production of charcoal, both of which can play an important role in alleviating the household energy problems of the rural and urban poor. Biomass also merits early attention as a source of substitutes for oil in the modern sector. The technology exists for producing alcohol that is economically competitive as a vehicle fuel in those developing countries where circumstances are favorable. Proven biomass technologies for the direct burning of wood fuels and the gasification of wood and crop residues can also help provide fuel for power and industry.

3.03 Technologies for exploiting renewable sources other than biomass appear to have considerable potential in the long run. The most "commercial" product of solar technology today is the flat plate collector. It can frequently be the most economical source of low-temperature hot water for residential, institutional and some industrial purposes, but the scope for application, particularly in poorer countries, is relatively narrow. Photovoltaic cells, while presently an economic source of electricity only for low power applications in remote areas, are undergoing rapid technical development, and prospects for reducing costs appear good. A firm technical basis exists for the development of small hydro and wind power projects, and they are economically attractive given suitable sites, but experience with them is limited. More work needs to be done on exploring suitable sites in order to obtain a better appreciation of the role they can play.

3.04 The principal factors limiting the developing countries' ability to develop their renewable resources of energy were discussed in Chapter I. Several of these factors tend to limit development across the board; others are of greater or lesser importance with respect to particular technologies. For example, both fuelwood and alcohol programs require careful planning and close integration with agricultural development efforts. Fuelwood programs demand experts familiar with local conditions, adequate extension facilities and local participation if they are to be successful. In alcohol projects, for which the technology can be readily imported, investment and operation will usually be the responsibility of established agroindustrial enterprises. Shortages of research and technical staff are likely to be particularly important in the case of technologies that are either new (e.g., photovoltaics) or require extensive local testing and adaptation (e.g., biogas production). The lack of resource data is particularly acute for site-specific technologies (e.g., small hydro and wind power), while the absence of such aids to dissemination as suitable credit facilities can be an important obstacle to the application of technologies that are ready to be commercialized (e.g., solar collectors).

B. Lending Program

3.05 The emphasis on biomass, particularly fuelwood, also takes into account that results are likely to be achieved more quickly and economically where new programs can be built on existing foundations. The Bank has substantial experience on which to build work in the biomass area. The expansion of lending for fuelwood over the past two years has involved the recruitment of additional expert staff, the broadening of knowledge of countries in this field, the accumulation of practical experience in project design and implementation and the build up of a substantial project pipeline. Fuelwood and other traditional biomass fuels have received increasing attention in the Bank's sector studies. Over the past year, staff have also built up considerable knowledge of the potential for alcohol production in different countries. For the other renewable energy resources, it is only possible to suggest where the potential lies pending the evolution of specific technologies, the strengthening of the Bank's expertise and the identification of suitable investment opportunities. Incorporating these technologies on a pilot basis in projects is one way for the countries and the Bank to gain experience with them and promote their development. Energy sector work and assistance in institution building also will assist developing countries directly and lay the foundations for expanded Bank activities in the future.

Household Fuelwood

3.06 The magnitude of the task posed by the fuelwood problem has been underscored by a review of the global supply/demand outlook. The main conclusions of this review were that about 50 million hectares of trees would need to be planted in the developing countries between now and the year 2000 to satisfy the projected demand for fuelwood for cooking and heating in the year 2000. This would necessitate a five-fold increase over current levels of planting worldwide. The gap between the present and the required planting levels is large in all regions, but particularly so in Africa, where it is estimated that planting rates would have to be increased as much as 15-fold to assure adequate fuelwood supplies. Sobering as these conclusions are, they tend, if anything, to understate the problem, since the weakness of the underlying data may have led to optimistic assumptions about the amount of wood available from existing forests, the likely effects of better stoves in limiting the growth of demand, and the possibilities for replacing wood with other forms of energy (such as kerosene and biogas). But, even if the projections do not understate the problem, there can be no doubt about the urgent need for greatly expanding existing fuelwood planting programs virtually everywhere in the developing world.

