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9. ABSTRACT

This is a report of an ad hoc Advisory Panel, made up of specialists from the United States and abroad, to: (1) Assess the state of the art in utilizing solar energy for developing countries and review current practical applications; (2) identify promising areas for research and development; and (3) examine the desirability of establishing an international solar energy institute in North Africa, to carry out solar energy research and development.

Panel members are listed. Bibliography is appended.

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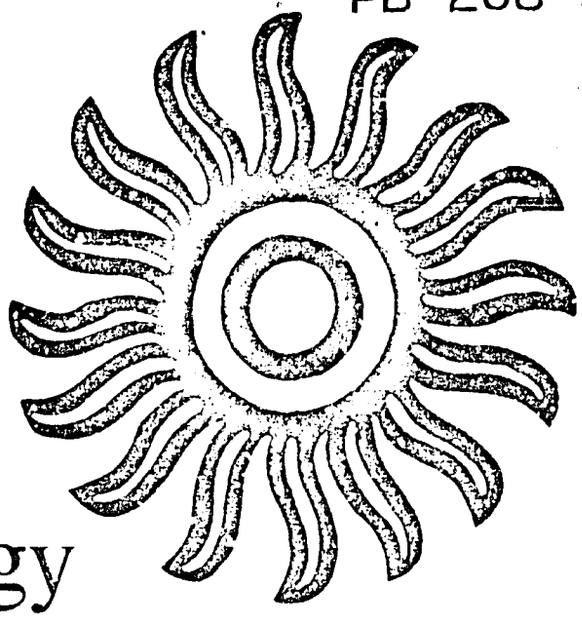

Solar Energy in Developing Countries: Perspectives and Prospects

A REPORT OF AN AD HOC ADVISORY PANEL OF THE
BOARD ON SCIENCE AND TECHNOLOGY FOR INTERNATIONAL DEVELOPMENT

OFFICE OF THE FOREIGN SECRETARY

NATIONAL ACADEMY OF SCIENCES
Washington, D.C. • March 1972

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This report has been prepared by an ad hoc advisory panel of the Board on Science and Technology for International Development, Office of the Foreign Secretary, National Academy of Sciences, for the Bureau for Technical Assistance, Agency for International Development, Washington, D.C., under Contract No. csd-2584.

NOTICE

The study reported herein was undertaken under the aegis of the National Academy of Sciences with the express approval of the Governing Board of the National Research Council. Such approval indicated that the Board considered that the problem is of national significance; that elucidation and/or solution of the problem required scientific or technical competence and that the resources of the National Academy of Sciences were particularly suitable to the conduct of the project. The institutional responsibilities of the Academy were then discharged in the following manner:

The members of the study committee were selected for their individual scholarly competence and judgment with due consideration for the balance and breadth of disciplines. Responsibility for all aspects of this report rests with the study committee, to whom we express our sincere appreciation.

Although the reports of our study committees are not submitted for approval to the Academy membership nor to the Council, each report is reviewed by a second group of scientists according to procedures established and monitored by the Academy's Report Review Committee. Such reviews are intended to determine, inter alia, whether the major questions and relevant points of view have been addressed and whether the reported findings, conclusions and recommendations arose from the available data and information. Distribution of the report is permitted only after satisfactory completion of this review process.

NATIONAL ACADEMY OF SCIENCES

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March 1972

Dr. Joel Bernstein
Assistant Administrator
Bureau for Technical Assistance
Agency for International Development
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Washington, D.C. 20523

Dear Joel:

I am pleased to forward the report of the Ad Hoc Advisory Panel on the Utilization of Solar Energy in Developing Countries. The report represents the best judgment of the very able men who made up the panel, based on their wide-ranging practical and scientific experience and their deliberations at the Academy.

Energy questions are central to any attempt at improving the quality of life of people in any nation. The panel establishes that the solar energy developments of the past have not yet led to a device or system likely to have a broad impact on national, regional, or international development, though solar water heaters may prove an exception in the near future. The panel is confident that solar energy will play an important role in the future as a source of energy for man's application. It is an energy source that does not exploit unrenewable resources, does not add undesirable chemicals to the earth's atmosphere or water, and does not add to the thermal energy of the earth.

The rational development of uses of solar energy to benefit the developing countries must rest on a clear picture of the "energy niche" in which solar energy will best fit. At present we have no data base for determining even the existence of such a niche in any given area. The panel recommends, accordingly, that the first step be a thorough analysis of the energy needs in a given area. This analysis should include a complete market survey, a survey of the sociological characteristics, and a general identification of all the boundary conditions that any device or system would have to meet to be viable. This survey should include all forms of energy, and the results may show that in any given area solar energy may fill a major energy requirement or that it has no role to play. Once the niche for solar energy is identified, rational development of devices for its utilization will be possible. Short of this approach, any solar energy R and D will run extreme risks of economic failure and social unnacceptability.

The panel recommends consideration of the feasibility of establishing regional energy-research centers as one means of obtaining the necessary data on a systematic basis. The concept of these centers--particularly their relationship to national programs--is a matter deserving substantial study, and the panel recommends that this idea be further explored by a task group more broadly representative of the field of energy production than this panel, which was chosen specifically for its knowledge of solar energy.

The proposed North African Center, whose evaluation by the panel was requested by AID, could be one of these centers, and it could have a major impact if it is not restricted to solar energy alone.

