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APPROPRIATE TECHNOLOGY FOR RURAL ENERGY

APPROPRIATE TECHNOLOGY FOR RURAL ENERGY SUPPLY IN DEVELOPING COUNTRIES

Background Paper

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APPROPRIATE TECHNOLOGY FOR RURAL ENERGY SUPPLY IN DEVELOPING COUNTRIES

by

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CHAPTER ONE

INTRODUCTION

1. SUMMARY

Developing countries face the dilemma of needing more energy for rural development, but being unable to pay rapidly rising costs. The consumption of traditional types of energy in rural areas is increasing due to higher prices of petroleum products and larger populations, but this poses a threat to the environment. While deforestation is on the rise, wood is inefficiently burned, mainly in cooking. Few villages have electricity, and most rely for about 80% of energy consumed on non-commercial or traditional sources.

While developing countries should explore for oil, gas and coal; efforts to reduce petroleum dependence are required. Centralized electrification schemes, especially nuclear power, have not reached the majority of rural villages. Decentralized electrification based on diesel generators and renewable energy systems should be evaluated and installed, while grids are extended.

Alternatives energies with great promise for rural areas include, in order of apparent feasibility; biogas, solar, wood and small-scale hydropower. Solar collectors for low-temperature heat have immediate applicability. Technical answers are available, but institutional questions of how to transfer alternative energy technology remain.

2. THE PROBLEM: SECURING ENERGY SUPPLIES

How can energy be harnessed in developing countries to do work at prices people can afford? Given the five-fold increase in the price of crude petroleum between 1971 and 1976, and the rising costs of other types of conventional commercial[1] energy, it has become apparent that developing countries require new energy sources at lower prices. This implies a reconsideration of energy mix, energy intensiveness and national energy policy.

The dependence of developing countries on imported energy, especially crude and refined petroleum, and the unequal consumption of energy between rural and urban areas, as well as between developed and developing countries (table I-1) are two major points which contemporary energy policies must address. Dependence on imported oil has evolved since about 1950 due to the initiation in the last three decades of industrialization on a significant scale in developing countries, and due to the very low relative cost of oil up to 1970.

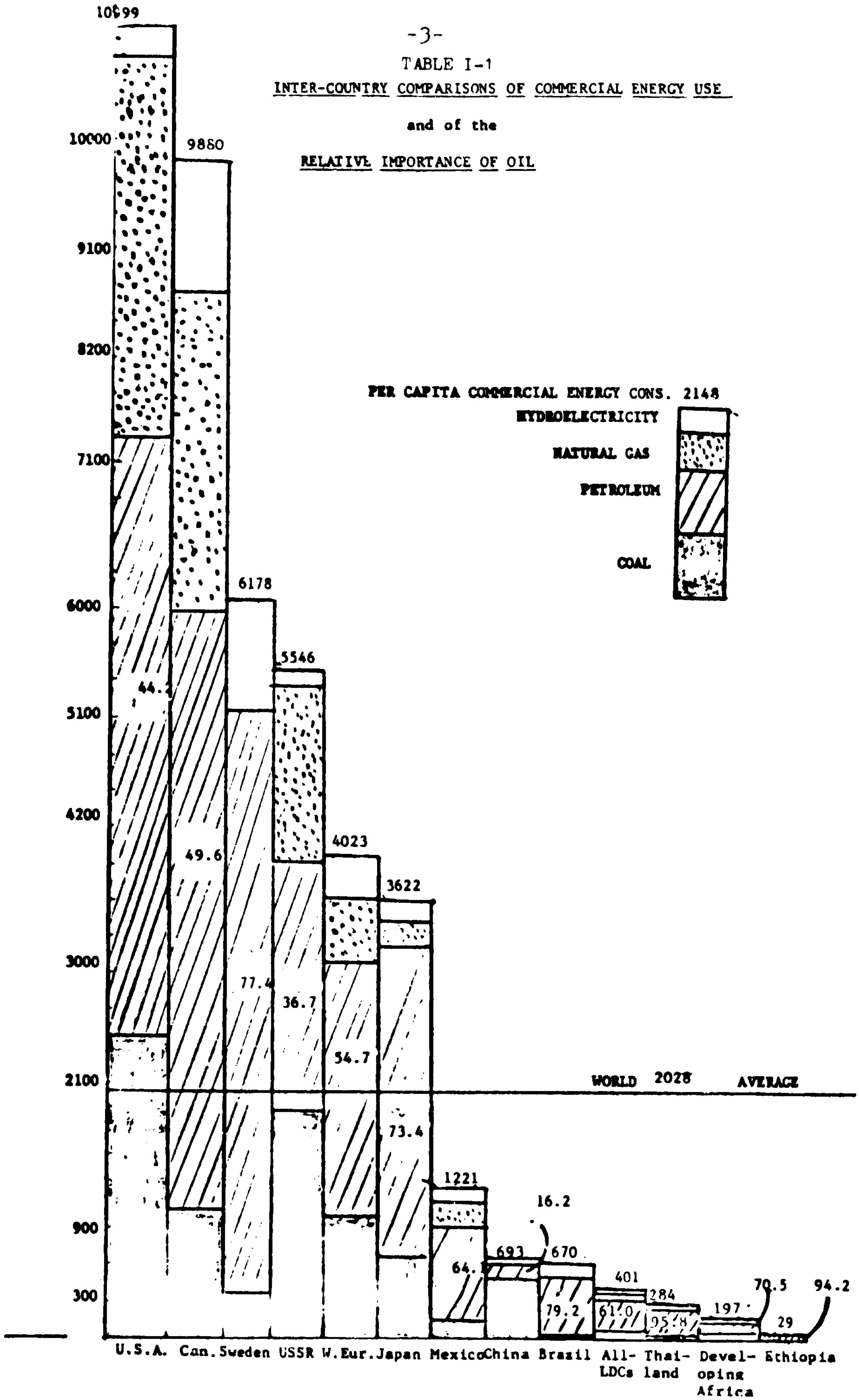
Nevertheless, per capita consumption of energy in developing countries is lagging dramatically behind that of developed countries.[2] Given the close correlation between energy use and economic growth, especially in the early stages of industrialization,[3] it is apparent that developing country consumption must rise significantly if an acceptable rate of growth in GNP is to be achieved, and if basic needs are to be met. The problem current facing the developing world is one of securing energy supplies sufficient to allow economic growth

TABLE I-1

INTER-COUNTRY COMPARISONS OF COMMERCIAL ENERGY USE

and of the

RELATIVE IMPORTANCE OF OIL



to proceed at the rate of 3.5% per annum or higher.[4]

World prices for energy are projected to increase sharply toward the 1990s, and many projections forsee a doubling of the price of oil in real terms by the year 2000, or before. Simultaneously, reserve depletion and discovery rates for hydrocarbons indicate that production will peak around the turn of the century. Not only does this imply increased competition among consuming countries for hydrocarbon resources, but also it highlights the inevitability of higher oil prices and the need to switch to other energy sources.

Developing countries are directly affected by the current high cost of energy imports and are suffering serious balance of payments difficulties in many instances. Thus, they are not well situated to compete for ever-shrinking oil supplies, even if new deposits are discovered in the non-OPEC developing countries. The circumstances of individual developing countries vary immensely due to differences in resource endowment and levels of industrial development. But the prevailing terms of trade make it unlikely that developing countries as a group can pay for required energy imports by exporting traditional commodities.

3. INTEGRATED RURAL DEVELOPMENT

The population living in rural areas of developing countries depends on non-commercial energy for over 80% of energy consumption.[5] Kerosene and other petroleum products have made inroads into the non-commercial sources since the 1950s but with higher petroleum prices in the last five years, consumption of kerosene appears to have declined. Consequently reliance of a larger and growing population on noncommercial energy has probably increased.

Among the implications of this development are, first, the negative impact it has on the ecological balance and on human welfare. Second, agricultural production has been affected for the worse, especially since high-yield crops depend very much on energy-intensive and fertilizer-intensive cultivation. A third serious implication of the increased cost of energy is the necessarily slower rate of growth of electrification programs, which had reached only some 6% of rural inhabitants by the early 1970s. Higher capital investment is required for non-oil fueled generation. Yet publically available capital is in short supply in those developing countries with negative balance of payments situations and poor credit-worthiness. Given these considerations, it is evident that new strategies for energy supply to developing countries, and especially to the rural areas, are required.

The conventional industrialization model of the developed countries is being reconsidered. There is increasing emphasis on a more appropriate development model featuring labor-intensive, small-scale technologies suitable to rural areas. In a similar way, the conventional energy supply system which features centralized electrification is being supplanted. The growing interest in integrated rural development is paralleled by greater awareness of the need for integrated, small-scale energy supply systems in rural communities.

Rural energy demand can be considered for each of four sectors - domestic, agricultural, basic amenities, and small-scale industries. In most developing countries, only the first two sectors are supplied with energy, although even here the supplies are insecure (as with scarce firewood) and inadequate. Basic amenities are in most instances rudimentary or non-existant and rural industries are in a state of decline or disruption. In some instances, industries are being started as part of an integrated rural development program. Since the interdependence of agriculture, rural industry and energy supply is marked, it may be useful to elaborate on the perspective suggested by integrated planning.

In the past three decades energy planning has been under-developed and ad hoc. Energy systems have evolved largely in connection with the needs of foreig investors in developing countries. Or they have grown in conjunction with urban-based industrialization programs. Rural energy supplies mainly for agriculture, irrigation and transport have been disproportionately available to plantation or large scale agricultural interests.[6]

Conventional energy development has failed to supply the needs of the mass of the rural population. Even its unsatisfactory rate of growth is unsustainable under current high cost conditions. But it is the widespread acceptance of the need for new strategies of rural development that has provoked planners and researchers to consider means of securing energy to satisfy indigenous, rural needs. Other motivations leading to current discussior and action on alternative energy technologies include commercial interest in securing a share of the markets for such technology, and concern that developing countries will not be able to afford petroleum products in the medium term future.

4. ENERGY NEEDS

Among the needs stemming from a program of integrated rural development are energy for agriculture and small-scale industry. Agriculture requires inputs such as fertilizer and pesticides which are produced from oil and gas. It also requires human, animal and mechanical labor. Mechanical implements require energy which, if provided by fuel or electricity, is immensely more efficient and productive than are human or animal energy inputs.[7] Water is another essential agricultural input which is most efficiently used if controlled. Water management requires energy, and the major proportion of electricity used in developing country rural areas powers irrigation pumps. There is scope for alternative technologies for irrigation in rural areas. The production of adequate food and the provision of the raw material basis of agro-industries depend on higher levels of crop production. These in turn depend in a major way on irrigation and thus on energy supplies.

Agricultural processing requires energy inputs, whether for simple drying, or for more complex extraction, cooking, refining and preserving. The milling and husking of grain crops is a significant consumer of energy. Non-food crops and byproducts can be processed at least to intermediate stages, in rural areas supplied with energy. Agricultural produce and inputs require transportation facilities, and in many instances, refrigeration.

Industry dispersal from urban to rural areas, and from centralized locations to households or small villages is part of the perspective implied by integrated rural development. Local crafts, weaving, leather work, the production of rural inputs for production and consumption needs, and other types of labor-intensive but capital-non-intensive industries have some potential in rural areas if inputs, including energy, are available.

5. AN INTEGRATED ENERGY SYSTEM

While the conventional industrialization model is unworkable in part because it is extremely energy and capital intensive, the integrated rural development approach also requires immense increases in energy consumption. The conventional method of energy supply through centralized electrification has not yielded adequate power. Nor does this approach meet the specialized demand requirements of small-scale rural industrialization and the energy needs of the social infrastructure associated with such industrialization. Energy planning needs to be integrated into rural development planning. It also should take into account the mixing of a number of conventional and alternative energy supplies in order to meet the specific requirements of a village or larger community. It is this second type of integration - of various types of energy - that is proposed by increasing numbers of energy economists.

The integrated energy system has been defined as a concept that encompasses[8]

> ...all the facets of the rural energy problem - an integrated approach which is expected to result in optimum matching of the needs with energy availability. The emphasis is on renewable sources which can result in local, decentralised options which are ecologically sound.

The proposal is for an integrated approach to alternative sources of energy through solar, biogas and wind energy. One step toward implementation is the design of a model integrated energy center either for a village or for a farmer, combining solar, wind and biogas energy systems with a cost not exceeding $3,750 to $5,000 (1977 dollars) per kilowatt. The advantages of such an integrated system, apart from relatively low cost, include independence from transport and fossil fuel constraints.

International energy economics and national development processes have posed the need for new energy strategies. Energy planning requires international, regional, national and local dimensions. But given the severity of affordable energy shortages in rural areas, and the preponderance of the rural population in developing countries, new energy strategies should emphasize the local and rural dimensions. From the perspective of the industrialized world, this approach has the advantage of freeing some petroleum for alternative consumption in the future, and perhaps making available some resources from developing countries for imports of industrialized country goods.

6. NEW ENERGY STRATEGIES

It is possible at this point to indicate the shape of these required energy strategies. They should

1. reduce the dependence on energy imports,
2. reduce the gap between industrialized country and developing country per capita energy consumption,
3. reduce the developing country rural-urban energy consumption difference,
4. rely increasingly on renewable sources of energy,
5. emphasize decentralized, integrated energy supply systems,
6. emphasize biogas, solar, wood and small-scale hydro systems,
7. feature technological adaptation and innovation with special attention to developing country experience and building materials and
8. actively foster cooperation among developing countries for exploiting all indigenous energy resources mainly for local use, but also for regional and international export.

There is no doubt that petroleum products will continue to play a vital, central role in commercial energy consumption in developing as well as in developed countries. This fact is sometimes lost in the current explosion of interest in alternative sources of energy. Nevertheless, developing countries must plan for a transition to a non-fossil fuel future. By starting now, industrial and agro-industry opportunities within developing countries can be identified and seized, and new technologies produced in and for developing countries.

These policy points emerge from an assessment of the energy needs for rural development and the various energy sources which could meet these needs in specific circumstances. Chapter two describes the energy supply situation in developing countries, with concentration on non-commercial energy, petroleum products and electricity in rural areas. Chapter three surveys the technology and cost of nonrenewable energy sources, including oil, gas, coal and uranium as well as electricity. Chapter four surveys the technology and cost of energy that comes directly from the sun. Chapter five examines the technology and costs for indirect solar energy in the form of vegetable sources, wind, water and forests. Chapter six examines policy choices and energy priorities for developing countries. The seventh chapter includes a summary and recommendations.

FOOTNOTES TO CHAPTER ONE

1. Commercial sources of energy are those which either involve a technology of energy conversion or enter commercial channels beyond a limited locality. Noncommercial sources of energy are consumed directly as fuel, without being altered significantly through the use of a conversion technology and without being formally marketed over a wide area. A distinction can also be made between primary energy - that used directly for heat or motive power, and secondary energy - electricity.

2. For developed market economies the per capita consumption of energy increased from 2.74 tons of coal equivalent (tce) in 1925 to 6.35 tce in 1974. In contrast, developing country consumption per capita increased from .08 tce in 1925 to .39 tce in 1974. J. Darmstadter, et. al, Energy in the world economy, (Johns Hopkins University Press) 1971, and United Nations, Statistical yearbook 1976, New York, 1977.

3. An increase of 1% in GNP is accompanied by more than an increase of 1% in energy consumption in the early stages of development, although this varies from country to country. The simple 1 to 1 correlation between GNP and energy consumption growth is however, not inevitable, as a recent study illustrated. See Darmstadter, et al, How industrial societies use energy, (Johns Hopkins Press, for Resources for the Future) 1977.

4. Exxon, World energy outlook, (New York: Exxon Inc.), 1977. This is the annual rate of growth that Exxon has projected for developing countries.

5. UNCTAD Secretariat, "Transfer and development of technology in the energy sector," draft, TD/588/10(5), May 23, 1978, Geneva.

6. The green revolution, which involves the combination of high-yield seed with capital-intensive irrigation, pesticide, fertilizer and other chemical inputs to produce agricultural commodities, is clearly premised on the assumption of low-cost oil and gas. But even prior to price increases, the energy required to make the green revolution was available to the more wealthy and thus more credit-worthy, rural inhabitants, or to agro-industrialists of national or foreign origin. Other inputs were similarly available mainly to the rich with the result that the green revolution created greater income differentials in rural areas.

7. At U.S.$1.50 per barrel of petroleum, the price at the end of the 1960s, one dollar purchased 4×10^9 joules (one joule = one watt-second or 0.239 calories) of energy. A person requires 1.05×10^6 joules (250 kilocalories) of dietary energy per hour of moderate activity. One dollar's worth of petroleum was thus equivalent in energy terms to 3,800 hours of human labor. With the price rise for oil but assuming all other costs reqmined the same, in 1978 one dollar's worth of petroleum is equivalent to 760 hours of human labor. FAO, "Energy and agriculture," (Rome: FAO) 1978, W/L1180, p. 1.

8. Nanubhai Amin, "Integrated approach to rural energy," Commerce Annual Number, 1977, Bombay, India, vol. 135, no. 3475, pp. 27-37. Amin notes further that "It must be clear to any student of the energy scene that an accelerated pace of development of rural areas is bound to result in increasing demands of energy and that only an integrated approach to this problem can avert a rural energy crisis which could cripple the very efforts at rural development." Ibid.

CHAPTER TWO

SOURCES AND USES OF ENERGY IN THE RURAL DEVELOPING WORLD

The energy crisis is nothing new for the population in rural areas of developing countries. In an influencial paper[1] published in 1977, Reddy and Prasad showed that extremely low levels of energy consumption by rural people was a chronic pattern.

Reliance on noncommercial energy has been aggravated by increased commercial energy prices since the early 1970s. But the endemic rural energy crisis predates the price rise. The low level of rural energy consumption is a key element of a situation in which the majority of developing country people struggle to avoid falling below the subsistence level.

The much publicized energy crisis of the 1970s is that of the urban, wealthier classes. Policies to confront the energy crisis of the rich will not necessarily solve the chronic and more serious energy crisis of the poor.

What are the sources of energy in rural areas? Who has access to them and at what cost? These issues are discussed in the present chapter. But first, mention should be made of the importance of political economy, in addition to technology, in both understanding and solving energy supply problems.

Energy analysts are increasingly in agreement on the point that there is no 'quick technological fix' to the energy supply problem. Rather, energy is so intrinsically a part of military and economic relations among countries, that to address the issue of changing the prevailing consumption patterns is inevitably to address questions of power, both internationally and on a national and local scale.

Technical solutions are necessary for harnessing energy at affordable prices, but these solutions are neither appropriate nor inappropriate in themselves. All groups are not similarly affected by the adoption of new energy technology. Nor is it likely that energy solutions to rural needs, in particular, are feasible without significant social change.

In short, the neo-classical economic conception of efficiency, as the result of the free play of market forces to produce the optimum service for the consumer, is not likely to be a fruitful basis for the study of rural energy supply. While it is unrealistic to reject this conception completely, the approach should be modified by considerations of regional, national and local optimization which may be at odds with an "internationally optimal division of labor" in the energy industry.

The objectives of increased per capita energy consumption, reduced import dependence for both energy and technology, and reduction in national consumption differentials are accepted in this survey as valuable in themselves, apart from their macro-economic implications.

I. NONCOMMERCIAL ENERGY IN RURAL AREAS

Some two and one half billion people rely on wood, dung, straw and human and animal power for energy that is used mainly in cooking, heating and for light. Table 2-1 shows the dependence of developing countries on noncommercial fuels.[2] Based on a consumption estimate of 400 kilograms of coal equivalent per person for rural populations[3], it can be seen that India, for example, relies on noncommercial energy for between 40% and 60% of total energy use. In contrast, Mexico relies on noncommercial energy for up to 20% of total energy use.

At the other extreme, 26 countries; among which are Bangladesh, Tanzania and Ethiopia, rely on noncommercial energy for between 80% and 98% of total energy use. While international energy statistics on noncommercial energy consumption have yet to be gathered, available data indicate a very high reliance on noncommercial energy in the developing world.

A. Five categories of developing countries: The energy balances of developing countries vary immensely and make necessary the categorization of countries according to energy-related variables. Several different categorizations have been established.[4] The one used here was developed by Brookhaven National Laboratories in the United States for 88 developing countries.[5]

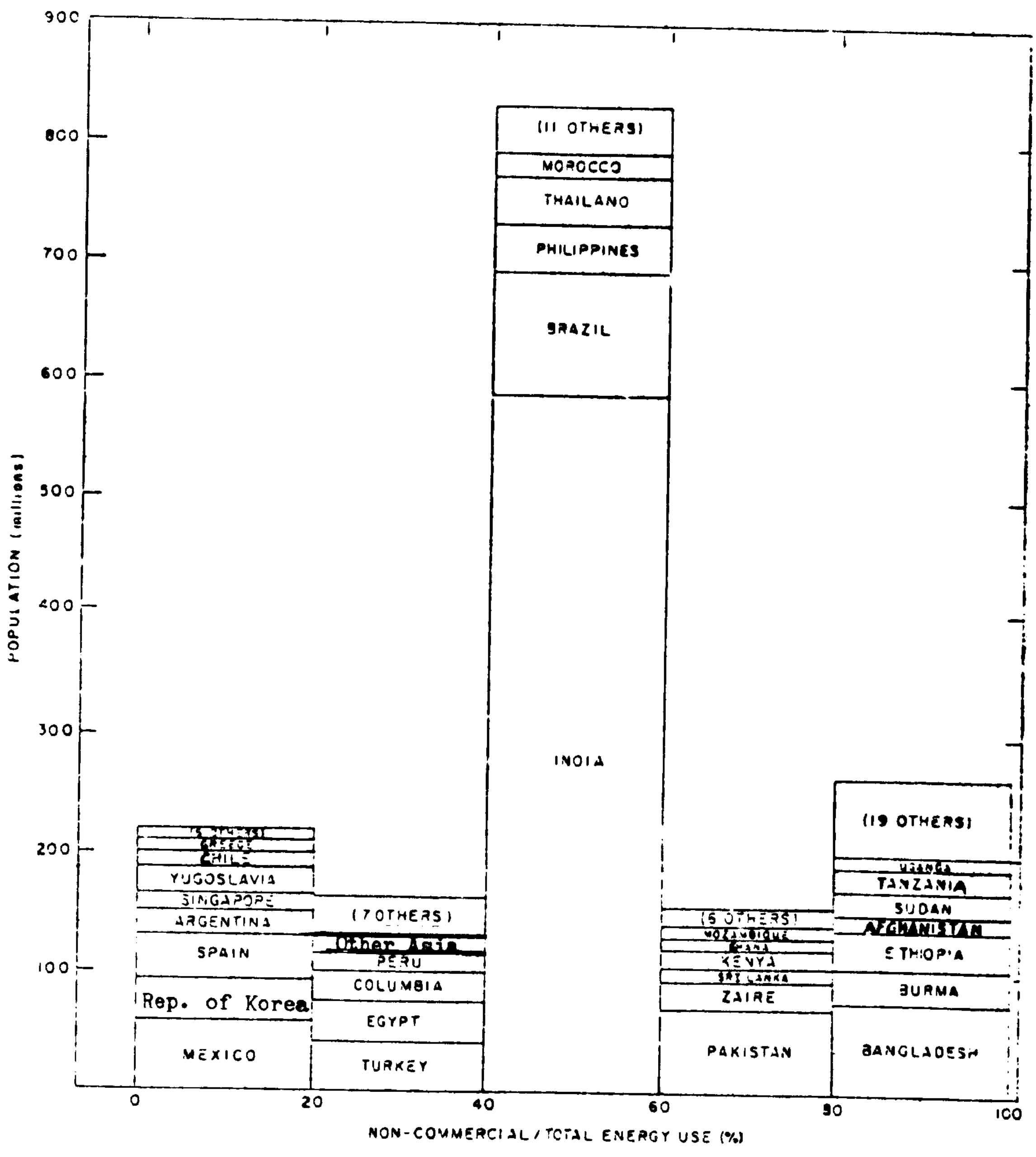
Five groups based on economic and resource structures emerge from the categorization as table 2-2 indicates.

Table 2-1

NONCOMMERCIAL ENERGY USE

AS A PERCENTAGE OF TOTAL ENERGY USE,

vs. POPULATION, BY COUNTRY



Sources: Brookhaven, **Energy Needs**, op. cit., p.68, based on

- 1974 (est.) Population (Table 18, U.N. Statistical Yearbook 1975.)
- Commercial Energy Use: (U.N. World Energy Supplies 1971-1975, 1977)
- Noncommercial Energy Use: 400 kgce/ rural population

Table 2-2

COUNTRY GROUPS

I. Industrialized

Argentina
Brazil
Chile
Republic of Korea
Singapore
Spain
Other Asia
Uruguay
Yugoslavia

II. Oil Exporters

Angola
Bolivia
Congo
Egypt
Malaysia
Mexico
Oman
Syrian Arab Republic
Trinidad and Tobago
Tunisia

III. Balanced Growth Economies

Colombia
Greece
India
Pakistan
Panama
Peru
Philippines
Turkey

IV. Primary Exporters

Botswana
Guinea
Guyana
Jamaica
Liberia
Mauritania
Morocco
Sierra Leone
Surinam
Togo
Zaire
Zambia

V-a. Agricultural Exporters

Costa Rica
Dominican Republic
Gambia
Guatemala
Honduras
Ivory Coast
Senegal
Sri Lanka

V-b. Other Agricultural

Afghanistan
Bangladesh
Benin
Burma
Burundi
United Republic of Cameroon
Central African Empire
Chad
Cyprus
El Salvador
Eq. Guinea
Ethiopia
Fiji
Ghana
Haiti
Jordan
Kenya
Lebanon
Lesotho
Madagascar
Malawi
Mali
Mauritius
Mozambique
Nepal
Nicaragua
Niger
Papua New Guinea
Paraguay
Rwanda
Somalia
Swaziland
Sudan
United Republic of Tanzania
Uganda
Upper Volta
Yemen Arab Republic

Source: Brookhaven, Energy Needs, op.cit., p. 14.

The groups indicate varying degrees of ability to pay for energy imports and technology. The classification also indicates the type of commodity the countries are able to export. The exclusion of OPEC members from this classification is a drawback. Some OPEC member countries have low levels of energy consumption (Indonesia and Nigeria consumed less than 200 kgce - kilograms of coal equivalent - per capita of commercial energy in 1973). The classification does not highlight the extent of dependence on energy imports, which is a further drawback. Because of these shortcomings, this classification is used only to illustrate the variability among developing countries in energy consumption and general socio-economic features.

The first group within these non-OPEC developing countries includes the industrialized countries, or those nine in which industrial activity accounts for a higher contribution to GDP than does agricultural activity. Also, as table 2-3 shows, these countries have the highest per capita energy consumption (1206 kgce) and import more than they produce (as do all the countries except those in the oil exporting group). Uruguay, Brazil and Singapore import over half the energy used in 1973.

The second group includes ten oil exporters. These countries are being viewed by oil consuming countries as possible alternatives to OPEC sources of oil. However, the interests of OPEC countries and these ten coincide on price and production control issues, in the medium and longer term. More countries are likely to join this group (for instance, Argentina,

Table 2-3

Basic social and economic indications - mean figures (by group)

GROUPS	GNP per capita 1974 US $	%Urbanization (1975)	Commercial Energy Consumption per capita (1975) kgce	Crude deathrate (per 1000) (1975)	Infant Mortality Rate (per 1000) (1970)	Life Expectancy (1975)	%Income Received by Lowest 20% (1975)	%Income Received by Highest 5% (1975)	%Mfg. Value Added (in Producers Values) to GNP	Export % of GNP	Arable Land (sq.km 10^{-3}) per capita
I. Industrialized	1120	60	1206	9	72	66	4.11	26	40	13	5.1
II. Oil Exporters	733	51	781	11	79	55	2.4	30	12	[illegible].1	4
III. Balanced Economies	225	25	298	15	122	51	5	25	18	5	3.3
IV. Primary Exporters	313	2[illegible]	246	1[illegible]	77	47	2.5	43.6	8.4	28.8	4.2
V. Agricultural Exporters	340	23	266	12	81	57	6.4	22	5.[illegible]	7.[illegible]	1.5
Other Agricultural	177	15	94	21	130	44	6	21.3	6.[illegible]	13.1	4.2

Population weighted averages of country data.

Source: Brookhaven. <u>Energy Needs</u> op.cit., p.16 based on Gordian Associates, report by Samuel Hale Jr.

Guatemala and Ivory Coast). The governments of these oil countries must decide whether to export their oil and the rate at which it should be produced. In addition, they must determine the role of foreign companies in oil development, the nature of tax policies and how the oil income will be used.

The third group includes eight 'balanced growth economies' so-called because they have a large industrial sector which is balanced by a still-dominant agricultural sector. These countries, with significant but only partly-developed resources bases, have begun to achieve self-sufficiency in the heavy industrial sector. The agricultural sector absorbs more than half the workforce (as in Turkey, Pakistan and India) and provides employment in service and cottage industries. Unemployment is a serious problem in balanced growth economies.

The fourth group is made up of 12 countries, primary exporters, dependent mainly on unprocessed minerals[6] for most exports and a significant share of GDP. Per capita income and energy consumption are lower than in the three previous groups. In Guinea, Sierra Leone, Togo and Zaire, per capita commercial energy consumption was below 200 kgce in 1973 when these countries were dependent on imports for over 50% of consumption. All import energy, and only Surinam, Zaire and Zambia produce significant amounts. In these three countries most local energy production is hydroelectric, and serves the mineral industries.

The fifth group, agriculturally-oriented economies, can be divided into two subgroups, according to whether agricultural commodities are exported or not. All are countries without significant commercial mineral resources. Life expectancy is low, most energy consumption is based on noncommercial fuels. Over half the energy consumed commercially in 1973 was imported.

The eight agricultural exporters face price fluctuations for their commodities such as do the primary mineral exporting countries.

Since noncommercial energy is absolutely most important in all groups, and especially so in rural areas, a description of its use and generation is in order. Some discussion of rural electrification follows.

B. Noncommercial energy use in rural areas: Photosynthetic production in plants provides fuel and food in rural areas. This in turn is used to produce more food. Heat energy from the burning of fuels and mechanical energy, often furnished by animal and human power, are used in agricultural production (mechanical), agricultural processing (mechanical/heat), cottage industry (heat/mechanical) and domestic cooking (heat).

Lighting, though a small user, is normally the first purpose for which oil products are purchased.[7] As pressure was applied to available wood supplies, the rural population has turned to the burning of dung and vegetable wastes which previously were returned to the soil. To the extent that soil fertility declines and depleted forests contribute to runoff and erosion, crop yields decline. The work involved in crop production and fuel gathering thus takes increasing amounts of human labor.

One of the few studies of energy use in a village in Africa (Bara, Kordofan Province, Sudan with a population of 10,050),[8] indicated that kerosene consumption was 17 kg/capita/year or almost four times the national average in this unelectrified village.

Second, the prices of electricity had increased eight-fold since ten years ago. In the last two years prices doubled (between 1974 and 1976). Among the reasons were increased reading by a larger population and a shortage of wood and charcoal.

Third, time gathering firewood has increased from 15-30 minutes to 1-2 hours in the last decade, with the result that women were increasingly finding it impractical to collect their own wood. Peasants who have lost their land to the desert now gather firewood for sale, and because of the labor-intensive nature of wood gathering, at harvest time the price of wood increased by 25%. Similarly, charcoal prices increased at harvest time, by 66%. In the last decade the price of charcoal has increased three-fold, mainly due to deforestation.

Three-fourths of the households which purchased charcoal used it only in lamps while the other quarter also had primus stoves. Charcoal is used most extensively in cooking, but also for space heating, melting soap and ironing. The charcoal was burned in stoves or heaters made from petrol cans.

Finally, desertification, soil erosion, and drought were increasingly serious problems. The population of Bara, Sudan was beginning to cut gum arabic trees for firewood rather than market their sap, and definite declines in the standard of living were experienced by the poorer majority of villagers.

Another survey of energy use in developing countries' villages was prepared on the basis of United States Peace Corps volunteers' reports.[9] Table 2-4 summarizes the tasks and energy sources for six villages. All soil preparation was done by animal or human energy, with the exception of one Latin American village. All planting and harvesting was done by hand as was initial processing, except for sugarcane in the Dominican Republic. All cereal growing communities had a grinding machine, whether a water wheel as in Nepal, or a diesel-powered grinder as in Ethiopia.

Wood or charcoal were used throughout for cooking, with some kerosene supplement. Water was available from nearby streams and in two instances, from wells. Four villages had electric lights. Homes were always built by hand while transport was by motor vehicle except in Nepal. The energy use profiles indicate heavy reliance on noncommercial energy sources, especially outside Latin America. Petroleum is the main replacement for animal or human power, and woodfuel.

The most significant findings of other studies of energy use in rural areas are that cooking and growing of food make the heaviest demands on energy budgets and labor time. For an Indian village, Revelle found that cooking accounts for 60% and agriculture for 22% of total energy consumption of 7,100 kcal/capita/day (which is 380 kgce/year).[10] Makhijani

Table 2-4

ENERGY SOURCES AND APPLICATIONS IN SEVEN VILLAGES

	Task	Dom. Rep.	Ethiopia	Korea	Micronesia	Nepal	Niger
1.	Soil Prep.	tractors; burro; oxen	hand hoe; oxen; horses	oxen	hand; (nuts, fruit, bread-fruit gathered wild)	bulls; hand	hand
2.	Planting	hand	hand	hand	hand	hand	hand
3.	Irrigating	electric pump	occasionally by gravity	none	none	none	hand (with scoops)
4.	Harvesting	hand	hand	hand	hand	hand	hand
5.	Initial Processing (threshing)	(sugar-elec. machine)	cattle trod	ox trod; hand	hand.	hand	hand
6.	Grinding	none	diesel; hand	gas (rice); hand (beans)	no cereals	water powered mill	hand; diesel
7.	Preserving	none	sun dry	kimchi; drying	copra in sun; salt or smoke fish; breadfruit buried	sun dry	sun dry
8.	Cooking	wood, charcoal	dung; wood, charcoal	charcoal coal, rice, straw	coconut husks; wood; kerosene	wood	wood
9.	Drinking Water	town pipes; water trucks	well; stream	well; hand pump	runoff; wells with bucket or pump	stream nearby	well
10.	Space heating	none	cooking fires	char-coal; oil	none	wood fire	none

Source: J. Howe, Inc., Energy for Developing Countries, op. cit.

Table 2-4, continued:

	Task	Dom. Rep.	Ethiopia	Korea	Micronesia	Nepal	Niger
11.	Water heating	none	none	charcoal	none	wood, hot springs	none
12.	Lighting	electric or kero-sene lamp	kerosene; straw; few electric lamps	electric	kerosene; flashlight	pitch pine; rarely kerosene	kerosene
13.	Electricity Source	diesel; hydro	diesel	?	none	none	none
	Coverage	streets; sugar factory; affluent	streets; bars; few homes	majority of homes; lights, T.V.	none	none	none
14.	Hauling	cart & ox; tractor	women; animals	cart by ox or man	hand; boat; cart (hand)	porters	hand; donkey; camel
15.	Home Con-struction	hand	hand	hand	hand	hand	hand
16.	Distance for wood	?	nearby	illegal to cut wood	nearby driftwood	2 hrs.	increasing many hours
17.	Imports & Exports from Village	pickup trucks	jitney	bus; train (diesel)	via inter-island boat or plane	porters	diesel truck
18.	Travel out of Village	motor-bikes; bus; foot	bus; horse; foot; jitney	bus; train (diesel)	via inter-island boat or plane	foot or heli-copter	bike; foot private vehicle lines
19.	Fertilizing	?	none	chemicals; manure compost by hand	?	manure & compost; chemical; by hand	none
20.	Fishing	hand	none	none	gas boats; hand	none	none

and Poole[11] calculated that agricultural and cooking needs absorb from 77% to 97% of total per capita energy consumption, which ranges from 670 kgce to 2260 kgce, as shown in table 2-5.

Reddy and Prasad[12] estimate that 130 kgce is used for cooking alone, out of a total per capita consumption of 300 kgce. An illustration of the variability of these estimates is provided by comparing those rather low figures noted above with the estimate of J. Parikh who suggests that 300 kgce is necessary for cooking alone.[13] Energy for cooking in a Bangladesh village were estimated to range from 500 kgce for the landless to 2000 kgce for the richest villagers.[14] Cooking is generally agreed to be the most significant use to which energy is put in rural areas. This has important implications for subsistence in the face of declining energy supplies, since demand (in terms of number of meals cooked) cannot likely be reduced significantly.

Energy consumption per capita varies tremendously among developing country villages, both in volume and mix. Table 2-6 illustrates this complex variability by type of commercial and noncommercial energy for 7 villages from different parts of the developing world.

The possibilities of finding substitutes for wood and dung used in cooking are limited. Kerosene is costly, has to be transported and requires relatively expensive stoves for use. Wood is also costly and entails travelling longer distances for gathering. The same constraints apply to charcoal, while both wood and charcoal use may have negative implications.

Table 2-5

COMPARISON OF ENERGY USE IN LDC RURAL VILLAGES
(kilograms of coal equivalent per capita)

A village in	Cooking & Domestic	Agriculture	Transp. & Misc.	Total	Total "Useful Energy"
India	150	280	125	555	30
China	730	305	120	1155	90
United Republic of Tanzania	810	85	25	920	44
Nigeria	550	88	32	670	33
Mexico	620	1500	140	2260	560
Bolivia	1220	245	245	1710	84

Source: Makhijani and Poole. Energy and agriculture in the third world, op. cit.

(a) Useful Energy is calculated as primary (resource) energy times the efficiency of use.

Table 2-6

Estimated per capita use of energy in rural areas of seven developing countries

(Source)	India (1)	China, Human (2)	Tanzania (2)	Northern Nigeria (2)	Northern Mexico (2)	Bolivia (2)	Bangladesh (6)
				10^3 Kcal/day			
Human labor	.67	.64	.64	.61	.75	.71	.67
Animal work	1.00	.92	--	.13	1.30	1.83	1.00
Fuel wood, crop residues, and dung	2.86	13.69	15.07	10.27	9.70	22.83	.93
Total non-commercial	6.36	15.25	15.71	11.01	11.75	25.37	4.82
Coal, oil, gas and electricity	.53	2.05	--	.02	19.81	--	.27
Chemical fertilizers	.22	.34	--	.05	5.33	--	.10
Total commercial	.75	2.39	--	.07	25.14	--	.37
Total all sources	7.11	17.64	15.71	11.08	36.89	25.37	5.19

Sources: (1) Revelle, 1976.

(2) Makhijani and Poole, 1975.

(6) Tyers, 1976.

for the ecosystem.

Fuel is used inefficiently for cooking: energy utilized ranges from 5% to 10%. While difficulties surround the introduction of more efficient stoves (especially their capital costs), the advantages to be gained are attraotive. They include reduced fuel demand, the availability of money for other expenditures, and the release of time and labor from wood gathering for more productive tasks or for leisure.

Energy is essential to the production of food, which is currently insufficiently available to between 450 and 500 million people, according to the United Nations Food and Agricultural Organization.[15] The food production tasks and the types of energy or machines commonly used to perform these tasks can be noted:

soil preparation:	human labor, heavy machinery
plowing:	human labor, hoes, bullocks, water buffaloes, hand-guided tractors, mechanical tractors
cultivating;	hand labor
irrigation:	animals or motors
harvesting:	human manual labor
preparation, processing	hand or machine grinding of grain
transportation	truck, animal drawn vehicles, pack animals, humans
water for cooking and drinking:	hand-hauled or machine pumped from a well, and carried for half-day's walk away in some cases
preservation	salting, sun drying, smoking, using wood or charcoal.

Human energy plays a vital role, but it is constrained by the low caloric intake. The food produced is depleted by poor storage conditions, with the result that agricultural production remains largely subsistence and the 'multiplier' effects of efficient energy use are not operative. The experience of some rural populations, notably that of China, indicates that this vicious cycle of insufficient food production and subsistence can be broken.

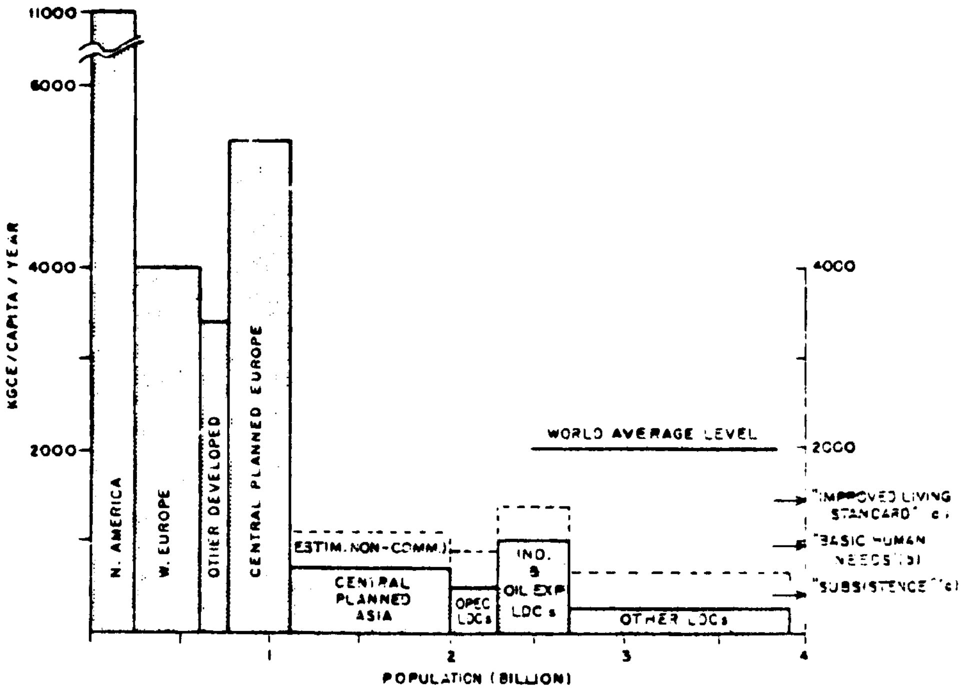
Estimates of the amount of energy required to provide subsistence vary with specific circumstances, and according to assumptions on which calculations are based. Table 2-7 shows per capita levels of energy consumption, which ranges from 11,000 kgce in North America to between 5% and 10% of that in developing countries even when noncommercial energy is included. Several studies[16] concur that approximately 300-400 kgce per capita per year would coincide with minimum provision of food and shelter in a rural agricultural setting.[17]

Initial findings of a study the the Overseas Development Council of the United States[18] suggests that the standard of living rises sharply when energy consumption increases from its lowest values, and a threshold occurs at approximately 1200-1400 kgce per capita. The study concluded that a tripling of the current average commercial energy consumption in poorer developing country groups to 900-1000 kgce would be required to attain a minimal adequacy for human life.[19]

Table 2-7

DISTRIBUTION OF WORLD COMMERCIAL
ENERGY CONSUMPTION

ANNUAL PER CAPITA CONSUMPTION
VS. TOTAL POPULATION
(AREA GIVES TOTAL ENERGY)



Source: Brookhaven Energy Needs op. cit. p. 22

C. Conclusions: Four broad conclusions can be drawn from the foregoing discussion: (1) Noncommercial energy is the major fuel for most of the rural population in almost all developing countries. (2) Replacement of noncommercial fuels implies a transition to petroleum products. (3) There is scope for increasing use of existing fuel sources through improving the efficiency of conversion of energy to useful services, but this requires capital investment in items such as stoves and machinery. (4) An improvement in living standards is likely to require increases in energy consumption per capita.