3.07 The Bank will make a maximum effort to expand its support for tree planting programs and other related activities. Nonetheless, lending for fuelwood at the levels planned for FY81-85, about US$425 million, would not constitute an adequate response to the "second energy crisis." The main features of the operational approach envisaged for the Bank are:

- the expansion of lending for fuelwood;

- the introduction of more efficient stoves as a standard feature in fuelwood lending and the incorporation of improved techniques for the production of charcoal in as many projects as possible; and

- greater use of loans and credits for technical assistance for small pilot projects to build up technical and economic infrastructure for fuelwood development.

Implementing this approach would take advantage of the momentum that has been built up with the expansion of the Bank's fuelwood lending activities over the past three years. An analysis of the scope for Bank lending indicates that a planting program of 1 million hectares over five years in the almost 50 countries tentatively identified in Annex 1 would be an appropriate target. This would involve Bank lending of about US$1,100 million during FY81-85.

3.08 Constraints within developing countries at the national government level, within implementing agencies, and at the level of the beneficiaries were taken into account in estimating the potential for lending. Some governments are not yet sufficiently aware of the urgency of the fuelwood problem or are not committed to making the national effort essential to an adequate response. National programs in a number of countries have been poorly designed and implemented and thus do not provide a basis for Bank support in the short term. In some countries, governments are not prepared to review the price and incentive structure that would be an important element of a sustainable national program. National forestry services frequently lack the inclination, experience and expertise to undertake the new tasks that fuelwood and other nontraditional social forestry activites demand. In addition, it takes time to mobilize the local support that is essential to the success of most fuelwood projects. Some Bank projects have had to be substantially reduced in size during preparation, when account was taken of such factors as the beneficiaries' dependence on free-ranging livestock that eat young trees, the limited availability of land for tree planting, and villagers' reluctance to commit themselves to self-help tree planting schemes in the face of more pressing tasks such as planting, harvesting and maintaining irrigation ditches. Because of the time needed to overcome these constraints, the five-year planting programs proposed for many of the countries analyzed would be small relative to their total needs. The programs would, however, make significant contributions to building up the infrastructure and institutional base needed to support larger subsequent projects.

Alcohol

3.09 Financing alcohol production operations would be a new venture for the Bank. The report on Alcohol Production from Biomass in the Developing Countries makes a clear case for such lending, on the following grounds:

- Biomass ethanol can substitute for a portion of the gasoline consumed in some countries and offers the most immediate prospect of using renewable energy to replace premium liquid petroleum fuels in the modern sector.

- The basic technology for producing ethanol from biomass is well known and equipment is commercially available on world markets.

- Ethanol production can be cost-competitive at present oil prices in developing countries that can produce feedstocks at low cost and/or where there is surplus biomass.

- Bank assistance, which has been requested by a number of governments, can be important in ensuring that national alcohol programs are economically sound and efficiently designed.

3.10 Alcohol production may, in some cases, compete with food crops for land and other agricultural resources, put pressure on food prices if food supplies are reduced, and adversely affect income distribution. Over the long run, research and demonstration of processes to produce alcohol from biomass that can be grown on less fertile agricultural land (e.g., cassava) or on forest land (e.g., wood) offer the soundest approach to alleviating this constraint and thereby widening the scope for alcohol production in the developing world.

3.11 The Bank can contribute to alcohol production by lending and in other ways. It is in a unique position to assist developing countries with the intersectoral analyses covering the agriculture, industry, energy, and transport sectors that are necessary to evaluate their alcohol production potential. It can also assist in disseminating experience with the planning and implementation of alcohol programs in developing countries. The proposed approach emphasizes:

- a program of country reviews of the scope for alcohol production, taking into account the links between the industrial, agricultural and energy sectors;

- technical assistance in the preparation of national alcohol programs, including the policies necessary for sound implementation; and

- support for research into broadening the feedstock base for alcohol production and increasing production efficiency.