Sincerely yours,

Harrison Brown
Foreign Secretary

PREFACE

The Ad Hoc Advisory Panel on the Utilization of Solar Energy for Developing Countries was charged with the following responsibilities:

1. To assess the state of the art in utilizing solar energy for developing countries and review current practical applications;

2. To identify promising areas for research and development; and

3. To examine the desirability of establishing an international solar energy institute in North Africa, to carry out solar energy research and development.

A distinguished panel of specialists from the United States and abroad was assembled in Washington, D. C. May 6 - 7, 1971. In selecting the panelists, efforts were made to provide a balance between scientists and engineers from developed and developing countries. Written contributions were solicited before the meeting, and two that were submitted are included in the Appendix. The first day was devoted to expositions by the participants of their views. The second day was devoted to analyzing the information and formulating recommendations.

The panel wish to acknowledge the invaluable help of Manfred Altman and John A. Duffie in the work of the panel and the preparation of this report.

BOARD ON SCIENCE AND TECHNOLOGY FOR INTERNATIONAL DEVELOPMENT

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I

SUMMARY AND RECOMMENDATIONS

In response to a request by the Agency for International Development (AID), an ad hoc panel convened by the Board on Science and Technology for International Development of the National Academy of Sciences has considered the present state of development of processes for utilization of solar energy, applications now being made of this energy resource, and possible future developments in solar processes, all in the context of energy needs in developing countries. The panel also considered the desirability of establishing an International Solar Energy Institute in North Africa.

Based on these considerations and on the experiences of its members, the panel drew several general conclusions: solar energy is an energy resource widely available in areas with energy needs in developing countries; useful applications of solar energy are now being made; other applications are in various stages of experimental development; knowledge of energy needs in developing countries is inadequate and must be improved; and research and development programs to meet these needs should include but not be limited to, consideration of solar energy. The panel concludes that solar energy is a resource that has the capability to meet energy needs substantially beyond the applications now being made, and that this potential can be realized only with further research and development.

The panel considered that the essential problems are energy problems, not solar problems, and that solutions to these energy problems require consideration of alternative sources of energy. From this the panel evolved,

and recommends to AID, consideration of the concept of regional energy research and development centers as institutions to study energy needs and the means (including solar) by which these needs might be met. The suggested international solar energy institute in North Africa, if expanded in scope to include other energy sources and with functions described below, could be one such regional center.

Applications of Solar Energy

The panel noted that some applications of solar energy are well established in developing countries, i.e., solar evaporation for salt production, and direct solar drying for processing crops.

Other applications are established, or becoming established, in more highly developed economies, with the corresponding technologies reasonably well developed. Solar water-heaters are widely used in some countries; and where the need exists, the technology of water heaters can be, and is being, adapted for use in developing countries. Solar distillation, for producing potable water for human or animal consumption, is in a "pilot plant" stage of development and is supplying a number of small communities with drinking water, on an experimental basis. Adapting solar-still technology to the situations of developing countries could solve some water-supply problems.

Other applications of solar energy, very much in experimental stages, are subjects for research and development:

- Solar drying, in enclosures to control the process and enhance product quality, may result in improved utilization of foods.

- Solar heating and cooling of buildings, and further consideration of scientific principles for control of thermal effects in simple housing, may be practical in some developing areas.

- Solar power systems based on heat engines are still a difficult challenge. Research on these processes is of a more difficult and speculative nature. The potential returns are larger, but so also are the problems in developing useful and economic systems.

- Solar refrigeration for food preservation, obtained by absorption cooling cycles, appears to be technologically feasible. The best systems and cycles have yet to be determined, as have the best scale of application and social and economic feasibility.

These processes are all thermal in nature. There are also biological and photovoltaic processes that might be used in developing nations:

- Photovoltaic conversion of solar to electrical energy is highly developed for space-vehicle use. It is now far too expensive for large-scale terrestrial use; but it is now useful for some highly specialized, very low-power applications, as in some applications to communications. Photovoltaic process research is best done in developed countries, and its potential contribution to energy economies of developing areas, other than for communication purposes, cannot be foreseen with present technological practice.

- Biological processes, for specially controlled agriculture or algae culture, are another class of solar processes that may become significant but were not considered in detail by the panel.

To summarize, the solar processes that are now useful or that could be brought to a stage of development in which they could produce useful results in the shortest time are evaporation, drying, distillation, and water heating. More extensive development of processes for refrigeration, new methods of solar drying, heating, cooling, and thermal design of buildings should make some of these uses practical within the decade.

Applications of solar power will require substantial development of new technology.

Determining Needs and Establishing Priorities

It was clear to the panel that it did not have enough information on needs for energy in developing countries to set firm priorities and to assign research and development resources to meet energy needs of particular countries, or to select those processes noted earlier that would be most useful. Further, the diversity of economic, geographic, social, and political factors in the developing countries make it impossible to assign a single set of priorities for R and D.

The panel recommends systematic approaches to energy resource-and-utilization programs for developing countries, or areas. The following approaches would be included:

1. Detailed studies of the needs for energy of the given region or country, as a basis for selecting the most useful energy processes to be developed;

2. Thorough understanding of the objectives to be achieved by the supply of energy;

3. An examination of the possible energy-supply alternatives, which would include solar energy but would not be confined to it;

4. A detailed set of criteria by which the desirability of actions can be measured;

5. Studies of the costs and worth of the available options of energy supply to meet known needs;

6. Surveys to determine the extent of investment and manufacturing capability required; and

7. The development of strategies to bring about desired action from suppliers and users, such as manufacturing in the appropriate location, suitable distribution, education of users, etc.