2. COMMERCIAL ENERGY IN RURAL AREAS

A. The prominence of oil: The converse of heavy reliance on noncommercial fuels in rural areas is the relatively small amount of commercial energy consumed by agricultural populations in the developing world.

Non-OPEC developing countries account for 41% of the world's population but consume only 9% of its commercial energy. Commercial energy production in non-OPEC developing countries has been increasing rapidly, with a 250% rise between 1970 and 1974. Per capita energy consumption increased 175% over this period but in 1974 still averaged only 400 kgce, or less than 4% of the U.S. average per capita use, as noted above.

The range of per capita consumption among the six non-OPEC developing country groups is large, with the agricultural non-exporters consuming 81 kgce and the industrialized developing countries consuming 1220 kgce. Individual country differences are even more pronounced. For instance, Spain, Singapore and Greece have a per capita average over 2,000 kgce, while at the other extreme, Rwanda, Burundi and Nepal had averages of 10 kgce per capita. Clearly, reliance on noncommercial energy is significant, given this slight use of commercial energy in many countries.

Nevertheless, the combined commercial and noncommercial energy consumption which ranges from 480 kgce for agricultural non-exporters to 1606 kgce for industrialized developing countries, leaves some 75% of the world's population at or below the energy consumption level which provides for basic human needs.

Commercial energy consumed in developing countries is overwhelmingly provided by oil products. For the developing world as a whole in 1975, liquid fuels accounted for 61% and natural gas for 15% of total commercial energy use. Of the oil importing countries, 29 of 40 African developing countries, 12 of the 20 Western Hemisphere developing countries, 3 of the 13 Middle Eastern developing countries and 5 of the 11 Asian developing countries depended upon liquid fuels for at least 90% of their commercial energy. In only four countries do liquid fuels represent less than 50% of total commercial energy consumption.[20]

B. <u>The cost of commercial energy</u>: In 1975 the oil importing developing countries imported an average of 2.7 million barrels of oil per day, worth some $12.8 billion (at $13 per barrel) or 7% of total export value from these countries. Non-OPEC developing countries have invested an average of $4.2 billion per year (7-8% of gross fixed capital investment) over the 1960-74 period, in developing energy resources and electricity production capacity. Most of this investment has gone for electricity generation and distribution systems.[21] Rising costs have negatively affected the ability of developing countries to maintain imports of commercial energy and to continue electricity production and distribution programs at the levels of growth achieved in the past.

Recent energy price trends have contributed to large balance of payments (current account) deficits. Terms of trade have deteriorated from an index of 100 in 1970 to 87 in 1976 [22] and debt has increased dramatically.[23] Consequently, developing country growth rates have slowed substantially - from 7.6% to 3.0% between 1973 and 1975. Prospects for increases in per capita income in the low-income developing countries above 20% between 1975 and 1985 (from $150 to $180) are not good. Among the implications to be drawn from this mix of circumstances is that increased growth is crucially dependent on increased energy consumption, but this energy is not likely to be supplied from commercial sources to the extent it has in the past due to capital shortages. The need for development of alternative energies and energy technologies is apparent, as is the need to develop all indigenous energy resources in new and less costly ways.

C. Electricity: Growth in electricity consumption in developing countries has been at a rate higher than that for other commercial fuels, but this growth is not uniform among country groups. Table 2-8 shows electricity growth in LDCs (less developed countries) between 1970 and 1975 at a rate of 9% per year. The table distinguishes between primary electricity which is that produced directly from hydropower, nuclear or geothermal and solar energy, and electricity produced by the burning of fossil fuels (coal, oil and gas). It can be seen that the growth rate in total electricity production is higher than that for primary electricity, indicating an increasing reliance on fossil fuels for generation. The proportion of primary electric energy to total electric energy has decreased by some 14% between 1970 and 1975. If Brazil's huge hydroelectric scheme were excluded, the growing dependence on fossil fuel electricity generation would be more marked.[24]

Production of nuclear energy on a commercial scale in developing countries is insignificant, with only four countries operating nuclear reactors as shown in Table 2-9 below. Geothermal electricity production is limited to .5 x 10^3 Gwh, located in Central

Table 2-8

ELECTRICITY GROWTH IN LDCs

10^3 Gwh[a]

	Total Elec. Consumption[a]			Primary Elec. Production[b]			Ratio: Primary Elec. to Total Elec.	
	1970	1974	Growth Rate %	1970	1975	Growth Rate %	1970	1975
Indust.	171.3	252.4	8.1	102.9	143.2	6.7	0.60	0.52
Oil Exp.	38.8	61.1	9.5	22.1	25.3	2.7	0.57	0.38
Bal	109.4	137.5	4.7	53.0	70.3	5.8	0.48	0.49
Prim. Exp.	9.3	17.4	13.3	6.3	10.9	11.6	0.68	0.55
Agric.	25.9	34.	7.0	12.1	15.0	4.3	0.47	0.41
Total	354.7	502.4	9.1	196.4	264.7	6.2	0.55	0.48

[a] Gwh = Gigawatt - hour = 10^3 Megawatt hours

Primary electricity includes hydropower, nuclear, and geothermal.

[b] 1974 Total figure was first increased by the calculated growth rate to get a value for 1975. This was then divided into the 1975 primary electricity figure.

Source: United Nations Yearbook of Industrial Statistics, 1974 edition and Brookhaven, Energy needs, op. cit., p. 48.

Table 2-9

LDC NUCLEAR PRODUCTION - 1975

Country	Electric Energy From Nuclear Power Gwh x 10^3
Argentina	2.5
Spain	9.0
India	2.6
Pakistan	.6
Total	14.7

Source: U.N. World Energy Supplies 1971-75.

America. Thus hydroelectric production in 1975 (249×10^3 Gwh) accounted for 94% of all developing country primary electricity production.

The prospects for increased hydroelectric development depend on site availability, taking into account uncertainties in water levels and requirements for navigation irrigation and fishing. Given the long lead-time in dam building, stand-in electricity generators may be required. Further difficulties arise from the often inaccessible location of dam sites and the need for expensive distribution grids and their maintenance. An Alternative is mini-hydro facilities which produce electricity in sub-megawatt range. Depending on local conditions, some hydropower production is likely to be available from installation of small low-head facilities supplying villages and small industries and agrobusinesses, but not integrated into a national grid.

An illustration of the variations in electricity consumption among countries is provided by Table 2-10 which provides data on African countries' population, GNP and energy consumption for 1974. Electricity consumption is highest in Swaziland (2,539 per capita in kwh) and Liberia (515) and lowest in Burundi (6) and Upper Volta (8). These consumption levels can be compared with an African average of 309 kwh per capita and a world average of 1,613 kwh per capita in 1974. These country figures do not reveal

Table 2-10

Population, GNP and Energy Consumption for 1974

Country	Population (millions)[1]	GNP per capita (U.S.$)[1]	GNP Growth Rate per capita (1965-73) (%)[1]	Commercial Energy Consumption per capita (kg. of coal) equivalent[2]	Electricity Consumption per capita[2] in kwh
Angola	5.8	580	3.2	191	109
Benin	3.0	120	1.5	42	17
Botswana					
Burundi	3.7	80	1.4	13	6
Un. Rep.Cameroon	6.3	260	4.9	86	179
Cape Verde	0.3		6.0	90	27
Central African Emp.	1.7	200	1.0	57	30
Chad	4.0	90	-3.3	17	14
Congo	1.2	390	1.9	216	75
Equatorial Guinea	0.3	260	-3.1	87	56
Ethiopia	27.2	90	1.6	31	25
Gabon	0.5	1,560	6.1	1,070	333
Gambia	0.5	170	2.2	73	39
Ghana	9.6	350	0.8	184	379
Guinea	5.4	120	0.1	94	116
Guinea Bissau			5.9	41	39
Ivory Coast	6.1	420	3.0	370	179
Kenya	12.9	200	3.3	177	86
Lesotho					
Liberia	1.5	330	4.7	482	515
Madagascar	8.6	170	0.9	71	44
Malawi	5.0	130	3.7	56	46
Mali	5.5	70	0.5	24	15
Mauritania	1.3	230	1.2	112	74
Mauritius	0.8	480	1.4	275	361
Mozambique	8.5	420	4.1	141	107
Niger	4.5	100	-4.6	31	15
Nigeria	73.0	240	8.3	94	46
Reunion			4.6	484	378
Rwanda	4.1	80	3.2	13	32
Senegal	4.2	320	-2.8	184	92
Sierra Leone	2.9	180	1.5	123	81
Somalia	3.1	80	1.6	40	14
Sudan	17.5	150	-0.6	125	19
Swaziland		@600	@5.0	2,754	2,539
Un. Rep.Tanzania	14.4	140	2.6	75	37
Togo	2.2	210	2.5	70	56
Uganda	11.2	160	1.2	51	47
Upper Volta	5.8	80	-1.1	14	8
Zaire	24.1	150	2.9	76	164
Zambia	4.8	480	-0.2	557	
Africa	392	290		359	309
World				2,059	1,613
North America	233	6,133		11,321	9,580

Source: James W. Howe and staff of Overseas Development Council, Energy for the villages of Africa, recommendations for African Governments and outside donors, (Washington D.C.:Overseas Development Council, mimeo) February 25, 1977, p. 126.

Footnotes to Table 2-10

[1] from World Bank Atlas, World Bank, 1975.

[2] from World Energy Supplies 1950-74, United Nations, Statistical Papers, Series J, No. 19, Tables 2 and 21.

Notes:

- South African Customs Union includes Botswana, Lesotho, Namibia, and Swaziland; population and GNP figures for those countries have been approximately aggregated here.
- Some data for several countries is tentative; for several countries the per capita GNP growth rate was based upon 1964-73. See original sources.
- "Africa" includes North Africa, South Africa, and Rhodesia.
- Per capita GNP figures for Africa and North America are for 1973.
- Figures for the United Republic of Tanzania are mainland Tanzania only.

the extent to which electricity consumption varies between rural and urban areas, and among sectors of the economy.

Reddy and Prasad described the pattern of Indian energy development over the past 30 years and suggested that it has led to "the growth of urban islands of energy-affluence amidst vast oceans of rural energy-deprivation."[25] For instance, some 70% of electrical energy in India was consumed by urban industry as Table 2-11 shows. Another 15% was consumed by urban domestic and public utilities, but only 12% was distributed for rural use. While data on use of electricity in rural villages is scanty, it is clear that inequities in access to power supplies are marked both among villages[26] and within them.[27]

A recent study by V. Byrappa of the Indian Rural Electriciation Corporation[28] stated that per capita electricity consumption in India increased from 18 kwh in 1951 to 38 in 1961 to a current level of 115 (1976-77), but the disparity among the states was high. In 1975-76 the maximum per capita consumption among Indian states was that of Punjab with 231 kwh, with Gujarat next (180) and Haryana, Karnataka and Tamil Nadu randing from 140 to 150 units. All others were below 100 kwh. But the proportion of electricity used for productive farm purposes was 60%, in India, or three times as high as the next highest among developing countries--Pakistan, with 20% of rural electricity use for productive purposes.

Table 2-11

ELECTRICITY CONSUMPTION PATTERN IN INDIA (1973-74)

Category	Number of Consumers (thousands)	Energy Consumed (million kwh)	Percentage of Total Consumption
Domestic	13,238	4,644.55	9.24
Commercial	2,871	2,987.52	5.95
Industrial	725	32,481.40	64.64
Public lighting	162	522.83	1.10
Traction	.04	1,530.76	3.05
Agricultural	2,391	6,310.21	12.56
Public water works	19	1,116.96	2.22
Miscellaneous	21	622.15	1.24

Source: Reddy and Prasad, "Technological Alternatives and the Indian energy crisis," op. cit., p. 1467, based on personal communication [illegible] Subramanian.

Over 20% of the electricity used in rural India was consumed by the industrial sector.[29]

The Economic Commission for Africa estimated that only 6% of the rural population of developing countries were connected with electricity grids in the early 1970s. While there is need for massive expansion in rural electrification, the prospects for supplying even the majority of the population with electricity by 2000 are not bright, assuming that conventional technologies and strategies continue to form the basis of rural electrification programs.

In this light it is useful to note Reddy and Prasad's conclusion that, given the reliance of a typical Indian village of some 500 population on non-commercial energy for around 70% of total requirements, most of which is used in cookkng, it is essential to base any scheme for energizing villages on improved energy supplies for cooking. The building of large, centralized power plants cannot meet these needs.

Furthermore it is undesirable to allocate expensive fossil fuels or import costly nuclear technologies for electricity generation when feasible options exist for the production of village energy supplies from local resources. A decentralized approach based on renewable energies includes electrification (mini-hydro plants, bio-gas, wind) to power as a matter of priority, communications, lighting and pumping equipment.

D. Conclusions: Among the conclusions to be drawn from this discussion are the following. 1) The reliance of developing countries on commercial energy is slight, though varied, and about 90% of commercial energy is provided by oil products in most countries. 2) Higher energy prices and the economic conditions in most developing countries make the growth in reliance on imported, commercial energy unattractive. 3) Electricity production is based almost equally on fossil fuels and hydropower but fossil fuels use has been increasing. 4) Major differences exist among developing countries in per capita electricity consumption, and urban areas consume perhaps as much as about 80% of electricity. Inequities in access to electricity also exist among villages and within them. 5) The prospects for rural electrification by conventional centralized production and grid systems are not bright, but alternative, renewable energies provide options.

FOOTNOTES TO CHAPTER TWO

1. A. K. N. Reddy and K. K. Prasad, "Technological alternatives and the Indian energy crisis," Economic and Political Weekly, (New Delhi), Special Number, August 1977, pp. 1465-1502.

2. The table shows the total population of those countries having a given percentage of noncommercial energy use as compared with total energy consumption.

3. Brookhaven National Laboratory Developing Countries Energy Program, Energy needs, uses and resources in developing countries, prepared for United States Agency for International Development under PASA No. ERDA/TAB-995-18-76 with the U.S. Department of Energy, (Upton, New York: Brookhaven National Laboratory), March 1978, p. 67. (Reference hereafter cited as Brookhaven, Energy Needs.)

4. The World Bank classifies non-OPEC developing countries into high, medium and low percapita income groups. UNCTAD categorized all developing countries to reflect energy consumption and trade positions, resulting in 9 groups. The trade groups used by UNCTAD show the proportion of total energy consumption which is imported, while the consumption categories show the per capita energy consumption of each country. This is a useful method of grouping because it shows at a glance the relation between energy dependence and low consumption and low levels of economic growth (to the extent that energy consumption is correlated with levels of economic development). Since the UNCTAD work is in progress it is not used directly in this study. (TD 588/10(5)

5. Brookhaven, Energy needs, op. cit., p. 13.

6. For instance, Zambia exported in crude form 60% of its cobalt, 95% of its copper, 75% of its lead and 60% of its zinc in 1974. For a discussion of processing minerals in these countries see, "Transnational corporations and the processing of raw materials: impact on developing countries," Report by the United Nations Centre on Transnational Corporations, February 1978, distributed by UNIDO (ID/B/209) 21 April 1978 id. 78-1539, for the twelfth session of the Industrial Development Board, Vienna, 16 to 26 May 1978, agenda item 10.

7. Exxon opened the Chinese market to petroleum products in the late 19th century by giving small lamps to the people free of charge and then selling kerosene to fuel them. See Michael Tanzer, The political economy of international oil and the underdeveloped countries, (New York and London: Temple Smith) 1969.

8. Digernes, Turi Hammer, Wood for fuel, the energy situation in Bara Sudan, Abstract of PhD dissertation, Department of Geography, University of Bergen, Oslo, Norway, July 1977.

9. . Howe, Inc., Energy for Developing Countries, Report to the International Relations Program of the Rockefeller Foundation, October 1977 (Rockefeller Foundation, New York, mimeo).

10. R. Revelle, "Energy use in rural India," Science, pp. 192, 969, June 4, 1975.

11. A. Makhijani and A. Poole, Energy and agriculture in the third world, (Cambridge, Mass.: Ballinger Publishing Co.) 1975

12. A. K. N. Reddy and K. K. Prasad, "Technological alternatives and the Indian energy crisis," Economic and Political Weekly, op. cit.

13. J. Parikh, private communication, quoted in Brookhaven, Energy needs, op. cit., p. 75. For a detailed note on the problem of noncommercial energy data and means of analysis, see Brookhaven, p. 77-78.

14. Mata Systems Workshop on Rural/Domestic Energy Issues, (Washington D. C.) January, 1978, mimeod report .

15. One serious drawback in the introduction of more efficient stoves is their initial capital cost. Denis Hayes discusses some of the obstacles of solar cooker introduction in "Energy for development, third world options," Worldwatch paper 15, (Worldwatch Institute: Washington D. C.), December 1977, p. 22.

15. FAO, "Energy and agriculture," op. cit., W/L1180. FAO reported that two-thirds of the developing countries had inadequate food supplies in 1970. Some 2,300 calories are an adequate per capita intake per day, but half a billion people in developing countries are estimated to consume only between 1,700 and 1,800 calories each day. Food and Agricultural Organization, The state of food and agriculture, (Rome: FAO) 1974.

16. Makhijani and Poole, op. cit., J. Parikh, op. cit., and Mata Systems Workshop on Rural/Domestic Energy Issues, op. cit.

17. Brookhaven, Energy needs, op. cit., p. 79 notes that this subsistence energy consumption level would have to rise as population density increased and because the amount of agricultural productivity on fixed amounts of land can increase only with added energy.

18. The Physical Quality of Life Index, discussed in Brookhaven, Energy needs, op. cit., p. 79.

19. These are all the groups described on p. 31, excluding the industrialized and oil-exporting developing countries.

20. India (23% oil) and Korea (48% oil) have the bulk of coal reserves found in developing countries. They have developed coal-based energy economies in which coal accounts for 73% and 51% of fuel use respectively. Pakistan (40% oil) has exploited its natural gas to provide 40% of total commercial energy while Zambia (36% oil) has invested heavily to develop hydropower (28%) and coal (36% of commercial energy). Brookhaven, Energy needs, op. cit., p. 23.

21. E. Friedmann, "Financing energy in developing countries," World Bank Reprint Series no. 27, March 1976

22. The value of exports divided by the value of imports. See World Bank, "World economic and social indicators," August 1977.

23. North-South Institute, The Debt Crisis and the Third World, (Ottawa: The North-South Institute), 1977. For 76 non-OPEC developing countries outstanding disbursed public debt increased from 11.9% of GNP in 1974 to 15% of GNP in 1976, while as a result of this debt increase and the importance of private lending at higher interest rates, debt service requirements increased from 8.4% to 10% of total annual export values. For nine countries, 1977 debt service is estimated to have risen to over 20% of export value.

24. The largest single increase in primary electricity, 38.7 Gwh x 10^3, was in Brazil. If this is excluded, the absolute increase in primary energy would have been only 30 Gwh x 10^3 and the annual growth rate in primary electricity over this period 2.9% rather than 6.2%.

25. Reddy and Prasad, "Technological alternatives and the Indian energy crisis," op. cit., p. 1467.

26. For instance, it has been estimated that, despite of notable progress in rural electrification in India, over2,500,000 villages will still be without electricity in 1980. Furthermore, most of these villages are 'economically unfavourable' for electrification and thus require very large investments with little prospect of return. In the State of Gujarat, out of about 18,000 villages, only 7,000 have been electrified. Out of the remaining 11,000 villages, 7,800 are considered economically unviable. See N. Amin, "Integrated approach to rural energy," Commerce, Annual number, 1977, op. cit., p. 29.

27. Even after villages in India are connected to an electricity grid, only a small fraction of the population can purchase power despite its being subsidized by the government. N. Amin, ibid., noted that "It is inconceivable that the cooking needs which rely on fire wood, dung and agricultural waste can be met by electricity. At present, whatever electricity is available in the villages is primarily used for irrigation purposes."

28. V. Byrappy, "Appropriate technologies for rural energy supplies--the Indian experience," (New Delhi: Rural Electrification Corporation Limited, mimeo) May, 1978, p. 11-12.

29. Ibid., quoting a World Bank study.

CHAPTER THREE

TECHNOLOGY FOR THE SUPPLY OF NONRENEWABLE ENERGY

With the exception of solar energy, all forms of energy require an exploration effort and investment in production. Some types of energy can then be used directly, as in the case of coal and high quality crude oil burned for heat or motive power. Hydropower is used directly for electricity generation.

Most energy resources must be converted through the use of technology to another form. Each stage of energy from exploration, production and conversion, requires specific technologies. These are represented in table 3-1. The present chapter surveys the technologies available for the supply of nonrenewable energy, with an emphasis on oil and gas, and electricity, generated from a variety of sources.

1. NONRENEWABLE ENERGY

A. Oil and gas: exploration and production potential

Developing countries are dependent on oil, the main source of commercial energy. Kerosene and diesel are the most significant commercial fuels in rural areas. Consequently, discovery of local petroleum deposits could ease the energy supply problems of many developing countries. Furthermore,

Table 3-1

The Main Energy Technologies

	Oil and Gas	Coal	Uranium	Solar	Hydro-elec.
Exploration	Geology Geophysics { magnetic survey, gravimetric survey, seismic survey } Drilling { Drilling Equipt. (Rig, Pipes, Mud, Bit); Logging }	Geology	Geology		Geology
Production	Reservoir engineering Drilling Completion Field Equipment Secondary & tertiary recovery	Mining Equipt. production	Mining equipt. Production Concentration Enrichment Fuel fabrication		Dam electrical eqpt.
Conversion	Power Plant, Refinery; Power Plant, LNG Plant		Reprocessing Power Plant	Collectors Photovoltaic Cell Biogas Plant	

dependence on imported oil is a major drain on foreign exchange and constitutes a strategic risk since supplies are by no means certain during periods of shortage or disruption. What are the possibilities for developing countries to explore for and produce oil?

B. Reserves:

OPEC countries account for two-thirds of the world's proven petroleum reserves and half of production (1978), as table 3-2 indicates. In contrast, non-OPEC developing countries account for only 7% of reserves. About half of these are in Mexico and Oman (see table 3-3). Less than 2% of world reserves are in the remaining seven net exporters (Syria, Angola, Tunisia, Congo, Bolivia, Malaysia and Brunei). The 11 net importing producers possess just over 2% of reserves.

C. Production:

Several of these oil importing developing countries do produce some oil. Three developing countries are major producers (outside of OPEC) - Angola, Oman and Brunei. In addition, six others are net exporters.[1] Mexico, Oman and Egypt accounted for 41% of non-OPEC oil production in developing countries in 1977. By 1985 it is estimated that Mexico, Brazil and Egypt may account for 40% of all non-OPEC developing country production and that Mexico alone may account for 25% of non-OPEC developing country production

Table 3-2

DISTRIBUTION OF PROVEN PETROLEUM RESERVES

as of January 1, 1978

	Billion Barrels	Percent
Non-OPEC LDCs*	44.0	7%
(Oil importing LDCs)	(10.2)	(2%)
OPEC	439.9	68%
Industrialized countries	63.9	10%
Centrally Planned Economics	98.0	15%
TOTAL	645.8	100%

*Not including China

Source: Oil and Gas Journal, December 26, 1977,(Tulsa, Oklahoma, Petroleum Publishing Company).

Table 3-3

Non-OPEC oil producing developing countries

A: Net exporters

country	production 000 bd 1977*	production million metric tons 1976**	imports	exports	net (e-i)**	reserves (1-1-78)*** oil '000 b	reserves (1-1-78)*** gas 10^9 cuft	refinery capacity (1-1-78) bd	refinery capacity (1-1-78) million metric tons
Oman	340	1[illegible].290	17.064[1]	-	17.064	5,650,000	2,000	-	-
Syria	200	9.900	2.413[1]	9.530[1]	7.117[1]	2,150,000	3,100	102,440	2.950[1]
Angola	195	8.000	-	6.880[1]	6.880[1]	1,160,000	1,500	31,429	1.750[1]
Tunisia	88	4.000	1.014	4.760	3.746	2,670,000	6,400	22,000	1.250[1]
Congo	35	2.010	-	1.780[1]	1.780[1]	360,000	10	-	-
Mexico	1,040	42.000	-	5.500[1]	5.500[1]	14,000,000	30,000	1,383,500	38.720[1]
Bolivia	35	2.000	-	1.088	1.088	350,000	5,000	40,300	1.290[1]
Malaysia[3]	430	7.850	na	na	.86[1]	2,500,000	17,000	168,000	3.750
Brunei	231	8.650	-	8.585[1]	8.585[1]	1,500,000	8,250	na	na

* Shell, Oil and gas 1977, (London: Shell Centre), March 1978.
** United Nations, Energy Statistics, J series (New York) 1977, p. 68.
*** Oil and Gas Journal, December 26, 1977

1. Data for 1975
2. Data for 1974
3. Includes peninsular Malaysia, Sarawak, Sabah.

Table 3-3, continued:

B: Net importers

country	production '000 bd 1977*	production million metric tons 1976**	imports (i) million metric tons 1976	exports (e) million metric tons 1976	net imports (i-e)	reserves (1-1-78)*** oil '000 b	reserves (1-1-78)*** gas 10^9 cuft	refinery capacity (1-1-78)*** bd	refinery capacity (1-1-78)*** million metric tons
Bahrain	56	2.880	9.272[2]	0.401[2]	8.871[2]	270,000	3,000	250,000	15.550[1]
Turkey	52	2.770	9.634[1]	-	9.634[1]	370,000	540	325,714	16.450[1]
Egypt	415	12.000	2.081[1]	0.923[1]	1 158[1]	2,450,000	3,200	234,000	8.750[1]
Zaire	23	.925	.615[1]	-	.615[1]	150,000	50	17,000	0.850[1]
Argentina	431	20.150	2.117[1]	0.016[1]	2.101[1]	2,503,000	8,120	655,189	31.310[1]
Trinidad Tobago	230	11.125	7.895[1]	6.835[1]	1.060[1]	650,000	8,500	461,000	23.050[1]
Brazil	166	8.260	35.533[1]	0.897[1]	34.636	880,000	1,200	1,161,000	51,500[1]
Colombia	143	7.600	-	-	-	960,000	6,360	165,000	8.670[1]
Peru	92	3.700	2.401	0.200	4.201	730,000	1,300	170,700	5.540[1]
Chile	33	1.120	3.525[1]	-	3.525[1]	440,000	2,000	129,500	6.850[1]
Cuba	2	.150	5.550[1]	-	5.550[1]	na	na		5.700[1]

*Shell, Oil and gas 1977, (London: Shell Centre), March 1978.
**United Nations, Energy Statistics, J series (New York) 1977, p. 68.
***Oil and Gas Journal, December 26, 1977.

1. Data for 1975
2. Data for 1974
- indicates nil
na indicates no answer

by 2000.[2]

By 1972 the oil-importing developing countries were importing 2.5 million barrels of oil per day, as shown in table 3-4. There has been little growth in the volume since then. However, the price paid for about one billion barrels imported in 1977 was $12.8 billion, as noted above. Estimates of recoverable world oil reserves vary from about 1.6 trillion barrels to nearly 3 trillion barrels. Since the largest areas yet to be explored, but with petroleum potential are located in non-OPEC developing countries, it has been projected by some geologists that perhaps half of the world's oil will be found there.[3]

Drilling density in non-OPEC developing countries is less than 1% as high as the density in the United States, as table 3-5 shows. Non-OPEC developing countries account for just under half of the world's prospective oil areas and demonstrate success ratios for wildcat drilling which are higher than the world average.[5]

At present, 11 of the 70 oil-importing developing countries produce some oil and have good prospects of increasing production (table 3-3). The main constraint on finding oil in the remaining countries is finance, but a number of options have been opening up in recent years which may enable increasing numbers of oil-importing countries to find and produce local oil. World Bank sources indicate that committments to large-scale expansion of exploration programs in these areas have been made by petroleum corporations.

Table 3-4

REGIONAL OIL IMPORTS OVER TIME*
millions of barrels/day

	1950	1960	1970	1975
Africa	0.06	0.14	0.22	0.30
South Asia	0.07	0.16	0.26	0.34
East Asia	0.04	0.16	0.77	0.87
Middle East	0.05	0.11	0.12	0.23
Latin America	0.32	0.48	0.75	1.09
Total OIDC	0.55	0.11	2.12	2.83

*Excludes OPEC members and other net oil exporting countries.

Source: U.N. World Energy Supplies, 1971-1975.

Table 3-5

WORLD DRILLING DENSITIES

as of January 1, 1978

Non OPEC LDCs	Petroleum prospective area (millions square miles)	Total wells drilled (thousands)	Wells per prospective square mile	% of U.S. density
Latin America	4.5	75.0	.017	2
Africa	3.6	3.9	.001	0.1
Asia	2.0	11.5	.006	0.7
Middle East	2.8	2.2	.001	0.1
Total LDCs	12.9	92.6	.007	0.9
OPEC	4.0	62.7	.02	2
Developed Countries				
Australia/N.Z.	2.4	2.5	.001	0.1
Japan	.2	5.3	.03	0.1
Canada	1.9	150	.08	10
Western Europe	1.4	50	.04	5
U.S.A.	3.1	2425	.78	100
Total Developed	9.0	2632.8	.29	37
Centrally Planned Economies				
U.S.S.R.	3.5	530	.15	19
China	1.1	8.5	.008	1
Total	4.6	538.5	.117	15
WORLD TOTAL	30.5	3326.6	.109	

Source: Data compiled by Gordian Associates from Bernardo Grossling, Window on Oil: A Survey of World Petroleum Resources, (London: The Financial Times Ltd., 1976)

D. Financing exploration: The possible ways of financing oil exploration include funding from international institutions, the OPEC Special Fund and other financing agencies. As important is the interest among independent and European state oil corporations in finding oil to satisfy growing demand. Because of impending oil shortages, it is probable that many corporations value future oil resources at above projected market prices. As a result, the corporations may be more disposed toward agreements with developing country governments for oil exploration, which are more favorable to the governments, than has been the case in the past. Examples of favorable terms are the recent Vietnam agreements with European state companies.

Another option for oil exploration is the 'do-it-yourself' approach by which developing country governments establish state oil agencies (over 80 currently have been created in the developing countries) and contract with the increasing number of international oil service firms, for the technical facilities and skills required to explore for and develop oil deposits.[6] In addition, co-operation among developing country state oil corporations is increasing. Consequently, oil-importing developing countries are able to tap a number of sources, including OPEC member countries, for investment funds and technology necessary for local oil exploration.

Nevertheless, this trend toward increased developing country cooperation is new and not without difficulties posed by market control by major private transnational oil corporations, a shortage of finance capital, and inexperience in oil exploration and production. The immense attractiveness of finding local oil resources outweighs the many drawbacks and promises to provide an incentive for accelerating developments in this area.

2. TECHNOLOGY FOR OIL AND GAS EXPLORATION AND PRODUCTION

An task that is prior to supplying energy to rural areas is securing the energy from its source. For the major commercial form of energy now in use - oil - this involves exploration and production, preferably in the country where consumption is to occur. Indigenous exploration, production and conversion requires a range of technologies, some of which are more appropriate and more accessable than others.

A subsequent step is the more efficient transport and use of oil products, especially in rural areas. Technologies for more efficient use are not assessed in this study, but do receive some mention below.

Exploration and production of oil and gas require knowhow and technology for a number of specialized operations as table 3-1 above shows. Contrary to widespread belief, the technology subsectors (which number more than 20) for exploration and production are not monopolized. With the exception of electric logging where a French firm, Schlumberger, controls 84% of the market, oilfield service and equipment suppliers are available from a small but increasingly diverse group of corporations.

In a pioneering study of technology for oil exploration and production, Carlos Anez described the evolution of the oil industry from the initial stage of in-company provision of technical services to the current multiplication of service firms.[7] Contractors to the oil companies became established when fluctuating demand for specific services made in-house capacity too costly for the oil companies. Contracting developed as specialization made possible the economic viability of a small number of service firms which catered to all the oil corporations. Today most oil corporations coordinate several contracting firms which do the actual work of finding and producing oil. This coordination role and the presence of several service firms in most technology subsectors, makes it possible for state-owned oil corporations to hire contractors and supervise their work, much as do the private foreign oil corporations.

3. ALTERNATIVES TO OIL

While technologies for finding and producing oil and gas are becoming more readily available through a proliferation of oil industry service firms (contractors, equipment manufacturers and construction firms), the discovery of hydrocarbons is not directly linked to improvements in the supply of oil products to the rural areas of developing countries.

Technologies for planning and putting into effect an efficient petroleum product distribution system are required. Due to deterioration, or very limited development of rail systems in many developing countries, dependence on road transport for petroleum products is increasing. This is placing a heavy demand on government resources for road building programs (which are in many cases urgently required for evacuation of rural produce and the supply of inputs). While some more industrialized developing countries manufacture haulage equipment, especially trucks, in most cases petroleum haulage equipment constitutes a major drain on foreign exchange. Despite efforts to invest substantial capital in distribution networks (storage tanks, pipelines, tankers and barges, trucks and distribution points), petroleum products have not been made accessible at low cost to much of the rural population.

Distribution costs are high, but petroleum products are themselves increasingly expensive. These considerations have directed attention to possible alternatives to higher dependence on petroleum products, especially in rural areas. In this connection, it is important to note that oil is most valuable as a transport fuel, and that any realistic replacements for oil will have to facilitate mobility. The more promising substitute is ethanol, produced from vegetable matter. Other substitutes for petroleum in transport include rechargeable batteries which, due to capital and operating costs, have little applicablility for the majority of the population in rural areas.

A. <u>Ethanol</u>: Ethyl alcohol (ethanol) can be used instead of gasoline in modified automotive engines, (minor compression ratio changes are all that is required) as is done for some racing cars. Unmodified engines can run on a mixture of up to 20% alcohol and 80% gasoline and the performance as far as fuel consumption and power delivered at the shaft appears satisfactory.

Ethanol is therefore a strong candidate as a renewable fuel that could replace gasoline in cars and eventually diesel motors in trucks. It can be produced from a variety of crops, especially sugar cane as the cane has a higher net energy balance than does sweet sorghum or cassava. Typical ethanol production rates in Brazil are 3,600 liters per hectare of cane, per year.[8]

B. <u>Costs</u>: The price of ethyl alcohol produced in large quantities is about $0.20 per liter, which makes it competitive with gasoline in many cases, given that taxes levied on gasoline in developing countries often raise its price to around $0.40 per liter. At such high prices, alcohol has been considered a solution for the petroleum shortage in Brazil. A full experiment is being conducted at present in Sao Paulo with large numbers of cars, some of which are using 100% alcohol.

If these experiments are successful, Brazil plans to produce 4 billion liters of alcohol in 1980 on one million hectares of land, or 1.5% of the country's fertile land. While this raises questions about alternative land uses, and social implications of agricultural for energy rather than for food crops, preliminary cost-benefit analyses favor the alcohol production program.[9] The Brazilian alcohol program represents an interesting step toward reversing the trend away from biomass energy sources. It provides encouraging indications that dependence on petroleum products for transportation is not inevitable.

A technological problem that deserves some attention is the improvement of the alcohol distilleries. At present their capital cost is rather high, reaching about $10 million for a plant of 500 barrels capacity per day. This compares unfavorably with an oil refinery that handles 100 times this amount but costs around $100 million. The large capital cost for alcohol distilleries is due to the extensive need for distillation columns. The sugar cane syrup from which the alcohol is distilled contains 93% water which is removed through complexes of columns. One solution may be to use solar heating to concentrate the syrup to the extent possible, and then to operate distillation columns at low temperatures (just above the water boiling point) to gain a higher efficiency.

The technology for using ethanol is already available in the form of conventional motor vehicles, generators and other petroleum using machinery. As noted above, this equipment requires minor modification to operate on a mixture of gasoline and ethanol.

Another area for concern is the generation of electricity from petroleum products, and the cost and insecurity (given possible shortages of fuel oil) of this practice. Many countries are considering a shift away from oil-based generation to hydropower The alternative of producing electricity in villages, using traditional energy sources, is also being considered (as discussed below).

A recent study by the U.S. Overseas Development Council highlighted the need to consider alternatives to increased petroleum dependence.[10] The study examined commercial energy consumption (the overwhelming proportion of which is based on oil) in 25 developing countries that have come near to achieving the 1974 Lima Declaration target of eliminating the worst aspects of poverty. The objective was to estimate the effects on world energy consumption is all developing countries achieved the Lima target by 2000. The study concluded that those nations (such as Brazil and Mexico) that have emphasized growth alone are relatively much higher per capita energy (especially oil) users than those countries (such as one south-east Asian country) that have pushed growth with equitable distribution of incomes, or those (such as Sri Lanka) that have focused exclusively on equitable income distribution and have not made such headway on growth.

Another conclusion was that even if all developing countries follow the relatively energy efficient growth with equity strategy, the goals of eliminating the worst aspects of absolute poverty cannot be met without imposing a claim on world oil resources larger than world oil production will permit. Therefore these development goals can only be met, in the view of the Overseas Development Council, if non-petroleum sources of energy are made available to these rural areas. Under these circumstances, exploring the use of small-scale, renewable sources of energy appears to be an attractive path.[11]

4. ELECTRICITY

The probability that developing countries will not be in competitive positions with regard to securing petroleum supplies in the future[12] has given rise to suggestions for alternative strategies for electricity generation. Coal and nuclear electricity generation provide options, as do small and large hydroelectric projects. Another option recently developed within the United Nations would combine several alternative energy technologies for electricity generation at the village level.

Coal is used in the few developing countries with significant developed deposits, for steel production, industrial processing, limited domestic purposes and primarily for electricity generation. It is therefore discussed along with uranium in connection with electricity generation. The technology for oil and gas production was examined above. This section considers technology for the production of coal and uranium, but focuses mainly on equipment and costs of electricity generation and distribution.

Coal production is becoming increasingly automated as open pit mining replaces deep shaft methods. This is a trend that emphasizes capital intensive equipment for earth moving and separation. An industry which has traditionally been labor intensive is thus evolving in a manner contrary to many developing country interests, such as reducing unemployment. Incentives are being provided by the U.S. government to encourage American coal mining firms to venture abroad. As a result, capital intensive mining technologies are likely to become more common.

Uranium mining is a sophisticated process that requires technologies for crushing large volume of rock while protecting the few operators from exposure to radiation. The mining of uranium is carried out in very few developing countries (Namibia, Gabon, etc) by large transnational mining corporations. The processing and enrichment of uranium are even more technologically sophisticated processes, carried out in the industrialized countries, - mainly in the United States. There is no medium term likelihood that developing countries where a demand for nuclear grade uranium exists, will reduce their dependence on industrialized countries for processed uranium.

A. <u>Technology</u>: Conversion of uranium and coal (as with oil and gas) into electricity requires heavy electrical equipment and nuclear power plants. The heavy electrical equipment industry produces generation, transmission and distribution technology including steam or water turbines, generators, power and distribution transformers, switchgears and rectifiers. This equipment is supplied by a relatively small number of large firms, based in industrialized countries.[13] Purchases are public utilities which tend to buy from domestic producers or from firms based in the countries with which they have historical or other significant economic ties. Smaller-sized equipment and technology using water turbines is accessible to electrical equipment producers in developing countries.

Technological leadership has been based on research and cross-licensing among main producers. Markets have been allocated by a formal cartel involving most European producers, the International Electrical Association.[14]

Because the heavy electrical equipment industry is characterized by uneven demand, and an excess of capacity due in part to industrialized countries' preference for national capabilities, there is considerable competition for access to markets of developing countries. Electrical equipment firms prefer to export, but when this proves impossible, they seek access to developing country markets via licenses or direct investments.

The operation of fuel and coal power plants involve techniques that are relatively easily transferred to developing countries. But engineering know-how is also essential to carry out adaptation and maintenance, especially in the case of nuclear power plants.

The technology associated with nuclear electricity generation poses serious saftey and reliability problems. Consequently, this option for electricity generation has been re-evaluated. In the late 1950s and 1960s nuclear energy was viewed as the 'transition' fuel to a non-fossil fuel period, but in the late 1970s solar energy is more attractive.

The major technical difficulty, saftey apart, has to do with the size of nuclear generating plants which exceed the demand of most developing countries. A basic electrical engineering precept is that major power grids should receive no more than 10% of their input from any one generating station. Since the smallest nuclear power plants presently designed and marketed are at least 600 MW (and the trend is toward larger stations, for economic and technical reasons), a grid should be at least 6000 MW in capacity to make use of one. This eliminates all but the largest developing countries.[15]

B. Costs: In comparing the costs of nuclear electricity with that generated from oil or coal (and taking into consideration the thermal unit obtained through nuclear electricity versus the themal unit directly obtained by fuel oil or coal) nuclear electricity is 3.3 times more costly than electricity from fuel oil for industrial heat and 2.7 times for household heating.[16] However, nuclear electricity proved to be slightly cheaper than electricity generated from fuel oil and coal in France in 1977. But for non-specific electrical energy needs, fuel oil and coal are cheaper: only a jump of 300% in the price of crude oil would render nuclear electricity competitive as far as these needs are concerned.

In developing countries nuclear power does not appear competitive even when specific electricity consumption (lighting, some industrial needs) uses are considered. Mention has been made of the lack of sufficient peak demand, and in addition the capital costs are much higher in developing than in developed countries.

The initial capital costs of nuclear fission reactors are considerable. Estimates for the end of 1977 were $1,240 per KW, or a total base cost of nearly $750 million for a 600 MW plant.[17] Despite lower land and labor costs in most developing countries, it seems likely that increased transportation, technical supervision, and training costs, and the large requirements of foreign exchange to pay for the sizeable imported portions of those costs may make the basic capital installation costs more burdensome for developing countries to begin with.[18]

Policy recommendations to discourage countries from pursuing the nuclear path were made in 1976 by the

U.S. Overseas Development Council. In view of the many problems associated with nuclear energy, it was suggested that countries should revise their international positions to:[19]

1. discontinue the subsidies they presently offer in the form of government financing on favorable terms for a portion of nuclear exports,

2. revise the mandate of the International Atomic Energy Agency so that the Agency would end its advocacy of the use of atomic energy and instead concentrate its efforts on its second main task, that of regulating the production and handling of radioactive and explosive nuclear materials,

3. discourage the developing countries from following the nuclear path and actively help them find better alternatives to meet their energy needs.