3.12 A Bank review of the Brazilian alcohol program found that country to have the agricultural and industrial base for economic alcohol production and a well-conceived national investment program. In Mali, it was found that surplus molasses could be economically converted to ethanol with modest additional investment in an existing distillery. Different as they are, these two cases are illustrative of the two broad sets of circumstances in which there is likely to be good economic potential for alcohol production and a role for the Bank. Brazil's potential rests on an agricultural resource base that makes for low-cost biomass production, Mali's on the surplus molasses produced by its existing sugar industry. In cases of the Brazilian type, continuing investment in alcohol production on a large scale to substitute for a major share of gasoline consumption may be feasible. On the other hand, where

the situation is more analogous to that in Mali, alcohol is likely to have much more limited substitution potential and investment requirements will probably be modest. From general considerations of agricultural resource endowment and present biomass production patterns, it appears that few countries are likely to be found in the first category but that the second group may be fairly numerous. It has been possible to tentatively identify six countries, in addition to Brazil, that may have potential to produce biomass at low cost, and over 20 countries that may have good potential to produce alcohol from surplus molasses.

3.13 Further reviews are required to confirm these indications of potential among countries. Reconnaissance work was performed for the Philippines by a recent energy sector mission, and regional survey missions that will combine visits to a number of smaller countries are being planned in East Africa and Latin America. Where the country review process yields positive results, and governments request Bank involvement, the next step will frequently be to provide technical assistance in the preparation of specific investment projects.

Renewable Energy Components in Other Projects

3.14 Over the next five years, the Bank's approach to other types of biomass-based energy, solar thermal and electric technologies, small hydro and wind power--will aim at (a) gaining operational experience with the most promising technologies and applications and (b) building local capacity to plan, design and implement future programs. Many of the projects of other aid agencies have so far been aimed more at demonstrating technical than economic feasibility. The Bank could make a contribution by promoting the use of these technologies in the projects it finances where they offer least cost solutions. Opportunities for incorporating these technologies in Bank projects exist in the following principal areas:

- in power projects, particularly to serve rural areas;
- to provide energy needed by projects in agriculture, industry, education, health and other sectors;
- as components of rural and urban development projects to meet household (cooking and lighting) and community (e.g., water supply) needs; and
- in small industry projects, through which the local manufacture of renewable energy equipment can be promoted.

The Bank's present lending program incorporates these technologies in only a small number of projects, but there is a broad range of opportunities for doing so in the future.

3.15 One of the most attractive uses of renewable energy is in small-scale, decentralized power-generating facilities in rural areas that can provide an economic alternative to the traditional extend-the-grid approach to rural electrification. Wood-fueled power plants and small hydro power stations appear quite promising in this connection in a number of countries and could be suitable for Bank lending.

3.16 The potential for incorporating biogas components in rural development projects to meet household and community energy needs was identified in a number of countries, including Nepal, Pakistan and Thailand. Coastal and other windy regions in countries such as Egypt, Pakistan, Thailand and Tunisia could offer appropriate sites for the use of wind pumps to provide power for village water supply. Urban projects can also be appropriate vehicles for the introduction of improved stoves, or for solar collectors to provide hot water for residences and institutions. Solar collectors, small hydro turbines, windmills and some other renewable energy equipment are being produced by small industries in developing countries. The potential for projects for the manufacture of solar hot water heaters has been identified in a number of countries, mostly in the Europe, Middle East, and North Africa Region.

Operational Aspects

3.17 Most renewable energy technologies involve an element of novelty, and working with renewable energy will frequently involve small projects and components even in the major lending areas of fuelwood and alcohol. Hence flexible and pragmatic approaches to project design and appraisal will be needed. Even the application of the more "commercial" technologies (such as solar collectors and photovoltaic cells) can entail a degree of technical or economic uncertainty not usually encountered in Bank project work, since there has been relatively little practical experience with their operation in developing countries. Particular care will be needed to ensure that equipment is correctly selected to meet special installation requirements and to guard against operating and maintenance problems arising out of local environmental conditions. Such problems will generally be manageable in normal Bank projects in the case of commercial technologies.