If this systematic approach is followed, then the question arises of how the needed information base can best be generated and the research and development proceed.

In the unanimous judgement of the panelists, the establishment of regional energy R and D centers is a valuable concept to consider for performing the above tasks. The panel feels strongly that the tasks can best be performed in situ, and that the regional centers should be staffed mainly with people from the region, if possible, and augmented by experts from developed nations. They should treat the practical energy problems of their regions, and at the same time exchange information and experiences with other regional centers, to avoid wasteful duplication and maximize the gains to the developing countries from their efforts. They must also be aware and ready to take advantage of advanced technology from developed countries that may be transferable to their regions.

The regional centers should have these specific responsibilities:

1. To help generate an information base on energy needs in the region;

2. To carry out the needed research and development to meet regional energy needs;

3. To field-test and provide feedback from users to the centers in order to improve energy processes and evolve useful solar (or other) processes;

4. To act as information, education, and training centers in cooperation with local universities; and

5. To maintain close contact with scientific and engineering developments and energy applications in other centers and in industrialized countries.

The needs of the developing nations can best be served if the centers do not confine themselves to solar energy. A rational decision, rather than a prejudgment, that solar energy will solve an energy problem should be made. The centers may, as a result of their studies, recommend the use of either solar energy or other energy sources. Participants from Niger and India gave very strong support to this position.

The panel recognized that the concept of regional energy R & D centers deserves further substantial, in-depth study. In particular, the relations between national energy programs and a regional center would have to be considered in detail.

The proposed International Solar Energy Research Institute in North Africa could constitute one of the regional centers envisioned by the panel. Its mission should be expanded to include consideration of solar and alternative energy resources. Support could include engineering and scientific laboratory equipment, library facilities, training of personnel, means of cooperation with similar institutions in other regions and developed countries.

There is an opportunity at hand for the United States. Energy and standard of living go hand in hand. Intelligent action on the part of this country could go far to help developing nations meet energy needs. A suitable method would be to assist in the development and operation of regional energy centers.

II

THE BASIS FOR CONSIDERING SOLAR ENERGY

There are several important reasons for considering solar energy as an energy resource to meet the needs of developing countries. First, most of the countries usually called "developing" are in, or adjacent to, the tropics and have available good solar radiation. Second, they do not have widely distributed, readily available supplies of conventional energy resources. Third, energy appears to be a critical requirement to meet the needs of developing countries, because it is related to the production of housing, clothing, food, and agricultural and industrial production. Most of the developing countries are also characterized by arid climates, dispersed and inaccessible populations, readily available labor, and a lack of investment capital.

Thus there are several compelling reasons for considering solar energy as a resource to meet the needs of these countries. They need energy, and have this resource available to them. It is tremendous in amount, and, in effect, is already distributed to the potential users. A substantial part of energy needs in developing countries is for thermal (heat) energy, and solar energy is most easily converted to thermal energy. Its use entails little or no undesirable side-effects on the environment. For some applications, the equipment needed is such that it might well be manufactured in the country of use, possibly saving foreign exchange. Use of solar energy could reduce dependence on, and financial outlay for, imported fuels, thereby contributing to the economic independence of developing countries. Solar processes have been devel-

oped, or are under development, that could meet specific needs of the countries (e.g., hot water, desalted water, etc.--to be discussed later). The probable costs of further developing these and other solar processes are not great, compared with the historical development costs of most conventional energy sources.

It must also be recognized that applications of solar energy entail some difficulties that result from the nature of the resource. The intermittent nature of solar energy results in problems of designing adequate levels of reliability into solar processes. The diffuse nature of solar energy dictates that large outputs of energy (or other products) can be obtained only with large areas of solar converters. Its applications are generally capital-intensive, with substantial investments (local currency and foreign exchange) needed to realize savings in operations. There may also be difficult social and educational problems in getting dispersed and technologically unsophisticated populations to take advantage of and use solar processes.

Recognizing these circumstances, the panel considered questions of the need for energy for various purposes in developing countries, the present status of solar-process development in relation to these needs, and what further activities would be appropriate (in terms of both research and development, and institutional arrangements) to assure that adequate assessment of the potential of solar processes is possible, the resource is appropriately utilized, and energy needs are met.

III

NEEDS AND USES FOR SOLAR ENERGY IN DEVELOPING COUNTRIES

It was clear, as the panel proceeded with its discussions, that its members were aware of a wide range of energy needs in developing countries that could potentially be met by solar energy. Many of the needs were general; others were specific. It was also clear that the panel itself was unable to assess adequately the total nature and extent of energy needs and uses in developing countries, a situation leading to a recommendation for study of these needs.

The statements brought to the panel by members from India and Niger are included in full in Appendices A and B; this information and other panelists' comments are briefly summarized here.

Fulfilling the material needs that center around food, housing, clothing, health, and education is a primary objective of the developing nations. Energy is a most significant requirement, and if solar energy is to have an impact on development, it must be able to contribute significantly to meeting one or more of these needs. Energy requirements include thermal, mechanical, and electrical energy, for use in such applications as heating, food cooling, cooking, lighting, water supply, cooling for human comfort, and the production of salt.