C. A rural energy center: Rural electrification has been a part of development plans directed towards the rural areas of developing countries since the beginning of the 1960s. According to the World Bank,[20] rural electrification may involve some 10% of total investment by these countries in the electric power sector, estimated to to total $10 billion between 1975 and 1985.

There are two conventional approaches to rural electrification. The first involves extending the national power grid that links central power stations using conventional sources of energy (hydro, nuclear, coal, or gas and oil). The second approach involves the installation of decentralized oil-fired (diesel is most common) generators in individual villages. Disadvantages of these approaches include the capital intensity of grid-generator networks, the high price of diesel, and the comparatively short life of 6 to 8 years of a diesel power generator. A diesel generator is difficult to operate and maintain in remote villages owing to the non-availability of spare parts and problems of oil transportation.

A third approach involves the harnessing of solar, wind and biogas, in a rural energy centre, in several technologies which would feed the power into a common storage battery bank of ordinary lead-calcium-acid accumulators. Electric power could then be tapped at any time for supplies to the village for lighting of homes, pumping of water and the operation of small village industries.[21]

The United Nations Environment Programme has decided to establish three rural energy centres for demonstration on an experimental basis in Sri Lanka, Senegal and Mexico.[22] In a typical village of 100 families, at a site where the solar insolation is about 6 KWh m^{-2} per day of 8 hours and the wind blows at an annual average speed of 5-6 m $sec.^{-1}$ for at least half the day and where animal wastes from about 200 animals can be collected for anaerobic fermentation yielding approximately 40-45 m^3 of biogas (60% methane) per day, it is possible to generate about 100-150 KWh per day by installing the following devices at the rural energy center:[23]

1. A solar thermal conversion device using either low grade heat (transferred from hot water heated to about 80°C-85°C by solar collectors to drive a freon turbine in a Rankine Cycle engine-generator capable of producing about 10 KW of power <u>or</u> using high temperature steam (300°C) to drive a conventional Rankine Cycle steam engine-generator of about 7.5 KW to 10 KW capacity.

2. Panel of solar cells of about 2 KW (peak) capacity which on an average day, would yield about 8 KWh.

3. Two wind generators of 2-4 KW rated capacity,

4. Commercially available diesel generators of 25 KW capacity modified to operate on biogas (60% to 65% methane) from animal wastes[24] and pyrolysis gas obtained as a byproduct of low temperature pyrolysis of agricultural crop residues and other wastes.[25]

5. A long life battery bank of lead-calcium-antimony cells, capable of storing about 150-300 KWh per day.

The system would be capable of producing a reliable 100 - 150 KWh of electricity per day, enough to meet the following needs of 500 persons (100 families) in a village:

-pumping drinking water from well 35 metres deep providing 20 litres of water per person and 40 litres per animal per day	7.0 KWh/day
-lighting of homes, streets, village community centre and school	18.0 KWh/day
-irrigation of about 5-10 hectares per day	50.0 KWh/day
-village industries (decortication and milling of grains, etc.)	50.0 KWh/day
Total	125.0 KWh/day

It is expected that energy for cooking food will be met by production of char by pyrolysing agricultural wastes, taking the energy consumption for cooking to be about 750 KWh (t) per capita per year. Some 20-30% of agricultural crop residues and such wastes as rice husks and peanut shells for low temperature pyrolytic would be / converted into char, oil and combustible pyrolysis gas. The char and oil could then be transported from the pyrolytic converter installed at the rural energy center, and their fuels supplied to individual families for burning as fuel in smokeless stoves for cooking.

The suppliers of the various components for the Sri Lanka Centre capable of generating about 100-150 KWh/day is estimated to cost approximately $300,000 to $350,000, of which half would be the cost of the equipment and half the cost of civil structures, fees of consultants/ experts and costs of training personnel.[26] Even the cost of the demonstration centers, necessarily high, compare favorably per unit of power (KWh) generated, with that produced by diesel power generators of equivalent capacity in countries where the real price of oil is 20 cents per litre or more, and financing of rural electrification is available at a rate of interest varying from 2-5%.

This survey of technologies and costs for the supply of oil and gas products, and of electricity to rural areas indicates that (1) reduction in the dependence on petroleum products is advisable, with ethanol being a possible substitute for gasoline in transport; (2) nuclear generation of electricity does not hold positive potential for developing countries in most instances and (3) conventional electrification schemes based on grids and decentralized diesel generators should be considered in conjuntion with rural energy centres based on renewable, alternative energy sources.

FOOTNOTES TO CHAPTER THREE

1. Malaysia, Bolivia, Mexico, Congo, Tunesia, and Syria.

2. Brookhaven, Energy Needs, op. cit.

3. B. F. Grossling. In search of a statistical probability model for petroleum resource assessment, U.S. Deaprtment of the Interior Geological Survey Circular 724, (Washington D.C.: Government Printing Office, 1975)

4. Drilling density refers to the number of wells per square mile of geologically promising territory. It should be noted that drilling density in the oil-producing LDCs is similarly low, with the exception of Brunei, Bahrain, and Trinidad and Tobago.

5. The world average success rate for wildcat wells is about 30%. Most of the non-OPEC LDCs have been exceeding this rate in recent years. Several countries have had particularly high success rates: Angola (80%), Brunei (64%), Tunesia (67%), and Peru (49%). Gordian Associates.

6. This approach has been advocated by Michael Tanzer. See, for example, "The state and the oil industry in today's world: some lessons for Puerto Rico, "Monthly Review" (New York: Monthly Review Press), March 1978, reprinted in P. Nore and T. Turner, Oil and Class Struggle, (London: ZED Press), 1978. Tanzer described the Indian experience with oil exploration. In 1974 the Oil and Natural Gas Commission (ONGC) undertook by itself exploration activities offshore in the Bombay High field. ONGC purchased an offshore jack-up rig from Japan and contracted an independent US drilling company to carry out the work and train Indian personnel for a set fee, totalling 26 million dollars. Oil was discovered, worth $ 14 billion, representing a gain over 400 times the investment.

7. Carlos Añez, Technology transfer to the exploration and production stages of the oil industry, (Science Policy Research Unit: University of Sussex), Falmer, Brighton, Ph.D. thesis, 1978.

8. Jose Goldemberg, "Alcohol from plant products: a Brazilian alternative to the energy shortage," (mimeo) Fourth Annual College of Biological Sciences Colloquium, Columbus, Ohio, September 1977.

9. Jose Goldemberg and Robert H. Williams, "Energy strategies for developed and less developed countries," Final report to the Overseas Development Council, Center for environmental studies, Princeton University. February 10, 1978 (mimeo), p. 22, chapter 4.

10. N. L. Brown, J. W. Howe, "Solar energy for village development," Science, 10 February 1978, vol. 199, pp. 651-657.

11. Ibid., p. 657.

12. See especially, The Rockefeller Foundation, "International energy supply: a perspective from the industrial world," International policy studies, (New York: The Rockefeller Coundation), May 1978. The study states that "The influence which major industrial oil-importing states might bring to bear on exporters' decisions /to produce more oil/ cannot be matched by that of developing nations. Their dependence on oil is also increasing, but their ability to compete for available supply is slight." p. 9.

13. The industry leaders are General Electric and Westinghouse in the U.S.; General Electric in England; Siemens and AEG in Germany; Hitachi in Japan and Brown Boveri in Switzerland. Several French, Japanese, American, Swedish and Italian companies also participate but in more specialized market lines. There are about 250 manufacturers of power and distribution transformers in the world, employing about 120,000 people. The 25 largest firms employ 90,000 people (75% of the labor force) and account for all exports. Unctad, "Transfer and development of technology in the energy sector," (TD 588/10(5)), draft, 23 May 1978, p. 45, citing A. Cilingiroglu, Manufacture of heavy electrical equipment in developing countries, World Bank, 1969, p. 16.

14. See B. Epstein and K. Mirow, Impact on developing countries of restrictive business practices of transnational corporations in the electrical equipment industry: a case study of Brazil, UNCTAD/ST/MD/9, 1977, chapter 3, for a discussion of the cartel.

15. Only Pakistan, India and Argentina presently have operating nuclear power reactors, but they will be joined during the next few years by Brazil, Iran, Mexico, South Korea, Cuba, the Philippines, Indonesia, Kuwait, Taiwan, Turkey, Egypt, and Libya. The International Atomic Energy Agency (IAEA) estimates that an additional 17 developing countries may be generating electricity with nuclear power by the year 2000.

16 UNCTAD, "Transfer and development of technology in the energy sector," op. cit., p. 55.

17. J. A. Lane, "Nuclear energy in developing countries," Petroleum and beyond conference, (London, Ontario: University of Western Ontario), March 31, 1978.

18. A large portion of the costs of nuclear reactors lies in the elaborate series of safety mechanisms necessary to safeguard against leadage of radiation and possible accidents or equipment failures. Even so the questions of waste disposal and reactor decommisioning remain unresolved.

19. James W. Howe and William Knowland, "Energy and development. an international approach," Communique on development issues, Overseas Development Council (Washington, D.C.), No. 31. December 1976.

20. World Bank, Rural electrification, (World Bank: Washington D.C.), 1975.

21. H. Usmani, "Rural electrification: an alternative for the third world," Natural Resources Forum 2(1978), p. 272. The paper reported that a system has been developed for the UN Environment Programme by the Oklahoma State University which enables the power output from any of the three sources, solar, wind and biogas obtained from anaerobic fermentation of animal wastes, to be used directly or through the battery bank. Ibid.

22. H. Usmani, op. cit., p. 272. The U.N. Centre for Natural Resources, Energy and Transport will be the co-operating agency and will assist UNEP in establishing these centers.

23. This data is from Feasibility report for a rural energy centre in Sri Lanka, Engineering Energy Laboratory of Oklahoma State University, June 1976, cited in Usmani, op. cit. The Rankine Cycle engine-generator driven by freon was developed by Sun Power Systems, Sarasota, Florida, while the conventional Rankine engine-generator was developed by Omnium-G company, Anaheim, California.

24. These generators which operate on biogas were developed by Onan power generators, Minneapolis, Minn. Usmani, op. cit., p. 277.

25. Developed at the Georgia Institute of Technology, Atlanta, by John Tatom and associates. Ibid.

26. Usmani, op. cit., p. 275.

CHAPTER FOUR

TECHNOLOGY FOR DIRECT SOLAR ENERGY

The last chapter dealt with non-renewable sources of energy - oil and gas, coal and uranium. This chapter discusses one category of renewable energy: direct solar energy.[1] Direct solar energy is converted through a wide range of technologies into energies of differing levels of quality ranging from low temperature heat to electricity. Table 4-1 illustrates with wide range of technologies for both direct and indirect solar energy, together with the village tasks to which each might be applicable. Technologies for converting indirect solar energy (vegetable matter, wind and water power) are discussed in chapter five.

Sunlight can be captured directly and used for a number of different ends. Most simply, solar collectors or pannels can collect the sun's heat for cooling, heating, drying and related tasks. Higher temperature heat can be gathered using parabolic merrors. Such high temperature heat is useful in smallscale industries in the food and textile area, for instance. Solar heat can be used for mechanical energy in heat engines, which have been used for pumping water. Finally, direct sunlight can generate electricity through photovoltaic cells (also known as solar cells).[2]

For each major type of direct solar technology there follows a description of the main features, and a summary of costs of producing the technology and energy from it.

Table 4-1

Solar Energy Applicability Matrix. Animals are included as a solar technology (based on photosynthesis). For many villages the use of animals would represent a modernizing step. It includes the use of dung for burning or fertilizing. Presentation by J. R. Williams.**

Symbols: ++, applicable; +, potentially applicable; -, not applicable.

Solar technology	Energy Use: Water pumping	Lighting	Cooling	Communications	Water desalting	Spinning	Sawing	Heating: Cooking	Heating: Space	Heating: Domestic water	Grinding	Drying	Transport	Fertilizing
Solar cells	+	+	+	++	-	+	-	-	-	-	+	-	-	-
Flat-plate collectors*	+	-	+	-	++	-	-	+	++	++	-	++	-	-
Concentrating thermal collectors	+	+	+	-	+	-	-	+	-	-	-	-	-	-
Solar, Stirling (small scale)	+	+	+	+	-	+	+	-	-	-	+	-	-	-
Solar, rankine	+	+	+	-	-	+	+	-	-	-	+	-	-	-
Wind (mechanical)	++	-	-	-	-	+	+	-	-	-	++	-	-	-
Wind generator	++	++	++	++	-	+	+	-	-	-	++	-	-	-
Water (mechanical)	++	-	-	-	-	++	++	-	-	-	++	-	-	-
Hydroelectric	++	++	++	+-	-	++	++	-	-	-	++	-	-	-
Bioconversion wood/charcoal	-	+	-	-	-	-	-	++	++	++	-	++	-	+
Biogas	+	++	+	-	-	-	-	++	-	+	-	+	+	++
Draft animals	++	-	-	-	-	-	-	+	-	+	++	-	++	++

*Includes solar stills.

**Source: Tanzania National Scientific Research Council, Energy for the Villages of Tanzania, (Dar es Salaam: National Scientific Research Council) 1977, p. 27.

1. SOLAR THERMAL TECHNOLOGY

A. Solar collectors: Solar collectors are the main components of solar thermal technology. In the most direct (or 'passive') systems, the sun's heat is used to warm water or enclosed living or work space. In a more 'active' solar heating and cooling system, there is a heat-storing medium (usually water, but also helium) which is warmed in the solar collector and circulated through the building.

I. Flat plate collectors for low temperature heat:

The collector panels are usually long, flat boxes located on the roof or on the ground near the buildings to absorb the sun's radiation. A typical collector is eight feet long and from two to four feet wide. Its design consists of a metal plate or metal tubing to absorb heat. Below the plate or tubing is conventional heat insulation. Black paint or other coatings are sometimes applied to the metal plate or tubes to increase their ability to absorb heat. A plastic or glass cover is placed on top to prevent the escape of heat. Another way of increasing the heat retention is to create a vacuum between the absorber plate and the transparent cover. Sometimes glass tubes are used instead of metal collector tubes or plates.

During sunless periods and nights, the energy which was stored can be utlized. Storage tanks for water-circulating systems are similar to hot water tanks. Air-type systems channel the heated air to large pebble bins, usually underground. Air or water can then be circulated through the heated pebbles to pick up the stored heat. If the solar collectors are being used for cooling, the energy of their heated liquid can drive a standard absorption air conditioner directly, or it can drive a small motor that powers a mechanical air conditioning system. The remaining elements of solar systems - pumps, valves, piping, insultation, thermostatic controls - are the standard items of the heating and cooling industry.

Flat plate collector technologies are tested, reliable and can be partly built and assembled at village level in many instances. Solar water heating is used widely in Israel, Japan and Australia, and in some buildings in West Africa (mostly private homes and commercial hotels). Open air crop drying could be replaced by or supplemented with solar crop dryers which also have the advantage of using no firewood.

Solar collectors can also be used to produce drinking water through distillation of brackish, muddy or polluted water by evaporation, moisture condensation and collection. Water distillation units constructed from glass, concrete and copper can deliver clean water for a few dollars per gallon over a life of 20 years. Such a unit would be located near a river or waterhole and provide clean water daily at low cost. However, one disadvantage is that there is very little economy of scale associated with distillation units. A solar distillation unit could be combined with a solar pump, to lift water for human, animal and irrigation purposes.

Solar water pumps are a promising application for flat plate collector technology. But before efforts are made to install solar pumping devices, it might be advisable to assess the potential for installing manually-operated pumps which have been designed for maximum efficiency and for operation by villagers.

In the solar pumps developed by the French firm, SOFRETES, flat plate water heaters are used to vaporize butane or another intermediary liquid which in turn operates a reciprocating engine.

In the United States there is much debate on the relative merits of 'active' and 'passive' solar systems.[6] The passive systems rely on structural walls, windows and other features of the building itself to provide heating and cooling. There are few moving parts, and no medium such as circulating water, which decreases capital and maintenance costs. However, because these designs are most applicable to new buildings rather than to technology manufacturers, they are the concern of architechs and are not dealt with explicitly here.[7] Because passive solar systems are efficient and currently used in one form or another in much traditional developing country architecture,[8] their potential should not be ignored. This is all the more important, given the relative neglect of passive solar systems by the companies presently engaged in commercializing alternative energy technology. The alternative energy industry does not include passive systems, presumably because of the need for specific building details for each unit, and the limited commercial opportunities offered by such systems (due to their minimal use of technologies).[9] However, the proponents of passive systems claim that they are in many instances more suitable that the expensive, complicated technologies for other types of alternative energy harnessing.

II. Concentrating collectors for high temperature heat: More sophisticated solar collectors are required for higher temperature heat. The solar concentrator involves intense concentration of solar radiation by means of either parabolic mirrors or mirror arrays (a number of anled mirrors). These may be aimed at a boiler, which in turn produces steam to operate engines or electric generators. Parabolic mirror, flat mirror and other concentrator types can produce heat with tempteratures ranging up to 3000°C. The main technical difficulty in both simple and more sophisticated solar collectors lies in raising the solar heat absorption capacity of the collector in order to obtain high temperature heat. Sun-tracking devices are a possible solution, since a collector which tracks the sun has a higher heat absorption performance than a fixed device. However, a tracking collector has a much higher costs since a rotating fixture of relative technological complexity has to be fitted.

High costs and complexity of operation make solar concentrator technology unacceptable for use in most developing

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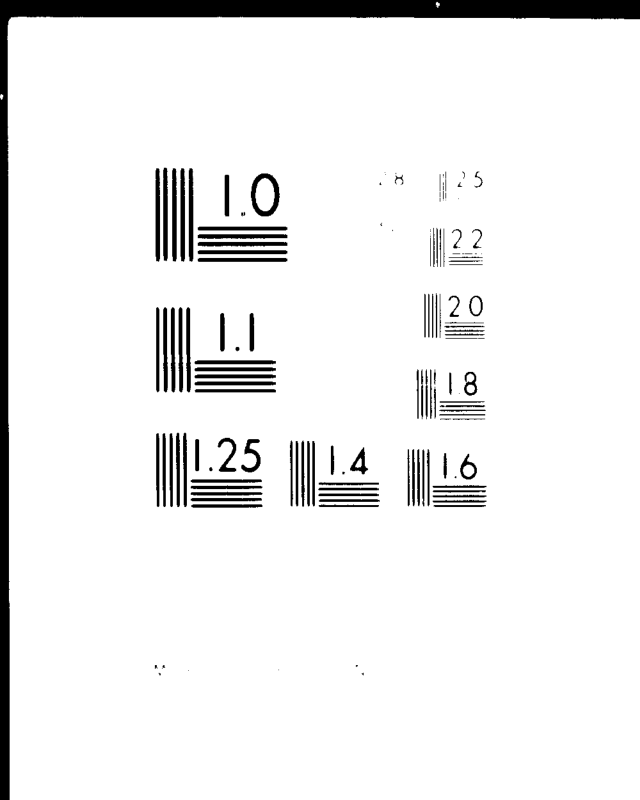

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countries, at present, especially in rural areas. Concentrators are used in solar cookers. But efforts to introduce such cookers into village use in the form of parabolas which focus radiation onto a flat metal burner plate or pot have had little success. This is due apparently, to cultural obstacles and to the fact that the cooker can only be used during the daytime. In addition, the unit is costly and clumsy. Experiments are being conducted on an acid storage cell which could absorb solar energy, store it, and then release the heat energy when inverted.[10] But there are serious technical obstacles to overcome in this cooker, including the use of sulphuric acid, a dangerous substance, as a base material. The United States Agency for International Development (USAID) is experimenting with other types of solar cookers in Haiti.

B. Improving solar collectors: One technological frontier has to do with the materials for making the collector and for coating it. Copper is the best absorber plate material since it resists corrosion. But it is more costly than aluminum or steel. Efforts are being made by U.S. firms, among others, to use aluminum panels or those made of steel (Honeywell) and inhibit corrosion through the addition of chemicals in ciruclating water. However, this requires constant regulation for chemical balance and is thus impractical for smaller installations, or for those located in rural villages.

Another cost-reducing approach is to vary the solar collector design. Two collector-producing firms, Owens-Illinois and Corning, are studying the potential of making collectors from long, narrow glass tubes, enclosing other liquid-containing tubes in a vacuum. Northrup's design includes a plastic lens and a wedge-shaped reflector, which tracks the sun, to focus the light onto an absorber plate.[11] Such devices are intended for driving absorption air conditioning units, since the 200°F or higher temperatures required are more efficiently produced by concentrating than by flat plate collectors.

General Electric, AAI and Sheldahl are developing solar collectors that can reach higher temperatures. For one unit, rows of mirrors rotate to focus light on a line of narrow pipes. Little copper is used but only direct sunlight can be tapped and complex tracking devices are necessary.

Costs can be reduced by making flat plate collectors more efficiently with improved coatings for the plate or the unit's cover. If more heat were captured, fewer collectors would be required. Some coatings absorb more heat than simple black paint. Others 'trap' heat, rather than allow it to escape through re-radiation as does black paint. A partial vacuum around the absorber plate also reduces heat loss.

Heat pumps can be used to reduce the number of required solar collectors. Such pumps raise the temperature level of heat by means of work input, and typically deliver 2.5 kilowatts of heat for every electrical kilowatt needed to power them.[12] Westinghouse and Sol-R-Tech are two U.S. solar equipment manufacturers who combine collectors with the pump. Solar-heated water is delivered to the heat pump which then boosts the temperature to the level needed for heating.[13] In 1973 Pennsylvania Power and Light built a house that had a solar-heat-pump installation, and Sol-R-Tech equipped a small commercial building in Vermont with a similar system. Sol-R-Tech claims its system used 65% less power than an all-electric heating system would have used.

The methods of increasing solar collector efficiency listed above may also be means of reducing costs. Today, solar heating and cooling systems are commercial, in that over 100 firms produce and sell the collectors and related components.[14] Nevertheless, costs remain high, compared to alternatives.

C. Costs: The minimum cost of a collector is in the range of $150 to $200 per square meter (current 1978 U.S. dollars). However, commercially installed systems may cost as much as $500 per square meter.[15] The major barrier to massive use of solar heating and cooling is the high cost of installations relative to standard systems.[16] Nevertheless, solar heating and cooling is the most immediately available and popular type of alternative energy technology. Solar domestic hot water heaters are the simplest type of unit, and also the least costly.[17]

The initial cost of installation is two to four times that of conventional heating systems. Operating costs are low. Solar-heating systems require between 200 and 400 kwh per year to cir-

culate air or water. In addition to the higher installation cost, a conventional system is usually required to back up the solar unit during sunless periods. A solar water heater, which can be readily fitted to an existing house now costs between one and two thousand U.S. dollars, installed.[18]
Such a solar water heater would pay for itself in fuel savings in five to seven years. However, an entire solar heating system costs from $5,000 to $10,000, installed and takes between ten and twenty years to pay for itself.

The costs of solar water pumps remain beyond the budgets of individual villagers or even villages in most areas of the developing world. Since 1968 demonstration pumps have been installed in over a dozen developing countries, mainly in Africa, where they have operated successfully. But because of their present cost in the range of $10,000 per installation (for a 50KW pump capable of raising from 14 to 25,000 cubic meters of water per day from a depth of 25 meters) they can be established in villages only with government or other subsidies.

The future of solar heating depends on market expansion and cost reductions. The technology is available from a large and growing number of sources. If installations costs could be reduced by one-half to two-thirds, the systems would become competitive with standard systems. If fuel savings over the systems' useful life are taken into account, solar heating and cooling is already competitive in many instances. Another variable in the economics of all solar energy is the price of conventional fuels, which are certain to be at least double by the end of the century.

2. SOLAR THERMAL POWER GENERATION

A. Technology: Just as solar concentrators can be used to intensify the sun's heat to produce steam for driving engines, they can be used to produce steam for driving electricity generators.[19] But the cost and complexity of concentrating collectors puts this solar technology out of the reach of most rural peoples. Efforts are being made in both the developed and developing countries to bring costs down. Electricity from the sun offers an attractive alternative to the widespread but inadequate grid electrification programs of the 1960s.

The technology developed for solar thermal power generation spans a wide range. The simplest is a 10 KW capacity plant which combines flat plate collectors and a vapour turbine in a Rankine Cycle motor. At the other extreme is a large-scale plant with a capacity of up to 100 MWe consisting of some 10,000 heliostats (moving mirrors) in a one square mile area to collect heat, transmit it to a high tower on which a boiler is mounted. The heat converts boiler water into steam which then drives a conventional turbine generator.

For solar-electric power plants, the annual sunshine hours should be as many as possible, and the humidity, which causes absorption and scattering, should be low. Examples of areas suitable for large power plants include India's Thar desert, Iran, Namibia's Kalahari Desert, Mexico, Saudi Arabia and in the industrialized countries, the U.S. Mojave Desert and West and Central Australia.[20] Solar electric systems are being conceived in combination with conventional systems as well as on their own. The over all solar electric system may serve as a backup, operating only when the sun shines, and equipped with a small energy storage capacity (perhaps one hour) to bridge temporary cloudy periods. Or the system could include a conventional fuel system to replace solar energy at night or on cloudy days. Finally, an independent solar-electric system could include a storage system to ensure continuous power-generating capacity.

The simple solar-thermal power systems consist of widely distributed flat-plate or parabolic collectors. The collectors focus sunlight on a heat pipe carrying the working fluid. The heat pipes are coated to maximize absorption and minimize heat emission. The flat plate collectors produce heated water to a temperature of 250-500°F (121-260°C) at the point of entry to the turbine. Much higher temperatures are possible with the parabolic trough collectors (550-1000°F or 288-538°C). The higher the temperature, the higher the efficiency and the smaller the land areas needed for a given power level. But high temperature systems are more expensive due especially to the costs of the piping and the coating.

A more complex type of solar-thermal electricity technology relies on centralized heat reception. Solar heat is concentrated by a large number of sun-following mirrors on a central point, on top of a tower. The power output of such a unit depends on the collector array area, which in turn determines the tower height.[21] The total area acts as a large parabolic mirror.

Both types of solar electricity systems require large areas. But the simplest, distributed receiver system can be divided into smaller modules, either on their own or together. Each would have a small standardized electric power station. The centralized receiver system is more efficient than the distributed system because the working fluid can be heated to a higher temperature. For instance, one square kilometer of collector area (not total area covered by the system) in the centralized design may yield 150-200,000 KWe while 1.5 sq. km would be required for the same output from a distributed receiver system.

To provide power during sunless hours, part of the energy generated during sunshine hours must be stored (thus reducing the amount of energy available during sunny periods). Among the storage options are heat retaining, mechanical energy (pumping water to elevated storage basins), or as chemical energy (electrolytic decomposition of water to hydrogen and oxygen). Wind generators could be attached to the central receiving systems, on top of the tower to take advantage of wind as well as sun.

Solar thermal generating systems at the lower end of the technological scale (distributed receiving systems) may have some applicability in remote areas which have no access to standard grid systems or supplies of conventional fuel. Five industrialized countries[22] produce the technology but require it themselves only in exceptional circumstances due to well-developed indigenous power grids. The Austrian Government will provide know-how for constructing a 10KW solar power system free of charge.[23]

B. Costs: Economic competitiveness of solar thermal generating technologies is not clearly established. Technological improvements are required to make the option viable for dependable power generation. Solar collectors are subject to refinement, and tracking devices need to be made more efficient. The manufacturing cost of the equipment needs to be lowered. However, an executive in an Indian engineering firm, Bharat Heavy Electricals Ltd., which is developing solar generating technology, predicted that

"Within ten years, small size power packs of 20KW to 500KW will become one of the economic solutions for rural energy supply in many parts of industrializing countries where the transmission and distribution systems are not established.[24]

3. SOLAR CELLS

A. Technology: Solar cells spread over an area of varying size can be used to produce direct current electric energy.[25] Via a process developed in the early 1950s, the photochemical cells transform solar radiation in the form of photons of light into electricity. The most popular and best developed are silicon solar cells, although cadmium sulfide and others are available. The cells are fragile and thin, and are normally arranged in units capable of generating 1 kw. They have been hitherto employed in specialized uses ranging from power for outer space technology to buoy lights in Japan, remote TV reception in Niger, and highway signals in the U.S.

The main advantage of the solar cell electricity generating system compared to the solar-thermal systems is the absence of moving parts and fluids at high temperatures. No cooling is needed and probably no sun tracking. Another advantage is the long life of the cells which could potentially last up to 100 years. Major disadvantages are the comparatively low efficiency (probably 20% even after extensive development) and the fact that thermal storage cannot be used. Considerable development is required before the system can be economically competitive with thermal solar generating systems, or more conventional electricity generation.

B. <u>Costs</u>: The main construction materials for solar cells--glass and silicon--are abundantly available and relatively cheap. But the manufacturing techniques are costly. The World Energy Conference estimated a minimum cost for solar cell systems of $15,000 per peak kilowatt of electricity. This is from 100 to 200 times more expensive than is generation by conventional methods.[26] Current costs for solar arrays are estimated to be higher by other sources. The U.S. Overseas Development Council estimated that costs at approximately $15,000 to $70,00 per peak KWe and $120,000 or more for an average KWe.[27] However, crystal ribbon growth techniques currently being developed, may well result in solar arrays being available at under $1,000 per average KWe in the next decade. The cost could go as low as $500 to $825, according to the Overseas Development Council. Efforts are being made to reduce fabrication costs. The U.S. government agency, ERDA, expects that by 1986 costs will be in the range of $500 per peak kilowatt or one-thirtieth of the present level.[28] Clearly, the technology for solar cells is in a state of rapid development which makes the future commercial possibilities difficult to predict.

The comparison between transistors and solar cells has often been made. Technological breakthroughs in the production of solar cells could make them commercially competitive in much the same way that transistors became available cheaply, and consequently revolutionized the electronics industry.

Costs of supplying electrical power by a solar cell array were estimated by the Tanzanian government in 1977.[29] The analysis was based on a solar cell cost estimate of $20 per peak watt, which is a high estimate chosen because a more favorable price would not likely be available for small volume purchases.[30] Table 4-3 summarizes the cost calculations. They indicate that an array with a peak power capacity of one kilowatt will produce, on average, 5.3 kWh daily, given Tanzanian insolation (sunlight).[31] Thus, for 300 kWh per day, an estimate of 60 KW was used. An interest rate of 10% per annum was used to calculate financing costs. The estimated cost of energy provided by solar cells, Sh 11 per kWh ($1.33/kWh), is approximately 12 times the average current (1977) cost of grid electricity in Dar es Salaam.

But the cost of solar cells is expected to fall, perhaps to $0.50 per peak watt by 1985 (U.S. Department of Energy). Electricity cost is sensitive to the cost of the solar cell array, as estimates by the Tanzanian government indicate. For an array

Table 4-2

Cost calculations are summarized in Table 9.* The size of the array needed to supply 300 kWh daily was based on World Meteorological Organization (WMO) insolation data for Tanzania.** These figures indicate that an array with a peak power capacity of one kilowatt will

TABLE 9 Cost of Supplying Electricity by Means of Photovoltaic Generators

Base Data	Lifetime of silicon solar cells	20 years
	Lifetime of batteries	6 years
	Efficiency of batteries	85%
	Cost of silicon solar cells	Sh 160/W_p (a)
	Cost of batteries	Sh 800/kWh
Equipment Costs	Solar-cell array 60 kW_p (b) @ Sh 160/W_p	Sh 9,600,000
	Battery storage (300 kWh @ 85% efficiency) 353 kWh @ Sh 800/kWh	Sh 280,000
	Total equipment costs (approx.)	Sh 10,000,000
Financing Costs (c)	Solar-cell array Sh 9,600,000 @ 10% for 20 years	Sh 1,100,000/yr
	Batteries Sh 280,000 @ 10% for 6 years	Sh 64,000/yr
	Total cost of financind (approx.)	Sh 1,200,000/yr
Cost of Electricity	Total energy generated	110,000 kWh/yr
	Unit cost	Sh 11/kWh

(a) W_p = peak watt
(b) See text.
(c) Based on amortization of loan in equal yearly installments.

produce, on the average, 5.3 kWh daily. Thus, for 300 kWh/day, an estimate of 60 kW was used. An interest rate of 10 percent per annum, currently prevailing in Tanzania, was used to calculate financing costs. The estimated cost of energy provided by photovoltaics, Sh 11/kWh, is approximately 12 times the average current cost of grid electricity in Dar es Salaam.

*In view of the uncertainties in the cost estimates, all numbers are given only to two significant figures.

**World Meteorological Organization, average of data for June 1966.

cost of Sh 4.1 per peak watt ($0.50 per peak watt), the total system cost illustrated in Table 1-A would be Sh 528,000 ($64,000). The annual cost would then be Sh 94,000 ($11,000) and the cost of the electricity Sh 0.83 per kWh ($0.01 per kWh). This is a very large decrease, bringing electricity costs to 10% below the cost of conventionally-generated electricity in Tanzania (with grid in place). The cost would drop to half the urban grid price if electricity was used only when generated, so there was no 'on demand' capability of the system.

The break-even array cost, which would enable on-demand electricity to be generated at the average current selling price in Dar es Salaam would be Sh 5.28 per peak watt or a solar cell price of $0.64 per peak watt. On these assumptions, solar cells for electricity generation would be economically competitive with grid electricity in less than 10 years in Tanzania.[32] For villages which require small amounts of electricity (enough to power a two-way radio, for example), but are distant from the current electricity grid, solar cells may already be cost-effective compared with conventional alternatives.[33]

Commercial applications for solar cells are growing. Estimates by the World Bank demonstrate solar cells to actually be cost competitive with regular dry cell storage batteries for use in Ivory Coast for remote TV reception. As a substitute for batteries in inaccessible locations, solar cells are particularly attractive. This use pertains mainly to high value applications such as radio and TV with low loads of between 1 to 100 watts.[34] There is considerable potential for solar cells in providing power for water pumps. A cell-covered surface of some 100 sq. meters can produce 5 KW capacity which is capable of pumping 470 cubic meters of water per day from 10-meter depth or 53 cubic meters per day from an 80 meter depth. SOFRETES[35] is experimenting with demonstration models in several developing countries. Under certain circumstances, solar cell-powered water pumps are nearly competitive with diesel-powered pumps. The present cost of diesel pumping was compared with the hypothetical cost of solar cell pumping (the cost of which was assumed to be $1 per peak watt) in India. Table 4-4 shows that the solar cell option is about 25% more expensive than the diesel water supply.[36] If solar cells can be produced more efficiently (and the cost-reduction projection suggest that this will occur), and if diesel prices increase as expected, solar water pumps may soon become competitive.

Table 4-3

Comparison of diesel versus solar powered irrigation pumps in India

Capacity: 50 kilolitres/day at 5 to 8 metres head, 300 working days
Assumptions: (i) Cost of solar cells is Rs. 10 (approx. $1) per peak watt as expected by CRDA by 1985
(ii) Cost of diesel oil is Rs. 1.50/litre

Solar water supply		Diesel water supply	
A. Capital cost			
(i) 1 kW solar panel	Rs. 10,000	(i) Diesel engine	Rs. 3000
(ii) Battery wiring, switches, etc.	Rs. 4,000	(ii) Pump set, bore well, pumping, etc.	Rs. 3000
(iii) 500 watt dc motor pump set, bore well, pumping, etc.	Rs. 3,500		
Total investment	Rs. 17,500	Total investment	Rs. 6000
B. Annual cost			
(i) Depreciation of solar panel (20 years life)	Rs. 500	(i) Depreciation (10 years life)	Rs. 600
(ii) Depreciation of other equipment (10 years life)	Rs. 750	(ii) 10 per cent interest	Rs. 600
		(iii) Diesel à 0.5 litre/h, 300 working days	Rs. 1125
(iii) 10 per cent interest	Rs. 1,750	(iv) Maintenance	Rs. 500
(iv) Maintenance	Rs. 500		
Total annual cost	Rs. 3,500	Total annual cost	Rs. 2825
Cost of water = Rs. 0.24/kilolitre		Cost of water = Rs. 0.19/kilolitre	

Source: Anil Agarwal, "Solar energy and the Third World", New Scientist, 9 February 1978, p. 358

The figures obtained should be looked at with much caution since the calculation is based on approximated values and simplifying assumptions.

FOOTNOTES TO CHAPTER FOUR

1. Denis Hayes, "Energy for development: third world options," Worldwatch paper 15 (Washington D. C.: Worldwatch Institute), December 1977.

2. Solar hydrogen gas production technology is in the initial states of development and therefore is not discussed here.

3. The dividing line between low and high temperature heat is 220°F.

4. Herman and Cannon, op. cit., p. 16. Only two of the 25 firms surveyed by the authors produced air-type collectors. These were Solaron and Sunworks.

5. National Academy of Sciences, Energy for rural development, (Washington D. C.: National Academy of Sciences) 1976, p. 76

6. New Times (Denver, Colorado), May 15, 1978.

7. Solar heating and cooling systems can be used effectively in combination with measures to insure a building's resistance to external temperature changes. Insulating steps such as roof and wall insulation, storm doors and windows, sealing of cracks, etc. increase the efficiency of solar technology. One estimate puts the energy savings resulting from careful insulation at 35%. Investment on such measures would pay itself back in energy savings within ten years.

8. For example, thick-walled buildings in Northern Nigeria are traditionally designed to maximize cooling in summer and heat retention in winter.

9. Passive solar systems are described in Bruce Anderson, Solar Energy: fundamentals in building design (New York: McGraw-Hill), 1977, and J. F. Kreider and F. Kreith, Solar heating and cooling, engineering, practical design and economics (New York: McGraw-Hill) 1977.

10. ODC, Energy for the Villages of Africa, op., cit., p. 17.

11. A disadvantage of the concentrating collector is that it can only use direct sunlight, rather than light reflected from clouds, buildings and other objects. In contrast an ordinary flat-plate collector without tracking device can use indirect or reflected light.

12. A typical heat pump includes a compressor which takes refrigerant vapor from a low-pressure, low-temperature evaporator and delivers it at a high pressure and temperature to a condenser. Ideally for 1 kilowatt-hour of electric energy input to the compressor there will be delivered sixty thousand Btu/hr as refrigeration or heating effect as required. This is a great improve-

ment over the alternative use of resistance heating where 1 kilowatt hour of electricity would deliver only 3413 Btu. Data from Encyclopedia of Energy, edited by Daniel N. Lapedes, McGraw-Hill, New York, 1976, p. 353.

13. Electric utilities are interested in th . approach, because such systems would use more electricity tha.ı all-solar systems, but less than standard electric "resistance" heating. Herman and Cannon, op. cit., p. 21.

14. Ibid., p. 15.

15. Unctad, op. cit., p. 57, citing World Energy Conference, World Energy Resources 1985-2020, (New York: IPC Science and Technology Press) 1978, p. 142.

16. This is a comparison based on U.S. conditions which may not be applicable to developing countries where standard heating and cooling systems may be more expensive. In the U.S. one fourth of all energy is used in heating and cooling buildings, which means that solar heating-cooling systems have a potential market that is very large.

17. Small companies in the U.S. South manufactured thousands of solar water heaters in the 1930s and 1940s only to be displaced by mass-produced water heaters operating on cheap electricity, natural gas or oil. Herman and Cannon, op. cit., p. 17.

18. **Alcan Aluminum Corporation** lists a water heating system using 7' x 5½' solar panels as costing $1,300 installed.

19. Solar energy can be used to generate electricity with photovoltaic cells, as discussed.

20. The interest in large 'power tower' solar electric generating systems is stimulated by the potentially vast amounts of alternative fuels which could be replaced. For instance, in the geographical areas noted above, if solar radiation over 1,000 km^2 is converted to electric energy at only 20% efficiency, the output is equivalent to the annual consumption of 734 million barrels of crude oil or 161 million metric tons of coal. Energy encyclopedia, op.cit., p. 630.

21. Energy encyclopedia, op. cit., p. 630. The horizontal distance of the farthest mirror from the foot of the tower is about twice the tower height, which ay range from 250 to 500 m. One plant can have a large number of such towers and accompanying arrays of mirrors.

22. Isreal, U.S., Federal Republic of Germany, France, Austria.

23. Unctad, op. cit., p. 59, quoting **Austrian** 10 KWe Solar Power Plant--a project of the Federal Ministry for Science and Technology (**Austrian** Federal Press Service: Vienna), 1977.

24. Unctad, *op. cit.*, p. 60, citing H. N. Sharan, "Solar thermo-electric power systems," presented at the International Solar Energy Conference, New Delhi, January 1978, p. 8.

25. Direct current is advantageous in long-distance transmission since losses are lower than in the transmission of alternating current. But for most uses, the direct current must be converted into alternating current.

26. World Energy Conference, *op. cit.*, p. 145.

27. Energy for the Villages of Africa, *op. cit.*, p. 17.

28. Unctad, *op. cit.*, p. 61. Another source, Scandia Laboratories, expects to produce solar cells capable of generating electricity at the cost of $250 per peak kilowatt by 1985.

29. Tanzania National Scientific Research Council, *Workshop on solar energy for the villages of Tanzania* (Dar es Salaam: Tanzania National Scientific Research Council), August 11-19, 1977, published 1978, p. 36-38.

30. In a recent large scale purchase, the U.S. government, the cost was $15 per peak watt, and in 1978 the price fell below $12 per peak watt. *Ibid.*, p. 36.

31. The size of the array needed to supply 300 kWh daily was based on World Meterological Organization (WMO) insolation data for Tanzania, June 1966.

32. Assuming a constant cost for grid electricity, which is optimistic as fuel prices for coal and oil will rise significantly in the coming decade.

33. Tanzania National Scientific Research Council, *op. cit.*, p. 83.

34. National Academy of Science, Energy for rural development, *op. cit.*, p. 97-106.

35. Anil Agarwal, "Solar energy and the third world," *New Scientist*, 9 February 1978, p. 358.

36. SOFRETES is an affiliate of two French firms, Renault, C.E.A. and CFP, the French state oil company.

CHAPTER FIVE

TECHNOLOGY FOR INDIRECT SOLAR ENERGY

In addition to direct solar energy, there is indirect energy to be captured from the sun in the form of wind, wave, tide and ocean thermal gradients. Plant matter can be burned or fermented as can human and animal waste and other refuse.