3.18 Where the technology involved has not been commercially proven or needs extensive local adaptation, a "demonstration" approach may be in order. Special provision, however, will have to be made to monitor and evaluate the economic, social, as well as the technical aspects of the demonstration. Such an approach can help the Bank and its borrowers to gain experience with new technologies. However, since many other aid agencies are involved in activities of this type, frequently with grant funds, the Bank will, generally, await the results of these demonstrations and help to finance their replication.

C. Sector Studies and Institution Building

3.19 More energy sector studies with more emphasis on renewable energy are essential for an effective and expanding Bank role in renewable energy development. Country sector work in renewable energy will be conducted with the same broad objectives as in other areas--i.e., to provide the Bank with the information and analyses necessary to advise governments and to plan its own activities in the sector. The specific objectives of renewable energy sector work will be to:

- ascertain the present role of renewable energy in a country's economy;
- assess the country's renewable resources and the potential for applying them to meet its energy needs;
- define the policy and institutional changes needed to stimulate the development of renewables; and to
- establish investment priorities and identify possible projects for Bank financing.

3.20 How far the renewable energy resources of developing countries are exploited will depend heavily on the institutions charged with planning and carrying out projects and integrating renewable energy programs into national economic and energy planning. In some countries, these institutions are dedicated to renewable energy work; in others, they have a much wider range of responsibilities. The principal functions are:

- assessing current and future energy requirements in both modern and traditional sectors;
- surveying agro-forestry, hydrological, wind, solar and other energy resources, both renewable and non-renewable;
- planning for the integrated development of renewable and non-renewable resources, and preparing the investment programs and projects necessary to put these plans into effect; and
- identifying, importing and adapting technologies developed in other countries, and sponsoring the use of modern materials and engineering techniques to improve on traditional local technologies;
- establishing the facilities and programs necessary to deliver proven technologies to end users, for example, through training, extension work, investment in manufacturing plant, or opening credit facilities.

3.21 Assistance to the institutions responsible for these functions will be strongly emphasized in the Bank's approach to renewable energy. Their principal needs lie in the areas of planning and policy formulation, preinvestment studies, delivery systems, and in support for the building of research and technological capabilities.

3.22 Planning assistance. Since the need for energy planning is a recent development, it is not surprising that there is as yet little capacity for it in the developing countries just as in the industrialized countries. But even where there is a substantial overall sector planning effort, renewables are frequently neglected, both because they seem to offer little in the way of immediate solutions to the developing countries' most pressing energy needs, and because governments lack adequate information on their renewable resources and the practical possibilities for exploiting them. Wherever appropriate, provision for work on renewable energy resources will be included in Bank-financed technical assistance for energy planning.

3.23 Preinvestment activities of two types--resource assessments and prefeasibility studies--will be particularly important to the development of renewable energy. Since data in most countries are sparse, sector work can be expected to reveal a widespread need for resource assessments aimed either at surveying a broad range of renewable energy resources or at obtaining detailed information on specific resources (e.g., small hydro power sites, wind regimes). Where the resource base has been established, prefeasibility studies will be needed to determine whether attractive investment opportunities exist, the extent of equipment adaptation that is necessary, and the problems of social acceptability. In some cases, this may involve demonstration projects.

3.24 A strong Bank role in the preinvestment area would help to accelerate the passage of renewable energy technologies from the laboratory to commercial application, as well as to build the foundations for expanding lending. The Bank can readily finance preinvestment activities by the usual means of adding components to investment projects and by including renewable energy activities in general purpose technical assistance or preinvestment loans.

3.25 As regards the delivery systems that are necessary to promote the widespread use of renewables, the Bank will assist, wherever appropriate, national extension services or other institutions, including private voluntary organizations. Bank fuelwood projects already have a heavy technical assistance orientation of this sort, and as project components to design and demonstrate wood stoves yield results, dissemination programs will become necessary. Effective dissemination should be supported by credit and other essential services, particularly for technologies involving the use of biogas plants to meet family or village needs, or wind or small hydro power for village water supply and small farm irrigation. In other areas, such as solar water heaters, promotion and incentive programs aimed at producers and consumers will be required.