The particular needs of agriculture are for energy to pump water for irrigation and watering livestock, and for drying agricultural and other products--including timber, fruits, grain, forage, oil seeds, fish, meat, slaughterhouse waste, gypsum, and brick. Most of the energy needs of public services are in communications and transport; the latter

will probably continue to be met by fuels. In public health and education, the needs in hospitals, dispensaries, nurseries, etc., are for lighting, air conditioning, water heating, distillation, and sterilization. For household use, air conditioning, water heating, and heat for cooking are needed. In the industrial sector, both mechanical and electrical energy are generally in short supply. Telecommunications and educational institutions need electrical energy.

In the future, the needs and uses for energy we identify today will remain important and will grow at a fast rate, probably 10 - 15 percent annually in some areas.

Commercial sources of energy used now in developing countries are coal, oil, gas, and hydrogeneration, and, to a very limited extent, nuclear material. In some countries (e.g., India) noncommercial energy sources such as firewood, dung, etc., are very important. In these countries, the use of other sources of energy could save large amounts of firewood, which would help control soil erosion and the denudation of forests; and dung not used for fuel could be used as fertilizer.

Some more specific requirements of energy supply that might be met by solar energy were noted. These concerned possible applications to distillation, cooking, refrigeration, and other processes to meet needs of particular peoples.

Assembling these generalizations and specific situations, however, does not provide adequate knowledge of the real extent of energy needs, their geographical and temporal distribution, and the implications of meeting the needs. It is not known which energy needs are the most critical, which are most readily amenable to solution by various technologies, which might represent opportunities for development of new

industries to meet the needs, which involve difficult social and educational components in their solution, and which are the most likely, if met, to have the effects desired by the developing nation.

The limited information available to the panel led it to conclude that solar energy does indeed have the potential to contribute significantly to the solution of many energy problems in developing countries, and that much more thorough study of the nature and extent of energy needs is desirable and is a prerequisite to planning the activities that will most effectively help to meet these needs.

IV

APPLICATIONS OF SOLAR ENERGY: STATUS AND POTENTIAL

This chapter begins with a brief statement of the major characteristics of solar energy and solar processes. It next reviews the present status of solar processes and applications and then for each application, outlines further research and development projects which could be useful in the context of developing nations. For the convenience of the reader, a list of important references on solar energy and its applications is included as Appendix C.

Characteristics of Solar Energy and Solar Processes

Solar energy is electromagnetic radiation from a source (the sun) at an effective temperature of about 6000°K. Outside the earth's atmosphere, the average intensity of solar radiation is 1.36 kilowatts per square meter on a plane perpendicular to the direction of the radiation. The radiation is attenuated by the atmosphere and reduced by geometric factors, with the result that the supply at the earth's surface is variable and intermittent. Its maximum intensity is about 1.2 kilowatts per square meter; zero intensity occurs on the average for about one half of the time. Integrated daily energy on a horizontal surface on good days in low latitudes is 6 to 8 kilowatt hours per square meter. Variability of intensity is predictable with respect to time, latitude, and season; superimposed on this is less predictable variability due to weather.

The result is a radiation supply intermittent and variable in its availability, with typical clear-sky intensity of a little over 1 kilowatt

per square meter. The spectral distribution of the radiation is very roughly one-half visible, one-half near infrared, with a very small amount of ultraviolet. Solar radiation is further distributed between beam radiation which reaches the receiver in a direct line from the sun, and diffuse radiation which reaches the receiver after being scattered by clouds, dust, and molecules of the atmosphere. On very clear days, solar radiation might be 90 percent beam; on cloudy days it is 100 percent diffuse.

Solar processes are based on either of two basic concepts, i.e., flat-plate collectors or focusing collectors. Flat-plate collectors, as the name implies, consist of flat, blackened surfaces to absorb (beam and diffuse) solar radiation. Transparent covers and back-insulation may be provided to reduce or control losses from the plate. On the plate, absorbed solar energy is converted to a desired form of energy, usually heat, and means are provided to remove that energy, usually as heated water or air. Flat-plate collectors are generally operated in fixed position. Ponds or basins of water used in evaporation or distillation are, in effect, horizontal flat collectors. The present upper limit of the temperature of operation of these collectors is about 100°C.

The second concept is that of the focusing collector. The basic element is an optical device, e.g., a parabolic reflector, to focus the beam component of solar radiation on a receiver smaller than the reflector The result is higher energy flux which allows collection of energy at higher temperatures. Energy-flux ratios (i.e., ratios of intensity of radiation on the receiver to intensity of the beam solar energy incident on the optical system) may range from 2 or 3 at the low end, to 10,000 -

20,000 at the high range. At any but the lowest of these ratios, some degree of "sun tracking" is required to orient the system to allow for the changing direction of the incoming beam radiation.

All practical solar energy systems now in use are based on flat-plate collectors. (The only exceptions are solar furnaces, which are in reality laboratory instruments.) Materials, costs, and operational problems have been major difficulties with focusing systems.

The intermittent nature of the energy supply dictates that storage of collected energy, or of other products of the solar process (such as product water from a solar still), must be provided if output from the process is to be available during periods of no radiation.