Which of these various types of indirect solar energy are most useful to developing country rural populations is the subject of some debate. For instance, UNCTAD determined that "wind technology, wave and tidal technology and ocean thermal technology are generally believed to be of less significance for the developing countries...."[1] Of the various types of biomass conversion, UNCTAD emphasized biogas, given its proven importance in developing countries.

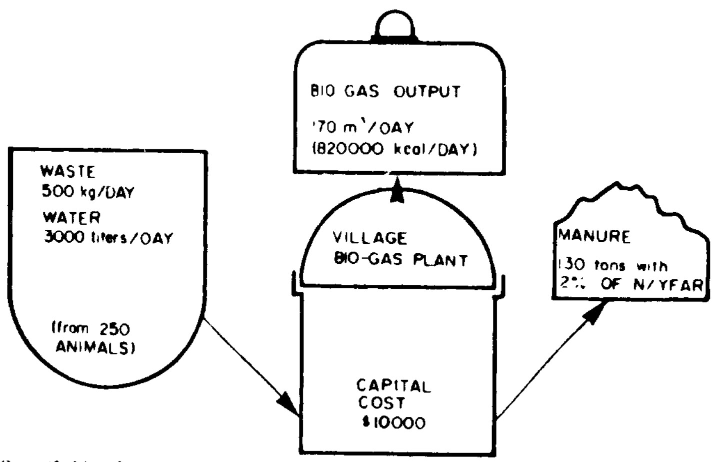
In contrast, the U.S. - based Overseas Development Council reporeted that for certain countries "wind represents one of the most promising sources of energy for water pumping, certain agricultural tasks and cottage craft industries, and low load, high value electrical demands such as lighting and telecommunications."[2] This debate is not surprising, given the early stage currently reached in the search for alternative energy sources. The following discussion focuses on biogas, small-scale hydropower, windmills and woodfuel. The bulk of the literature would appear to support the UNCTAD endorsation of biogas as the leading alternative energy option.

1. <u>BIOGAS</u>

A. Technology: Biogasification involves the anaerobic (airless) fermentation of animal dung, human night soil and organic farm and household debris and wastes in relatively air tight tanks, to produce methane gas (with about 60% content) for fuel. This fuel (also known as gobar gas) is useful in agricultural, domestic and cottage craft activities. Cooking and small-scale power generation can be fueled with biogas. The remaining liquid (a nitrogen-rich slurry) is valuable as a fertilizer, especially in that it is partially sterilized. The diagrams below illustrate the operation of a biogas plant and show what a village system would look like.

Technology for the production of biogas is known and reliable, particularly where livestock are abundant. It has been used by large numbers of wealthier farmers in Korea, Taiwan, China and India. Problems do arise with regard to consistency of output during the cold season in high latitude or high altitude countries. In addition, costs for construction materials (steel, cement, tubing, gas appliance fixtures, adapted equipment such as plastic or rubber instead of steel and cement) can be an obstacle. Nevertheless, biogas is one of the most promising of all small scale energy technologies. It is most attractive if installed to serve a whole village rather than one family.

Diagram of a village biogas plant



Quantified benefits per capita

1. Availability of 6×10^6 kcal/yr of energy in a convenient form
2. Availability of 5.2 kg of nitrogen per year and consequently 52 kg of additional foodgrains per yr.

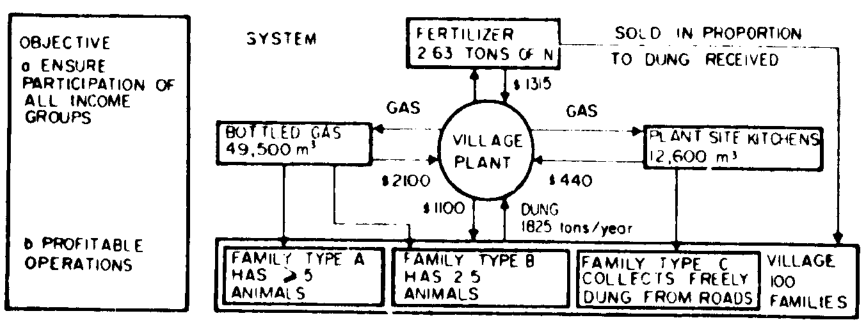
Per capita costs

1. Initial investment of $20
2. Annual maintenance cost of $7

Village level benefits in general terms

1. Domestic energy needs of 500 persons met
2. Prevention of deforestation
3. A smokeless fuel for all
4. Improvement in sanitation, cleanliness and health
5. At least 10 tons of additional foodgrains per yr.
6. Only local renewable sources required
7. A more efficient and versatile fuel is produced

Operating system for a village plant



Source: J.K. Parikh, K.S. Parikh, "Mobilization and impacts of biogas technologies," Energy, vol. 2, p. 451., Pergamon Press, 1977.

Biogas plants can be made in various sizes ranging from capacities of 2 cubic meters (for a family) to 140 cubic meters per day for a community. The smallest unit requires dung from a minimum of four animals, which makes this technology feasible for only the more well-to-do individual farmers in developing countries.

The plant can be constructed with relatively little specialized knowhow or equipment, which accounts in part for its widespread use, especially in Asia. The Indian Department of Science and Technology estimated that between 40,000 and 50,000 biogas plants were operating in India in 1977, and that most of these were for single families.[3] The community-sized plants in India are installed for demonstration purposes. Several biogas plants are also operating throughout Africa, especially in Tanzania. Controlled studies have been carried out in Tanzania on the use of biogas for cooking, lighting and pottery firing.[4] As a result, a considerable amount of information has been systematized concerning the operation of these promising alternative energy technologies.

B. Costs: Table 5-1 shows the costs of supplying biogas in Tanzania for cooking, lighting, mechanical power and electricity. Experiments show that the use of biogas should be considered not only for village lighting and cooking, but also for the generation of electricity or mechanical power.

Table 5-1

Cost of Supplying Cooking Fuel, Lighting, Mechanical Power, and Electricity by Biogas

Base Data	Cattle dung:	10 kg/cow/day
	Biogas production: @ 0.6m^3/kg dung =	0.6 m^3/cow/day
	Energy content of biogas @ 60% methane: (This means that about 4 kWh of biogas energy is available daily from each cow.)	6.4 kWh/m^3
	System lifetime:	20 years
	Conversion efficiencies Internal-combustion engine:[c] Electrical generator:	 25% 90%
Plant Cost	Single-family plant (3 m^3)	Sh. 6,000
Financing Costs[a]	Single-family plant Sh. 6,000 @ 10% for 20 years:	Sh. 705/yr
	Engine/generator to provide 1 kWh/day Sh. 5,400[d] @ 10% (5 hr/day)	Sh. 5,940/yr
	Engine to provide 1 kWh/day mechanical energy Sh. 3,200[d] @ 10% (4 hr/day)	Sh. 3,520/yr
Energy Costs[b]	Cooking and lighting directly by gas (20 kWh/day)	Sh. 0.10/kWh
	Cooking and generation of electricity @ 1 kWh/day	Sh. 18.2/kWh
	Cooking and generation of mechanical power @ 1 kWh/day	Sh. 11.6/kWh

(a) Based on amortization of loan in equal yearly installments.
(b) Cost of energy production only--does not include cost of appliances, or cost of collecting dung.
(c) Efficiency at peak loading. At lower loading rates, engine efficiency would drop off rapidly, with consequent higher gas requirements.
(d) Retail costs, Dar es Salaam, August 1977.

Source: Tanzania National Scientific Research Council, Energy for Tanzanian Villages, Dar es Salaam, 1977, p. 32.

The use of cattle dung was assumed in the Tanzanian case, with average production rates and methane concentrations. As table 5-1 indicates, the gas requirements for cooking three times a day are about 1.4 cubic meters a day per family, which could be supplied from the dung of three or four cows. In contrast, to supply the electric lighting needs of a family (which average about 1 KWh per day) by using biogas to operate an engine-generator set (at peak load) would require 4-5 KWh per day of heat energy. This could be supplied by two cows. This method of lighting therefore, is almost four times as efficient, in energy use, as a kerosene gas-mantle lantern, even though the biogas technology requires much more capital investment, compared to the purchase or home fabrication of a lantern. The gas supplied by dung from one cow could provide methanical power at 1 KWh per day.[5]

Biogas can be used as a replacement for wood and charcoal in the firing of clay pots which are used in cooking and water storage. For smallscale pottery production, 8 cubic meters of methane, over some 5 hours, are required to fire earthenware to 1,000°C in a kiln having a volume of 6 cubic feet ($0.2m^3$). This amount of methane is equivalent to about 13 cubic meters of biogas, which could be supplied by a 4-day accumulation of biogas from the dung of 5 cows. Larger production capacities for village industries, could be scaled up accordingly, and would represent another important use for community biogas digesters.

In sum, heat energy, even from a single-family biogas plant, can be supplied at well below the equivalent cost of electricity. In fact, electricity is some nine times more costly.[6] Furthermore, Tanzania's communal villages (Ujamaa villages) have experience with community-wide projects and are therefore favorable contexts for successful operation of biogas units. The economies of scale in biogas plant construction make advantageous the installation of community systems for use in schools, community latrines, community cattle dung digesters (especially where cattle are enclosed or herded together as among Tanzania's Masai settlements).

The economics of biogas production have also been examined in the Indian context. Four variables are relevant to determining comparative costs:[7] 1) the amount of gas and fertilizer slurry produced by a volume of cow dung in a digester compared to the fertilizer value of the dung if used in scientific composting; 2) the value of the biogas in terms of the equivalent amount of energy from kerosene, electricity or soft coke; 3) the value of the manure and 4) indirect costs and benefits. Clearly these variables differ depending on location, alternative fuels, size of units and other factors. But the increasing prices of alternative fuels work towards making biogas more economically attractive. One study conducted on the comparative costs of using conventional and renewable energy sources for powering small irrigation pumps in developing countries found the community size biogas plants to be the least expensive renewable source. It was presently competitive, given current fuel oil prices (assumed to be $0.10 to $0.25 per litre) in most countries in the study.[8]

Much of the work on biogas technology has been summarized by J. Parikh and K. Parikh,[9] who recommend biogas plants as examples of appropriate technology for rural environments. They require low investment, do not need highly skilled labor and can be operated with local materials and self-help in rural areas, and particularly in the one half million villages in India. In one study the economic benefits to a family using a bio-gas plant were evaluated, and it was found that the scope of such plants is likely to be limited. Even if 21 million family plants were installed (the 2.8m^3 size, costing $250 each) and supplied the energy needs of 90 million people, less than %20 of rural domestic energy needs would be supplied. This would yield significant fuel savings as Table 5-2 indicates. Again, only the 12 million families with five or more cows can install the plants, provided they have from $290 to $250 to invest. A family would be unable to use excess gas produced during warm periods, if the plant were large enough to supply sufficient gas during cold periods.

Village-level plants could utilize farm waste from smaller holdings, thus effectively using most of the collectable waste of the village. In cases of excess gas production, small industry or additional (poorer) families could be supplied rather than have the gas go to waste. Table 5-3 shows the impact of a village biogas system on three different imcome groups. The larger community plants would yield economies of scale in terms of land utilized, investment necessary and labor time for operating and maintenance.

Biogas plants have been successfully operating in other countries. Recently, Rep. of Korea, Thailand and other South-East Asian countries have also stepped up their efforts in introducing biogas plants. However, by and large, the practice of burning dung remains quite prevalent in many developing countries, especially in the Far East.[10]

Development of biogas technology has been carried farthest in China, despite the fact that China's climate is far from ideal for fermentation. After initial failure, a few hundred plants were built in Szechwan in 1970-72, and on the basis of their success a national program was launched, including the training of 100,000 biogas technicians by 1975. In may 1977, The New China News Agency reported 4.3 million working units--many of them communal plants producing up to 100 cubic meters

Table 5-2

Fuel saved by installing 12 million biogas plants of 2.8 cubic meters each to meet the fuel needs of 90 million people

Fuel	Unit	Annual consumption per person	Annual consumption for 90 M persons in million tons
Coke (7500 kcal/kg)	kg	2.44	0 22
Coal (5000 kcal/kg)	kg	2 33	0.21
Firewood (4750 kcal/kg)	kg	269.00	24 20
Kerosene	kg	4.76	0 43
Electricity	kWh	0.61	0.055

Source: see below.

Table 5-3

Impact of a village biogas plant on three income groups

	FAMILY TYPE A (HAS > 5 ANIMALS)	FAMILY TYPE B (HAS 2 5 ANIMALS)	FAMILY TYPE C (COLLECTS DUNG FROM ROADS FOR FREE)	VILLAGE 100 FAMILIES
IMPACT	PAYS $28 45 FOR GAS $23 60 FOR N RECEIVES $22 00 FOR DUNG	PAYS $28 45 FOR GAS $ 8 40 FORGONE EARNINGS FROM COMPOST RECEIVES $11 00 FOR DUNG	PAYS $21 00 FOR COOKING RECEIVES $22 00 FOR DUNG	
RESULT	CHEAPER THAN OWN BIO-GAS PLANT	FUEL COST LESS THAN PRESENT EXPENDITURE OF $25	BETTER TO SELL DUNG THAN TO BURN IT	

Source: J.K. Parikh, K.S. Parikh, "Mobilization and impacts of biogas technologies," Energy, vol. 2, pp. 441-455, Pergamon Press, 1977, p. 451.

of gas per day, each able to meet the needs of 50 Chinese peasants. Some 17 million people are using biogas for cooking and lighting in Szechwan province alone. In China the capital cost of a ten-cubic meter tank to serve a 5-person family is between $15 and $20, depending on the material used, and costs have fallen by more than half since 1972. In Hunan province, such a biogas plant is expected to save a typical family 40 person-days and about $15 per year.[11]

This brief survey of biogas costs leads to two conclusions. First, the technology is attractive compared to other sources of village energy. But second, it is within the reach of villages but not of most individual families. Family sized units cost about $200 to $300 to install, an amount which exceeds the incomes of all but the richest farmers. Thus, like electrification programs for rural areas, family-oriented biogas programs would reach a few percent (perhaps less than 10%) and leave the problems of energy supply unsolved. For biogas to be a realistic component of rural energy systems, it must be community-based. Some of the social questions this raises are discussed below.

2. SMALL-SCALE HYDROPOWER

A. Technology: One of the oldest sources of energy is that provided by water flowing from a higher to a lower level, used to rotate shafts that replace manual work. In conjunction with dams and controlled sluices, water can be used to operate wheels or rams for mechanical power, or water turbines for either mechanical or electrical power.

Waterwheels of many types have long been used mainly for grining grain. They are mature technologies and can be constructed in villages from wood as occurs in Afghanistan and Turkey today. Before the advent of cheap electricity from coal and oil, waterwheels were in wide use in Europe and America.

The water turbine, with much higher revolutions per minute and higher efficiency than water wheels, is best know for its use in hydroelectric generation (key in the industrial revolution). The hydraulic ram is a simple device with two moving parts which uses the power of flowing water to pump part of that water to heights even above the original head. It has obvious potential for irrigation pumping.

The intermittent flow of water can be compensated by the building of dams or penstocks and sluice gates which channel part of the flow to the turbine.[12] Very few small hydropower devices (waterwheels of 1-10 kW hydroelectric units are used traditionally) are in use in sub-Saharan Africa, which may be due to the seasonal nature of rainfall, particularly in West Africa. Nevertheless the watersheds of Africa contain streams which contribute to the world's largest hydroelectric potential. While little is known about small stream gauge data it would seem that a number of villages are near streams with flow and fall sufficient to power waterwheels, small hydroelectric units or hydraulic rams.[13] Once the discharge and stage data are known for a particular village, and the energy need is calculated, then it is possible to select the appropriate hydropower device.

Estimates of the potential impact of hydropower on energy supply vary. While the Chinese example is of great interest, there is a serious shortage of reliable information about hydropower developments in China.[14] However it is reported that tens of thousands of hydropower stations of less than 100 kW are in use in China. In 1973, the operation of from 20,000 to 35,000 units, averaging 34kW each, were reported. For the Chinese villages involved, the use of such small-scale hydropower, which represents some 20% of total national hydropower capacity, is significant for irrigation, lighting, machine operation and electrical grid equipment. The contribution of small scale hydropower to national output is calculated at approximately 7.5 billion kwh in 1974, or over 50% of rural electric power consumption.[15] Other reports on Chinese use of hydropower suggest that medium-sized units serving about 10,000 people are also common.[16]

B. Costs: Experiments with small scale hydroelectric power generation in Tanzania showed that the installations were competitive with present large-scale systems and were worth serious consideration in rural areas. An added advantage was freedom from negative environmental and social consequences of large-scale hydroelectric projects.

The findings of the Tanzanian hydropower study can be summarized briefly. Four cases were considered, based on known cost figures for the technology. Two situations were considered: one in which the needs of the village (300kWh/day in 5 hours) would be supplied directly by the generator during the hours of use (that is, 60kW), and a second situation in which a smaller generating capacity (15 kW) would be used with storage batteries to supply the required 300kWh/day by generating over a period of 20 hours. These cases and the types of equipment considered are summarized in Table 5-4 below. Table 5-5 (a,b and c) shows the cost calculations for these four ways of supplying hydroelectric power.[17]

Estimates showed the competitive economics of small scale hydroelectric installations in Tanzania for single villages. When these estimates were extrapolated to a region containing 500 villages where water and rainfall were sufficient. The local

Table 5-4

Types of Hydroelectric Power Equipment Considered

Case	Type of Power Generated	Type of Power Used	Power Conditioning Required	Storage Required	Generating Capacity
1	DC	AC	Yes	No	60kW
2	AC	AC	No	No	60kW
3	DC	AC	Yes	Yes	15kW
4	DC	DC	No	Yes	15kW

Source: Tanzania National Scientific Research Council, Energy for Tanzanian Villages, Dar es Salaam, 1977, p. 28.

Table 5-5

Cost of Supplying Hydroelectricity with Small-Scale Systems[a]

a. Base Data

Power (kW)	Head (m)	Flow (m^3/min)
60	48	12
	24	25
	12	50
	6	100
	etc.	
15	24	6
	12	12
	16	24
	etc.	

Item	Lifetime (yr)	Unit Cost (Shillings)
Generator/ Turbine	30	4,000/kW
Power Conditioning	30	6.00/W
Batteries (Eff. 85%)	6	800/kWh

Table 5-5, continued:

b. Equipment (Fixed) Costs (Shillings)

	Case 1	Case 2	Case 3	Case 4
Generator/Turbine	240,000	240,000	60,000	60,000
Power Conditioning	360,000	-0-	90,000	-0-
Installation	60,000	24,000	15,000	6,000
Subtotal	660,000	265,000	165,000	66,000
Battery Storage	-0-	-0-	280,000	280,000
Installation	-0-	-0-	28,000	28,000
Subtotal	-0-	-0-	308,000	308,000
Total (approx.)	660,000	270,000	470,000	370,000

c. Financing Costs @ 10% Annual Interest Rate (a), (b)

	Case 1	Case 2	Case 3	Case 4
Annual Cost in Shillings (c) for				
30-year loan	70,000	29,000	89,000	78,000
10-year loan	107,000	44,000	99,000	82,000
Cost of Electricity in Sh/kWh (Based on 110,000 kWh/yr)				
30-year loan	0.64	0.26	0.81	0.71
10-year loan	0.97	0.40	0.90	0.75

(a) Cost of dams and penstocks not included.
(b) Based on amortization of loan in equal yearly installments.
(c) In both cases, it was assumed that the cost of the battery storage would be amortized over six years.

Source: Tanzania National Scientific Research Council, Energy For Tanzanian Villages, Dar es Salaam, 1977, p. 29-30.

capital requirement for equipment in case 1 (see Table 3) was estimated at Sh. 330 million (about $40 million).[18] If a low-interest loan could be secured to finance capital costs,[19] the economics of small-scale hydroelectricity applied over a large region would be very attractive.

Possible costs of electricity from small-scale hydro units over a large region, in cases of financing with conventional loans where the government intends to make money, are shown in Table 5-5c. Under a 10-year conventional loan, and electricity prices shown in the above mentioned table, the government's annual income would be Sh.23 million ($6.4 million), while under a 30-year conventional loan, it would be Sh. 35 million ($4.2 million). The government would thus have between 25 and 40 million shillings for other projects. However, if energy was sold to villagers at the rate required to repay the 40 year cost of a soft loan, (10 years grace, and 40-year payback period) the rate would be Sh. 0.17/kWh which is only one-fifth the current cost of electricity in Dar es Salaam. It is a cost which villagers included in the scheme could probably afford.[20]

Hydroelectric costs were estimated by the U.S. Overseas Development Council. For villages with demands for 0.2 to 10 kW of power,(and nearby access to sufficient seasonal or regular streams capable of generating falls of 8 to 25 feet and flows of 70 to 1,000 cubic feet per minute) hydroelectric generating turbines exist commercially from around $3,000 to $3,500 for the smallest units, to $12,500 to $15,000 for the largest units.[21] Hydraulic rams for water pumping and irrigation are marketed in the U.S. These can adept to falls of from 2 to 12 feet or more. They range in cost from $200 to $2,600 and are capable of lifting from 5 to 25% of the flowing water for irrigation purposes.[22]

3. WINDMILLS

A. Technology: For areas with suitable wind regimes, wind represents one of the most promising sources of energy for water pumping, certain agricultural tasks and cottage craft industries, and low load, high value electrical demands such as lighting and telecommunications. Traditionally, windmachines have been used in China, Iran, Northern Europe and the European Mediterranean (but not Africa[23]) for a variety of tasks.

Most windmachines are designed for 10 mph+ winds, and their suitability cannot be judged in the absence of wind velocity data which has not been widely collected. Available wind data has not been systematically analyzed. As yet there has been only marginal efforts to adept Western conventional windmachines from other parts of the world to be able to better utilize winds which do an average of only about 6-10 mph. Since doubling of the wind speed results in the cubing of available power, it can be seen how important it is to locate windmachines in areas of greatest average wind velocity. Selecting a site with 10 mph average wind over a site with 8 mph average wind may result in a power difference of 100%.

Windmachines can be classified into the horizontal axis and the vertical axis groups.[24] The vertical windmachine may be powered by wind coming from any direction. It is, however, capable of powering only relatively low torque loads and some designs require supplemental starting. The horizontal design, such as is commonly found in the U.S. and Europe, can serve for both low and high torque loads.

Within each group of windmachines are found windmills (mechanical power) and windgenerators (electrical power). Windmills can do slow, high torque work, and are subject to potentially damaging mechanical and heat stresses under faster activity. Windgenerators are capable of producing high rpm's sufficient to satisfy the requirements of low torque electrical generators to which the windmachine must be carefully matched, to avoid damaging the generators. These are suitable for pumping shallow water, but not deeper water.

Wind-driven generators are available commercially with up to 15 kW rated power. Larger units up to 200 kW outputs are in the research and development stage. European and U.S. research institutes are active in developing lower cost, small units such as those used in the Omo River Project in Ethiopia (see Appendix 4). Electricity systems based on wind power require some sort of energy storage system if electricity is needed on demand, since wind conditions may not always be sufficient. The storage system used in Tanzania, for example, had been lead-acid storage batteries which are available for about $ 100 to $150 per kWh. Lifetime of these batteries range from 6 to 10 years depending on the number of units and the charging cycles. A number of windmills are being tested in Tanzania, as described in Appendix 4.

B. Costs: Windmachines are available from a number of commercial sources. The U.S. National Academy of Sciences listed sources of smaller scale windmills suitable for use by individual farmer or village for either mechanical shaft power or electricity generation. These would be subject to local modification. In the U.S. Dempster Inc. supplies conventional commercial windpump units for irrigation for $500 to $4,500, excluding towers.[25] American models range up to 20 kW units. These units are also produced in Argentina by Aeromotor, Inc. Conventional commercial windelectric units are available for $500 to $2,000 per KW in 5 to 15 KW capacities and for from $3,000 to $6,000 per KW in up to 5KW capacities. Wincharger Inc. (US) units produce .2 KW at a maximum windspeeds of 23 mph and cost $450. American Energy Alternatives, Inc. have units costing $1,500/KW up to 1.5 KW and $600/KW up to 5 KW, while Independent Power Developers, Inc. has 15-18 KW units for $500--600/KW, without towers. Such units may be used either in conjunction with diesel-electric generators to cut fuel costs, as units integrated into local power grids, or in conjunction with battery storage.

The costs of using windmill generators to supply a village's electrical energy needs were estimated in Tanzania.[26] It was assumed that windmill generators capable of producing 10 kW at wind speeds of 20 mph (9 meters per second) would be large enough to provide significant amounts of power for village use. Winds of from 18-22 mph, available 25-30% of the time are common in the lake and coastal regions of Tanzania and would suit windmill generators of the type under discussion. Under these velocity/duration assumptions, some 100 kWh daily would be provided, on average, with electricity costs of less than Sh 2/kWh, as illustated in Table 5-6. To provide the proposed 300 kWh daily to a village of 300 families, three such installations would be re-

Table 5-6

Cost of Supplying Electricity by Means of Windmill Generators

Base Data	Useful life of windmill generator	15 years
	Lifetime of batteries	6 years
	Efficiency of batteries	85%
Equipment Costs	Windmill generator (10 kW)	Sh 170,000
	Wiring, controls	Sh 42,000
	Installation	Sh 42,000
	Battery storage (100 kWh @ 85% efficiency) 118 kWh @ Sh 800/kWh	Sh 94,000
	Total equipment costs (approx.)	Sh 350,000
Financing Costs (a)	Windmill generator, wiring, installation Sh 254,000 @ 10% for 15 years	Sh 33,000/yr
	Batteries Sh 94,000 @ 10% for 6 years	Sh 22,000/yr
	Total cost of financing (approx.)	Sh 55,000/yr
Cost of Electricity	Total energy generated	36,000 kWh
	Unit cost	Sh 1.5/kWh

(a) Based on amortization of loan in equal yearly installments.

NOTE: In many places, maintenance cost estimates of commercial systems usually run about 5 percent of initial capital cost per year. This would add about Sh 0.5 to the cost of the electricity per kW. However, this can vary either way significantly depending upon the location.

Source: Tanzania National Scientific Research Council, Energy for Tanzanian Villages, Dar es Salaam, 1977, p. 35.

quired. If the task is pumping water, serviceable wind pumpers can be made with substantial savings by using local materials and skills.[27]

4. FORESTRY

A. Technology: The technical-economic dimensions of fuel supply from woody substances are as complex as those for other types of renewable, solar energy. This reflects the close interaction between human settlements and forested or wooded areas. Although the forest area in developing countries exceeds 1,000 million hectares, it is being consumed at such a rate for agricultural settement that it could disappear within 60 years, unless some fundamental changes occur to alter the current trend, or unless extensive reforestation programs are undertaken to offset the losses.[28] Over 90% of wood consumption in developing countries is accounted for by fuelwood. This is the major fuels for cooking, household uses and cottage crafts. Tables 5-7 and 5-8 show consumption of firewood and charcoal by country group, and the share of wood energy in total energy consumption.

Uncontrolled forest exploitation could have serious negative consequences. Higher consumption of existing fuelwood resources, exacerbated by higher prices for other energy sources, and dried livestock dung to use for heating and cooking instead

Table 5-7

World Consumption of Fuelwood and Charcoal, 1961-75

Area	Consumption 1961	1965	1970	1975	Growth rate 1961-75 (percentage per year)
	(million m³ roundwood equivalent)				
World	1,023	1,084	1,113	1,183	1.0
Developed	138	109	70	56	−6.2
Developing	644	715	788	862	2.1
Centrally planned	241	260	255	265	0.7
Developed	138	109	70	56	−6.2
North America	48	37	19	17	−7.1
Western Europe	69	58	42	33	−5.1
Oceania	4	3	3	3	−2.1
Other	17	11	6	3	−11.7
Developing	644	715	788	862	2.1
Africa	190	208	234	256	2.2
Latin America	186	207	220	226	1.4
Middle East	29	38	39	41	2.5
East Asia	234	258	291	335	2.6
Other	4	4	4	5	1.6
Centrally planned	241	260	255	265	0.7
USSR	98	105	86	83	−1.2
Eastern Europe	16	17	15	14	−0.9
Asia	127	138	154	168	2.0

Note: Details may not add to totals due to rounding.

Source: FAO, *Yearbook of Forest Products* (Rome: FAO, various years).

Table 5-8

Woodfuel Consumption as Percentage of Total Energy Consumption, 1974

Region	Commercial energy (1) (million tons CE)	Woodfuel (2) (million tons CE)	Total (million tons CE)	Woodfuel, as a share of total (percentage)
World	7084	456	7540	6
Developed economies	5994	53	6047	1
Developing economies	1090	403	1493	27
Southeast Asia and Oceania	100	92	192	48
South Asia	115	88	203	43
China and rest of Asia	492	49	541	9
Middle East and North Africa	87	22	109	20
Western and Central Africa	12	36	48	75
Eastern and South Africa	13	39	52	75
Central America and the Caribbean	110	11	121	9
South America	161	66	227	29

Note: CE means "coal equivalent."

(1) Includes energy generated from coal and lignite, crude petroleum, and natural gas, as well as hydro and nuclear energy. Excludes energy from the burning of wood.

(2) 1 m3 woodfuel is 0.33 tons coal equivalent.

Sources: *UN Statistical Yearbook (1974)* for commercial energy data. FAO, *Yearbook of Forest Products*, 1973, for woodfuel data.

Source: World Bank, Forestry, Sector policy paper, 1978.

of improving soil fertility. Thus, in many areas, especially the Sahel in West Africa and in parts of Asia the supplies of firewood and woody underbrush are dwindling so rapidly that lands are being devegatated. This causes ecological damage including soil erosion, floods, droughts and an imbalance in the ecosystem upon which human settlements depend. Table 5-9 illustrates humanity's dependence on forests.

Large-scale removal of the forest cover, if not accompanied by reforestation for catchment protection may lead to repad water run-off, soil erosion, silting, and flooding in the rainy season, followed by reduced downstream flows from rivers in dry weather. Many streams have stopped flowing in the dry season, and agricultural production has been negatively affected.[29] Since half of humanity lives in mountain areas and adjacent lowlands, trends' in watershed environments are clearly of great importance. Increasing population pressure, and other factors to do with land tenure and economic well-being, results in the cultivation.of steeper mountain slopes, where crops and topsoil quickly wash away. Forest resources, which are vital for flood control and soil stabilization, are used for fuel and dust bowls replace pastures.

Table 5-9

The Role of Forests

Ecological effects	Catchment protection	Controlled runoff, water supplies, irrigation, soil fertility, oxygen
	Ecology and wildlife conservation	Recreation, tourism, national parks, protection of endangered species of flora and fauna
	Soil erosion control	Windbreaks, shelter belts, dune fixation, reclamation of eroded lands
Indigenous consumption	Fuelwood and charcoal	Cooking, heating, and household uses
	Agricultural uses	Shifting cultivation, forest grazing, nitrogen fixation, mulches, fruits and nuts
	Building poles	Housing, buildings, construction, fencing, furniture
	Pit sawing and sawmilling	Joinery, furniture, construction, farm buildings
	Weaving materials	Ropes and string, baskets, furniture, furnishings
	Sericulture, apiculture, ericulture	Silk, honey, wax, lac
	Special woods and ashes	Carving, incense, chemicals, glassmaking
Industrial uses	Gums, resins, and oils	Naval stores, tannin, turpentine, distillates, resin, essential oils
	Charcoal	Reduction agent for steel-making, chemicals, polyvinyl chloride (PVC), dry cells
	Poles	Transmission poles, pitprops
	Sawlogs	Lumber, joinery, furniture, packing, shipbuilding, mining, construction, sleepers
	Veneer logs	Plywood, veneer furniture, containers, construction
	Pulpwood	Newsprint, paperboard, printing and writing paper, containers, packaging, dissolving pulp, distillates, textiles and clothing
	Residues	Particle board, fiberboard, wastepaper

Source: World Bank, Forestry, Sector policy paper, 1978.

Larger populations increase the demand for fuelwood. In The Sahelian zone an average family requires more than one cubic meter of stacked firewood a year, or wood equal to the average growth from 2 hectares of natural forest. Until recently, Bamako, the capital of Mali, with a population of 300,000 persons, could be supplied with firewood for domestic use gathered from forests less than 50 kilometers away from the capital; in 1975 the distance was 100 kilometers. By 1990, Bamako will need each year, wood produced from over 100,000 hectares of forest plantations, or an amount well beyond the current resources of the government to plant in the available time.

Uncontrolled commercial extraction of forestry products, especially timber, should be noted as a major cause of serious deforestation. Natural regeneration takes from 25 to 30 years and reforestation programs speed up this process considerably. But in certain countries, for instance, the Phillipines and Brazil, cutting trees has been unplanned, resulting in extensive loss of forest area and serious destruction of watershed environments.[30]

Concern for environmental deterioration among other considerations has motivated various institutions to develop proposals for alternative methods for energy supply.[31] This reflects an appreciation of the long-term nature of ecological decline and the serious obstacles posed by reclamation of encroaching desert. It also reflects a growing awareness that ecological change in one part of the world impinges on the international ecological balance and is thus directly of concern to people in other parts of the world. These considerations lend credence to the view tjat new sources of energy can reduce the extent to which terrain surrounding is stripped of vegetation as villagers gather woody material for cooking, crop drying or other purposes. An alternative source of energy to meet such needs could stop or reduce wood gathering, thus permitting trees, brush or other vegetation to grow. This would reduce erosion and in some areas would stop, slow or even reverse the spreading of the desert.[32]

The approaches to the issue of adequate fuelwood and forest growth include afforestation and reforestation projects, substitution of dependence on fuelwood with alternative fuels and the improvement of the efficiency with which woody substances are used for fuel.

Reforestation of certain areas and afforestation of land currently without forest cover would both provide firewood for future generations and help arrest soil erosion and shifting sand.

Employment of other types of solar energy for heating, crop drying and other amenable tasks could relieve some of the pressure on forest consumption. More efficient indigenous cooking stoves, oven facilities and charcoal production techniques would reduce the amount of wood needed per task.

One technology for improving the use of wood has to do with the more efficient production of charcoal. Woody celulose matter can be burned in relatively airless enclosures to yield charcoal and various forms of alcohol fuels, charoil and chargas. This technique (pyrolysis) has been used in the industrialized countries and is of interest for urban organic waste processing, although its complexity and capital intensity make its relevance to developing countries questionable. However, the U.S. Agency for International Development has assisted with demonstration projects in Ghana. These small scale pyrolysis units (one ton per day continuous batch feeders) may be of use throughout the developing world where charcoal is widely used. The feasibility study in Ghana yielded estimates that a six-ton per day (dry feedstock) continuous feeding pyrolitic converter produces charcoal yield up to twice that of the indigenous charcoal production methods (burning slowly in earth-covered chambers). The traditional method causes the loss of both charoil and chargas. The BTU value of the traditional charcoal pit might produce only 25% of that in the original woody material, while that of the charcoal, oil and gas in a modern plant might yield as much as 90%. Chargas can be used on site for crop drying, and charoil may be used in boilers, cooking stoves and lamps (but not for combustion engines). Improved pyrolysis may have significant potential in areas with sufficient wood.

Other focuses relating to firewood include improved cooking stoves, chipping wood for more efficient burning, and tree-planting. Forestation programs on both large and small scales are becoming standard parts of development plans,, and are actively encouraged by international agencies including the World Bank. Small scale forestry programs, sometimes called 'social forestry' (as in India's development plan and in the World Bank) because they are family or small village projects, have a number of advantages relating to fuel production, agricultural potential, ecological balance and labor-creation. The implementation of social or large-scale plantation forestry schemes pose a range of problems, discussed below.

B. <u>Costs:</u> The cost appraisal of technology designed to use wood more efficiently or evaluation of projects to produce more woody material are difficult due to the large number of uses associated with land and forests. An important trend in the last twenty years has been the growing importance of tropical hardwoods in world production and consumption.[33] Favorable climatic and ecological conditions of many developing countries make it possible to establish fast-growing plantations at less cost than in countries situated in temperate regions. Thus there are important export implications of planned forestation programs, especially if the capability to process tropical hardwood logs is developed locally. Ecological costs and benefits have not received priority attention in many developing countries to date. The reasons have to do in part with the indeterminate and long-term nature of social benefits and costs. However, environmental considerations will increasingly affect worldwide forest development policies and strategies, especially since awareness of these dimensions is growing in ternational organizations.

The International Development Research Centre which specializes in forestry research and demonstration held a workshop in Singapore in July 1977 which identified priority areas for forestry research in the south-east Asian area. Among these were fast growing plantations for industrial or fuel uses.[34] However IDRC has expressed concern that the cost of establishing plantations is excessive, noting that

> Some of the present projects have shown the unacceptably high cost of mechanized planting, and in Sahelian regions, where the rainfall is both meager and unpredictable, hand-planting of large areas is not practical in the few days when there is a good chance of survival. 35

These cost considerations have led IDRC to undertake research on techniques for natural regeneration, possibly with pelletized seeds or by planting species at wide intervals and letting animals who eat the seeds do the subsequent spreading. This and other uses of nature are methods of reducing costs.

Forestry projects have hitherto been considered within the agricultural development framework, rather than within a context of energy planning. But forestry projects differ from agricultural schemes, in terms of cost measurement. The benefits of forestry projects are often environmental and thus hard to measure. Again, these benefits may not accrue directly to those who grow the trees. Another difference is that many years elapse before a forest becomes a major source of income. Poor agriculturalists may not be able to afford to wait for forestry projects to mature in the absence of alternative energy and income sources. In sum, considerations which make costing of forestry projects difficult are questions of land valuation, ecological benefits, considerations of equity, effects of saved time, the long payback period and the uncertainty of forestry schemes.

FOOTNOTES TO CHAPTER FIVE

1. Unctad, op. cit., p. 56.

2. ODC, Energy for the Villages of Africa, op. cit., p. 22.

3. Unctad, op. cit., p. 116, quoting official of the Indian government during an interview.

4. Tanzania National Scientific Research Council, Workshop on solar energy for the villages of Tanzania (Dar es Salaam: Tanzania National Scientific Research Council), August 11-19, 1977, published in 1978, p. 30-32.

5. Tanzania Natkonal Scientific Research Council, op. cit., p. 31. The variations in methane composition that may occur in actual practice may reduce the efficiency of the internal combustion engine by an unknown amount from the figures shown in Table 2.

6. Tanzania National Scientific Research Council, op. cit., p. 32.

7. R. Bhatia, "Economic appraisal of biogas units in India, Framework for social benefit cost analysis, Economic and Political Weekly, special number, August 1977, p. 1504. Cited by Unctad, op. cit., p. 117.

8. V. Mubayi and T. Lee, Irrigation in less developed countries, a study of the comparative costs of using conventional and renewable energy sources for powering small irrigation pumps in developing countries," Draft Report, Policy analysis division, Upton, New York, March 1977.

9. J. K. Parikh and K. S. Parikh, "Mobilization and impacts of biogas technologies," Energy, vol. 2, pp. 441-455, Pergamon Press, 1977.

10. Parikh and Parikh, op. cit., p. 454.

11. Denis Hayes, "Energy for development: third world options," Worldwatch paper 15, December 1977 (Washington D. C., Worldwatch Institute), p. 31 and Vaclav Smil, "Energy solution in China," Environment, October 1977. The substantial difference between Smil's data on biogas plant cost in China and those of Parikh for India may result from the inclusion of all piping in the Indian estimate but not in the Chinese one, and in the difference in materials prices in each country.

12. Overseas Development Council, Energy for the Villages of Africa, op. cit., p. 18. The report states that with such regulating devices, small-scale hydropower can "contribute to a much more controlled source of power than other intermittent sources such as wind or sunshine.

13. ODC, op. cit., p. 19. The report notes that for the Sahel, continuous records of river discharge are made at 44 stations in Niger, Senegal and Chad, while river stage measurements are made at over 250 stations in six countries. But small streams are ignored. It is recommended that this data be investigated along with on-site visits and studies of villages along side the streams that feed the watershed for these rivers, to obtain a picture of the applicability of small-scale hydropower for these areas.

14. Interview, July 11, 1978, Tony Pryor, Rockefeller Foundation, Program on energy in developing countries. It was pointed out that much information on Chinese hydro was from a very few non-Chinese speaking Americans who have extrapolated small use of hydropower to the whole of China.

15. ODC, Energy for the Villages of Africa, op., cit., p. 20, citing Thomas Rawski, private communication, June 10, 1076.

16. Interview, James Ridgeway, Editor, The Elements, April 12, 1978, Washington D. C. More information on Chinese hydropower is available from CIDA, Ottawa, Canada.

17. Tanzanian National Scientific Research Council, op. cit., p.27-30. Dams and penstocks, where needed, were to be constructed with local labor and materials (timber, earth) without significant capital costs. Techniques for using local labor and materials to construct dams and penstocks for installation capable of producing power in tens of kilowartts have been developed in Colombia at the Centro de Desarrollo Integrado. Table 4 includes assumptions about water requirements, amortization of batteries, cost of protective housing for the batteries or power-conditioning equipment and maintenance. Ibid., p. 28.

18. 8.3 Tanzanian shillings equalled US$ 1.00 in 1978.

19. A 'soft loan' from the International Development Association, of the World Bank involves no repayment for the first 10 years, and then repayment in equal annual installments over the next 40 years at an annual rate of interest of 0.75 percent. For this example this would mean a financing cost of Sh. 9.6 million per year from the eleventh through the fiftieth years. Ibid, p. 29.

20. Ibid., p. 29. Electricity could be provided even more cheaply, under the assumptions of cases 1 and 2 where the systems are capable of supplying energy at the same 60kW rate over 24 hours. If the capacity were used for more than five hours daily, the cost per kilowatt-hour could be reduced as much as a factor of four or five. Thus, with load factors greater than 0.2 (five hours' use per day) the cost of electricity production by small-scale hydropower systems of the type considered could approach Sh. 0.1 - 0.2/kWh.

21. ODC, op.cit., p. 19, based on 1977 estimates of costs from the turbine manufacturer, James Leffel Co., Ohio, USA.

22. Ibid., based on estimates in 1977 from Rife Hydraulic Engine Manufacturing Company, Millburn, New Jersey, producer of hydraulic rams.

23. Europeans living in Africa have used windmills to pump water and generate electricity. They are in use today in Namibia in expatriate establishments.

24. See Appendix 4 for a discription of each group of wind-machines.

25. National Academy of Science, Energy for rural development, op. cit., p. 114-35. The lowest cost windpump unit with tower would cost $700.

26. Tanzanian National Scientific Research Council, op. cit., p. 34-36. In addition to these estimated costs, wind-velocity and duration measurements must be made before any specific site is chosen for locating a windmill.