D. Support for Renewable Energy Research

3.26 With few exceptions, renewable energy technologies exploit energy resources and scientific and engineering principles that have been understood in general terms for decades or, in some cases, centuries. However, advances in electronics, synthetic materials and equipment design have opened up a variety of new approaches to the solution of old problems that need to be explored. Much renewable energy research and development is underway in the industrialized countries but there are important gaps both in developing countries' abilities to select from and adapt to their own needs the results of this research and in research on technologies whose greatest potential is in the developing countries. The Bank will assist in filling these gaps both by directly supporting national research programs and by examining the need for an international program of support for research and development in renewable energy.

3.27 National research programs serve two important functions. They are, in the first place, a vital part of the technology transfer/absorption mechanism since they enable scientists and technologists in the developing countries to acquire direct working experience with the new technologies. And, second, they enable the developing countries to acquire the technical capability to adapt imported technologies to the local environment and to improve on traditional local technologies. The Bank will support national research and technology programs on renewable energy by including technical assistance components in appropriate investment projects or in general industrial and agricultural research and development projects.

3.28 An international program of support for research and development could perform a number of valuable functions. It could serve to improve the access of developing countries to information about renewable energy technologies, to develop internationally recognized standards for measuring and reporting the performance of renewable energy equipment, and to provide assistance to national research programs on renewable energy resources. It can also involve the development of cooperative international research programs for some technologies that are of particular interest to developing countries--technologies which may not presently be receiving adequate research attention, (e.g., those involving biomass production and conversion).

E. Aid Coordination

3.29 As already noted, most development assistance agencies have shown increasing interest in renewables in recent years. An informal survey of the principal bilateral programs indicates that they vary widely in scope, content, and stage of development. While a great deal of valuable and pioneering work is being done under the bilateral programs, most appear to have been more concerned with demonstrating that renewable energy technologies

"work" rather than providing economically competitive and socially acceptable means of meeting the energy needs of developing countries. This pattern is now changing. Several aid agencies are adopting a more needs-oriented approach in the selection of projects and are giving greater emphasis to technical assist. for resource surveys, adaptive research, and the training of local personnel.

3.30 The Bank will play a role in coordination through sector and energy planning missions, by identifying research and investment opportunities, and by assisting in project formulation and through its consultative groups. In addition, the Bank will support efforts of specialized or regional organizations working on renewable energy activities. As operational experience is gained, the Bank, together with others, can consider the most effective mechanisms for disseminating this experience widely among developing countries and development institutions.

ANNEX 1

COUNTRIES WITH POTENTIAL FOR FUELWOOD LENDING, FY81-85 1/

Region	Countries	
Eastern Africa	Botswana Kenya Lesotho Madagascar Somalia	Sudan Swaziland Tanzania Uganda Zambia
Western Africa	Cameroon Gambia Ghana Ivory Coast 3/ Liberia Mali	Mauritania Niger Nigeria Senegal Togo Upper Volta
South Asia	Bangladesh Burma India	Nepal Pakistan Sri Lanka
East Asia & Pacific	Indonesia Lao PDR Papua New Guinea 3/	Philippines Thailand
Europe, Middle East & North Africa	Morocco Portugal 2/ Tunisia	Turkey 2/ Yemen AR Yemen PDR Yugoslavia 2/
Latin America & Caribbean	Bolivia 3/ Brazil 3/ Costa Rica 3/ Ecuador Guyana 2/	Haiti Jamaica 3/ Mexico 3/ Peru 3/

1/ Selected from countries in which Bank staff estimates indicate that present planting programs need to be substantially expanded to ensure adequate fuelwood supplies.

2/ Lending would be for industrial forestry projects but these would produce substantial amounts of fuelwood as a by-product.

3/ These countries are not shown as having a fuelwood problem in Table 2, of the report, Energy in the Developing Countries, (Washington: World Bank, August 1980) because per capita energy consumption now and by the year 2000 could be met from various sources, including fuelwood. Nonetheless, expanded planting programs in these countries are desirable to meet fuelwood requirements and reduce environmental degradation.