With this background, the present state of applications can be summarized. A review of the present status of solar energy applications indicates that those recently put into most widespread use have been based on carefully engineered equipment, usually factory produced, and in some cases for community-scale use. Small-scale application of "homemade" devices has not been widely made. An examination of the successful developments indicates they have the following characteristics: they are adequately engineered and will produce the desired result; "quality control" in the manufacture of the equipment is adequate; they meet a realistic need and fit with the economic and social situations of the users; and, except for solar evaporation, they are applied primarily in areas of relative affluence.

The applications (other than on spacecraft) enjoying most success today are (1) solar evaporation; (2) solar water-heating with factory-manufactured heaters; (3) solar distillation on a small-community scale, which is now in an advanced "pilot plant" state of development; and (4)

solar drying, particularly of crops. Beyond this there have been many experiments, some enjoying a high degree of technological success, but their economic and social feasibility is doubtful or has never been established. These experiments have concerned space (comfort) heating and cooling, refrigeration and ice making, desalting of water, cooking, pumping of water, production of salt, drying, hot-air engines, lighting, solar furnaces, horticultural systems, growth of bacteria to produce methane, and photochemical conversion.

Solar Process Applications Now Being Made

Solar evaporation, water heating, distillation, and drying are the four applications now being made on a scale which results in significant contributions to local energy economies.

Solar Evaporation. This has been a historical, traditional method of obtaining salt from sea water or brines; it remains important today on both a small and a large scale in many nations. The basic concept is simple: In areas where evaporation exceeds rainfall a shallow pond of brine is exposed, resulting in evaporation of water and ultimately in crystallization of salt. Solar evaporation is used in many developing countries--India, Pakistan, Mexico, Colombia, Chile, etc. It is also an important industrial process in the United States. Modern developments have been concerned with improved pond construction and harvesting techniques.

There appears to be little further research on traditional solar evaporation processes that cannot as well be done by the industries using the process. The suggestion has been made, however, that further studies of "solar ponds" might lead to improved salt production and by-products of power or distilled water. [Solar ponds are large-area brine

ponds of approximately 1 meter depth, in which vertical gradients of salt concentration are maintained so that the most concentrated and most dense solutions are at the bottom of the pond. The concentration gradients are such that the hottest solutions are at the bottom of the pond (rather than at the top, as is the case without concentration gradients). This arrangement permits collection of solar radiation in the bottom layers, which may reach 80 to 90°C, with the top at 25°C.]

Water Heating. This application has long been used in southern Florida, and has more recently been developed and applied in Israel, Japan, and Australia. There is now an established solar water-heater industry in Australia with a production of about $1 million per annum. In Niger production of solar water-heaters is being undertaken, and small-scale manufacture may be undertaken in several other countries. (Application in Florida is less extensive than formerly because availability of natural gas has diminished the market for solar heaters. However, heaters are again being manufactured on a small scale.)

The main elements of a solar water-heater are a flat-plate collector and an insulated storage tank. Water circulates through the collector, is heated, and is held in the tank for use when needed. In Australian practice the absorbers (collectors) for household-scale use are typically 0.8 to 1.6 square meters, with a 300-liter water-storage tank, optionally fitted with a thermostatically controlled 1-kilowatt electric booster, producing about 180 liters of hot water on a good day. Domestic installations employ thermosiphon circulation, which allows the water to recycle through the absorber without pumps, but large commercial and industrial plants delivering some thousands of liters of hot water per

day use forced circulation with thermostatic control. One group of residential structures in Darwin has nine separate banks of solar water-heaters with a combined output of hot water of 13 cubic meters per day. Solar water-heaters are proving to be the most economical way of providing hot water in many parts of the Australian continent, particularly in the Northern Territory, where it is Australian government policy to install solar water-heaters in all government houses.

Hundreds of thousands of water heaters have been manufactured in Japan, many of a design that combines the collector and storage functions in horizontal plastic containers designed to produce hot water for use at the day's end.

Experiments with solar water-heaters have been undertaken in many areas, such as Chile, India, Egypt, etc. To the best of the panel's knowledge, however, use in countries other than the United States, Israel, Australia, and Japan has, to date, been quite limited. The technology of this process is well developed.

Water-heater technology is well established, and the needed development is largely to adapt the technology to use materials and manufacturing capabilities of the country in question. Hot water for hospitals, schools, and other institutions, and for families, could become much more widely available with these developments. The nature of equipment is such that it can be manufactured in developing countries, and adapting it to their conditions seems to be straightforward.

Solar Distillation. This is a process now in the "pilot plant" stage of development, the basic method being to admit solar radiation through a transparent cover to a shallow, covered brine basin; water evaporates from the brine; and the vapor condenses on the covers which

are so arranged that the condensate flows therefrom into collection troughs and thence into a product-water storage tank. The idea was first applied at Las Salinas, Chile, in 1872 in a plant supplying drinking water for animals used in nitrate mining and transport. The Las Salinas plant reportedly operated for 30 years. Modern developments in solar distillation have been directed at using new materials and designs for economical and durable construction, to reduce product water cost.

Solar distillation is used on a small commercial scale to supply small towns and motels in isolated areas in Australia and small communities in the Mediterranean basin and the Caribbean. The process must still be regarded as experimental, but small community-scale stills are near to extensive commercial application. Durable designs have been developed in the United States, France, Spain, and Australia which require little day-to-day attention and operate with minimal maintenance.

In addition, some experiments have been done on small family-scale distillation units, for possible use on Pacific islands and for emergency use.