27. On the Ome River Valley in Ethiopia, simple sail wind pumpers were built with local materials. The cost of mills that pumped 800 imperial gallons of water per hour to an elevation of 9 feet in 13 mph winds was only $375 for each sail mill. See Apendix 4.

28. Between 1900 and 1965, about half the forest area in developing countries was cleared for agriculture, and more than 300 million hectares (or 30% of the world's exploitable soils) are currently under shifting cultivation. World Bank, Forestry (World Bank: Washington D. C), February 1978, p. 5.

29. Studies have shown that the incidence of flooding in the Indus River system in Pakistan has been far higher in the last 25 years than during the previous 60 years. Increased flooding, which is attributed to the denudation of catchment areas, has been accompanied by serious silting of the dams and canels of Pakistan's irrigation system. World Bank, Forestry, op. cit., p. 17. However, the link between human fuelwood use and soil erosion-silting is not direct, as much erosion occurs in non-inhabited areas. Interview with T. Pryor, Rockefeller Foundation Progran in International Relations, New York, July 1978.

30. In many developing countries, afforestation programs are currently running at less than half the rate recommended by expert panels of the World Forestry Congress, a body that meets every six years under the auspices of the FAO for intergovernmental consultation on forestry policies and issues. The Congress last met in 1972 in Buenos Aires, Argentina.

31. Overseas Development Council, Energy for the Villages of Africa, (Washington D. C., Overseas Development Council) February 1977. In addition to the ODC, the Worldwatch Institute has produced studies on energy use in rural areas which emphasize ecological dimensions. See for instance, D. Hayes, Energy for development: third world options (Worldwatch paper 15), December 1977, and Erik Eckholm, The other energy crisis (Worldwatch paper 1) 1975, both from

Worldwatch Institute, Firewood, 1776 Mass. Ave. NW, Washington D. C. 20036, USA. The Canadian International Development Research Centre actively supports reforestation and programs to halt environmental decline. See Tree, Food and People: land management in the tropics (IDRC: Ottawa) 1977.

32. A World Bank policy paper stated that "Forestry's role in preventing soil erosion, in stabilizing sand dunes, in protecting water catchment areas, and in providing shade for livestock and humans may be less obvious /than industrial uses/ but it is frequently more important than the production of timber." (my emphasis). Forestry (World Bank: Washington D. C.) February 1978, p. 7. The multifaceted value of forestry is further developed in P. Sartorius and H. Henle, Forestry and Economic Development, (New York; Praeger) 1968; and in Erik Eckholm, Losing Ground: environmental stress and world food prospects, (New York; Norton) 1977.

33. Tropical hardwood log production increased by over 25% yearly in the last decade. Developing countries' exports of forest products rose from $1,500 million in 1970 to over $3,000 million in 1975, and future world market demand for tropical hardwoods suggests that this trend will continue. World Bank, Forestry, op. cit., February 1978, p. 6.

34. International Development Research Centre, Trees for People, an account of the forestry research program supported by the IDRC (Ottawa: IDRC), 1977, p. 51.

35. Ibid.

CHAPTER SIX

POLICY CHOICES AND ENERGY PRIORITIES IN DEVELOPING COUNTRIES

1. INTRODUCTION

There is wide agreement among planners in the energy sector about the present availability of technology for rural energy supply. The technology has been developed, and while improvements are required, especially in order to reduce production costs, the hardward for harnessing alternative energies is relatively well-known and reliable. The more fundamental requirement concerns the 'software' for harnessing alternative sources of energy. As the World Bank's new energy policy paper stated, the issue is an institutional, not a technological one.[1] How can the broad range of institutions in developing countries solve the problems associated with rural energy supply?

Energy planning is required, and new sources of energy as well as alternative technologies need to be financed. A program of rural energy supply includes a number of policy implications such as incentives to equipment producers and subsidies for the establishment of decentralized, small and medium scale energy supply systems. Finally, local social institutions and groups are the varied recipients whose acceptance of new technology is a condition for its success. The need to involve villagers in the multi-faceted programs of integrated rural development, and particularly in the energy supply aspect, is broadly accepted. The social implications of introducing new energy technology thus need to be assessed in advance and through pilot projects. Some of the crucial questions have to do with measures to ensure a reasonably equitable distribution of benefits from alternative and new technologies. There is the further concern for ensuring that relatively inexpensive energy sources provide maximum benefit to the rural poor through increased rural employment, decreasing the drift to the cities and improving conditions of living in rural areas.

The recognition that improving the availability of alternative sources of energy is primarily an institutional problem, has focused attention on the need for comprehensive, country-wide plans to create appropriate institutions. In this connection the World Bank initiated a special pilot exercise in 1977 to set up a rural energy planning unit in Colombia with the objective of preparing a national rural energy plan, consisting of regional subplans. The plans will be designed by nationals working in government departments and universities. The regional plans will include the utilization of conventional, noncommercial and other local sources of energy. The necessary equipment and materials will be produced locally under a special industrial program. If this approach proves successful it could be adapted in other developing countries.[2]

In this chapter, some policy choices and energy priorities for developing countries are discussed under four headings. First, the need for planning should be appreciated. There is growing recognition of the need for energy planning within the wider plan for integrated rural development. Second are policy choices relating to finance, its magnitude, expenditure and sources. Third are subsidiary government policies to encourage the implementation of energy supply programs. These will vary considerably from country to country, depending on the nature of the policicitical economy. Fourth are the social implications of alternative energy systems and technologies. How can the acceptance of energy alternatives be encouraged, and who stands to gain or lose by their introduction? The nonrenewable and renewable energy sources introduced in previous chapters are assessed in terms of these four considerations. Forestry receives special attention because of the many positive functions fulfilled by tree planting programs.

2. NON-RENEWABLE ENERGY

Of the four non-renewable energies assessed in this survey (oil, gas, coal, nuclear from uranium), only petroleum products are of direct significance as fuels used in rural areas. Kerosene and gasolene (petrol) are the most important of the petroleum products. However, all four non-renewable energies are important as fuels for electricity generation.

The question of policies for the supply of non-renewable energy to rural areas can be examined at two levels. First, policies may be devised to obtain more oil, gas, coal and uranium. The potential value of local exploration and production, especially of oil, was emphasized above. Second, policies may be devised to improve the energy delivery system to rural areas, at prices which people and small production units can afford. The second category of policies are of most interest here.

A. Planning: Oil and gas distribution in developing countries has historically been carried out by international oil companies, through a network of gas (petrol) stations serviced by road tanker and less often, by train tankcar. More recently, with the establishment of dozens of state oil corporations in oil-importing developing countries, the state has played a role in production of petroleum products and their distribution. This has meant that in addition to devising policies to regulate foreign oil companies, the government has had to formulate socio-economic strategies for fuel supply itself.

Developing countries, especially the rural areas, often experience shortages of key petroleum product on which transportation and daily production and domestic life depend. 'Petrol shortages' are chronic, even in oil-exporting countries because of bottlenecks in refinery operations, and more particularly, in distribution. Estimating supply and demand patterns is a complex operation, storage facilities represent major capital investments as do trucks (lorries) and other transport equipment.

Planning for product distribution starts at the refinery, or for countries without any or adequate refinery capacity, with import schedules. It is essential to forecast the kinds of quantities of petroleum products required.[3] Organization to determine the means of transport and storage corresponding to the least cost in each case, is vital in distribution. Valumes for each product on an overall and regional level have to be forecast, after which price forecasts may be made. Oil companies normally co-operate with each other in distribution, using computer models for optimizing patterns, including refining activities and and product delivery to deports. Co-operation is marked in tanker and barge transport, pipeline transport, depot sharing, and train tankwagon use. Improvements have been made in rail transport of petroleum products by the rail road authorities in India (where 50% of oil and products are moved by train) by introducing a block pattern of operation, utilizing a single train rather than a few tankwagons on several other-purpose trains.[4]

Secondary petroleum products transport is mostly by road. But this is generally economical only over a short range (in India it is uneconomical beyond 125 km for motor spirit and 75 km for gas oil, kerosene or fuel oil). Government policies in several developing countries have restricted the use of road vehicles for long hauls, mainly to prevent road congestion. Such legislation takes the form of increased taxation on road vehicles, or higher taxes on movements beyond a certain distance from point of vehicle registration, or reserving movements beyond a point to rail. In India, the pricing system of petroleum products is designed to discourage uneconomical or irrational movements by any mode of transport. Product pricing is based on distribution by the cheapest mode of transport--sea, rail, road, barge or

In most developing countries where the railroad system is not as developed or well-maintained as in India, road transport predominates. However, due to limited vehicle manufacturing capacity and the condition of the roads in many developing countries, it is difficult to take advantages of sophisticated, large vehicles. The best use of available means of transport involves efficient route planning and scheduling of vehicles, reduction of delivery and turn-around times, and an increase in the payload and delivery size. Fuel costs for road tanker operation constitute as much as 25% of operating costs. Diesel for tankers may include as much as 25% tax in its cost.[5]

Distribution planning is related to product pricing policy. Nigeria and Trinidad and Tobago are among the oil producing countries which subsidize product prices by providing petroleum products at cost. Among the considerations that affect pricing policy are (1) proportion of oil produced locally and imported, (2) relative consumption of non-commercial fuels, and their supply, (3) conservation and energy efficiency schemes, and (4) physical and management capability to deliver oil products to consumers. There is a close connection between oil product prices and volume of consumption as well as rate of growth in consumption.[6] Internationally, governments impose significant taxes on petroleum products. The level must be determined in conjunction with a range of other energy and economic considerations.

In sum, distribution is the most complex sector of the oil industry, and perhaps the least rational. Its organization requires the use of complex mathematical models which contrast with the practical know-how necessary at the level of basic sales operations. Finding the optimum or lowest-cost method cannot depend on conventional methods of individual judgement and trial and error. A total systems approach and the use of operations research techniques, including linear programing, are necessary for managing oil transport and distribution in many developing countries. The complexity of oil product distribution, and the high cost of imported oil to which is added the cost of delivery to the consumer, are arguments in favor of policies to develop alternative, decentralized energy systems for rural areas.

Planning rural electrification programs in the past had been premised on simplistic views that extending distribution lines to villages is a good thing in itself, and that electricity is a need in itself. The result is that critical energy problems of rural people have not been solved. While developing countries have spent from 15 to 20% of their capital budgets on electrification, of which a considerable proportion goes to rural electrification, most villages are without electricity, while in those that do most people cannot afford to use it.[7] For instance, rural electrification efforts India have reached only about 5% of the rural population.[8] Clearly, new directions in electricity planning are required.

One of the objectives of rural electrification schemes should be to provide electricity via an institutional arrangement which will reduce inequality in income distribution. It may be advantageous to delay electrification programs and allocate resources to development of cheaper and less refined forms of energy. The high capital costs of large-scale electricity generation and grid systems are reasons for considering village-based power generation from hydro, solar or diesel energy sources.

The World Bank has been the major international advocate of the electrification strategy which has proved so unsuccessful in developing countries. However, in 1978 the World Bank revised its policy on electrification. The emphasis is no longer on large hydroelectric schemes and oil-fueled generating systems with grids. "Special emphasis is now being given to non-oil sources of generation, mainly hydro, coal/lignite and geothermal. In line with general Bank concerns for the urban and rural poor, a greater proportion of lending is also being allocated to investments in distribution systems designed to provide service to these groups."[9] The Bank "has re-examined the use of rural electrification both globally and in specific countries."[10] It now aims to (1) determine the proper role of rural electrification in satisfying rural energy requirements (i.e., end uses for which it was economically and socially justified) and (2) compare the costs of power supply from decentralized (mostly diesel) and centralized (grid) systems that frequently use hydroelectric generation.[11]

B. Financial implications: of improving petroleum product supply to rural areas, and of electrification programs include the the prospect of allocating even larger sums than the very considerable amounts spent before the price increases of 1973-74. Oil importing countries are facing the trade off of reducing petroleum purchases or cutting back on imports of other items. In some instances all imports are being curtailed by growing debt and diminishing credit-worthiness. Capital equipment for transporting and storing petroleum products is costly to purchase and maintain. Thus, there are strong arguments for reducing dependence on imported fuel, and encouraging the use of non-oil energies, especially in rural areas.

There are equally good reasons for initiating programs for exploration and production of oil and gas. Financing is available from international oil companies, from state oil agencies and from the international lending banks. A great deal of attention is given to 'political risk' faced by oil companies in developing countries, and the consequent need to provide guarantees of investment security in order to attract private oil exploration capital. But in practice, private exploration investment in developing countries has increased since 1973.[12] Furthermore, the riskiness of exploration is exaggerated. Developing countries should attempt, if at all possible, to finance exploration and reap all the benefits from possible discoveries. If indigenous financing is not feasible, advantageous terms may be secured from state-owned petroleum corporations, governments and independent contractors to the oil industry. These parties may value access to small deposits of new exploration areas more highly than do the international oil companies.

Electrification programs in developing countries were projected to require about $45 billion foreign exchange financing over the 1976-85 period.[14] Loans for these electricity system expansions are committed by the World Bank over a period with an average lead time of about 2-3 years. Therefore, by 1977/78 annual commitments were at a level of about $4 to $4.5 billion, or about twice the amount in real terms of the average level of commitments made over the period 1968-73.[15]

One of the contributing factors to higher electrification costs is the price of oil. Power expenditures were expected to increase as proportions of GNP and gross fixed capital formation because of "the need to substitute previously planned oil-burning plants for much higher capital cost nuclear, lignite and hydro alternatives."[16] Studies of shifts in power generation mix for two groups of developing countries to 1986 and 1990 indicate a sharp decrease in the percentage of oil-burning plants and significant increase in nuclear plants.[17] As a result of various factors— continued faster than GNP growth of power demand, less scope for economies of scale, larger than average price increases in equipment and heavy construction and a particularly rapid shift to higher capital cost plant--the proportion of national investment taken by power expansion in developing countries was projected by the World Bank to increase by about one-half, from about 7% to 8% in the past decade to about 10% to 12% in the next. In terms of public rather than total investment, this means an increase from about 17% to about 25%, indicating that "a difficult reallocation of public investment funds will be required."[18]

About one-fifth of World Bank lending has gone into energy, totalling over $9 billion as of June 1977. Of this, $8.7 billion was allocated for some 300 loans in tne power sector, for 69 countries.[19] The program is expanding, with 106 projects for the 1978-82 period, costing $6.9 billion (compared to 90 in the 1974-78 period costing $4.5 billion).

Latin American countries are expected to borrow an increasing proportion of their electricity project funds from private capital markets. World Bank lending will concentrate on countries with less developed institutional strength, managerially and financially, especially in Africa. For rural electrification, the World Bank intends to emphasize decentralized diesel, centralized grid systems (based on hydropower) and small hydroplants as well as solar cell generation for remote, economical uses. As noted above, this interest by the Bank in decentralized electrification marks a turning point in the lending institution's policy. It may pave the way for loans from bilateral and private financial sources for rural electrification based on decentralized planning.

C. Policy implications: After a government makes a committment to energy planning, especially as part of an integrated rural development program, and has assessed the financial options open for specific projects, policies have to be devised and implemented. If efforts are to be made to increase the supplies of oil and gas to the countryside, transport policies are affected, in that more roads (especially feeder and access roads) are required. However, there are cost and availability arguments for minimizing the use of petroleum products. In the cases in which governments chose to reduce dependence on petroleum products, or to slow the transition from traditional to fossil fuels, policies would include oil price variations (such as increased taxes on petroleum products), subsidization of alternatives to oil such as solar sources, and efforts to conserve petroleum consumption through more efficient use in better equipment, and through substitution of petroleum by such fuels as ethanol (ethyl alcohol) from crops such as sugar cane, cassava and sweet sorghum.

Since the major use of petroleum products in developing countries is in transportation (or motor power, to include tractors, plows, etc), it is essential that policies to limit the rate of growth in petroleum product consumption include dimensions to make alternatives such as methane available. The experience of Brazil is instructive in this regard. The government has priced ethanol in the Sao Paulo area at half the price of gasoline and a full experiment is being conducted with one million cars running on a mixture of 20% ethanol and 80% gasoline. There is some prospect for integrating a number of alternative energy source technologies in the production of ethanol by pre-heating and evaporating the sugar syrup from which ethanol is produced by solar collectors.

The policy implications of electrification programs similarly depend on choice of a centralized or a decentralized electrification strategy. Coinciding with these poles of a policy continuum are broader development approaches which emphasize either rapid growth and the expected spread of of productivity and growth to rural and poorer sectors, or distribution and social welfare objectives. Clearly there are intermediate and combinations of approaches which many developing countries are pursuing. However, it is necessary for any government policy in the electrification area to consider the evidence that subsidized grid rates tend to favor the strata that are richer, and remain beyond the reach of the poor. Furthermore, the slight success which centralized electrification programs have had, have not in turn led to rapid small-scale industrialization in rural areas, with associated job creation. Consequently, there may be grounds for providing incentives only to communal, village-level electrification projects.

Decentralized electrification schemes might include several alternative energy technologies, such as the 'packages' designed by the UN Center on Natural Resources, Energy and Transport, described above as being cost-competitive with generators fueled with diesel, or grid systems. Incentives for more widespread use of electricity include specific organization work at the village level, aimed at introducing comprehensive small industry projects which rely on electricity, and which are assured of raw material inputs and markets.

There is a possibility that incentives should be introduced to discourage use of electricity while allocating resources to other, less expensive energy development. Electricity, whether generated in centralised or decentralized plants, is capital intensive. For some uses, it may be cheaper to use local fuels or small hydropower installations to provide motive power directly to meet the energy needs of agriculture and small industry.

Lighting is one area where electricity, despite its capital intensity, is cheaper than other forms of energy because it is vastly more efficient, particularly when used in flourescent lamps. The need for light for a few waking hours of darkness must be weighted with very pressing needs for water, sanifation, cooking fuel and irrigation. In many instances, considerations of equity, village organization and cost may mean that incentives for electrification should be negative so as to allow substantial gains to be made in addressing prior and more pressing issues in rural areas.

If this delaying approach is adopted, the resources for providing community lighting for streets and public buildings can be raised in the village itself under certain circumstances. For instance, a small 3 kilowatt generator could provide community lighting for a village of 1,000 people at a total capital cost of $2,000 to $3,000. The electricity could be generated in micro-hydropower plants or with internal combustion engines using biogas.

Electricity for domestic lighting, community food storage and small industries can alos be locally generated within an organization such as a small public utility,(described below). Thus, providing household electricity could be integrated with housing programs, piped water supply, and perhaps village reconstruction. Two policy implications which follow from these considerations are (1) rural electrification is an integral aspect of broad development strategies for rural areas, and in many ways is dependent upon the choices made in these wider perspectives, and (2) decentralized electrification based on local energy sources (rather than expensively imported diesel) should be considered for support via incentives but even this form of electrification should, in some instances, be subordinated to more pressing demands for scarce resources.

D. Social implications: The unplanned growth in use of petroleum products, and the poorly-considered rural electrification schemes (grid systems) which have been prominent in most developing countries in the last two decades have had two important social implications. First, a dependence on petroleum products and technologies using them, has developed. This is a deep-seated dependence based on emulation of the industrialized world consumption patterns, habit, availability of technology to use oil products (especially in the transport area), marketing networks, and the individualization of communities as consumption units. The key feature of petroleum dependence growth was, without doubt, low product prices. With low prices an experience of the past, developing countries are left with social habits and relations formed, in part, by petroleum dependence which can no longer be maintained. No systematic study has been made of the implications of that higher oil product prices have on rural social relations and activities. Even the common observation that kerosene consumption has declined, and wood or waste use has increased, is not based on cross-national analysis, but is little more than an impression. But it is likely that the unplanned growth in the use of petroleum products has promoted village stratification because most technologies for using oil products are designed for individual consumption. Consequently, there is considerable momentum geared towards maintaining and extending these consumption and production patterns, despite the changed economics which make them much less viable. In short, the history of oil dependency has produced a contemporary situation that is not readily amenable to re-orientation towards increased use of communally-based renewable sources of energy.

Electrification through grid systems has absorbed the very large proportions of developing country public expenditure, with little benefit to the rural poor whose agricultural labor is often the main source of state income. The village level use has been slight (with most villages outside the grid's reach). Even more than with oil product use, electricity has been used by the more wealthy strata. At both state and local levels, electrification has been pursued for the benefit of a few, but paid for by the many. Given the deep-seated nature of these relations which the oil dependency and electricity programs are manifestations, the prospects for decentralized, community mobilization do not appear promising. Nevertheless, such mobilization towards integrated rural development is probably the only means of reversing the negative social implications of past energy-use patterns, and making energy for production and domestic use more widely available.

3. SOLAR ENERGY TECHNOLOGY

There is considerable potential for the use of solar energy as decentralized energy sources for developing countries. But widespread use depends on the extent to which high capital costs for solar devices can be reduced, costs and reliability of related equipment improved, and obstacles to introduction of new technologies overcome.

A. Planning: for the introduction of solar energy technologies[20] is at an early stage in most developing countries; therefore, pilot and demonstration projects are required, and institutions for research and development need to be established or strengthened. Industrial production of solar technologies has begun in both developed and developing countries, but the expansion of this production to take advantage of economies of scale awaits government action to create a mass market.

While the need to plan is widely accepted as a general precept, energy planning and more particularly, solar system projects have yet to be incorporated into strategies of integrated rural development in the vast majority of countries. In mid-1978 the World Bank recognized that the 1973-74 increase in oil prices made appropriate sources of energy for rural areas more interesting. The Bank announced "a continuing examination of a number of potentially attractive localized technologies,"[21] including solar heaters, solar refrigeration and solar pumps (thermal and photoelectric). In addition to financing a number of projects (see below), the World Bank, in response to the recommendations of June 1977 of the (North/South) Conference on International Economic Co-Operation, is providing assistance "especially in the planning of the energy sector as a while."[22] Given this commitment, it is likely that increasing numbers of developing countries will begin to plan solar energy programs, especially for the rural areas.[23]

Technical adaptation and development of direct solar equipment is necessary, but even more important is the accumulation of experience on transferring these technologies to rural areas. Installing potentially hundreds of thousands of decentralized energy systems poses major institutional questions: how to encourage villages and farmers to accept new energy sources, how to transfer necessary technical, economic and systems operations knowledge, how to assure quality on-site installation, how to arrange for local operation and maintenance supplemented by infrequent outside assistance, and other issues. Furthermore, there is the question of the impact of such systems on the structure of the local economy and society. Studies of many newly introduced technologies, such as one on Indian biogas systems, suggest that they may have widened the gap between rural rich and poor.[24] The introduction of solar-based decentralized energy systems presents the challenge of avoiding this pattern.

How far has planning for solar energy systems proceeded in developing countries? Recommendations have been made by United Nations, bilateral and national agencies that specific planning institutions and procedures be established.

UNIDO has indicated that the potential for solar technology application for water distillation, water heating, drying, cooking, refrigeration and airconditioning is attractive. In addition, technologies are available at present for conversion of solar raditation into mechanical and electrical energy. UNIDO emphasized that "The essential need is for the development of a programme for applied research and development and eventual manufacturing activity, with emphasis on technology transfer from industrualized countries, domestic promotion of research and development capabilities and co-operation among developing countries in the field of solar technology.[25] In order to proceed with planning for solar energy, developing countries need more information in five areas:

1. The criteria on which policy should be based, particularly with regard to energy utilization
2. The appropriate governmental structure and machinery for development planning with respect non-conventional sources of energy;
3. Indigenous technology relating to the application of non-conventional sources of energy;
4. Local potential for engineering development and manufacture of production equipment, as well as product demand analysis;
5. Appropriate institutional facilities, work programmes and technical manpower for developing engineering and production capacity.[26]

As to the criteria on which alternative energy policy should be based, the World Bank has issued cost-benefit analysis guidelines[27] which consider solar energy projects within the same framework that is used for other project appraisal. Reservations about this approach, especially from the perspective of practicality and equity, are summarized in the conclusion to the present chapter.

The second information requirement pertains to appropriate government planning structures. The experience of Tanzania is of use here. On the basis of experiments and a workshop in 1977, the Tanzania National Scientific

Research Council[28] described institutional factors for solar energy programs in that country.[29] Broad government involvement is envisioned, including 10 ministries, 5 parastatals (research, electricity, petroleum, capital development, Rufigi Basin Development and banks), academic-research institutions, and village organizations. Given the key role of villagers, it is useful to note some features of village organizations.

The Tanzanian Village Act of 1975 and the Urban Ward Act of 1976 gave legal status to all the villages and urban wards within Tanzania as multipurpose economic entities. The Village Council and the Village Assembly are the bodies responsible for village/ward development. The council has five committees: planning and finance; production and marketing; education, culture and social welfare; security and defence; and finally, building and transport. All are involved in solar energy projects.

The first step in establishing a village energy program is the design of an initial program. The objective is to gain experience at the village level to determine:

1. solar technologies that might be applicable to various tasks of the village,

2. how these technologies compare with conventional ones in cost and performance, and

3. how to ensure the active interest and cooperation of villages and their capacity to make use of, maintain, and repair such technical devices.

The design of an initial program is a national function which can be divided into several stages:

-selecting villages for the testing phase
-establishing a training unit
-enlisting village support
-soliciting feedback
-engaging in research and liaison
-performing analysis
-ensuring program validity

Villages should be selected to represent a broad cross-section of the country's climatic, economic, topographic and cultural features in order to allow for an adequate comparison of various proven solar devices. A minimum number is 15 villages, to be selected according to the following criteria: human skills, village needs, economic viability of project, social utility of project, and village interest in participation.

A training unit needs to be established, preferably at the regional level, to train a number of mechanically apt people from each village in operation, maintenance and repair of the solar devices. This need not be an elaborate training unit at the testing stage, and solar technology training could be eventually incorporated into the program for village management technicians training.

Enlisting village support is essential, both in project planning and implementation. The success of the project is directly related to the level of village organization and the extent to which representatives are in touch with villagers. Enlisting the support and involvement of non-representative village authorities will not facilitate the solar energy program since operation of the devices requires communal committment.

Soliciting feedback: National authorities should work with regional, district and village authorities to ensure that experience of the village with the technology is reported to, and taking into account by those doing research on solar energy. There should be scope for innovation by villagers and adaptations should be reported to research centers. National authorities should undertake continuing research on solar technology for villages, and keep informed of similar research elsewhere in the world.

National solar authorities should analyse village experience with solar energy technology, and formulate recommendations on the role such technologies should play in meeting expanding village energy needs in the next decade. The village experiences should be available to other villages, and representatives of the village councils along with local technicians who have received solar maintenance training would benefit from regular meetings. The meetings could provide input for recommendations on expanding or modifying the solar energy program. The constant involvement of technology users will help ensure program validity. The information from such test program is sought,not as an end in itself, but as facts to guide village development.[30]

The government agencies must co-ordinate to assure that account is taken of solar energy potential, rather than installing diesel or gasoline engines without considering solar alternatives. The research program could consider worldwide developments in solar technology, adapt relevant innovations to local needs, and generate wholly original local ideas.

The Tanzanian program recommended that the government establish an organization to take charge of solar energy programs (coordination, research and implementation).[31] Second, an inventory was recommended of people and institutions involved in alternative energy in the country. Third, the electricity parastatal should incorporate in its planning the investigation of solar energy sources generated on-site in conjunction with electrification by diesel or gasoline engines or from a central grid. The solar energy sources which the electricity authority should consider are mini-hydro generation utilizing dependable streams, wind, organic wastes, as well as diesel and sunshine.[32]

Perhaps the major thrust of recommendations for solar energy planning is data collection. The International Energy Agency (IEA)[33] has developed a number of means for measuring performance of solar technology, and the physical conditions under which it is to operate. These tools are to be applied in developing and developed countries to ascertain most appropriate technologies and siting. For instance, the IEA has developed an insolation handbook and an instrumentation package, and recommends that governments plan to collect data with these aids. While such information is highly useful to developing countries, attention should be given to indigenous needs and capacities, which may differ from the commercial concerns that the IEA data and standards program is explicitly designed to foster.[34] The IEA also promotes the development of solar energy information systems, the main one being that of the U.S. Department of Energy (formerly ERDA), ERDA Energy Information Database. These information systems include some of the estimated ten thousand articles or reports on solar energy currently available (in English and increasing at the rate of about 200 a month).

UNIDO has recommended that governments develop a program of data collection action on solar technology. This may require "allocation of a solar technology program to an existing appropriate institution and provision of relevant finances and technical manpower and development of a practical work plan."[35] It is also recommended that government, through existing meteorological institutes, " initiate the necessary steps for collection of appropriate data, with a view towards assisting and guiding a solar technology programme."[36]

B. <u>Financial requirements</u>: solar energy technology vary from relatively low in the case of simple flat plate collectors, to high in the case of solar cells. Current capital costs per kilowatt of installed capacity are substantially higher for solar photovoltaic systems than for, say, hydropower, except for very small facilities. Capital costs will decline only with volume production. While solar thermal collectors are less expensive, the Rankine cycle engines necessary to convert solar to mechanical energy are both expensive and relatively unproved in field conditions. They also appear to require fairly sophisticated operations and maintenance. Moreover, even at lower costs, large scale implementation of solar thermal and solar cell systems will require substantial capital.

The initial capital cost of solar technology is higher than that for conventional energy, as noted above. But this cost is falling and in any case, the stage reached by solar energy programs warrants modest expenditure for pilot and demonstration projects. In addition, research and development in national laboratories requires financing.

Funds are available for solar enerty development from governments, international agencies and private corporations. Assistance among developing countries has not yet become significant, although several proposals for joint work to be financed jointly, have been made (see conclusion below).

Most active among government financing of solar energy development is the U. S. government through the National Academy of Sciences, USAID, the Department of Energy and other agencies. There has been widespread acceptance within the U.S. government of the 1976 recommendations from the Overseas Development Council:[37]

> -studies and pilot programs comparing the cost and performance of conventional and alternative approaches in rural areas be carried out,
>
> -As promising village-scale technologies are identified from these pilot programs, aid may be warranted to install them in village experiments on a wide scale and, if experience so indicates to
>
> -finance their export to developing countries on a major scale through loans with favorable terms (as every country that exports nuclear fission facilities has done). This not only would help to meet an important need for rural development but also would provide a large market for small-scale energy technology.
>
> -refocus a portion of government energy research and development programs on small-scale renewable sources of energy.
>
> -take the lead in creating energy research networks to gain the benefits of international cooperation
>
> -eventually the U.S. government should subsidize the sale of suitable small-scale technologies to developing countries and help those countries develop their own energy hardware production facilities.

The World Bank is financing alternative energy development programs including those that focus on windmills, small hydroplant s (in the 0-500 KW range), solar heaters, solar refrigeration and solar pumps (thermal and photoelectric). The Bank has given financial support for the development of low-cost devices appropriate to local conditions: to make practical use of solar energy in the Bolivian Altiplano, to improve the efficiency of earthen charcoal kilns used by Philippine smallholders, and to improve the efficiency of cooking stoves in several countries.[38]

Two UNIDO Expert Group recommendations pertain to solar program financing.[39] The first urged that a program be initiated by UNIDO to "secure financial contributions from industrialized countries for integrated solar energy projects...." The second recommended that governments of developing countries earmark appropriate finances for the initiation of a solar activity program, and that UNIDO secure "appropriate contributions (financial and in-kind--physical facilities, technology, etc.) within the framework of co-operation among developing countries."[40]

While the World Bank does not assist manufacturers of equipment in industrial countries with export credits, it does loan developing countries funds for imports of such equipment.

Thus, it is of interest to note the marketing advice given by C. Weiss, Bank advisor, to solar cell manufacturers in the U.S, before reviewing corporate financial activities.[41] Given that the economic competitiveness of solar cells depends on a guaranteed lifetime of at least six years, Weiss stated that a six-year guarantee, backed by an enterprise of long standing and a competent maintenance organization, is about the minimum for acceptance of solar photovoltaic cells in developing countries.[42]

The solar cell is capital-intensive, costing about three times the cost of a gasoline generator. For this reason, the cost and availability of capital will be a major concern for potential developing country customers (which, according to Weiss will be mainly the government ministries of education, forestry, telecommunication and defense). They will "no doubt wish to know whether credits can be obtained, at conditions sufficiently favorable to make solar units attractive compared with conventional sources."[43] While the Bank's policy is to finance solar energy along with other sources of power and to accept it where it appears to be the most economical and effective solution, Weiss advices the firms that there are "agencies specifically intended to guarantee commercial financing for U.S. exports, and it may be appropriate to approach them for guidance on how the market for U.S. manufactured photovoltaic devices in developing countries might be broadened."[44] These points serve to underline the importance that industrialized countries attach to being in the lead in the competition for access to alternative energy technology markets in the developing world.

Solar equipment manufacturers finance some projects involving different solar technologies and equipment, as part of their campaign to explore market potentials. Mention has been made of SOFRETES' (French) experiment with solar water pumps in 25 countries. A subsidiary of Elf, the French state-owned oil company, is sponsoring solar water pump experiments in Senegal and Cameroun.[45]

Finally, developing country governments are committing funds to solar energy research and development programs. Table 6-1 indicates the broad range of solar research, including solar heating, crop drying techniques, and solar thermal electric generation. Wind technology is receiving less attention.

C. Government policy implications: Developing country governments have only begun to formulate alternative energy policies, as described in the planning section of the above discussion. However, in some countries plans are advanced for producing capital equipment (solar technology) which may be encouraged in the private sector by conventional industrial

Table 6 - 1

1977: Solar Energy R and D in Selected Developing Countries

Country	Solar heating	Solar cooling of buildings	Crop drying	Water pumping	Solar electricity; thermal	Solar electricity photovoltaic	Wind energy	Biological energy	Energy from the sea	Geothermal energy
Argentina	x		x			x	x			
Barbados			x				x			
Bolivia			x			x	x			
Brazil	x		x			x				
Chad		x			x		x			
Chile	x				x					x
China	x		x							
Costa Rica	x		x				x			
Cuba		x					x			
Ecuador	x									
Egypt	x			x	x		x			
El Salvador										x
Guatemala	x		x							
India	x			x	x	x	x			
Iran	x		x		x	x				
Iraq	x									
Israel	x	x		x	x	x		x		
Jamaica	x		x							
Jordan	x									
Kuwait	x				x	x				
Malawi	x		x							
Malaysia		x	x		x	x		x		
Mali		x			x					
Mauritius		x								
Niger			x	x	x					
Nigeria			x							
Oman					x		x			
Pakistan	x	x	x			x		x		
Papua New Guinea			x	x						
Peru	x		x							
Philippines	x		x				x			x
Qatar					x					
Saudi Arabia	x		x	x	x	x				
Senegal	x				x					
Singapore					x			x		
Sri Lanka	x		x	x			x			
Sudan			x							
Thailand			x	x			x			
No. of countries engaged	22	7	21	8	15	1o	12	4	-	3
% of No. of countries listed	58	18	55	21	39	26	32	11	-	8

Source: UN. "Research in non-conventional sources of energy; Report of the Secretary General", (E/C.8/56), January 1978, Annex (Summary of Response sent by the Member States of the United Nations to the Secretary-General's uote verbal concerning their current programmes on research and developmant.)

incentives (tax holidays, pioneer industry status, etc.). Government sponship of research in public institutions or on contract to private firms is another avenue for encouraging solar technology development.

Governments can encourage the development of alternative energy supply systems, by providing loans to village committees. These loans are probably most effective in programs which integrate several different energy sources (biogas, woodlots, more efficient cooking stoves) under the direction of an elected village committee established to oversee public utilities.[46] In addition, there is scope for public works programs for tree planting, building small earth dams, water supply, etc. These should be tied to the creation of permanent jobs, to halting deterioriation of rural land and water resources, and to the creation of local savings so that further progress can be sustained by the local communities themselves. There may be scope for directing government loans and public works programs towards villages with the potential of establishing small-scale local industries, for instance in the weaving area.

Some specific country experiences will illustrate the direction taken by governments. The Tanzanian solar energy program has already been described in detail and emphasizes more than others (except the Chinese example) the importance of village participation.

India. The Indian Department of Science and Technology funds and co-ordinates solar R & D nationally, with an emphasis on rapid commercialization. Solar cells, and thermal devices are important aspects of the program, which means that Indian manufacturers will play a role.[47] The Indian government is facilitating research solar cell manufacture and on sophisticated power towers (large-scale solar thermal generation), but most attention is devoted to biogas units. The Indian Government is providing incentives to villagers by providing about one-fifth of the capital cost of $2.8m^3$ family biogas plant costs--a grant of $50.[48] Over 20,000 small family units have been installed over the past 15 years, under the auspices of the Khadi and Village Industries Commission which has been in charge of the biogas program.[49]

A comparison of biogas plants and coal-fueled fertilizer facilities will illustrate the importance of government incentives to encourage the most economical and socially-beneficial industrial strategies.[50] In India, where there is strong demand for nitrogen fertilizer, a large coal-fueled fertilizer factory will produce 230,000 tons per year, as would 26,000 biogas plants. But the biogas plants would cost $15 million less to build, and the investment would be spent in India, saving some $70 million in foreign exchange. The biogas plants would provide 130 times as many jobs and these would be located in rural areas where most people live and where employment is needed. Biogas plants would also produce the fertilizer where it is needed, eliminating the transportation requirements. Finally, the coal-fired plant consumes enough fuel every year to meet the energy needs of 550 Indian villages, while the biogas plants would produce enough fuel each year to meet most of the energy needs of 26,000 Indian villages.

In the Philippines, the Energy Development Board seeks to supply 5% of national energy consumption through solar technologies by 1985, with a major emphasis on biogas, and wood thermal power plants (75MWe).

Brazil is committing R & D funds to solar power generation research in sever public-sector institutions. Likewise the Kuwait Institute for Scientific Research is focusing on solar R & R and has initiated work on solar cooling and heating of buildings, solar thermal electric conversion (100KWe capacity) and agricultural application for solar technology. Oil producing developing countries (Mexico, Algeria, Indonesia, Iran, Nigeria, Saudi Arabia and Venezuela) are investigating the potential of solar energy technology.

D. Social implications: The institutional and social dimensions of solar technology can be illustrated by reference to the problems faced by establishing village level biogas plants.[51] Some of the questions which arise in considering how a biogas plant for a complete village can be made to work include: what kind of social management and organizational problems would be encountered? How does one collect farm waste and how does one distribute gas and fertilizers? How does one ensure cooperation from 'rich' families who could set up their own plants while also involving poor families who spend hours in collecting fuel?

A desirable project would involve the top 14% of village families who own their own cattle by providing incentives such that they would be no less well-off than if they established their own plants. It also provides for net benefits for the poor who own no cattle but collect dung from the streets.

In the scheme dung is purchased daily for money.[52] The fertilizer available is sold to the sellers of farmwaste at a fixed price with a limit in proportion to the farmwaste sold by them. Those who cannot afford to buy gas can come to the plant sites to cook their meals at a community kitchen that is attached to the community gas plant. They can do so in exchange for a few hours of service per week for the operation of the plant, such as collecting farmwaste or bringing water to the plant, maintaining cleanliness, etc., or for a price paid to utilize the burners for a certain time. One may even consider giving it free of cost if the situation permits and misuse is prevented. Cylinders and gas burners are rented out to users who would pay a deposit for these. There may be families too poor to be able to spare even a deposit of $20 and for them community kitchens have to be provided. In fixing prices of the various inputs and outputs, special attention has to be given to ensure that no one is worse off by the introduction of bio-gas plants.

Large scale adoption of biogas plants could result in a contribution from biogas amounting to between 10% and 15% of total energy use in India in 2000.[53] It has been proposed to set up a cluster of public latrines and attached them to a biogas plant in slum areas of Indian cities. The right to the products of the plant, namely gas and fertilizer, are transferred along with the responsibility of maintaining the cleanliness of the latrines to someone in the slum.[54]

A number of social problems which could arise with the installation of alternative energy technology can be noted. In the case of hand pump operated tube wells, such as those installed for communal water supply in India's Deccan plateau, the failure rate is very high. Broken pumps are comman. It is now recognised byat the principal causes of failure are social, not technical.[55] Installation was usually effected without villager involvement with the result that the government was expected to make

repairs, for which there was usually no budgetary provision. Again, those from the lowest castes were denied access to the clean water, communal tensions erupted and led to damage through deliberate wrecking of pumps and tubewells.
A village public utility was proposed as a means of overcoming these social difficulties.[56] It would be responsible for the physical and fiscal integrity of the facilities in its charge and ensure that all villagers have access to its services. It would be managed by an elected committee whose members would be individually subject to recall.

Village wide meeting which report accounts and progress would be held every two months. The accounts would be kept by the committee and they would be public. A supervisory committee (also elected) would handle grievances and be responsible for auditing. Overlapping membership between the managing and supervisory committees would be prohibited. Funding would come from individual villagers, existing community funds, voluntary labor and loans from outside sources (banks, government rural development agencies). The management committee would prepare plans for water, fuel, cooking stove supply, with outside assistance, and approved by the entire village. Payment for goods and services supplied would be through provision of labor.

The woodlot for supplying 1,000 people (200 families) with 200 tons of fuelwood a year for (more efficient) ccoking would require 10 hectares of lang, with a renewable yield of 20 tons per hectare per year. As in China, a substantial portion of this land requirement could be met by lining the village streets, approach roads, windbreak areas and commons with trees. Management of the woodlot by villagers themselves would considerably reduce illegal felling of trees.[57]

Makhijani calculated the economics and loan repayment schedule for a village public utility for an Indian village of 1000 people.[58] For an initial investment of about $12 per capita the utility could be generating substantial funds of its own, having paid off the starting loan, within five years. Each family would obtain water for household use, fuelwood, a stove, and the use of community sanitation facilities in return for 30 to 35 days work (6 to 7 per capita). This is less than the amount of labor which the poor spend on gathering fuelwood alone. This work would be directed towards (1) producing one or two crops per year on the three hectares of agricultural land acquired by the utility, (2) maintaining and managing the facilities of the utility and (3) extablishing and maintaining the village woodlot.

The circumstances of particular areas will determine whether approaches to rural energy and utilities supply such as the one described by Makhijani are practical.[59] He noted that "usually the very possibility of communal projects depends on measures directed at reducing current inequities (e.g., land reform)."[60]

4. FORESTRY

A. The need for planning: Reforestation and aforestation projects is especially important because of the long lead times associated with maturation While the time required to introduce more efficient technologies for using fuelwood is not so extended, the social implications of changing traditional cooking and other wood uses are considerable. Another reason for emphasizing the importance of planning for the forests is the neglect of the area in the past, due to its being subsumed under agriculture or, less often, industry (logging). Only recently have the fuel and ecological dimensions of forestry received planners' attention. Finally, the fact that the majority of the world's people depend on fuelwood for most of their energy consumption,[61] means that planning in this area should command serious attention.