Designs are now available for solar stills that are serviceable and that can be used with a reasonable degree of confidence. Further research in this application would involve further adaptation of existing technology to the specific needs of developing countries, through design modifications to allow use of locally available materials and locally manufactured components. Studies of this type could improve the economics of solar distillation, widen the areas in which it might be useful, and thus contribute to the solution of water-supply problems, particularly for small communities in good climates.

Solar Drying. A traditional and widespread use of solar energy is for drying, particularly of agricultural products. This is a process of substantial economic significance in many areas. The customary technique is to spread the materials to be dried in a thin layer on the ground to expose it to solar radiation and wind. In recent years innovations have been adopted, particularly for fruit drying, in which fruit is placed in carefully designed racks to provide controlled exposure to solar radiation and wind, and to improve material handling. Improved process control and product quality have resulted.

Other experiments have centered on crop drying, using either solar-heated air in more or less conventional air dryers, or a combination of direct and air drying by placing the materials to be dried in flat-plate collector-dryers. Development of solar drying can conceivably benefit from further development of collector-dryer combinations, and flat-plate air heaters and energy-storage systems to supply hot air to dryers. Design and control of these processes, for the particular crops or other materials to be dried, are areas of research that could lead to more practical application in developing countries which could result in improved utilization of food supplies.

Solar Process Applications in Experimental Stages

All other solar processes are in experimental stages of development and have not been used in developing countries (or elsewhere) on any basis other than as experiments. The present status of several processes and the observations of some of the major problems associated with them are noted.

Space Heating. This is not a primary problem in most developing

countries, but providing comfort-heating in some areas would improve living conditions. Much traditional architecture has evolved, in part, to control or minimize temperature fluctuations in the structure. This has been done by designing openings to control admission of solar radiation and designing the heat capacity of the structures to minimize undesirable low (or high) temperatures. However, traditional building methods have not always been followed in times of growing population; and there are modern scientific developments that can be applied to building design to control temperature somewhat under extremes of both high and low temperature. Thus space-heating in developing countries represents a limited problem, but one which may be improved by application of well-established principles.

Research and development efforts in solar heating have been aimed almost entirely at applications in the temperate climates of industrialized countries. About 15 experimental solar houses have been built and operated with the heating system comprised of the collector, a heat-storage unit, and appropriate heat distribution and control systems. Extensive economic studies have also been made, but are applicable to developed economies.

Solar heating in developing areas presents a set of problems which have received relatively little attention. Of several possible approaches, the first involves design of the structure to utilize fenestration, shading, insulation, selective paints, etc., to minimize heat needs. A second approach is to devise heating systems that can operate with no mechanical energy for fluid circulation. Systems have been proposed and studied (e.g., the Altenkirch solar house) using only natural circulation; there may be other possibilities worth considering for appli-

cation to small residences. A third approach is to adapt solar heating systems (with mechanical circulation) that have been developed for applications in developed economies, perhaps for use in larger buildings, particularly in urban areas, where there are significant annual heating loads to be met.

The panel knows little of the real extent of needs for space heating in developing countries, nor of the possible role of solar energy in meeting these needs.

Air Conditioning or Comfort Cooling. This process has received some attention for application in temperate climates by operating absorption coolers with solar heat; and other methods may be possible. These studies, aimed primarily at United States and Australian application, are still in early stages. Technological feasibility appears to be assured; economic feasibility is now under study. As with space heating, there are opportunities to use building design to increase comfort.

Designing air conditioning systems for use in developing nations again presents a different set of problems, of both potential utility and design. It has been suggested that air conditioning of factories and offices would significantly improve the productivity of people working in them; and there is also the prospect of applications to residences. There are also technological problems of system design for operation without mechanical power, and for solar operation of other types of cooling processes. Building designs to minimize needs for cooling may be productive. The best methods of obtaining cooling with solar energy in developing countries are far from clear at this time, and the immediacy and extent of needs for air conditioning are not known.

Solar Refrigeration. Closely related to air conditioning, solar refrigeration is intended generally for food preservation (or storage of biological and medical materials). There have been experiments in the United States, Ceylon, France, the Soviet Union, and elsewhere on solar-operated coolers, using absorption-cooling cycles, most of which are aimed at household-scale food coolers, or small-scale ice manufacture. A single experiment in Mexico with a solar-operated, household-scale cooler was unsuccessful; the machine was simple in its design but overly complicated in its operation, and was not usable by the people for whom it was intended.

There are many possible refrigeration cycles and systems that can be considered for solar refrigeration. It has yet to be established what may be the best scale on which to operate solar refrigeration for developing countries; community-scale systems may offer advantages of larger scale, reduced educational requirements for users, and (if appropriate) the possibility of distributing ice to smaller users (i.e., households). Thus there are a substantial number of open questions regarding solar refrigeration, and the application has the attractive possibility of better utilization of available foodstuffs if refrigeration could be successfully provided.

Conversion to Mechanical or Electrical Energy. This conversion remains an elusive, yet intriguing problem. Thermal conversion systems using heat engines and focusing collectors are one approach; perhaps the most difficult problems are the substantial difficulties of cost and long-term operation of focusing collectors which have received attention but are far from solved. Another approach is to use flat-plate collectors with heat engines operating at lower temperatures (and

thus lower efficiences). There are experiments on solar power now underway which are based on flat-plate collectors.