Planning in the forestry sector can be divided into data and training on the one hand and rural development projects on the other hand. At present, not enough is known about the extent to which total forest resources can contribute to a viable energy supply. A leading forestry specialist, Vaclav Smil, stated that "the information currently used is based on too few samples resulting in inevitably misleading conclusions."[62] Thus, a higher priority could usefully be placed on forest inventories, and land use and soil surveys. Information from these evaluations is

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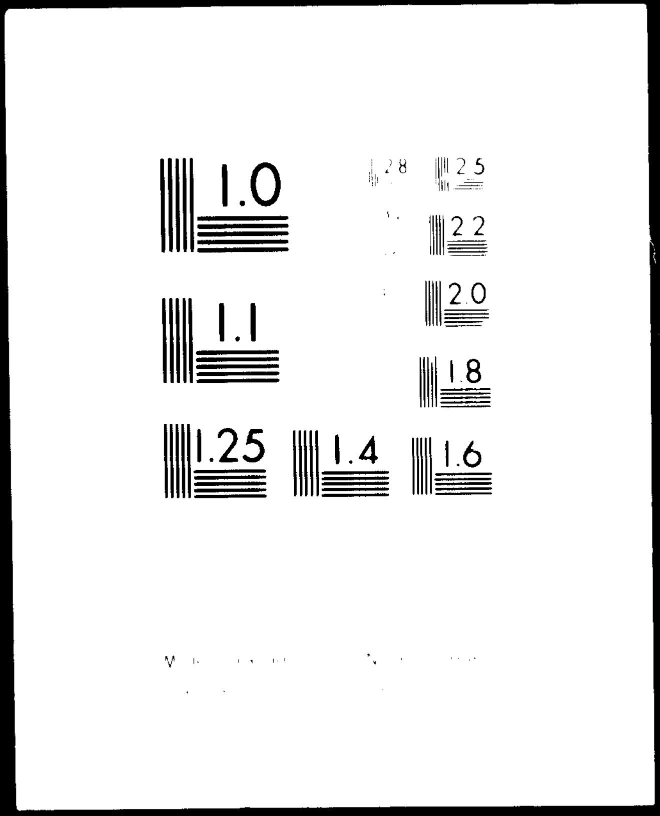

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essential as a foundation for programs to protect forest located in water catchment basins, agricultural settlement projects and sand dune stabilization in arid areas. There is a corresponding need for institution-building projects for training, education, and forestry research with special emphasis on pilot trials and combined agro-forestry/crop combinations.

Forestry-related rural development projects which could be considered within a wider planning context include the establishment of village woodlots for fuelwood and timber production, farm forestry, shelter belts, soil conservation measures, planting of fruit, fodder-producing and fiber-producing trees, and the encouragement of rural, small-scale industries that use wood. Some industrial forest projects [63] might also form part of forestry planning.

Both the information and project dimensions of forestry planning highlight a new direction for policy in this sector. Forests can no longer be thought of simply as a natural resource to be harvested for export and industrial use. Rather, they can more usefully be considered within broadly based national programs with a wide range of components. This change in approach to forestry development necessitates the development of new concepts, technologies and institutional approaches. The change is based on the reality that the major contribution of forestry to development will come from its impact on the rural population, through watershed aforestation, land rehabilitation, dune fixation, land reclamation, shelter belts, village woodlots, intercropping with plantations, various tree/grazing and house garden/tree-planting combinations, fodder trees, labor-intensive plantations, saw-milling, joinery workshops, and rural wood-based industries.

Among the forestry policies which planners might consider when drawing up energy programs are the determination of environmental and ecological effects of forestry destruction, and the definition of rural development strategies that will assist low-income groups without, at the same time, leading to ecologically destructive patterns of development. Particularly attractive projects may be those dealing with agroforestry and fuel-wood plantation development. Fuelwood/building pole components might be incorporated into agricultural or rural development projects if the need is evident. Rural forestry programs might be considered in connection with employment generation in rural areas. Planning of agricultural settlements and special plantations could incorporate research into the capability of fragile tropical forest soils to support intensified agriculture and forest cropping.

Planning of educational and research programs could usefully cover forestry research, especially in the areas of agroforestry, fuelwood development and environmental studies. There may be need for institution-building in the public sector to strengthen agencies that deal with fast-growing fuelwood or industrial plantation programs. Comprehensive rural aforstation development plans could be the outcome of preliminary data collection and experience gained from including forestry components in wider rural development projects. In the course of this planning and experimentation, the key technical, organizational, managerial and personnel or laborpower constraints that inhibit the development of forestry can be identified.

B. Estimates of <u>financial requirements</u>: Forestry projects are difficult to specify due to the industrial bias of previous programs, and to the intangible aspects of rural forestry projects. One indication of the magnitude of costs is provided by the World Bank which has committed $500 million to forestry projects between 1979 and 1983. In addition the Bank has included forestry components in a number of agricultural and rural development projects. The average size of these components is small, about $250,000 for each project, and the total volume of planned Bank lending for such forestry activity over the 1978-82 period (about $6 million) represents a very small proportion of planned agricultural and rural development lending.[64] However, even small forestry components in larger agricultural projects can be significant in terms of development impact.

While the financial requirements vary immensely from one country to another, in general, it can be said that forestry programs are probably among the least costly solutions to energy shortages in rural areas. Their advantages include the low requirement for foreign exchange and their intensive use of labor which may have a low opportunity cost.

Fuelwood plantations constitute some of "the best examples of recent official responses to forestry needs."[65] Certain trees such as the Australian eucalyptus are fast growing and can produce more than 20 times the annual growth of natural forest. One hectare of this kind of plantation can support the firewood needs of from 15 to 20 people. Eucalyptus plantings require little technical skill, and the costs can frequently be kept below $100 a hectare.[66] Labor makes up the main economic bost of plantation establishment, but in some instances this may be provided free, with adequate government encouragement through provision of incentives.

Financial requirements for forestry projects can be assessed and justified on the basis of conventional project appraisal techniques with certain modifications. For instance, land to be used in forestry projects may not need to be costed as a capital cost because it is in excess supply and is likely to be so for the life of the projects. But if the land can definitely be used, either a cost must be attributed to land and entered as a capital cost, or some estimate of the net value of output from the land in other likely uses should be made and deducted from the net benefits. While forestry projects have beneficial effects on water catchment areas and can conserve soil, such benefits are hard to measure. However, some effort to estimate ecological benefits of a forest (such as the cost of desilting canals or lakes) is possible with large margins of error. Other considerations which would enter into financial assessments are those having to do with equity, time savings from local wood supplies, the interaction of multiple projects (plantation and lumber planing mill), long payback periods, uncertainty about the end use of the wood and prediction of contigent environmental effects.[67]

Funding for forestry programs is available from international organizations, bilateral aid plans, transnational corporations and national research institutions. The World Bank, in the period 1953 to 1976 lent $240 million for 17 forestry and forest industry projects.[68] Reflecting a change in strategy, the Bank's lending for 1979-83 is directed towards village rather than industrial forestry needs, and emphasizes fuelwood and research. In close collaboration with FAO and UNDP in the preparation of of forestry projects, the Bank intends to lend five times the amount lent in the 1972-76 period, with a yearly target of $100 million.[69] Twenty-five projects are under preparation in 1978 and account for half the $500 million five-year budget. The average project size is between $10 million and $15 million, with from seven to ten forestry projects a ydar. In addition to forestry projects, forestry components are being included in at least five agricultural or rural development projects a year.

The Swedish International Development Authority has a forestry funding program for developing countries as does the International Development Research Centre (IDRC).[70] A new International Council for Research in Agroforestry (ICRAF) was established in October 1977, to be located in a developing country. Its program includes the study of managing and harvesting of wood for fuel in all ecological zones.[71] It is funded to date by the Netherlands, Switzerland, IDRC and UNEP (United Nations Environment Programme), [72] and will sponsor projects in forestry in developing countries.

C. Government policy implications: Programs of rural energy supply can be encouraged by a number of government policies, including incentives to manufacturers and villagers. Given that the highest cost in establishing fuelwood plantations is labor, it is valuable to note the experiences of India and the Republic of Korea. The governments provided an adequate supply of seeds or seedlings, and extension advice. Villagers were induced to undertake tree planting on their own land, or collectively in village woodlots. The South Korean program is to plant 50,000 hectares of village woodlots annually, while India expects to establish over 500.000 hectares of fuelwood plantations a year. Government policy in Niger was one of consultation and encouragement through provision of seeds, with land being alloted by villages. In the Zinder district of south-central Niger, farmers are growing trees as part of the farming operation. Since 1974 when consultation began between village councils and forestry extension workers, six villages have taken land out of farming to establish village woodlots, for community firewood. It is projected that in five years some 70 such woodlots will be established, and will reduce the labor and time in firewood gathering.

Pakistan's Forestry Service is experimenting with species of trees for planting along canal banks to provide windbreaks and fuel, as well as shelter for livestock, people and crops. The Senegalese government is attempting to demonstrate the superior value of trees as multiple sources of income, in order to discourage cutting. At M'Bidi in northern Senegal, grazing has left grounds around wells bare. A scheme of reforestation that is a model of integrated land use is now underway on a 200-hectare site. Trees will produce wood for fuel, shelter for vegetable gardens and gum arabic (from acacia trees). In the Philippines there is a project to propagate fast-growing ipil-ipil for production of fuelwood, charcoal, pitprops, animal fodder and pulp and paper manufacture. China has developed plantations in the countryside and cities with considerable success.

Adoption of technology that will favor the creation of employment and result in the expansion of domestic manufacturing can be a viable economic alternative to capital-intensive industrial forest projects in some areas. For instance, governments can adop policies to generate additional employment and income by organizing reforestation ane cutting and extraction through labor-intensive methods using suitable technology rather than tree-planting machines and bulldozers, with added benefits in terms of saving foreign exchange.

Government policies on forest extraction by foreign or national corporations may require review. Concession arrangements, fiscal policies and the institutional arrangements for forest extraction operations have hitherto promoted the development of log, timber or plywood export industry. In some cases concessions have favored unduly the licensee.[73] Renegotiation of some terms may be desirable, especially the level of royalty taxes, clauses relating to reforestation or forest management obligations of the licensee, and arrangements for cost sharing in relation to forest road and infrastructure programs. Policy decisions are also required in connection with private tree farming and corporate-owned or state-owned industrial plantations. If a country's developmental objective is to help the rural poor, priority should clearly be given to encouraging small farmers to grow industrial wood. But problems in doing so include the long maturing time (about 15 years) of forests which poses difficulties for small farmers who cannot wait that long for a return on investment. In such situations, government subsidy of plantation investment is essential and a component wihch will yield returns in the medium term could be built in. Another difficulty with the policy of encouraging forestry by small farmers rather than large plantations is that most large, privately-owned pulp corporations insist on controlling directly from 25 to 30% of their wood supplies.

Government policies relating to the substitution of other fuels for wood are those mentioned in previous sections as inc entives for development of alternative energy technologies. In addition, wood used for housing can be replaced by mud bricks in wood-deficient countries. Government forestry policy could explicitly recognize the role that substitutes might play and encourage their wider use. Finally, incentives for the development of more efficient cooking equipment and wood burning or charcoal-making technology include tax holidays, direct subsidies on imported items, and campaigns to disseminate information on efficient woodfuel use.

Among the many types of tools and equipment which use energy, stoves or cooking units are perhaps the most vitally in need of improvement to increase energy efficiency. Wood conservation (and savings of other vegetable and waste matter for fertilizer) would be promoted through the use of multi-purpose clay stove-overs; improving the heat retention of charcoal braziers; or using the more efficient Norwegian two-chamber stoves which burn both wood and gases released from initial combustion. Government policies to make energy conservation technology available at prices rural population can afford include efforts to produce designs and units locally. The skills existing personnel such as blacksmiths, automobile mechanics and eletrical repair people, can be enlisted to manufacture and sell energy-saving tools and equipment. USAID is sponsoring such projects with the governments of Ghana, Liberia and Zaire.[74]

D. Social implications of policies to increase the supply of woodfuel are complex and numerous, largely due to the land tenure patterns and the intimate dependence of villagers on wood for a multitude of uses. The most apparent social implication is the possibility that fuelwood which was traditionally available to the gatherer at no cost will become commercialized, and priced beyond the ability of many villagers to pay. Another issue concerns the means by which fuelwood and other forestry projects can be witheld from use until maturity, or used moderately in a context of energy shortage. If they are village cooperatives, the institutional framework of their administration and management is required, and over several years. As with other forms of village fuel and energy technology, a premium is placed on communal organization at the village level.

In assessing the costs and benefits of forestry projects, several social implications demand attention. Possible alternative uses for land must be considered before woodlots or plantations are established. Possible increases in the income of poor people should be weighted more heavily than the same increases in income going to the wealthier strata. In order to determine equity considerations, the destributive implications of a project must be identified. For instance, if planting a woodlot makes more income available to the poor than does a pineapple plantation (which generates more overall income but to different groups), the first should be favored.[75] A fuelwood lot has the distinct advantage of reducing time spent walking long distances to gather wood, a task which normally falls to children and women. The labor saved is a benefit even when it is not used in alternative fashion for generating productive output, measured in money. Leisure is a social benefit, as is time spent in education or other pursuits.

Social conditions play a role in determining the type of forestry development that will probably be most successful. For example, the accepted ownership pattern of forested lands may prohibit plantation forestry but may be highly suitable for the establishment of village woodlots. Other social factors including population density and the major source of household fuel are important in assessing the most attractive forestry policy. In densely populated areas such as Bangladesh, Indonesia (Java) and India severe fuel shortages exist. These combined with forest management services that are often understaffed and underbudgeted contribute to situations of confrontation between government officials managing fixed forestry reserves and poor farmers.[76]

Indigenous social features which have contributed to deforestation and wood depletion require attention in connection with forestry planning. Some key features leading to fuelwood shortage are an increase in the size of a population with a static farming technology, tenure insecurity and exclusion of people from better land by inequitable patterns of land ownership, and the use of traditional technology and relatively infertile soils that make 'slash and burn' agriculture necessary. Again, too many cattle relative to the grazing potential poses a problem for forest policy makers. Dry regions where grazing is the main form of land use, are also faced with serious shortages of wood.

Many of the methods of dealing with social conditions and cultural patterns connected with wood shortages are costly and politically unpopular. Reduced stocking, voluntary migration and resettlement in sedentary pursuits may be impractical. Regulating land use through restrictions is also difficult to implement. The best solution, although it is a long-term one is increasing agricultural production through the use of improved social organization and technology.

Social habits have mitigated against the acceptance of solar cookers which would relieve some of the pressure on woodfuel. The cookers require adoption of new methods of meal preparation and restricts meal preparation to daylight hours. Even when they were given away free in Mexico and India, solar cookers failed to gain acceptance.[77] A simple acid storagebattery solar cooker currently under development requires fewer cultural adjustments. Other approaches such as slow reflective cookers, baking ovens and stew pots are being developed, but as with more efficient wood-burning cookers, these represent expenditures of scare capital and thus are probably out of reach of most rural people whose incomes are often less than $50 a year.

5. CONCLUSION

Planning for the installation of systems to supply energy to rural areas may be premised on at least two different approaches. On the one hand, conventional cost-benefit analysis may be employed. Alternative energy systems would have to appear competitive both from the cost and the return sides, in comparison with electricity from grids or diesel generators, etc. The key point about strictly economic evaluation frameworks is that they depend on profitability and hence, on consumer ability to pay. The consumer of energy, whether a single business or a social service within a community, or a public utility (village water supply) must be engaged in commerce or exchange-oriented production, and profiting from this activity in order to have the income to pay for the energy. There is little reason to expect that the proportion of individuals or villages currently able to purchase energy would change significantly with the introduction of alternative energy systems. Slightly less expensive energy may provide some currently marginal businesses with the opportunity to mechanize and increase production. But, as with the green revolution, only the wealthier rural strata are likely to be in a position to benefit from energy supplies.

On the other hand, a social cost-benefit analysis could underpin efforts to install alternative energy sources. While many elements in such an assessment are not subject to easy quantification (improvements in health, for instance), the benefits of establishing communally-operated energy supply systems which are accessible to all members of the community are considerable. They include an improvement in the quality of life and the experience of securing a tangible gain through communal work. Clearly such an approach, which has as its goals village self-reliance, would ultimately lead to increased production. The crucial difference between a social and a conventional cost-benefit approach is the starting point. The social perspective would chose technology most appropriate to the capacities of villagers, especially those in the poorer strata. Its introduction and adoption would be facilitated by the work of special 'mobilizers' working in pairs with villagers (preferably chosen by election) who would be responsible, probably on a part time basis, for co-ordinating the work associated with the energy system.

When the present state of the art in solar technology and its application is considered, the social approach becomes more attractive. Little is known about unit costing and long-term operation, and less about social acceptance. Installation of pilot and demonstration plants yield valuable data, but the applicablity of this information in subsequent village operations is questionable. The more promising method of securing practical information about alternative energy systems is through programs of installation based, not on immediate profitability, but on social benefit.

The interests of villagers, especially poorer rural residents, must be considered in comparison with the interests of firms commercializing alternative energy technology. Differences in design of the technology, size, fabrication materials, and operating features are likely to emerge from the village as contrasted with the manufacturer. However, a range of possibilities exist for government sponsorship of alternative energy technology production which would suit village needs. Such production units might be decentralized so as to respond to the particular features of a group of villages for which equipment is produced. This conception of decentralized, communal development has much in common with plans for integrated rural development. But it does exclude narrow economic cost-benefit analysis as a decision-making tool.

Government planners concerned with solar and alternative energy technology are being inundated with information and advice from foreign firms, governments and international organizations. The thrust is often either limited to technical data or to proposals for demonstration projects. These are components of larger, corporate marketing strategies and product development-testing experiments. The type of technology and the terms under which it is introduced (conventional cost-benefit) are those consistent with corporate profitability.

It is therefore important that solar energy policy makers consider explicitly whether the national interest is served by this approach, or whether alternatives along the lines suggested above are more suitable.

Co-operation among developing countries in the area of solar energy technologies has been discussed in several international meetings, especially under United Nations auspices. While concrete programs have yet to evolve, mention should be made of recommendations in this respect, for UNIDO action.[78] They include the strengthening of existing institutions in selected developing countries (which have technological, industrial and infrastructural capabilities) and transform the same into specialized solar energy centres, with the objective of developing an applied R & D program for the benefit of other interested developing countries.

It was recommended that UNIDO ascertain the interest of selected developing countries in being associated in the program, to become one of the nucleus of cooperating developing countries, and assist the local institutions to develop an integrated work program of applied R & D, assessment of technologies, and evaluation of prototypes and products, disseminate technological information and techniques, train personnel from other developing countries and promote entrepreneurship development. Co-operative programs could be developed between the various solar energy centres.

There is considerable scope for con-operation among developing countries in the solar area for two reasons. First, both raw materials for technology fabrication and markets are in the developing countries, which avoids the issues of market access in the industrial world. Second, the capital surpluses of some developing countries (mainly those OPEC countries with revenue surpluses) might be invested in developing solar technology to the benefit of all developing countries involved. The possibilities for cooperation among developing countries is being discussed in preparation for the United Nations conference on Technical Co-operation among Developing Countries (1978) and on Science and Technology for Development (1979).

FOOTNOTES FOR CHAPTER SIX

1. World Bank, "The World Bank's energy activities," (World Bank; Briefing Paper, Washington D. C.) May 23, 1978, p. 4. The paper stated that "We believe that the introduction of 'appropriate technologies' is primarily an institutional problem."

2. World Bank, "The World Bank's energy activities," Briefing Paper, (World Bank: Washington D. C.) May 23, 1978, p. 4

3. For discussion of refinery product patterns and the development of refining capacity in developing countries see Terisa Turner, "Two refineries: a comparative study of technology transfer to the Nigerian refining industry," World Development, 1977, vol. 5, no. 3, pp. 235-256 and "The transfer of oil technology and the Nigerian State," Development and Change, (The Hague) 7 (1976), pp. 353-390.

4. K. Ketharaman, "Aspects of petroleum transport in developing countries," Natural Resources Forum (United Nation), vol. 2, no. 3, April 1978, p. 253. The article provides useful insights regarding possibilities for cooperation among developing countries in the sea tanker transport of crude and products.

5. S. Katharaman, op. cit., p. 254.

6. In OPEC member countries the average annual increase in total commercial energy consumption (largely oil) was 12.2% between 1970 and 1973. In contrast, the average annual increase was only 6.3% in other developing countries where the cost of imported oil is a major demand on foreign exchange and where prices of petroleum products are subject to less or no subsidization.

7. In Latin America only 2% of the electricity generated is used in rural areas, where half the people live; in India 10% of the electricity is used in rural areas where 80% of the people live. The picture in other countries is similar. Makhijani, "Energy policy for the rural third world," International Institute for Environment and Development (London and Washington D. C.), September 1976, p.42.

8. Ibid.

9. World Bank, "The World Bank's energy activities," briefing paper, May 23, 1978, p. 1.

10. Ibid.

11. World Bank, "The World Bank's energy activities," op. cit., p. 2.

12. World Bank, "Petroleum and gas outlook in non-OPEC developing countries: 1976-85," (World Bank: Washington, D. C.) May 1978, p.1.

13. The World Bank did not finance oil activities until mid-1977 when it lent India $150 m. for development of the offshore Bombay High field. The bank's energy policy paper states that "no Bank financing of exploration is contemplated ... Exploration particularly 'wildcat' drilling, is a high risk investment.... In may OI LDCs (Oil Importing Developkng Countries) with scarce resources and limited experience in oil development it would not make sense for the country to invest its own resources in this type of high risk venture or even to borrow for this purpose." "The World Bank's energy activities," op. cit., p. 3.

14. Efrain Friedmann, "Financing energy in developing countries," Energy Policy, March 1976, p. 46. World Bank reprint series, no.27.

15. Ibid.

16. Efrain Friedmann, op. cit., p.38.

17. Ibid.

18. Ibid. Friedmann states that "we are not sure that this face /the reallocation of public investment/ is fully grasped by decision makers in countries and developing institutions." p. 39.

19. World Bank, "The World Bank's energy activities," briefing paper, May 23, 1978, p. 1. The policy statement noted that "The Bank is by far the major external source of financial support in this sector, providing far more than the combined lending by all other official multilateral and bilateral sources." Ibid.

20. Flat plate collectors for water distillation or pumping, concentrating collectors for cooking, solar thermal power generation and solar cells; biogas, hydropower and wind and wood is discussed the subsequent section.

21. World Bank, "The World Bank's energy activities," Briefing paper (World Bank: Washington D. C.), May 23, 1978. p.3.

22. Ibid.

23. The World Bank is joined by the United State Overseas Development Council in encouraging energy planning, especially in the solar area. See Energy for the Villages of Africa, op. cit. Agencies of the U.S. Governement are considering a number of projects to heighten awareness in developing countries of the potential of solar energy. One project aimed, among other things, "to enhance the ability of the participants /from developing countries/ to contribute to present and future evaluations of the economic and technical feasibility of these energy technologies and application in their countries." Institute of International Education, "Proposal for study tour on renewable energy resources," March 23, 1978, mimeo. To office of Energy, Agency for International Development.

24. Brookhaven, Energy needs, op.cit., p.93. See also Reddy and Prasad, "Technological alternatives and the Indian energy crisis," op.cit.

25. UNIDO, Technology for solar energy utilization, Development and transfer of technology series, No. 5, (ID/202) (United Natkons: New York) May 1978, p. 3

26. These five information deficiencies were identified by an Expert Group Meeting on the Existing Solar Technology and the possibilities of manufacturing solar equipment in developing countries, organized by UNIDO in co-operation with the Austrial Solar and Space Agency (ASSOA in Vienna, 14-19, February 1977. The five points are reprinted in UNIDO, Technology for solar energy utilization, Ibid.,p.4.

27. S. Pak and C. Taylor, "Critical factors in economic evaluation of small decentralized energy project," Science and technology report series, No. 25, November 1976, (World Bank: Washington D. C.) mimeo. In the discussion of biogas below, some of the factors identified in this paper are summarized.

28. The program was jointly sponsored by Tanziania and the U. S. National Academy of Sciences. See Tanzania National Scientific Research Council, Workshop on solar energy for the villages of Tanzania, (Dar es Salaam: Tanzania National Scientific Research Council) 1978.

29. In Tanzania all development activities are publicly-controlled, and are based on the Ujaama village which aims to become a co-operative, communal unit. While these institutional recommendations will have less applicability to free market countries, they are nevertheless important in that the Tanzanian approach to solar energy may be most promising.

30. This discription of a solar energy program is adapted from Tanzania National Scientific Research Council, Workshop of solar energy for the villages of Tanzania, op.cit.,pp.21-25.

31. There is no apparent preference as to the nature of this institution. Recommended options included a unit in the President's office or in the main ministry concerned (Water, Energy and Minerals) or separating the three functions under different ministries, and a number of other possibilities.

32. Tanzania is building a new capital at Dodoma, and this provides an opportunity to utilize renewable energy. The electricity authority was intructed to provide information, advice, and encouragement to the Capital Development Authority to promote solar and other renewable energies in rural areas adjacent to the capital and in the city itself.

33. The IEA, established in November 1974 by members of OEOD (France is an observer), has a Solar Energy Expert Group that promotes a number of solar projects. Among its activities are data system development snd standardization. See Appendices 2 and 3 of UNIDO. Technology for solar energy utilization, op.cit., pp.150-154.

34. Mass production by firms based in IEA member countries is possible only on the basis of uniform specifications on the one hand, and market creation on the other. There is some possibility that

developing country governments may plan initial solar activities to facilitate production in the OECD countries of solar technology most suitable to large-scale, capital intensive techniques. This may not be the most appropriate technology for developing countries. A further concern is the planning may function as market development for foreign firms, rather than serve local priorities.

35. UNIDO, Technology for solar energy utilization, op. cit., Annex 1, recommendations of the expert group meeting, February 1977, p.148.

36. UNIDO, op. cit., p.148.

37. James W. Howe and W. Knowland, "Energy and development: an international approach," Communique on development issues, no. 31, (Washington D. C. : Overseas Development Council) December 1976.

38. World Bank, "The World Bank's energy activities," Briefing paper, (Washington D. C.: World Bank) mimeo, May 23, 1978, p. 4.

39. UNIDO, op. cit., p.149.

40. UNIDO, op. cit., p. 149.

41. Charles Weiss, Science and technology advisor, "Solar photovoltaic cells in developing countries," Science and Technology Report No. 26 (World Bank: Washington D. C.) November 1976, p. 4. Weiss's views do not represent those of the Bank.

42. Because a six-year guarantee would be economically feasible only for a large market, Weiss observed that for smaller markets manufacturers might incorporate into their product provision for quick identification of defective components and easy replacement with spares, to reduce service calls. Ibid, p. 4.

43. Charles Weiss, op. cit., p. 4.

44. Ibid. Weiss observed that the developing country purchaser is "likely to prefer to buy a complete package including not only the solar cells but also the end-use item--the television set or irrigation pump or whatever--with a guarantee of back-up service and replacement if necessary" Ibid., p. 3.

45. UNCTAD, Energy technologies, op.cit., p. 115. For a list of other corporation activity, financing solar projects in developing countries, see Herman and Cannon, Energy Futures, op. cit.

46. A Makhijani described such a scheme in "Energy policy for the third world," International Institute for Environment and Development," (London and Washington D. C.) September 1976, pp. 30-40. See discussion below.

47. For instance, BHEL is developing a 10 DW solar thermal electric generation unti for demonstration purposes in partnership with MBB of the Federal Republic of Germany, Unctad, op. cit., p. 115.

48. J. Parikh, K. Parikh, "Mobilization and impacts of biogas technologies," Energy, vol. 2, pp. 445-6.

49. Khadi and Village Industries Commission, Gobar Gas: why and how (New Delhi, January 1974).

50. Based on A. K. N. Reddy, "Power to the poor," (Indian Institute of Science, Bangalore: mimeo) summarized by D. Hayes, "Energy for development: third world options," op. cit., p. 43.

51. See J. K. Parkh and K. S. Parikh. "Mobilization and impact of biogas technologies," Energy, Vol. 2, pp. 441-255. (London: Pergamon Press) 1977.

52. The scheme is from Parikh, op. cit., p. 447.

53. Parikh and Parikh, op. cit., p. 452. The authors state that " Though not insignificant, the impact of biogas energy from out calculations is modest compared to that shown by Prasad et al who suggest that the total rural energy requirements (i.e., domestic, agricultural and industrial requirements) can be met entirely by village biogas plants. Their estimates of rural energy needs are extremely low. The estimates of domestic energy needs used by us are consistent with the various systematic sample surveys carried out in India." Also see C. R. Prasad, K.K. Prasad and A. K. N. Reddy, "Biogas plants: prospects, problems and tasks," Economic and Political Weekly, IX, 32-34, Special number, Bombay, August 1974.

54. Parikh and Parikh, op. cit., p. 453. The cost of an $8.5m^3$ biogas plant along with the associated pipe connections would be around $700. With this expenditure the government saves on costs of sewage and gains products with $240 every year.

55. A. Makhijani, "Energy policy for the rural third world," International Institute for Environment and Development (London and Washington, D. C), September 1976, p. 34.

56. A. Makhijani, "Energy policy for the rural third world," op. cit., p. 36.

57. Other measures to allow the woodlot to mature include wood-supply organized by the community by harvesting or collecting a store of wood during off-peak labor periods, and the installation of more efficient stoves. Coppicing, the practice of cutting trees in short rotation and allowing the sprouts to reappear from the stumps, can reduce the time of maturation of a village woodlot.

58. A. Makhijani, "Energy policy for the rural third World," op. cit., p. 38.

59. The larger the income disparities and land ownership, the less likely is such a communal strstegy likely to be successful, since the wealthy are likely to block efforts to create common interests. Makhijani mentioned the rural areas of Brazil where the dual latifundio-minifundio economy persists as a vehicle for perpetuating rural poverty, and North Bihar in India where land ownership is often

concentrated in the hands of a few people. If landlords are absentee the possibility is improved, especially if communal schemes are linked with projects of common interest such as health care systems Makhijani, op. cit., p. 40.

60. Ibid., p. 41.

61. Wood is the major component of traditional non-commercial energy sources, which still supply about one-half of total energy in developing countries and more than 85% of energy used by the 2.2 billion people in the rural areas of these countries.

62. Smil stated further that "if accurate estimates of the petential energy in the world's forests are to be calculated, vastly improved data must become available. Without such information any appreciation of the future role of phytomass as a viable, large-scale energy sources is impossible." He recommended extensive use of satellite images to provide information on forest area and the employment of multispectral analyses. Smil records the available forest area information from FAO and the International Biological programme, noting that a 50% discrepancy exists between the lowest FAO estimate and the value estimated by the former agency. Vaclav Smil, "How much energy in the world's forests," Energy International, March 1978, p. 25-26.

63. Planning has traditionally focused almost exclusively on the industrial aspect of forestry. It has fostered fast-growing industrial plantations, credit for planting by private tree farmers, forestry conservation and protection as an integral part of agricultrual settlement projects, log extraction operations, pulp and paper mills, and experimentation with different varieties of trees, along with the strengthening of forestry institutions. These concerns will become increasingly important in the future, but should evolve along with more people-oriented (ratner than industry-oriented) projects.

64 World Bank, Forestry, op. cit., p. 9.

65. World Bank, Forestry, op., cit., p. 22.

66. Ibid.

67. For guides to handling these issues of forestry project appraisal. see World Bank. Forestry. op. cit., Annex 7, p. 61.

68. These were industrial plantations, forestry extraction projects (where foreign exchange constituted over 65% of total costs due to importation of road construction, logging, sawmilling and plywood equipment), pulp and paper projects, three rural development forestry projects, forestry conservation and technical assistance with forestry pilot projects.

69. The World Bank lending budget assumes that developing countries will be receptive to Bank involvement in forestry and that lending policies on such matters as local cost financing and short grace periods will not be seriously constraining. The program also takes into consideration the limited capability of forestry institutions in many countries to absorb forestry loans or credits. World Bank, Forestry, op. cit., p. 51.

70. See, M. R. Bhagavan and A.M. Din, "The output-input structure of energy and resources in forestry and associated industry," Swedish International Development Authority, Stockholm (mimeo, 1978), and International Development Research Centre, Trees for People, an account of the forestry research program supported by the IDRC, (IDRC: Ottawa) 1977.

71. Communication from J.G. Bene, International Development Research Centre, May 18, 1978.

72. International Council for Research in Agroforestry, "Background, Formation and progress to date," (Royal Tropical Institute: Amsterdam, mimeo), October 20, 1977.

73. Most logging operations have been established by overseas lumber manufacturing companies located in Japan, the United States or Western Europe that seek raw material to feed industrial plants located in the country of origin. Governments frequently offer long-term concessions - 25 years or more - in order to attract investment capital and to induce overseas firms to construct forest roads. World Bank, Forestry, op. cit., p. 35.

74. ODC, Energy for the villages of Africa, op. cit., p. 15.

75. World Bank, Forestry, op, cit., p. 62. Or, it is suggested that if taxes and redistribution via the state are realistic in the specific context, they can be used to achieve equity and the project which generates more overall income would be prefered.

76. World Bank, Forestry, op. cit., p. 32.

77. Denis Hayes, Energy for development: third world options, (Worldwatch Institute: Washington D.C.), Worldwatch paper 15, December 1977, p. 24.

78. UNIDO, "Technology for solar energy utilization," op. cit., recommendations of the expert group meeting on existing solar technology, Appendix 1, p. 148.

CHAPTER SEVEN

SUMMARY AND RECOMMENDATIONS

1. SUMMARY: PRIORITIES AND STRATEGIES

A great deal of attention is being focused, internationally, on questions of energy supply to rural areas, and on technologies linked to the supply of energy. Shortages of conventional and traditional energy are envisaged. Therefore, new sources are sought. Because these require different and innovative technologies, an effort is being made in dozens of countries to identify the more appropriate technologies and the parameters for most efficient use. This survey has attempted to describe trends in the search for appropriate energy technologies, and situate the issues of energy supply for integrated rural development in an institutional, and also within an international framework.

Some of the main considerations can be summarized here. A fundamental starting point, in energy assessment, is demand for energy, or pace of economic growth. How fast will the developing countries grow? Is the Lima Declaration target still feasible, or too optimistic? If the more pessimistic growth projections of OECD are accepted as realistic, is there need for reconsideration of basic growth strategies among developing countries within such forums as UNCTAD?

In 1977, estimates of developing countries' rate of energy consumption growth, based on GNP projections, ranged between 3% and 4%. But in 1978, the World Bank and other institutions (eg., The Rockefeller Foundation) published reports that assumed no increase in oil imports. This assumes that developing countries will not secure increasing proportions of total world energy traded among countries, in the future. And yet this issue has not been considered by developing countries themselves. The industrialized countries in the International Energy Agency and other fora have taken steps to allocate future energy production, imports, and conservation targets. These allocations assume levels of consumption and energy imports for developing countries. Thus, there is a need for developing countries to address the many, interrelated energy issues in a direct way.

If developing country oil imports are not to increase, and if growth is to continue, then energy must be secured from other sources. This is one basis of the interest in alternative energy technologies. Tied in with the focus on rural areas is the commercial and planning interest in agricultural schemes, especially for food production, in developing countries. The links between broad environmental issues are being made more explicit; and include food, energy and the noncommercial fuel consumption patterns of villagers.

The main thrust of much research, and the plethora of consultancy reports on rural energy supply, is that villagers are threatening the ecosystem through excessive use of woody substances for fuel. A number of questions are raised by this focus. First of all, do rural populations destroy the ecological balance? It may be that other causes of environmental deterioration are more important than the (unsubstantiated as yet) claim that villagers are overconsuming fuel. Even if wood is being used faster than forests are being regenerated, it is shortsighted to blame rural inhabitants.

The reasons for negative changes in the ecosystem need to be assessed in a wider framework that includes the pricing of petroleum products, and the energy-use patterns of developing countries. This perspective will contribute to avoiding the restricted reaction that seems to underpin much rural energy analysis. The reactive approach to be avoided makes simplistic links between rural wood use, ecological imbalance, and perscriptions for limiting wood consumption, or increasing wood production. It implies that rural people are passive and disorganized, a view which is contradicted by more sensitive analysis.

A second thrust of much alternative energy analysis is the need for government planning. Alternative energy and commercial, conventional energy planning must be done in an integrated way. Historical separation and the recent status of energy planning make necessary a deliberate effort to unify planning for oil and solar energy, for instance. In each developing countries, and within regions or continents, institutions might be allocated the responsibility for devising strategies for integrated rural energy supply. The Tanzanian, Brazilian, Chinese and Indian attempts at planning are instructive as examples.

Third, rural energy discussions have posed a distinction between centralized supply systems, and decentralized systems. At the level of strictly technical installations (a national electricity grid versus local diesel generators) this distinction is useful. But the assumptions that decentralized systems automatically imply decentralized decision-making and community control are not so obvious. For example, the solar technologies are manufactured by large, centralized firms (Exxon, Alcan, Westinghouse) that manage the product in much the same way as large corporations manage other products. The attraction of decentralization is explicitly used by some large firms as a market development device. Thus, the actual social gains that may be associated with decentralized energy technology, must be demonstrated rather than assumed (as Denis Hayes and Amory Lovins assume them).

A fourth issue has to do with energy and employment provision. A narrow perspective might suggest that energy technologies will increase unemployment by making mechanical what was previously done manually or with animal power. But because energy is so inextricably a part of domestic and other production, and because this production can take place at a higher level only if basic needs are supplied, energy supply increments should be taken as valuable in themselves. Efforts to demonstrate cost-effectiveness are not likely to be successful. The key to ensuring increased employment is the introduction of energy supply technology under the control of producers.

Fifth, much debate centers around which alternative energy technologies are most attractive for rural areas. There is pressure from commercial manufacturers to define product specifications as a prelude to mass production. However, alternative energy technologies are site-specific, and thus are not as readily evaluated outside their context of use, as are other technologies. Nevertheless, there is much agreement based on experiments and social acceptability, that technologies for the production of biogas, solar, wood and small-scale hydro energy are most applicable to the needs of rural areas.

These alternative energy priorities are consistent with the recommendations of UNIDO identify solar technologies for water distillation,water heating, drying, cooking, refrigeration and the conversion of solar radiation into mechanical and electrical energy as those with definite application at present.

Government incentives are required to encourage research, development, demonstration projects, manufacture and installation of these alternative energy technologies. However, it must be emphasized that the state of knowledge to date, points to the importance of institutional rather than technical questions. Government incentives should thus be directed towards fostering alternative technologies with practical applicability in given social circumstances. Equity as well as commercial-economic practicality and technical feasiblity should be considered in any incentive program.

The importance of emphasizing basic needs when making decisions on which alternative energy technologies are given priority, lies in the close connection between equity and practicality. Unless a technology is accepted by the rural population as a means of improving living conditions, it will not be absorbed, maintained and used. And the process of introducing and making functional items of alternative energy technology may require social change in rural areas.

The institutional implications of alternative energy technologies is the sixth focus of analysis, especially in studies completed in 1977-78. It has been established that there are workable alternative, renewable energy technologies. Preliminary evidence exists that some of them may be cost effective and that, in many cases there is a ready backup system that entails no capital costs. The Tanzanian experiments are instructive here.

But there is still very little experience with installing such technology in rural villages of developing countries under circumstances where good cost and performance data have been kept. In fact, many of the experiments in placing technology in villages have ended in failure. A number of windmills and a few methane digesters have been tried in African villages, for instance, with far from encouraging results. Outside technicians came into villages with a preselected technology to perform a preselected village task, and without very much interaction with villagers they erected and operated the energy-producing hardware. A few weeks or months later, the visiting technicians left and shortly afterward the technology fell into disuse. Windmills established on the Cape Verde islands in 1977 are, with the exception of two units, no longer operating because of this haphazard approach.

This pattern is not unique to small-scale renewable energy hardware. Whether it be farm machinery, or transport or construction equipment, to provide such capital goods to a village without first training a cadre of people able to operate, maintain, and repair it, and without ensuring that there is a local institutional infrastructure to support it, has universally proved to be futile. The institutional support might come from a government institution such as a school, or a cooperative society or a private entrepreneur. Without trained people and a responsible institution, the chances are that energy technology will not be properly or long used. To give such technology a realistic test, it is necessary to enlist the cooperation of villagers. This means villagers must be involved in selecting the task to be mechanized, in selecting technology for energy supply, and in determining what village institutions should be responsible for its maintenance and use.

The implications of this approach to installing energy technology include the need to train 'mobilizers' to actually facilitate its introduction. The mobilizers might train counterparts who remain in the villages, and they could also be experienced in multi-faceted integrated rural development program implementation. For example, energy technology tied closely to health care and literacy programs might have advantages, especially in mobilizing villagers.

A seventh and final consideration has to do with international dimensions of the energy supply issue. Clearly oil has priority as the main fuel for the next thirty years or so. Every effort should be made to find and produce oil in developing countries. Which countries are able to secure oil supplies, and under what price regime is currently among the main international questions. Competition among industrialized countries for energy supplies, and related to this, competition for access to developing country markets for alternative energy technologies, is an increasing feature of the world scene.

The costs of oil are rising, and many experts agree that prices must go up if alternative souces of energy are to be produced. Thus, alternative energy technology may not be all that inexpensive, especially if it is designed, produced and marketed by large energy or other transnational corporations. This raises the question of which countries will produce the alternative technology required for the supply of renewable energy to rural areas?

Cooperation among 'southern' countries in the formulation of policy with regard to alternative energy technology would seem to be required. This policy formulation might best occur within a wider, energy planning framework. There is an unusual potential for cooperation to reduce energy dependence and foster trade and industrial development among developing countries in the energy sector. This potential arises from the complementarities of OPEC finance and major markets as well as raw material supplies within developing countries themselves. There is no need to petition for market access to the industrialized countries for manufactures, since they would be produced mainly for the developing world. And there is a possibility that the less sophisticated energy technologies can be mastered on a large scale in developing countries. Such technologies could be generalized outside the conventional commercial patent and licensing systems.

2. RECOMMENDATIONS

Developing country governments might devise overall energy policies that include the following objectives:

1. Reduce dependence on energy imports,
2. Reduce the gap between industrialized country and developing country per capita energy consumption,
3. Reduce the developing country rural-urban energy consumption difference,
4. Rely increasingly on renewable sources of energy,
5. Emphasize decentralized, integrated energy supply systems as part of a wider integrated rural development strategy,
6. Give priority to development of biogas, solar, wood, and small-scale hydro power systems,
7. Feature technological adaptation and innovation with special attention to developing country experience and building materials, while giving priority to the institutional and social dimensions of installation, and
8. Actively foster cooperation among developing countries for exploiting all indigenous energy resources mainly for local use, but also for regional and international export.