A tremendous investment has been made in photovoltaic conversion processes for use in space. The costs of the converters, which convert solar to electrical energy, is now very high by ordinary terrestrial standards (from 100 to 500 times the cost of electrical energy from conventional sources). In developing countries there may, however, be applications in communications, which require power in very small quantities.

The possible applications of successful development of economic solar-energy conversion to needs for mechanical or electrical energy are wide; for example, pumping of irrigation or stock water and cooling by mechanical refrigeration. Therefore, several lines of study, of a more long-range nature, appear to be justified, although the difficulties inherent in the problem must be recognized. First, more development work on focusing-collector systems and their materials of construction might be productive and should be undertaken. Second, studies designed to raise the practical operating temperatures of flat-plate collectors would, if successful, help to solve solar power problems. There may be energy-storage and engine research which should be coupled to the collector studies. Third, further research and development in solar cells might, in the long run, reduce their cost and widen their areas of application, although the prospects of generating electrical energy at the same costs as energy from conventional sources are dim. (Research and development on photovoltaic processes is an activity best carried out by very well-equipped laboratories of industrialized countries.) Identification of the nature and extent of needs for electrical and mechanical

energy in particular areas, and the economic and social considerations that will affect the utility of solar power systems, are needed to plan development activities properly.

Solar Cooking. This application appears to be simple in its technology and significant in its advantages--if it can be successfully applied. Efforts to design and introduce successful solar cookers have been carried on for many years, with cookers of two types. One is based on concentrating the solar energy by a reflector onto a cooking vessel, and is the analog of a surface heating unit. The other is a solar oven which depends on some concentration of radiation, combined with the greenhouse effect, for trapping heat within a small space in which the food is placed. Both approaches have been developed to a degree of satisfactory technical performance for providing for at least partial cooking needs of families. However, extensive field trial efforts in India, Mexico, and Morocco have so far not resulted in social acceptance of these devices. After an initial period in which some degree of utility has been shown, the users revert to their traditional methods of cooking.

Solar cookers depend on focusing collectors, and their successful long-term utility will depend on solving the materials and operational problems of focusing collectors--as well as the social and economic problems that have deterred acceptance in experiments to date. It is possible that energy-storage or heat-transfer techniques to permit indoor or evening cooking might help solve some problems of social acceptance.

Biological Processes. Conversion of solar energy to useful materials, foods, or fuels in a sense represents an extension of agricultural

practice. Study of algae growth has been going on for some years with limited production in Japan. Water hyacinth has been proposed as another plant having relatively good ability to use solar radiation in photosynthesis to produce plant materials, and seaweeds may represent other possibilities. The resulting plants could provide fuel (directly or through fermentation to produce methane), useful protein, or plant fiber. (The panel devoted most of its attention to thermal processes, rather than biological. These observations simply draw attention to the existence of problems and possibilities of biological processes.)

IV

DISCUSSION

The panel membership included a wide spectrum of experience with solar energy research, developments, and applications. During the deliberations, a number of generalizations relating to solar processes, their development and application became clear. Of these, questions of the nature and extent of energy needs in developing countries were important enough to be treated separately in Chapter II and the Appendices. This chapter deals with several other general considerations that, in addition to the scientific and engineering aspects, lead to the recommendations and conclusions.

The developing countries, from an energy need/use/supply point of view, represent wide differences in living style and in the needs of village communities, cities, nomadic people, remote industrial towns, schools and hospitals, and industry. Physical situations, including climate, topography, and natural resources, are highly variable. Beyond these challenges, developing countries present problems of logistics; for example, in the rural areas where much of the need for energy exists people are scattered, facilities for transport are poor, and communications are difficult. People's skills and their levels of education vary. Clearly, no single description or set of criteria can be applied to these countries; corresponding variations in solutions to their energy problems may be expected.

Further, there are degrees of development, which can be expressed by such indices as per capita energy consumption or per capita production.

The degree of development affects the desires of people for energy or its products, their willingness and ability to invest in capital-intensive solar processes to obtain benefits therefrom, and the extent to which education is required to train users of solar processes. It was suggested that the best level at which to aim solar developments is the "middle" of the development scale, because some poorer countries may be unable to take advantage of an otherwise successful solar energy application because of lack of capital and social incentive.

Total energy resource needs for the next 20 - 30 years are now being projected for many countries, particularly the industrialized countries. Serious questions are being raised as to whether the developed countries can continue to use, at present and projected rates, the fossil fuel and nuclear energy sources now available to them. Pollution is a real problem; furthermore, other countries which today are major energy-resource suppliers may be less eager in the future to share their now-abundant energy sources. Developed countries may have an "energy ceiling" (particularly on fossil fuels) imposed on them as other populous nations, such as India or China, compete for shrinking supplies of natural resources. In addition, the developing countries' quest for higher living standards may result in an intolerable level of the side-effects of today's methods of producing and using energy. It can be foreseen that in the long run present and future demands for energy will pose tremendous problems to all societies unless environmental degradation and exhaustion of natural resources are controlled. Aspirations, energy needs, and resource utilization are highly time-dependent, and the needs of the large part of the world's population in the developing countries cannot, in the long run, be considered independently from energy planning in the industrialized nations.

Process reliability of solar processes is of primary importance. There are two sets of considerations, the first of which deals with more or less predictable reliability problems arising out of weather variability and energy (or other product) storage requirements. Desirable degrees of reliability can be designed into solar processes, depending on solar energy availability (i.e., climate) and on costs and availability of alternate supplementary energy sources.