APPENDICES

1. Units
2. United States firms producing solar energy technology
3. Solar cell marketing: an example from an Exxon subsidiary
4. Windmills
5. Critical factors in economic evaluation of small, decentralized energy projects

APPENDIX 1

UNITS

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

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

k - kilo = 10^{3} = 1,000

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

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

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

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

APPENDIX 2

UNITED STATES FIRMS PRODUCING SOLAR ENERGY TECHNOLOGY: heating and cooling, solar thermal electric conversion, solar cells, wind generators

-Summary of R&D for selected U.S. companies producing solar energy technology.

-from Herman and Cannon, Energy Futures, Praeger Publishers, New York, 1977.

Solar Heating and Cooling

company; business	major products and objectives†
*AAI** research and development firm	installed solar-heating system on a Maryland school; is developing and plans to produce high-temperature (to 600°F) concentrating collectors.
Alcoa producer of aluminum and aluminum products	has applied selective coatings to aluminum collectors produced by other firms; plans to produce plastic collector.
Corning manufacturer of specialized glass products	developing tubular glass collector (to 300°F); marketed the device during 1975, but has cut back its program; wants eventually to produce glass collectors; no commercial plans at present.
Dow Corning manufacturer of silicon and silicone products	tested collector design and silicone fluid for use in collectors; markets the fluid and hopes eventually to mass-produce collectors; no commercial plans at present.
General Electric manufacturer of electrical equipment	installed solar-heating systems on laboratory, and for three ERDA-funded projects; helped design ERDA demonstration program; produces aluminum collectors for demonstration projects; no commercial plans at present.
Grumman aerospace manufacturer and defense contractor	produces solar water-heating kit using aluminum collector; has developed larger collector to sell to demonstration projects; wants to develop product line.
Honeywell manufacturer of automation and control systems; defense and aerospace contractor	installed solar-heating system on Minnesota school; gathers solar data in a mobile laboratory; will produce collectors for demonstration projects jointly with Lennox Industries; wants to assist federal programs; no commercial plans at present.

*Did not participate fully in survey.

†All collectors are flat-plate, water-type, unless otherwise noted.

InterTechnology research and design firm	installed solar system on school in Virginia; helped design ERDA demonstration program; setting up collector-manufacturing venture; wants to design solar installations under contract.
*Lockheed** aerospace manufacturer and defense contractor	designed solar system for community building in California; has investigated solar heating of greenhouses.
Martin Marietta aerospace and defense contractor; producer of construction materials and aluminum	sells aluminum collector, with special coating, for demonstration projects; no commercial plans at present.
Northrup manufacturer of heating and air-conditioning equipment	developed and sells wedge-shaped concentrating collector (300°F and higher).
OCLI producer of optical coatings	testing various special coatings on collectors; wants eventually to coat panels produced by other firms; no commercial plans at present.
Owens-Illinois producer of glass containers and other packaging products	developed and now sells tubular-glass collector (to 240°F); wants to mass-produce collectors.
Pennsylvania Power and Light electric utility	built and tested house incorporating solar collectors and heat pump; wants to experiment further and to encourage use of heat pumps by electricity customers; no commercial goals.
PPG **producer of chemicals, glass, coatings, resins, and fiber glass**	sells aluminum collectors; wants to establish product line.
Revere Copper + Brass **manufacturer of copper and aluminium products**	sells copper collectors for demonstration and commercial projects.

* Did not participate fully in survey.

Sheldahl manufacturer of products using plastic films	developing a concentrating collector (about 350°F) that uses plastic-coated reflectors; hopes to manufacture the device; no commercial plans at present.
Solaron solar venture	produces and sells solar systems using mass-produced air-type collectors.
Solarsystems solar venture	produces and sells vacuum-enclosed copper collectors (to 250°F).
Sol-R-Tech (Queechee Construction) solar venture	produces and sells aluminum collectors and solar heat-pump system.
Sunworks (Asarco) solar venture	produces and sells copper collectors, both air- and water-type.
Texas Instruments manufacturer of electronic and military equipment, electrical controls, and metal composites	experimented with potentially low-cost aluminum-copper composites for collectors; discontinued research; no commercial plans at present.
Thomason Solar Homes solar venture	licenses patented solar system for manufacture by others.
TRW producer of automotive parts and space, electronic, energy, and communications systems	studied solar heating and cooling for the government; wants to develop expertise to advise government; no commercial plans at present.
Westinghouse manufacturer of electrical equipment	fitted Atlanta school with largest solar heating and cooling system in the U.S.

note: Many other companies are producing solar systems or components for use in domestic water heating, space heating and cooling, and industrial process heat. For a listing, see *Catalog on Solar Energy Heating and Cooling Products*, prepared by ERDA (publication ERDA-75).

Solar Thermal Electric Conversion

company; business	major projects and objectives
Boeing airplane producer; defense and aerospace contractor	designing and experimenting with heliostats for central-tower powerplant for ERDA.
General Atomic nuclear-power development venture	studying trough-collector powerplant concept; may license patented ideas.
Honeywell manufacturer of control and automation systems; defense and aerospace contractor	studying trough-collector and central-tower powerplant concepts; designing 10-Mw central-tower plant and experimenting with heliostats for ERDA; no commercial goal at present.
McDonnell Douglas military and commercial airplane manufacturer; defense and aerospace contractor	designing 10-Mw central-tower powerplant and building heliostats for ERDA; wants eventually to engineer commercial plants and manufacture heliostats.
Martin Marietta defense and aerospace contractor; producer of construction materials and aluminum	designing 10-Mw central-tower powerplant and experimenting with heliostats for ERDA; built model solar boiler; hopes eventually to produce heliostats of its patented design.
Sheldahl manufacturer of products using plastic films	experimenting with rotating mirror collector; hopes to sell plastic mirror films for demonstration collectors.

Solar Cells

company, business	major projects and objectives
*D.H. Baldwin Co.** bank holding company	developing potentially low-cost cadmium-sulfide cell; no commercial plans at present.
Bell Laboratories research laboratory	developing cells with cadmium sulfide; no commercial goal at present.
Comsat global communications company	developing silicon cells to maximum efficiency for use in space; no commercial plans for using the technology on earth.
Dow Corning manufacturer of silicon and silicone products	developing ways to produce silicon for cells; hopes eventually to produce such silicon in quantity; no commercial plans at present.
Exxon oil company	developing potentially low-cost types of cells using unconventional materials; hopes eventually to produce solar cells commercially; no commercial plans at present.
General Electric manufacturer of electrical equipment	studying, for ERDA and EPRI, the uses and costs of cells on buildings and in powerplants; developing solar-cell modules and techniques to produce large silicon sheets; experimenting with cadmium-sulfide cells; no commercial plans at present.
IBM manufacturer of business machines	developing less expensive techniques for producing gallium-arsenide and silicon cells; will eventually license technology to other companies.
A.D. Little, Inc. technical consulting firm	patented and is promoting concept of satellite solar power station (SSPS); hopes to obtain contracts to assist federal SSPS work.
Mobil-Tyco (Mobil Oil and Tyco Laboratories) silicon solar-cell venture	developing technique to produce silicon sheets for solar cells; hopes to mass-manufacture cells by 1985.

Motorola manufacturer of electronic products	developing technology to produce silicon cells; hopes to mass-manufacture cells by 1985.
OCLI producer of optical coatings	markets silicon cells for space and earth use.
*RCA** manufacturer of electronic products	developing silicon-cell technology as well as cadmium-sulfide cells.
SES (Shell Oil) manufacturer of cadmium-sulfide cells	produces cells for earth use; developing technology to reduce cost of cell production.
Solar Power Corporation (Exxon) manufacturer of silicon cells	produces cells for earth use; is developing lower-cost cell.
Solarex manufacturer of silicon cells	produces cells for earth use; is developing techniques to use potentially less expensive silicon.
Spectrolab (Hughes Aircraft) manufacturer of silicon cells	produces cells for space and earth use; studying, for ERDA, the costs and uses of cells on buildings and in powerplants; experimenting with sunlight concentration to reduce system costs.
Texas Instruments manufacturer of electronic products, military equipment, electronic controls, and metal composites	developing techniques to use potentially less expensive silicon for mass-manufacture of cells; no commercial plans at present.
Westinghouse manufacturer of electrical equipment	developing techniques to produce silicon and cadmium-sulfide cells; studying, for ERDA, the use and cost of solar cells on buildings and in power plants; no commercial plans at present.

Wind Generators

company; business	major projects and objectives
Boeing airplane producer; defense and aerospace contractor	is experimenting with one- and two-bladed wind generators under ERDA contract; is interested only in large devices; has no commercial goals at present.
General Electric manufacturer of electrical equipment	is studying U.S. wind resources and designing generators under ERDA contract; hopes to build devices to produce up to 1.5 Mw for ERDA; is interested only in large machines; has no commercial plans at present.
Grumman aerospace manufacturer	has tested and modified Princeton "Sailwing" design, with output of 13 kw in 25-mph wind; exploring advanced concepts with ERDA and company funding; hopes to produce generators for demonstration projects.
Kaman diversified manufacturer	is designing generators and hopes to build a device to produce up to 1.5 Mw for ERDA; is building rotors for Sandia Labs generator; hopes eventually to manufacture wind-generator blades, but has no commercial plans at present.
Zephyr Wind Dynamo wind-generator manufacturing venture	produces devices that generate 9.5 kw in 24-mph wind, commercially available for home use.

	Fiscal 19[illegible] ERDA Outlay (in millions)	Portion of All R&D Funded by ERDA[1]	Number of Companies in INFORM Sample[2]	Companies Offering Commercial Products or Services, or Engaged in Commercial Activities	Corporate Estimates of Years to Commercial Availability[3]	Corporate Estimates of Maximum Potential Contribution to National Energy Supplies[4]	Major Negative Environmental Impact
Coal liquefaction	$92.9	most	15	0	10-25	no consensus; as much as 5%-10% of national energy demand by 1995	land use: if coal strip-mined, 6.65 square miles stripped over lifetime of a commercial plant processing 24,000 tons of coal per day; water use: 180 gals/barrel oil produced; air emissions; water emissions
Gas-turbine topping cycle							
retrofitting oil-and gas-fueled steam generators	$00.0	none	4	4	0	10% of electrical capacity could be fitted with gas turbines to conserve oil and gas	air emissions (nitrogen oxides)
coal-fueled systems	$7.5[9]	most	3	0	10-15	no estimates	[illegible]
Alternate topping cycles							
MHD	$18.4	virtually all	6	0	10-20	no estimates	[illegible] (nitrogen oxides)
Thermionics	$1.6	virtually all	2	0	20	no estimates	negligible
Potassium turbines	$0.6	virtually all	1	0	no estimate	no estimate	risks accidental explosion or release of poisonous fumes
Fuel cells							
using liquid or gaseous fuel	$4.7	some	3	1	0-5	no estimates	negligible
using coal	$1.0	little	1	0	no estimates	no estimates	requires mining and gasification of coal (see above)
Nuclear breeder reactors							radioactive and highly poisonous wastes; risks accidental release of dangerous amounts of radiation; risks creation of nuclear bomb from by-product
LMFBR							
liquid metal type	$428.0	most	4	0	2	10% of electricity by 2000	
GCFR							
gas-cooled type	$6.1	much	1	0	no estimate	no estimate	
MSBR							
molten salt type	$4.1	virtually all	1	0	no estimate	no estimate	

1 These are very rough estimates, arrived at by balancing the expenditures of companies in the INFORM sample against the ERDA budget. Contributions of the EPRI, occasionally significant, were not included in the comparison.

2 This column does not add up to 142 (the number of companies in the INFORM study) because many companies were surveyed for their work in more than one technology, and are often involved in two sub-categories within a technology.

3 The data used was gathered with no attempt to verify the estimates using outside sources, or to analyze the basis of the companies' opinions. Comparisons could therefore be misleading.

4 The figures in this column are highly conjectural, and represent the more optimistic of corporate estimates. Those provided for the technologies in some areas are based on industries which do not yet exist.

5 The figures in parentheses indicate the rough percentage of total national energy demand that would be provided by the technology. Note that the percentages provided refer to today's energy demand, not energy demand in the future.

6 This estimate of commercial availability for laser fusion refers only to its use in generating electricity. It is believed that its usefulness for breeding fuel for fission powerplants could be demonstrated much earlier.

7 Of the four types of trash-to-energy conversion covered in the INFORM study -direct incineration, production of refuse-derived fuel, pyrolysis and anaerobic digestion-the first three are commercially available, while the last is expected to be commercially available in five years.

8 All the companies surveyed that were involved with "dry" steam resources are considered to be engaged in commercial ventures.

9 The $9 million covers only research to develop advanced gas turbines. Other research in coal-fueled gas-turbine topping cycles is included in low-Btu coal gasification.

10 A barrel of oil is equal to 42 gallons.

	Fiscal 1976 ERDA Outlay (in millions)	Portion of All R&D Funded by ERDA[1]	Number of Companies in INFORM Sample[2]	Companies Offering Commercial Products or Services, or Engaged in Commercial Activities	Corporate Estimates of Years to Commercial Availability[3]	Corporate Estimates of Maximum Potential Contribution to National Energy Supplies[4]	Major Negative Environmental Impact
Solar heating and cooling	$24.8	some	25	11	0	few estimates, no consensus	negligible
Solar cells	$16.4	much	18	5	10-20 for inexpensive solar cells	few estimates, no consensus	negligible
Solar thermal electric	$15.6	virtually all	6	0	10-20	no estimates	land use, 1 sq mi 90 Mw; water thermal pollution
Ocean thermal electric	$6.0	virtually all	3	1	0-10	5% of electricity by 2000 (1%-2%)[5]	expected to be negligible
Wind generators	$11.1						negligible
large		virtually all	4	0	no estimates	5% of electricity by 1995 (1%-2%)	
small		little	2	1	0	no estimates	
Nuclear fusion							radioactive wastes
magnetic	$144.8	virtually all	4	0	after 2000	no estimates	
laser	$79.1	virtually all	3	0	after 2000[6]	no estimates	
migma	$00.0	none	1	0	no estimates	no estimates	
Hydrogen production							depends on energy source (nuclear, solar, etc.)
electrolysis	$0.7	some	2	1	10, for advanced technology	no estimates	
thermochemical processes	$1.0	little	2	0	20	no impact until after 2000	
fusion	$0.0	none	1	0	no estimates	no estimates	
Bottoming cycles	$1.0	some	4	2	0	few estimates, 6% of electricity eventually (1%-2%)	negligible
Trash-to-energy conversion	$1.0	little	22	15	0-5[7]	generally, a few percent of national energy demand	air emissions
Geothermal	$31					5% of electricity (1%-2%)	noise; odor; disruption of remote areas
"dry" steam		some	14	14[8]	0		
"wet" steam		some	17	0	5-10		
Oil shale							
aboveground	$00.0	none	13	2	0	5%-10% of the nation's oil demand by 2000 (2%-5%)	land use: creates 1 ton rock waste/barrel oil[10]; water use: 100-300 gals/barrel oil produced; surface water pollution
in situ	$10.1	some	6	0	10	10% by 2000 (5%)	water use: 1/3 to 1/2 of aboveground plants; groundwater pollution
Coal gasification							land use: if coal strip-mined, 6-65 square miles stripped over lifetime of a commercial plant processing 24,000 tons of coal per day;[11] water use: 1 ton water/ton coal processed; air emissions; water emissions
low-Btu	$36.0	most	14	5	0-10, depending how advanced the technology is	no estimates	
high-Btu	$[illegible]7.3	most	26	7	10-20, for advanced technology	no consensus; as much as 20% of natural gas by 2000 (6%)	

APPENDIX 3

SOLAR CELL MARKETING: AN EXAMPLE FROM AN EXXON SUBSIDIARY

In a world of dwindling resources, harnessing the inexhaustible energy of the sun is becoming less a dream and more a vital necessity. The goal of Solar Power Corporation is to meet this pressing need, and supply solar electric energy wherever it may be utilized.

Who is Solar Power

Solar Power Corporation, an affiliate of Exxon Enterprises, Inc., was founded in 1969 for the express purpose of designing and manufacturing economically high performance photovoltaic energy systems for terrestrial use. After an extensive research and development program in the laboratory and in the field, production facilities were opened in Massachusetts in 1973. In these facilities, Solar Power Corporation uses the most modern design, processing, and testing tools available today. Products are sold and serviced through a world-wide network of representatives and distributors. Continuing research and development, both at the Solar Power Corporation facilities, and at Exxon Research and Engineering laboratories in Linden, New Jersey, insure that our customers benefit from the latest advances in the field of terrestrial solar power. This organization structure offers the services necessary to provide the most reliable, economical, and advanced solar energy systems available today. Solar Power Corporation is happy to help with systems design support and to supply the solar electric power systems to meet your vital energy needs.

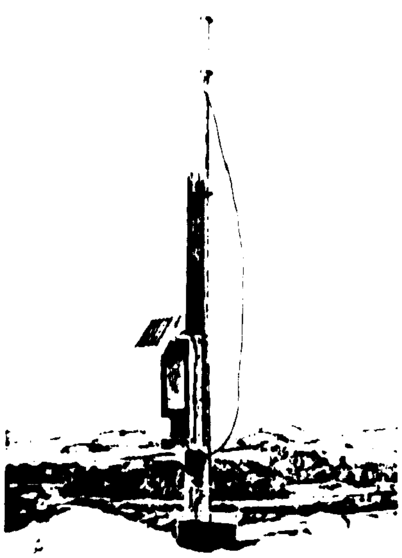
Our Solar Energy System

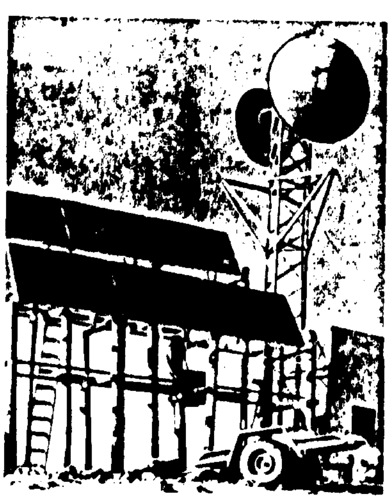
Silicon based semiconductor solar cells have evolved as the major practical product implementing the photovoltaic effect; that is, the generation of electricity directly from sunlight. The technology and these devices were first utilized in the U.S. space program, powering critical on-board flight systems for satellites. To provide cost-effective, reliable energy systems for earth, Solar Power Corporation has developed a complete line of silicon-based solar cells optimized for terrestrial applications. These highly efficient cells are the foundation for Solar Power Corporation's solar energy systems.

SPC's solar cells provide high energy output and consistently high reliability — key elements of a cost-effective energy system. The cells are manufactured in a variety of sizes to offer design flexibility. The cells are then combined into 'modules' using the most advanced mounting, interconnect, and encapsulation techniques. This flexibility allows SPC to specify and guarantee the most economical and efficient solar energy systems for each application and environment.

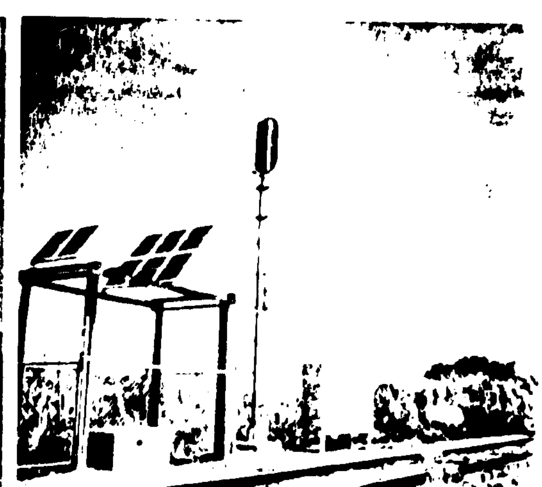
Solar Power Corporation is more than just a supplier of cells and modules. SPC identifies the optimum system parameters through a proprietary custom computer analysis and provides this to each customer, detailing each installation. Through this computer analysis, SPC can provide the most economical combination and number of modules (called an 'array' or solar electric generator) as well as matching the storage batteries and voltage regulator, where needed. This analysis also specifies the proper angle of tilt, optimized for both location and economics, and the monthly average system performance projections. Installation supervision is available to provide the final element for successful implementation of these practical, low maintenance energy systems.

Solar Power Corporation's solar energy systems are presently in use around the world in applications where clean, safe, quiet, reliable power is needed. These systems are fuel-free, contain no moving parts, and require minimal maintenance and, thus, provide a practical and cost-effective power alternative for remote applications. With the increasing costs and uncertainty of supply of conventional power systems, SPC's solar energy systems are becoming the viable choice for all energy requirements.





Solar Power Corporation's generators provide economical operating power for unmanned communications repeater stations



Solar Power Corporation's generators provide low maintenance, economical power for railroad systems — to operate lights, switches and safety signals

Applications

Solar Power Corporation's high efficiency cells are packaged in a variety of modules to optimize performance and cost factors for each application. Basic solar cells are available with 57mm, 90mm, 100mm diameters. Half cells, quarter cells, or other smaller configurations are utilized where the applications warrant. Different packaging and encapsulating materials are used to maximize economy and to satisfy different environmental requirements. For many applications, silicone is used to hermetically seal and protect the cells. Polycarbonate or glass cases are available where high impact resistance or maximum protection is required. All modules are constructed to be self-cleaning, minimizing on-site maintenance. The addition of batteries, voltage regulators, and mounting hardware, as required, completes the system. The solar generator system is a complete, self-contained, reliable, quiet, pollution-free source of energy designed for long-term, year-round use for any prime or stand-by power requirement. Present applications include:

RADIO RELAY STATIONS
Microwave and VHF-UHF repeater stations atop mountains, in deserts, and along pipelines are often relatively inaccessible. Use of Solar Power Corporation's solar energy systems allows complete freedom of site location and eliminates the need to transport fuel and mechanics to these remote sites, avoiding costly maintenance trips. SPC's solar generators are powering communications, environmental monitoring, and supervisory control systems in the United States, Fiji, Italy, Ethiopia, Australia, New Guinea, and other countries.

NAVIGATION AIDS
Solar Power Corporation's solar electric generators are in continuous service powering lights, fog horns, and bells on unmanned oil rigs, buoys, and other marine installations in such areas as Boston Harbor, the Gulf of Mexico, New Zealand, and offshore Scotland and Venezuela. The reliability and ruggedness of SPC's solar generators serve to protect against this corrosive environment, and the low maintenance required allows tremendous savings over traditional primary battery-powered systems.

RAILROADS
There are approximately 175,000 unprotected railway crossings in the United States alone. Solar Power Corporation's solar generators are being installed to reduce this hazard by providing reliable, continuous energy for all lights, bells, and gates required to protect these crossings both day and night. Track circuits and semaphore signals are also being powered by SPC's solar generators. In both cases, solar generators have replaced primary battery systems, supplying power for these key safety devices.

Railroad communications networks, following the right-of-way, are another important application. Again, the reliability and economics of Solar Power Corporation's solar energy system provide key benefits over traditional thermoelectric generator or diesel sources. Railroad companies in the United States, Canada, and Mexico are depending on SPC solar energy generators to power these critical operational systems.

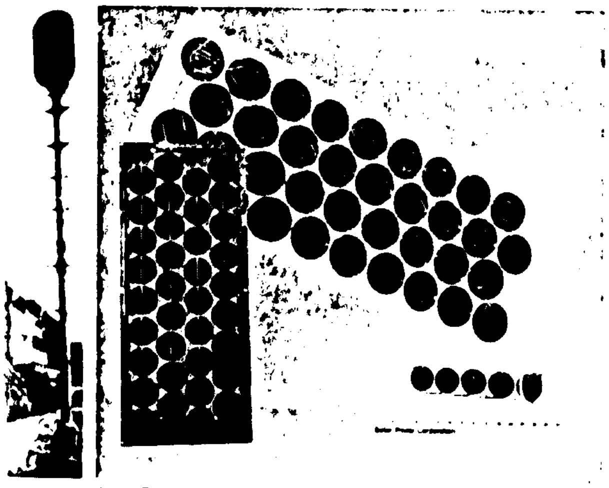
CORROSION CONTROL
Cathodic protection systems provide essential corrosion control for well-heads, bridges, pipelines, and transmission cables and pipes. Solar Power Corporation's solar energy systems provide continuous power to protect these unattended structures in a wide variety of environments from the plains to the deserts. Long-lived, fuel-free, low-maintenance, and highly reliable, Solar Power Corporation's solar power systems eliminate the need to string expensive power lines or support the high maintenance costs of diesel generator units.

EDUCATIONAL TV
Miles from the nearest conventional power source, educational TV programs are provided to children in African villages, using Solar Power Corporation solar energy systems. Conventional remote receiver power systems, such as batteries or engine generators, are too expensive and require too much regular maintenance to be practical and cost-effective. SPC has been furnishing solar systems to operational television stations in Niger, the Ivory Coast and other African states.

OTHER APPLICATIONS
A wide range of additional applications are taking advantage of the unique characteristics of Solar Power Corporation's solar energy systems.

These include:

- Obstruction lights for airports
- Water pumping for drinking and irrigation
- Facilities power for firetowers and second homes
- Emergency location and alarm transmitters
- Electric fences and intrusion alarms
- Battery float charge systems
- Highway signs
- Portable backpack radios



Solar Power Corporation's wide selection of modules allows design of the most efficient and economical power system

Solar generators make possible the reception of educational TV programs for children in developing countries

Solar Power Corporation's generators provide economic, reliable power for corrosion protection of pipes, well-heads, bridges and other structures.

System Optimization

Every Solar Electric Generator is subject to a wide set of variables affecting its operation. For instance, the amount of power needed, the geographic location, and the average sunlight per year (insolation) are three major considerations. Other considerations are the environment, including weather, pollution, and surface reflectivity, and seasonal factors.

Solar Power Corporation has found that a specially designed computer program is the best way to organize, integrate, and interpret this information. This program is designed to supply the answer to the basic question: What is the most reliable and least expensive combination of solar modules and storage batteries needed to assume continuous, year-round operation for a certain power requirement?

The program selects the smallest array size possible for the load and then calculates the output for every day of the year, based on insolation. The output is then compared with the load demand per day, and the difference is multiplied by the number of days when the array output is below the load. This indicates the number of days of storage needed to insure the continuous operation of the load. After computation of the number of days of storage for this array size, the program selects other closely rated array sizes and repeats this routine until it determines the most economical system configuration.

The computer program specifically accounts for battery discharge rate, maximum battery discharge allowed, charging efficiency, and annual battery self-discharge. In addition, parameters such as the tax rate, the cost of money, and the projected battery life may be factored in when relevant.

The computer also determines the angle of tilt for the modules which yields the most uniform output over the course of a year. This angle is calculated to smooth the insolation versus time-of-year curve and to make the maximum contribution to the determination of the most economical array size and battery requirement.

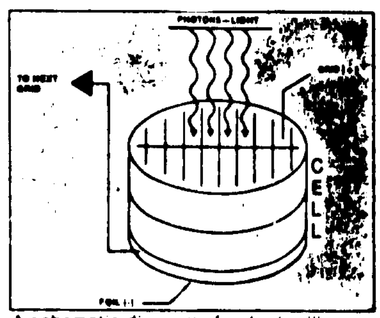
For example, a flashing light in Boston Harbor has a daily 12-volt load of 10 ampere hours. An array of 28 modules with three 100 ampere hour, 12 volt batteries is the optimum for continuous operation at this location. The same load in Marseilles, France would require 28 modules with two batteries. Tampa, Florida calls for 21 modules with one battery. Fairbanks, Alaska calls for 35 modules with six batteries.

In all these cases, this computer-aided design approach provides the most economical energy system available for the load and location.

OUR SOLAR CELLS

Silicon-based photovoltaic semiconductors—solar cells—have evolved as the most practical and reliable application of the "photovoltaic effect". A simple, rugged semiconductor junction device is produced from single-crystal silicon, and contacts are added to tap the electrical energy produced when the cell is exposed to sunlight. Approximately 0.45 volt D.C. is generated across each cell regardless of dimensions. The current available, and thus the power, is dependent on the cell area exposed to the sun. Available cell power varies from approximately 0.25 watt for a 57mm cell to approximately 1 watt for a 100mm cell, under standard conditions*. By combining cells in series to increase the output voltage and in parallel to increase the output power, the module outputs can be tailored to the application load requirements.

*Standard conditions are defined by NASA as 100 mW/cm^2 solar intensity, 28°C cell temperature at sea level

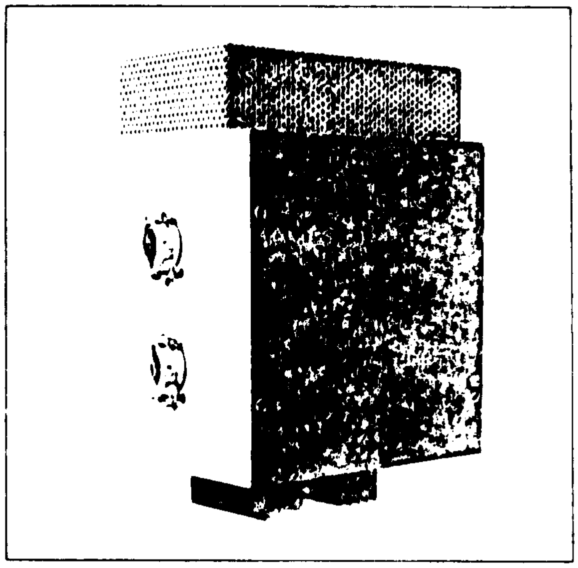


A schematic diagram of a single silicon solar cell shows the wafer between upper and lower contacts. The dual composition causes electron flow when light strikes the surface. The grid contact on top and the foil contact on the bottom allow connection to the other cells in the module.

Solar Power Corporation 232

Affiliate of EXXON Enterprises, Inc. **BVR SERIES**

BVR
Battery Voltage Regulators



Solar Power Corporation's BVR series Battery Voltage Regulators are designed to provide exacting voltage battery control, low quiescent power consumption and reliable, long service life.

Available in weather resistant or nonweather-resistant configurations, the BVR series Battery Voltage Regulators are of shunt design. Once the regulating voltage is set, the BVR series regulators allows only enough current to flow into the battery as needed to maintain a full state of charge. Additional solar array output current is then diverted through power dissipation devices in the battery voltage regulator. In cases where the battery falls below full charge, the regulator circuit draws only enough power to operate the terminal voltage level detector (typically 1mA or less). The low "off" state power drain of the BVR series Battery Voltage Regulator prevents unnecessary waste of valuable solar generated power in the regulator circuits when the battery is below a full charge. The battery voltage upper limit is selected to minimize electrolysis of water in the electrolyte. In addition to preventing unnecessary electrolyte loss, BVR series Battery Voltage Regulators protect against equipment or battery damage due to excess voltage.

Battery Voltage Regulator Specifications [1]

MODEL NUMBER	[3] TYPICAL REGULATING VOLTAGE (VOLTS D.C.)	[4] CURRENT (AMPS)	DIMENSIONS (IN.) LENGTH	WIDTH	DEPTH	WEIGHT (LBS.) NET	SHIPPING
[2] BVR12-0 3	14 4	0 3	3	1 1/2	1	1	N/A
BVR12-0 7	14 4	0 7	7	8	4	3	8
BVR12-2 0	14 4	2 0	6	9	4	4	9
BVR12-6 0	14 4	6 0	9	13	6	7	12
BVR12 10 0	14 4	10 0	9	13	6	8	13
BVR24-0 7	28 8	0 7	6	8	4	3	8
BVR24-2 0	28 8	2 0	7	9	4	4	9
BVR24-6 0	28 8	6 0	14	13	6	13	20
BVR24-10 0	28 8	10 0	13	14	6	15	22

Notes:

1. The regulators listed above are supplied in non-weather resistant enclosures. Optional weather resistant enclosures are available.
2. BVR12— 3 regulator is designed for use with the E12—3652 solar module. It is supplied in a weather resistant enclosure and is mounted on the rear of the module.
3. Regulating Voltage Range $\pm$1% for Lead Acid Battery.
4. Maximum Value.

All BVR series Battery Voltage Regulators utilize completely solid state devices. Industry standard 723 voltage regulators in a military temperature range, hermetically sealed metal package are used in the heart of the voltage regulator. Precision metal film resistors are used in voltage level detection circuits. Reverse polarity protection and the system blocking diodes are incorporated into the unit. All power handling devices are generously derated to assure long life, even at constant maximum power dissipation levels. Connections to printed circuit boards are made via terminal blocks capable of handling up to #10 AWG wire, and provide a solid gas tight seal. Either weather-resistant feedthroughs or strain relieving cable clamps are offered.

BVR series Battery Voltage Regulators are available in standard voltage ranges shown in the specification table. If other voltages are required, please contact the Customer Service Department at Solar Power Corporation.

Installation and adjustment

Neither weather-resistant nor nonweather-resistant models of the BVR series Battery Voltage Regulators should be installed in areas exposed to heavy weathering. Weather-resistant BVR Battery Voltage Regulators may be mounted external to an equipment cabinet or hut. However, it is desirable to mount weather-resistant regulators behind the solar panel for protection.

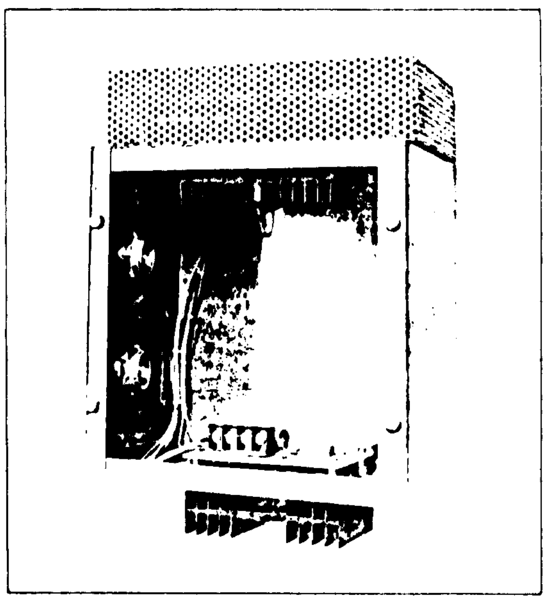
Nonweather-resistant models must be installed within an enclosure. In both instances, air flow around the heat sinks and resistor cage must not be impeded.

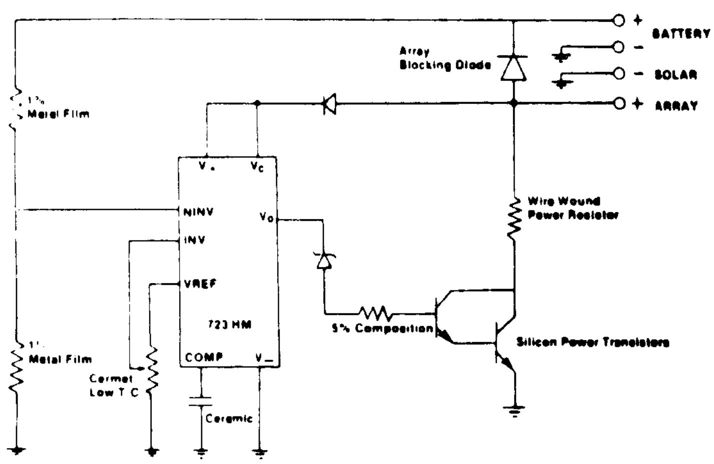
Connect as follows:

1) Connect the solar array leads to the terminals marked "ARY" observing correct polarity.
2) Connect the battery to the terminals market "BAT" observing correct polarity.
3) The BVR series Battery Voltage Regulator is now completely installed.

To adjust the regulating voltage level:

1) Disconnect the battery bank from the terminals.
2) Connect a suitable high impedence voltmeter across the battery terminals.
3) Adjust the regulating voltage via the small potentiometer on the PC board. Clockwise to decrease, counterclockwise to increase the voltage level.
4) Reconnect the battery to the regulator terminals observing correct polarity.





Solar Power Corporation

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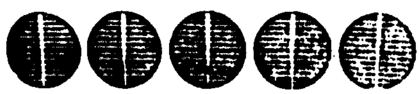
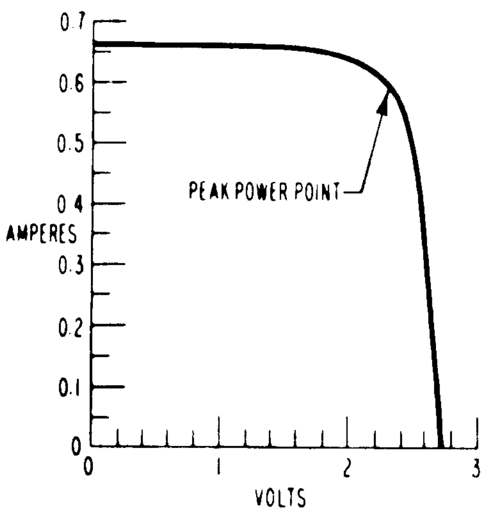
P-Series

P-1002
Solar Electric Generators

P-1002 Solar Module





Current vs. Voltage characteristic for 1002 module indicating peak power point.

The P-1002 solar module is a sealed durable, and easily arrayed photovoltaic building block whose package offers the ultimate in protection against human and natural environments.

Module 1002

Each P-1002 module consisting of five 57 mm (2.24 in.) silicon solar cells wired in series produces 2.3 V @ 0.60 A which allows for trouble-free matching of power output to the load. Each module is tested for maximum power output, and its fiberglass reinforced printed circuit board designed to MIL specification G-10 is dimensionally stable to minimize stresses on the solar cells. The UV-stable case is made of Lexan* polycarbonate and provides protection from impact, wind, temperature, and the most severe weather conditions. In addition, the UV-stable encapsulant hermetically seals the module for protection from moisture and humidity, and cushions the solar cells from impact. Cadmium-plated terminals are internally threaded for positive life-long mechanical electrical connections.

Electrical Specification

Output rated at 28C° cell temperature and 100 mW sq. cm incident AM1 sunlight

TYPE	PEAK POWER POINT VOLTS	PEAK POWER POINT AMPS	PEAK POWER WATTS*
P-1002	2.3	0.60	1.4

*Peak power is within ± 10% of rated value

Environmental & Mechanical Specifications

Operating Temperature	55°C to +60°C
Humidity	0 to 100%
Altitude	up to 25 000 feet
Wind Loading	array built to withstand winds in excess of 175 mph

TYPE	DIMENSIONS (INCHES) LENGTH	WIDTH	DEPTH	Weight (lbs) Arrayed (approx)	Weight (lbs) Shipping
P-1002	13 5/8	3	5/16	2.5	3.5

Per module

Solar Insolation Effect

Voltage: Operating voltage is attained at approximately 10 mW/sq. cm (dark overcast sky)

Current: Peak output is at 100 mW sq. cm. Changes in output are proportional to solar insolation, e.g. at 50 mW/sq. cm. output current would be 50% of rated current

P-1002 Generators and Arrays

Solar Power Corporation supplies complete solar electric generator systems consisting of solar modules arrayed, voltage regulators, and batteries. We can supply the total system or just the arrays or modules.

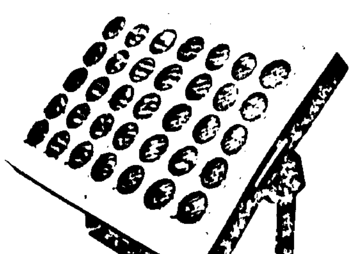
P-1002 solar arrays consist of P-1002 modules (number of modules is determined by voltage and current requirements) mounted on a rigid fiberglass backing, which is in turn mounted with stainless steel bolts on a rigid aluminum supporting structure. The mounting frame is as tough as the module it holds. Heavy gauge fiberglass panels with gaskets, front and rear, will withstand all severe weather conditions, and the frame of "C" channel aluminum, covered with two coats of MIL specification enamel, is designed to resist winds of greater than 175 mph. Either telescoping legs with foot pads or a universal mount is supplied.

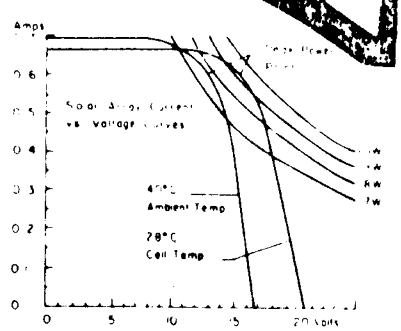
Interconnections are soldered or screwed down inside the mounting frame. All connections are silicone rubber-encapsulated for corrosion resistance, hardware is corrosion-resistant stainless steel. The output cable of SJO neoprene is resistant to oil and water, weatherproof feedthroughs provide a lifelong seal against wetness.

All arrays include a blocking diode. The diode is a low voltage drop Shottky barrier device that prevents battery discharge during night operations.

The module designation of P-1002 arrays indicates system voltage and number of modules (diagram). Arrays can be developed to match most system voltage and amperage requirements. Modules are mounted in series to provide the required voltage. Seven are used to provide charging power for a 12 V battery, fourteen in series for a 24 V battery system, and twenty-one in series for a 36 V system. Modules are then added in parallel to provide necessary current for system operation.

Model P12-071002 Solar Array with universal mounting bracket





Current vs. Voltage characteristic for P12-071002 Array.

CODE EXPLANATION

Example — P-Series

P12-071002

- **Module utilized**
- **Number modules in array**
- **Array voltage (nominal)**
- **Array type**

Computerized System Design

Solar Power Corporation provides a computerized system design and quotation service based on customer load specifications. System design specifies the solar array and battery storage necessary for low-maintenance, year-around operation.

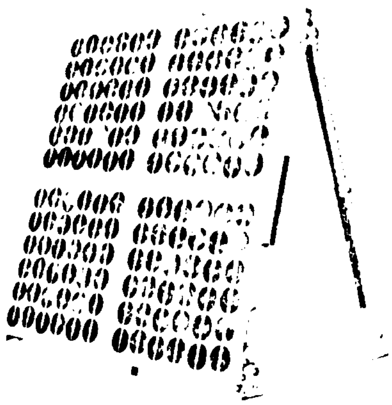
Information necessary to provide quotation requires

1. Electrical load (AH/day)
2. Location (altitude, latitude, longitude)
3. Nominal system voltage

Solar Power Corporation

Affiliate of EXXON Enterprises, Inc.

"E" Series Solar Electric Generators



Model E12-04369 Solar Array with telescoping legs and footpads

"E" **Series modules** provide a durable, yet economical approach to solar electric power

The modules and arrays are designed in voltage increments to meet the nominal system requirements for most applications. Modular construction allows a build-up of current to meet load and location requirements.

By adding modules in series, or in parallel configurations, "E" Series modules can be arrayed in larger units to conform to a wide range of power requirements.

"E" Series Module Construction: Terrestrial tailored silicon solar cells are wired together on a fiberglass base. Cells and interconnections are protected from the elements by encapsulation in transparent UV stable silicone rubber. The encapsulant is applied in a double layer to provide resilience as well as a tough, hard, self-cleaning surface. Each module comes with 10 feet of neoprene jacketed Type SJO weather-resistant cable. An energy-saving, low voltage drop Schottky barrier blocking diode is incorporated into the module to prevent the battery from discharging during the night.

Array Construction: The "E" Series module is mounted with stainless steel bolts on a rigid enamel coated aluminum supporting structure. Small arrays have a universal mounting bracket, which allow them to be mounted on flat platforms or attached to poles. large arrays are provided with telescoping legs and foot pads (as shown).

Battery Storage: High quality rechargeable batteries are usually used to allow operation at night and in inclement weather. All modules and systems are designed to provide peak current at the charging point of the battery. Most systems are designed to use lead acid or nickel cadmium batteries.

Solar Power Corporation provides a computerized system design and quotation service based on customer load specifications. Information necessary to provide quotation requires electrical load (AH/day), locations (altitude, latitude, longitude), and nominal system voltage.

Electrical Specifications

Output rated at 28°C cell temperature and 100 mW/sq. cm incident AM1 sunlight. Charging point based on lead acid battery near full capacity.

Model No.	Charging Point* Volts	Charging Point* Amps**	Peak Power Point Volts**	Peak Power Point Amps**	Peak Power Watts**
E4-125	4 5	0 64	4 9	0 60	2 9
E6-185	6 8	0 64	7 7	0 60	4 6
E6-365	6 8	1 29	7 7	1 20	9 2
E6-369	6 8	3 22	7 9	3 04	24 0
E12-3652	13 6	0 3	16.0	0.3	4 8
E12-365	13 6	0 65	16 0	0 60	9 6
E12-369	13 6	1 62	16 5	1 52	25 0

* Lead acid battery system near full charge

** Nominal values at 28°C cell temperature and 100mW/sq. cm incident AM1 sunlight. Diode and cable are included. Peak power is within ± 10% of nominal value.

Environmental and Mechanical Specifications

Operating Temperature: 55°C to +60°C

Humidity: 0 to 100%

Altitude: to 25,000 ft

Wind Loading: Array built to withstand winds in excess of 175 mph.

Model No.	Dimensions (in.) L	Dimensions (in.) W	Dimensions (in.) D*	Weight (lbs.) Net	Weight (lbs.) Shipping
E4-125	11 1/4	10	1 5/16	2	4
E6-185	13 1/4	10	1 5/16	2.3	4.5
E6-365	24	10	1 5/16	4	8
E6-369	24	24	1 5/16	9	25
E12-3652	13 1/4	10	1 5/16	2.3	4.5
E12-365	24	10	1 5/16	4	8
E12-369	24	24	1 5/16	9	25

*Depth of all "E" Series modules includes 1 1/16 in. depth of junction box

Solar Insolation Effect

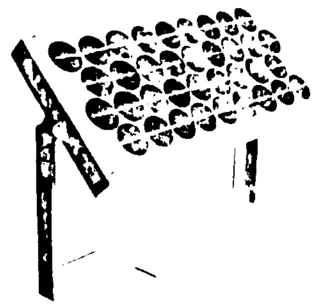
Voltage: Operating voltage is attained at approximately 10 mW/sq. cm. (dark overcast sky)

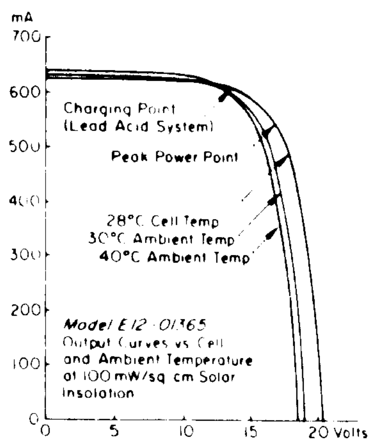
Current: Peak output is at 100 mW/sq. cm. Changes in output are proportional to solar insolation, e.g. at 50 mW/sq. cm. output current would be 50% of rated current.

OUTPUT CHARACTERISTICS

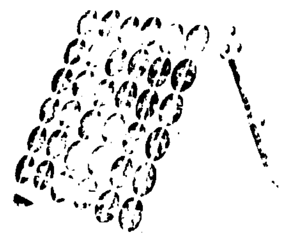
Current vs Voltage curves are shown for each E Series solar generator indicating peak power point and charging point for a lead-acid battery system Curves are drawn for various cell and ambient temperatures at 100 mW sq cm solar insolation

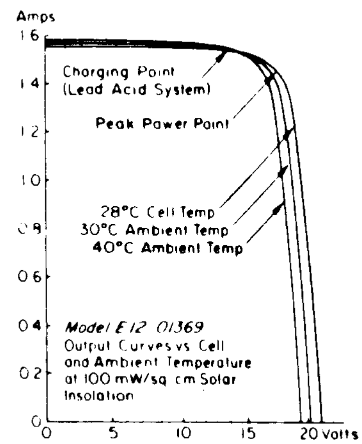
Model E12-01365 Solar Array with universal mount





Model E12-01369 Solar Array with telescoping legs and foot-pads



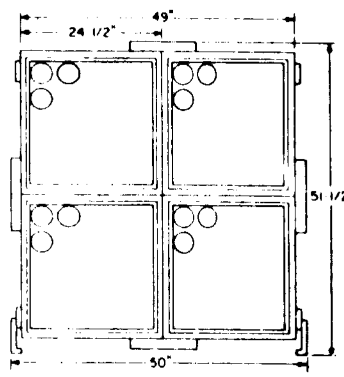


CODE EXPLANATION

E 12 - 01 369

- Cut cell number [where applicable]
- Module utilized
- Number modules
- Array voltage (nominal)
- Array type

Multiple unit E Series Solar Array



Solar Power Corporation **Affiliate of EXXON Enterprises, Inc.**

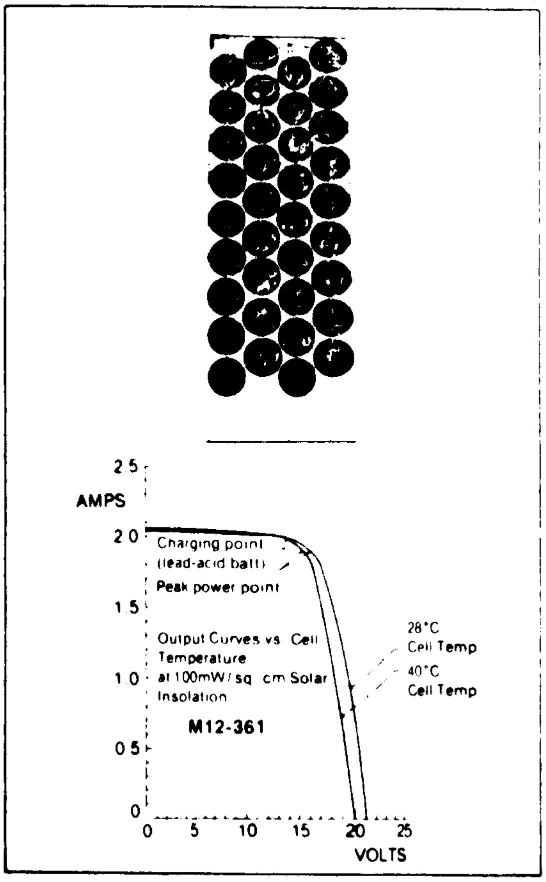
5 EXECUTIVE PARK DRIVE, NORTH BILLERICA, MASSACHUSETTS 01862, TELEPHONE (617) 667-8376 TWX 710-347-6792

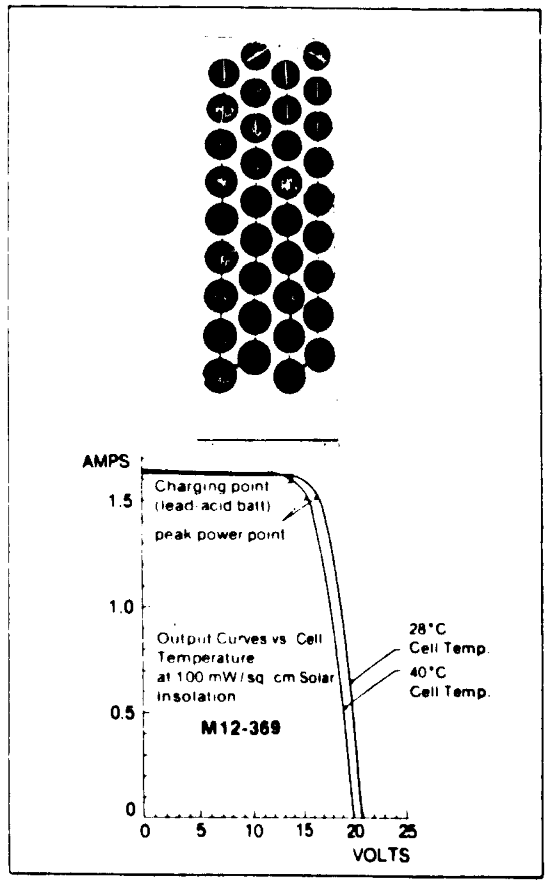
Branch Offices Solar Power Limited 110-111 Strand London WC2R OAA England Tel #01-836-8918 Telex 24973

Solar Power Corporation One Kingwood Place Suite 200 Kingwood, Texas 77339 Tel #713-358-3126

OUTPUT CHARACTERISTICS

Current vs. Voltage curves are shown for each M Series solar generator indicating peak power point and charging point for a lead-acid battery system. Curves are drawn for various cell and ambient temperatures at 100 mW/sq. cm. solar insolation.





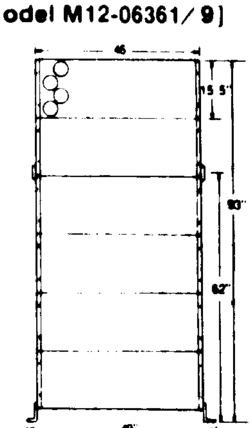
ORDERING CODE EXPLANATION

M 12- 01 369

- M — Product Type
- 12- — System Voltage
- 01 — Number of Modules in Array
- 369 — Module Utilized

NOTE: 6V and 4V "M" Series modules are also available. Please consult factory for specifications.

MULTIPLE UNIT M-SERIES ARRAY [Model M12-06361/9]



Solar Power Corporation Affiliate of EXXON Enterprises, Inc.

20 CABOT ROAD, WOBURN, MASSACHUSETTS 01801, TELEPHONE (617) 935-4600 TWX 710-348-0602

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PRINTED IN U.S.A. 3/78

Solar Power Corporation

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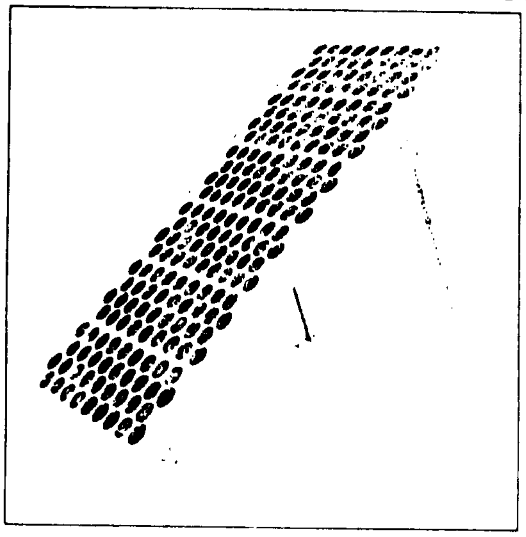
"M" Series Solar Electric Generators



"M" Series Solar Modules

The new M-Series Solar Modules feature a unique construction that affords a practical and economical solution for a wide range of power requirements. Utilizing Solar Power Corporation's larger diameter silicon solar cells (90mm or 100mm) and unique reinforced mounting surface, the M-Series Solar Modules feature two layers of silicone encapsulant, a blocking diode, and ten feet of output cable.

Thirty-six interconnected cells are arranged in recessed wells on a rugged, molded base made of glass reinforced polyester. A 40 cell version is also available. 12V, 6V, and 4V outputs may be ordered in either version.

The 90mm solar cells use a "dagger" electrode and the 100mm solar cells use a "forked" electrode grid pattern with redundant interconnects. Both are designed to maximize the M-Series solar cell current collection efficiency and collection area of the solar cell, while minimizing voltage drop in the electrode. M-Series solar cells are protected by two layers of silicone encapsulant. The lower layer is a highly transparent, UV-stable silicone rubber that seals and protects the cells. The outer encapsulant is a highly transparent, UV-stable silicone varnish selected for low friction to shed dirt, dust, and precipitation. All interconnections in the solar module are either soldered or screwed down to the mounting base. The connections are also encapsulated for corrosion resistance.

A low voltage drop blocking diode is built into the M-Series solar units to prevent storage battery discharge through the solar module at night or during low illumination periods. Ten feet of neoprene-jacketed, two conductor output cable is also provided. This Type SJO cable is resistant to oil, grease, water, acids, and ozone.

Arraying

The design of M-Series base incorporates a molded rib structure that provides sufficient stiffness to allow field installation without extensive external bracing. Arrays requiring more than one module are bolted together and stiffeners are added to each side. A layout for six (6) M-Series modules arrayed in this fashion is shown on reverse side of spec sheet.

Solar Power Corporation will supply complete solar arrays with stiffeners, telescoping support legs and footpads. The construction of the M-Series module also allows the user to easily fabricate his own structure using commonly available materials.

Solar Electric Generator Systems

SPC can supply complete solar electric generator systems including self-arraying modules, voltage regulators, and batteries. You may order a total system, or individual arrays and modules.

High quality rechargeable batteries are used to allow operation at night and in periods of inclement weather. All modules and systems are designed to provide peak current at the charging point of the battery.

Computerized System Design

Solar Power Corporation provides a computerized system design and quotation service based on customer load specifications. Information necessary to provide a quotation includes electrical load (AH/day), location (altitude, latitude, longitude), and nominal system voltage.

Electrical Specifications

Exceeds JPL Environmental Performance Requirement No. 5-342-1. Output rated at 28°C cell temperature and 100mW/sq. cm

Model No.	Charging Point*		Peak Power Point		Peak Power
	Volts	Amps	Volts	Amps	Watts
M12-369	13.6	1.62 ±10%	16.5	1.52 ±10%	[illegible] ±10%
M12-361	13.6	2.0 ±10%	16.5	1.90 ±10%	31.0 ±10%

*Lead acid battery at or near full charge

Environmental and Mechanical Specifications

Operating Temperature: -55°C to +60°C
Humidity: 0 to 100%
Altitude: to 25,000 ft (7620 m)
Wind Loading: Module with supporting structure built to withstand winds in excess of 175 m.p.h. (280 k.p.h.)

Model No.	Dimensions						Weight*			
	L		W		D		Net		Ship	
	in.	cm.	in.	cm.	in.	cm.	lb.	kg.	lb.	kg.
M12-369	46	117	15.3	38.9	2	5.1	18	8.2	30	13.6
M12-361	46	117	15.3	38.9	2	5.1	18	8.2	30	13.6

*Excluding support legs, stiffeners, and footpads.

Solar Insolation Effect

Voltage: Operating voltage attained at approximately 10mW/sq. cm. (dark overcast sky).

Current: Proportional to solar insolation, e.g. at 50mW/sq. cm. output current would be 50% of rated current.

APPENDIX 4

WINDMILLS

A. Types of windmills being tested in Tanzania.

B. Basic windmachine designs.

C. Windmills in use in the Omo River Project, The Gelebs of Ethiopia.

A. Types of windmills being tested in Tanzania

1.	Location:	Kurasin, Dar es Salaam (Maji godown)
	Type:	Fan mill, water pumper
	Diameter of Rotor:	6 m--18 blades
	Height Above Ground:	15 m
	Transmission System:	Through 10-ton Bedford truck near axle through a vertical rotary shaft step-up in transmission 1:7
	Starting Speed:	2.5 m/sec.
	R.P.M.:	10 of the fan mill
	Pumping Height:	15 m
	Supporting Structures:	4-pole steel truss
	Purpose of Construction:	Prototype for testing
2.	Location:	Department of Electrical Engineering, University of Dar es Salaam
	Type:	Savonius Rotor (made up of 3 drums)
	Diameter:	1 m
	Height Above Ground:	4 m
	Transmission System:	Pullys connected to a 12-volt dynamo with rubber belt
	Supporting Structure:	Wooden pole-frame
	Purpose of Construction:	Research and student demonstration for generating electricity
	Prototype Costs:	Sh. 500 to 600 without the generator
3.	Location:	Tandale, Dar es Salaam Tanzania Food & Nutrition Center
	Type:	Fan mill, water pumper
	Diameter:	3.6 m--6 blades
	Height Above Ground	10 m
	Transmission System:	A shaft system operating a piston pump. Thirty-eight cm stroke

Source: Tanzania National Scientific Research Council, Energy for Tanzanian Villages, Dar es Salaam, 1977, pp. 33-34.

Types of windmills being tested in Tanzania, continued:

	Starting Speed:	2 to 3 m/sec.
	Pumping Height:	10 m
	Supporting Structure:	3-pole steel truss
	Pumping Capacity	100 m^3/day at average wind speed of 5.6 m/sec. (predicted output)
	Purpose of Construction:	Water pumping for a small irrigation project
	Prototype Cost:	Sh. 4,000 for material and 100 hours of labor--approximately Sh. 3,500: Total cost Sh. 7,500.
4.	Location:	University of Dar es Salaam
	Type:	Wind charger type (propeller blades, not yet installed)
	Diameter:	3.6 diameter; 2 blades, wooden
	Height Above Ground:	8 m
	Transmission System:	Pully connected to a 12-volt dynamo with a rubber belt. A brake system installed together
	Supporting Structure:	A single wooden pole
	Purpose of Construction:	Research and student demonstration
	Output:	1/2 kW or 1 h.p. at 400 r.p.m.
	Phototype Cost:	Sh. 10,000, including generator.

Basic windmachine designs:

Horizontal Axis

Sailmill - typical of the windpumpers used in the Greek isles, these windmachines may have up to eight large triangular or jib sails capture the wind. In order to capture more energy at lower wind speeds, more sails are left on, while as the wind increases, fewer sails are needed to produce the necessary torque such that at high speeds, only one or two sails may remain on the head of the machine.

Multiblade "fan" windmachine - Typically up to 16 metal blades are shaped such that the appearance of the head is similar to that of a fan. The famous American windpumper of the 1800's and 1900's is characteristic of this variety.

Propeller windgenerator - Typically two or three propeller shaped blades of metal on wood, for generating electricity. The famous Jacobs "windplant" of the 1930's - 1950's falls within this category.

Hybrids - A number of hybrid designs have been developed or are in the prototype stage. Among them are the "bicycle wheel" turbine, so named because it is shaped like a bicycle wheel, with thin strip blades like spokes connecting a hub to a rim. A belt is attached to the rim, which drives a shaft, alleviating the need for gears.

Basic windmachines designs, continued:

Vertical Axis

Savonius-rotor (S-rotor) - Descendant of a windmachine developed and used in ancient times by the Persians, this S-rotor is so named because of the shape of its S-shaped or hour-glass shaped twisted wind capturing surface. It is capable of carrying out light to moderate mechanical loads.

Darrieus - Commonly described as the "egg-beater," this new wind-generator design consists of two or three thin metal convex blades connected at the top and bottom. It is used strictly for electrical generation and is one of the newest windgenerators to become commercialized.

Other Designs

There existed a great deal of ongoing research and development on windmachine design. Suffice it to say at this point that the aim of this research is largely to accomplish the following:

a) Improve the efficiency of the design so as to approach the theoretical 59.3% figure. The bicycle wheel turbine is a result of this kind of work.

b) Augment the power available from a given wind regime by artificially creating stronger wind, either by shrouds, channels, or tornado/cyclone cylinders.

c) Enlarge the cross-section area intersecting the wind, e.g., by means of using lift-augmentors such as the "continuous venetian blind belt" design of the D.J. Schneider Lift Augmentor Company, which is currently investigating the technology in Texas.

Source: Overseas Development Council, Energy For the Villages of Africa, (ODC: Washington DC) 1977, pp. 24-5.

Windmills in use in the Omo River Project, The Gelebs of Ethiopia

-from Overseas Development Council, Energy For the Villages of Africa, (ODC: Washington DC) 1977, pp. 91-93.

The experience of the American Presbyterian Mission at the Omo River Mission Station with the Geleb people near Lake Rudolf in southwestern Ethiopia provides an excellent case study of use of village source energy to improve the quality of life of the villagers.[1] The missionaries, using windmills of ancient Crete design but modern materials, succeeded in introducing the Gelebs to windpumped irrigation which has now permitted year-round cultivation that was otherwise impossible.

The Omo River area of the Gelebs near Lake Rudolf is a semi-desert arid area which is inaccessible except by 4-wheel vehicle or plane. It receives less than 10 inches of rain a year, most of which falls in April, flooding the Omo River banks. The temperature ranges between 70°F - 104°F. The Geleb people are semi-nomads, living in small villages or clusters. Stock raising is the major economic activity, but enough vegetables, grains and tobacco are grown for one harvest a year after the floodwaters have receded. Food is always in short supply during the six months prior to harvest. During 1973-74, the Gelebs received emergency air drops of food in order to avoid mass starvation during the disastrous drought and famine that hit Ethiopia.

The idea to bring windpumps into the area originated in early 1974 with the missionaries who wished to import standard American made Dempster windpumps to replace a diesel-electric pump used for the mission's vegetable and fruit garden that was too difficult and expensive to maintain and fuel. When the windpumps arrived, they found there were too many for their own needs: these were sold on a subsidized basis to a couple of farmers who had expressed interest and curiosity in the ones already operating at the mission. By April, 1974, one of the Dempsters was successfully installed, with missionary assistance, and irrigating 1-1/4 acres of land cultivated by several families. Peter Fraenkel of ITDG relates the outcome:

> "The windmills were an immediate success with the Gelebs, which is perhaps surprising when it is considered that these people are almost completely without any formal education and have had very little contact with outside influences or with machinery of any kind. However, the wind and the machines are relatively reliable and the people very quickly recognized that this could help provide food all the year around and thereby remove their chronic annual food shortage which had caused them great misery in the past."[2]

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1 Peter Fraenkel, Food from Windmills, (London: Intermediate Technology Publications, Ltd., 1975).

2 Ibid.

However, the Dempsters, even with the discounts the missionaries managed to receive, cost $1,000 each, much too expensive for wide scale use by the Gelebes. Instead of continuing a search for a cheaper, equally powerful unit in the U.S., which they felt would prove fruitless, the missionaries instead went to the island of Crete. There they found an indigenous windmill design and power capacity using sails instead of blades which could be appropriately modified for the Gelebs. Upon returning to Ethiopia, the missionaries first attempted to build the Cretan design using local driftwood, woven mats, and whatever meager timber was available in the semi-arid region, but the construction, partly affected by termites, proved fragile and unreliable in operation. So steel parts were imported as well as a diesel-powered welding set, drills, a lathe, and other tools which were the only capital investments for the windmills construction operation. Within a couple of months, the first sailmill was erected, and almost one a month has been built since then. During this time other designs were also being investigated on site, among them, the modern vertical Savonius Rotors (S Rotors), but they were not as efficient as the Cretan design because they intersected smaller cross section of wind and needed higher wind speeds to self-start pumping. Furthermore, the Cretan sailmills, costing around $375 each, pumped twice as much water in the same wind and were cheaper to build than the Savonius Rotors. As it turned out, the sailmills also lifted as much or more water than the $1000 American-made Dempster, which required imported spare parts and regular lubrication. One of the Gelebs was taught by the missionaries how to maintain, assemble and install the windmills. Each farmer receiving a windmill also received a package of hand tools and seeds. The missionaries planned the proper loction of the windmill and the layout of the irrigation networks, using simple meteorological equipment on loan from the Ethiopian Government.

Omo is located at 5^{o}N, well within the tropical equatorial belt in which the global wind pattern is considered to be mild and marked by low average annual wind velocities not amenable to the use of windmills. There is only marginal change in climate with the seasons of the year. The primary wind regime is diurnal—a "sea breeze" from Lake Rudolph a few kilometers away during the day which carries 10-15 mph mean wind velocities in the morning that taper off to nothing in the evening, at which time a night "land breeze" arises, tapering off until the morning "sea breeze" the next day. Because the sailmills require careful supervision of the sails to add sails when wind decreases and remove sails as wind increases (in order to avoid damage), all irrigation is done daily in the morning from 7 a.m. to noon while the wind is at its peak. Almost all of the Cretan windmills have 10-11 ft. diameter wind wheels and can pump up to 800 imperial gallons of water per hour in 13 mph winds. The sail mill consists of the following parts:

1) Suction line pipe and foot valve starter pump—both parts made in Ethiopia—represent about 25% of the cost or about $95.

2) Dempster design piston pump and connecting rod--made in Ethiopia at about 50% discount—represents about 10% of the cost or $40.

3) Head assembly and tail unit--made in Ethiopia--for about 5% of the cost or $20.

4) 12 ft. tower, wind wheel, and sails represent remainder of cost, about $120. The tower and wheel are made of metal piping; the sails were made of donated yacht sail material which is impervious to heat and ultra violet damage and are known to minimize material runs, tears, and flapping in gusty winds.

Other costs averaged out over the thirty sailmills add another $125 to each, thus total costs are around $375 for each sailmill. Whereas the missionaries have been charging the Dempster owners $5/year for 20 years for the $1000 machines, the sailmill owners are paying $2.50/year for 20 years for the $375 machines. Such subsidized charges seemed to be enough to establish sincere interest on the part of the Gelebs, who are nevertheless very low on currency, being so isolated from cash markets. Any efforts to reduce capital costs must not sacrifice the simplicity, longevity, or the low cost per gallon water lifted which are what make the sailmills practical and affordable to the Gelebes. Such cost reductions might involve wider diameter windwheels of 16-20 ft. variety with double pumps (and consequently higher towers), which would pump up to twice the water of the 10-11 ft. diameter windwheels.

Approximately twenty such sailmills were in use by Geleb families by August of 1975. Although there were some Gelebes who had difficulty adjusting culturally to the need for more time spent in cultivating the newly irrigated land instead of watching the stock animals, sufficient adjustments were made within the family in most cases to settle such time conflicts. The new opportunity for cultivation not only enabled the well-to-do, land-owning, cattle-owning villager to prosper, but also the landless, cattle-less villager to benefit from the newly arable land and abundant water supplies which the sailmill operators rented out to them. Not only did production of traditional grains like millet and maize increase, but new nitrogen-fixing protein crops like soybean and groundnuts were introduced with success. Surplus grains and beans, as well as new vegetables and fruit like cabbage and papaya were sold for cash at a nearby policy station which enabled some villagers to buy more cattle. The farmers using the sailmills attest to not having been hungry since the introduction of the windmills—one has even succeeded in growing five harvests between April 1974 and August 1975.

The Geleb experience, of course, cannot be duplicated everywhere. It does indicate that in some cases small scale technologies can be successfully transferred and modified to meet local needs, using modern materials if necessary. It shows that such adaptive technology can compete favorably with the best of the tried-and-true or modern designs of the U.S. It is not inconceivable that if such windmills were produced on a mass scale, the fixed capital cost per unit would decline sufficiently, and economies of scale in production would arise, perhaps dropping the cost per unit to as low as $240 or even less. Over a 20 year period, such windmills used five hours a day, 5 days a week, 50 weeks a year would have operating costs around 1¢ an hour or $12 per year, which certainly would put the sailmill within the affordable range, particularly for farmers living within closer proximity to markets and a cash economy.

APPENDIX 5

CRITICAL FACTORS IN ECONOMIC EVALUATION OF SMALL DECENTRALIZED ENERGY PROJECTS

-paper by S. J. Pak and C.R.H. Taylor, (World Bank: Washington D.C.) November 1976, not representing the views of the Bank Group)

CRITICAL FACTORS IN ECONOMIC EVALUATION OF SMALL DECENTRALIZED ENERGY PROJECTS

Introduction

1. In the rural areas of most developing countries the traditional sources of energy have been animal and human effort and crudely utilized forms of animal and vegetable matter. To a limited extent, water and wind power have also been important. In the last 20 or 30 years, rural electrification schemes have begun to play a part, providing energy for a number of uses including lighting, pumping for irrigation, and rural industry. Petroleum-based technologies have also grown in importance: kerosene has appeared as a major lighting fuel; diesel pumpsets have been introduced by more prosperous farmers; and diesel generators have started to provide electricity in those areas not reached by rural electrification. At the same time, work has been going on to develop new, decentralized technologies and to refine the use of traditional energy sources. This research and development effort, and the programs to disseminate the new technologies, were greatly intensified when oil prices increased sharply in 1973. Biogas, solar energy, wind energy and mini-hydro plants have suddenly become more competitive and have come to be seen as alternative new energy sources.

2. Much of the work which has been done to date has rightly concentrated on the technical aspects of these alternative energy sources (AES). Much remains to be done to improve their effectiveness. But at the same time, there is a proper concern to evaluate their associated economic costs and benefits in order to ensure that the most appropriate technologies are adopted, before substantial public and private investments are made. The present literature on the economic analysis of AES leaves something to be desired, partly on account of the approach adopted and partly because of the constraints imposed by availability of data and funds.

3. This paper addresses some of the critical factors concerning the economic evaluation of AES projects with particular reference to the biogas technology. It is not intended for professional economists but for decision makers and technologists involved in placing AES projects. Nor does it discuss a method for evaluating the scientific merit of research and development efforts, but rather for judging the economic worth, of a single investment, or a major investment program in the field. A more complete discussion of the appropriate methodology for the economic and financial appraisal of AES projects is under preparation. The present paper represents some of our preliminary observations, based on a review of the literature, on the economic evaluation of AES projects. We hope that these observations about data requirements and methodology will be useful to the engineers and scientists experimenting with AES projects and to those in government and aid agencies likely to finance AES projects.

General Characteristics of the AES Technologies

4. Several aspects of AES technologies make them particularly interesting and potentially important in developing countries. First of all, the economics of the AES technologies are location specific. Local factors such as climate and cropping patterns will influence not only technical design but also costs and benefits in a significant way. Secondly, AES projects tend to require proportionately larger initial investments and smaller operating and maintenance costs than conventional energy projects using coal or oil. Thirdly, at least some of the AES technologies are characterized by limited economies of scale; hence, the competitiveness of small decentralized installations, especially where distances are large or physical infrastructure is poor.

5. Choosing among alternatives. AES projects are not an end in themselves, but are introduced to provide energy which in general could be provided by other means. For this reason, the costs and benefits associated with different AES projects and with diesel and rural electrification alternatives must be compared. The criteria for choice in the private sector is profitability; that is, the investor wishes to earn as much as possible from his available financial resources. Similarly, where we are comparing AES projects, we should be interested in achieving the best use of resources available to the economy: we should choose the alternative that we expect to generate the greatest net benefit 1/ to the economy. Thus, the difference between this economic evaluation of AES projects and the private financial decision process is that we estimate costs and benefits to the economy rather than the individual immediately concerned.

6. Consider as an example a proposal to install a biogas plant in a remote village. We may suppose that 90% of the gas is to be used for cooking and 10% for lighting, and that the sludge will be used for fertilizer and soil conditioner. The first alternative to consider is to do nothing at all, in which case, we may assume, the traditional use of firewood and dried dung for cooking, and some remaining untreated dung for fertilizer, would persist and the village would do without lighting. A second alternative might be to electrify the village for lighting and cooking and continue to use the untreated dung as fertilizer. A third might be to use firewood for cooking, but to establish a plantation to maintain the local stock of wood.

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1 Net benefits can be compared by summarizing the costs and benefits of alternatives as the net present value or the economic rate of return. Where two alternatives lead to the same benefits, it is sufficient to compare the costs (See Annex).

7. In evaluating and comparing these alternatives we stressed the need to look at the costs and benefits to the economy. This implies it is necessary to trace through as far as possible the secondary effects of AES projects, and of the various alternatives which are to be compared with them. In the above example, firewood may well be costless to the individual who collects it, but deforestation is not costless to the country at large. Estimating and including that cost in the first alternative will, relatively speaking, improve the return on the biogas plant. Similarly, if rural electrification should be considered.

8. This example also serves to illustrate a second important general point, namely, that all costs and benefits should be considered. Risk of accident should also be estimated. Among the costs of the biogas proposal should be included the cost of raw material collection, of gas distribution and the cost of appliances. The secondary benefits would probably include improving the health of the villagers, and there will no doubt be effects on the income and wealth distribution in the village. It may be difficult to estimate and quantify these costs and benefits, but even so, they should be noted and taken into account as far as possible in evaluating AES projects. Some of the main costs and benefits to be considered are reviewed in the next two sections.

Estimating Benefits

9. The benefits expected from decentralized AES are frequently overestimated in physical quantity. This is sometimes the result of using the plant capacity as the estimated output, regardless of anticipated periods of slack demand, when energy which cannot be stored will either not be generated or will be wasted.

10. For example, consider the case of a small biogas plant which converts animal and vegetable waste into biogas and a residue of sludge. Because the biochemical changes are more effective at higher temperatures, the daily output of gas may in the summer be as much as four times as high as in the winter. Unless the demand for gas matches, or continuously exceeds, the changing daily output, a significant portion of the gas produced during the warm season may be wasted and should not be considered as a benefit. Similarly, not all the sludge from a biogas plant should be valued as a benefit as fertilizer and soil conditioner unless all the sludge produced can be used. If the sludge has to be stored in the open air in certain agricultural seasons, there will be nitrogen losses to take into account in reducing the estimated value of the sludge.

11. In theory, it may be possible to achieve high utilization rates, of both equipment and output for many types of energy technology, but in practice it has proved difficult. For example, the load factor for most rural electrification schemes remains very low. Unless concrete ways of utilizing the surplus energy outputs and of maintaining high rates of

capacity utilization are clearly identified and incorporated into a project, average energy output effectively utilized will be less than capacity, and the periodically generated surplus energy should not be counted as a benefit in a project analysis.

12. Once the physical quantities of usable outputs from an AES project are estimated, an economic unit value must be estimated. If these outputs are readily traded, the estimate can be based upon the market price adjusted for any significant price distortions caused by subsidies and taxes.

13. When the output is not traded, the replacement value can be used instead. For example, suppose that biogas is to be introduced in a village for cooking purposes where previously kerosene was used. Then the unit value of the gas may be estimated as the value of kerosene replaced. Note, however, that if firewood was a cheaper alternative than kerosene (taking all the economic costs into account), it may be more appropriate to estimate the gas value from the value of firewood replaced.

14. When it is difficult to value the replaced fuel, it may be more appropriate to value output by estimating its impact on the production of other goods. For example, sludge from a biogas plant should increase crop yield when used as a fertilizer, and the value of the increase in yield can be taken as the value of the sludge (provided account has been taken of any changes in other inputs into the farming).

Estimating Costs

15. Estimating costs requires that a list of inputs in physical terms be drawn up, and then values be assigned to each input. These values may or may not be the market values. For example, it may be possible to employ laborers on the project only if the going wage is paid, and yet, the alternative for these men may be unemployment: since the alternative has no value for the national economy, their employment involves no cost (no foregone opportunities) to the economy. Thus, we might value labor at zero for the purposes of the economic evaluation. This is an example of a "shadow price" - the shadow wage rating being zero in this case. 1/

16. A comprehensive list of inputs for an AES project would include the following items:

(i) expert service - as the AES technologies are location specific, each project may require expert services for its own design and siting;

(ii) land - the market value of land required for the project may be zero, but its real economic resource cost may not;

1/ This may not be true if increasing employment is felt to be so socially desirable, that "useless" employment is socially useful.

(iii) labor for construction, maintenance and operation - shadow wage rates may not always be zero and may change from season to season;

(iv) equipment - transportation and installation costs of equipment should also be included:

(v) spare parts and maintenance inputs;

(vi) all raw material inputs - for example, the two major inputs for biogas projects, water and cow-dung, may both have positive value;

(vii) appliances needed to utilize the outputs from the AES project - when biogas is to be used for cooking and lighting, cooking stoves and lamps should be included as cost items; and

(viii) provision for any traditional function displaced by the project.

17. As in the case of benefits, once physical quantities are well estimated, unit values must be assigned, which will usually be either on the basis of market value or replacement value. It is useful to distinguish between inputs that are traded internationally and those which are not. 1/ This will be important for such AES technologies as solar-voltaic cells, but less so for biogas plants. The reason for making this distinction is that foreign currencies may be scarce, the official exchange rate in a developing country may be such that imports are generally undervalued (and exports over-valued) by their price in the domestic currency. If this degree of under- (and over-) evaluation can be estimated as a ratio (this is a job for an economist!) this ratio can be applied to the value (in domestic currency) of all traded inputs, to more accurately reflect the cost to the economy of using these in the AES projects concerned.

18. We observed above that physical benefits are often overestimated. In a different sense, costs can sometimes be seriously underestimated too. We have noted a number of studies that give equipment (and civil works) lives that are much longer than we would expect. The effect, of course, is to reduce the annual cost corresponding to the capital costs (or increase the number of years over which operating benefits accrue) and improve the appearance of the project. Equipment life must be estimated with care, and, if it appears likely that the economic evaluation will depend crucially on

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1/ Apart from petroleum products, fuels and energy itself are not usually traded internationally so that this point is generally less important for AES benefits than costs.

this estimate, two or three alternative estimates should be used to estimate economic viability to bring out this point.

19. The implications for data collection. The first and most basic need is to collect comparable data from outside the AES project areas. A "base line" is needed, a history of what happened over the same period in comparable villages where, say, rural electrification took place, and where no energy investments at all were made. It is not a valud argument in favor of AES projects to say that, for example, foodgrain production increased by so many percent over the project implementation period, if it cannot be contrasted with less impressive growth elsewhere. This type of data helps rule out the influence of pervasive changes in weather, the social and economic situation, and so on. 1/

20. The second point is that within the village concerned, data from outside the AES project's immediate vicinity is needed. For example, the costs which need to be recorded in considering a biogas investment include the labor costs of collecting animal dung. The costs of using kerosene as a cooking fuel should include the costs of a suitable appliance. On the benefits side, any attempt for example, to show agricultural output increases when sludge from a biogas plant replaces untreated dung will require extensive observation of crop yields. It is worth noting too, that establishing reliable data on utilization rates will require observations over time of sufficient frequency to trace out seasonal variations.

21. Finally, we might note physical quantities should be recorded in the first place; then unit values estimated and finally values of cost and benefit streams can be derived. Apart from the advantage of making valuation assumptions clearer in this manner, the data on physical quantities will in many instances be more useful internationally, than the aggregated summary data. For example, if an economist from one country were interested in the labor input to the civil works associated with a biogas plant in another country, it is no use to be told that the labor input was ignored because the shadow wage rate was zero.

22. Through standardization of the type of data collected, and by rigorously applying economic analysis techniques our hope is that, over time, a useful body of international knowledge on the economics of AES projects will develop.

1/ This type of comparative analysis might be very useful in judging the health impact of biogas plants.

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THE EVALUATION OF AES PROJECTS

1. This Annex briefly explains and summarizes the economics of cost-benefit analysis. This is a set of techniques for making consistent comparisons between alternative investments with a view to choosing the investment which uses available national resources best.

2. For the purposes of this discussion, we assume that only two alternatives are being considered. We can characterize each alternative as a series of yearly costs and benefits. We represent the cost in the i^{th} (first or second) alternative in the j^{th} year of the project as C_{ij}. C_{i0} will almost certainly include all the capital costs unless some capital costs are incurred over a year after the project begins, in which case C_{i1} will also include capital costs. The costs in each year, C_{ij}, are of course the sum of the costs we identified above. Similarly, we can symbolize the expected benefit from the i^{th} project in the j^{th} year by B_{ij}. We can represent the life of the first alternative by n_1 and the second by n_2.

3. Concentrating on the first alternative, we can summarize the stream costs and benefits in two ways. The internal rate of return (IRR) is the rate of "profit" from the project, and is given by the value of i in the formula:

$$0 = \sum_{j=0}^{n_1} (B_{1j} - C_{1j})(1+i)^{-j} \qquad (1)$$

If all the capital costs are concentrated in the first year, and if no benefits are derived in the first year, (1) can be rewritten as:

$$C_{10} = \sum_{j=1}^{n_1} (B_{1j} - C_{1j})(1+i)^{-j} \qquad (2)$$

which, in words, is:

[capital costs] = [net benefits over time discounted at the rate of "profit"].

If we were able to calculate the IRR satisfactorily for the two alternatives, we should normally choose the alternative for which the IRR is highest.

4. The second way to summarize the stream of costs and benefits is using the accounting rate of interest (r) to derive the net present value (NPV) of the alternative being considered:

$$NPV = \sum_{j=0}^{n_1} (B_{1j} - C_{1j}) (1+r)^{-j} \qquad (3)$$

If the same calculation is made for the second alternative, we would normally choose the project with the highest NPV. This criterion and the IRR criterion are equivalent in the sense that we would usually make the same choice whichever was used.

5. The accounting rate of interest may be loosely defined as the lowest IRR that most government projects are expected to earn. In most developing countries it will fall somewhere between 10 and 15%. A very few (poorly justified) public sector projects may earn only 2 or 3%, but these should not be taken as a standard. The accounting rate of interest is difficult to estimate accurately, and estimation usually requires considerable judgment. The bank rate is not directly relevant, since the rate is affected by inflation and short-term economic phenomena such as the stage of the business cycle.

6. We have been considering the choice between alternatives, but there is also the question of whether either alternative should be undertaken. If the NPVs are negative, or the IRRs are less than the accounting rate of interest, this indicates national resources would be wasted if investment was made in either alternative: neither should then be undertaken.

7. It may be possible to avoid estimating the benefits of two alternative AES projects in order to choose between them, if the benefit streams are expected to be virtually the same. We can then choose the least cost alternative, using the accounting rate of interest in each project to add together cost in different years:

$$PVC_1 = \sum_{j=0}^{n_1} C \; (1+r)^{-j}$$

$$PVC_2 = \sum_{j=0}^{n_2} C \; (1+r)^{-j} \qquad (4)$$

If the present value of costs (PVC) is less for alternative 1, clearly that is the alternative which should be chosen.

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