The second set of reliability criteria may be self-evident, but again needs emphasis: A prime requisite for success of any solar application is that the process perform as intended over extended periods of time, e.g., the anticipated lifetime used in calculating the annual capital costs of the process. Developing countries should not be expected to expend their very limited capital resources on a solar device unless they have adequate assurance that it will perform for those extended periods. Process engineering must be adequate; poorly engineered systems are a disservice to those who are led to invest in them.

The capital-intensive nature of solar processes, in comparison with energy systems using conventional fuels, has been noted in the preceding sections. Because of their intrinsic shortage of capital, the developing countries rely on outside support. Solar, or other, energy resources must compete for capital investment, wherever the capital comes from--for roads, schools, water supplies, agricultural implements and improved animal husbandry, basic public health facilities, to say nothing of the non-constructive uses of capital for military purposes or prestige projects.

This situation emphasizes the importance of careful selection of research and development programs, to direct development toward appli-

cations with realistic prospects for returns in a particular country or area, and to assure that the developed processes will be reliable.

The scale of applications and manufacture was discussed. Two approaches to solar-energy applications have developed, interrelated but with different philosophies. One approach has been to develop simple, inexpensive, household-scale devices, designed to be made with local labor and materials on an individual or very small scale. The other approach has been to design more carefully engineered systems with controlled manufacture, often factory produced, and sometimes for larger-scale applications.

At present most useful solar-energy applications fall into the second category. Extensive efforts to develop applications for individuals have not enjoyed much success, except for solar water-heaters which have been factory produced. Experience suggests that carefully engineered and manufactured systems are more likely to affect developing countries in the next decade; this is the more fruitful approach. The best route to solar applications may be through systems designed for the middle and upper classes, or for community or industrial users, with the expectation that success there might lead to ultimate applications by the less affluent or smaller-scale users. It is further likely that some solar applications will result from technology developed for use in industrialized areas, by transferring and modifying the technology for the developing country.

Small-scale applications on a household scale should not be ruled out, but it will probably take longer to realize the benefits. Any

applications that involve educating potential users to accept, utilize, and maintain equipment naturally take a longer time than those for which the technology is in the hands of a few and the product is distributed to individuals. The effective, widespread application of small-scale solar processes in developing countries may well be coupled to educational extension programs. (It took a generation of extension activity in Mexico before the economy felt the full effects of the Rockefeller Foundation - Mexican Department of Agriculture wheat and maize crop research.)

The advantages to developing countries of domestic production of solar-process equipment are evident. However, low cost is essential to economically viable solar processes, and some sophisticated items of equipment, such as refrigeration equipment, should be produced in a limited number of large-scale manufacturing facilities, if the economic advantages of large-scale production are to be realized. Equipment less demanding to manufacture could probably be economically produced in more widely dispersed facilities.

Finally, the objectives of energy development should be clearly understood. In a developing nation, with its particular needs for energy, what should be the goals? To meet rudimentary needs of rural populations to improve an undesirable state of existence? Or other kinds of results, such as sharply increased industrialization and redistribution of population (an end which might be served better by providing large central power stations)?

The panel felt strongly that the objectives of research and development on energy needs should be to meet those energy needs by whatever sources may be available. Thus, energy R and D for developing

countries should not be restricted to consideration of solar energy, even though solar energy will be a primary consideration in such R and D.

In view of these discussions, why have more applications not been made of solar energy in developing countries? The answers are not entirely clear, but these essential points can be made:

- The research and development efforts that have gone into solar processes for terrestrial applications have been very limited, in relation to the problems involved and in contrast to funds invested in other energy resources.

- R and D activities have been carried out with insufficient knowledge of energy needs or human problems in technological innovation--a case of hindsight. The result was, in part, an emphasis on developments that appeared easy but that in fact were very difficult, such as solar cookers.

- Work to date has not resulted in cost reduction sufficient to make solar processes attractive in the economies of many developing countries.

- Incentives for industrial development and manufacture of solar-process equipment have not evolved.

The summary conclusions and recommendations, presented at the beginning of this report, reflect these situations, the present status of solar applications, and the panel's assessment of appropriate steps to be taken to help solve the energy problems of developing countries.

APPENDIX A

ON SOLAR ENERGY UTILIZATION FOR DEVELOPING COUNTRIES

Abdou Moumouni

The countries or states falling within the scope of this paper are those partly or totally located in the sahelian zone of West and Central Africa: Mauritania, Senegal, Mali, Upper Volta, Ivory Coast (northern part), Niger, Nigeria (northern region), Chad, Cameroon (northern part), Dahomey (northern part), Sudan; possibly Ethiopia, Uganda, Kenya, and Tanzania. The author is aware of the interest in, and potential importance of, solar energy utilization for such countries as Morocco, Algeria, Tunisia, Libya, and the United Arab Republic, but because of a lack of personal familiarity, this paper does not concern them.

Needs and Uses for Energy Today in the Developing Countries of West and Central Africa

It is somewhat difficult, if not impossible, to assert precisely the needs and uses for energy in the countries concerned. Tentatively, a qualitative analysis will be done here.

It is a widely accepted opinion derived from the observations of various development attempts that the process of development in non-industrialized countries should be based on

- The development of agricultural production (food, export products) and efficient exploitation of cattle-breeding products (milk, butter, meet, skin, etc.);

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- The growth of local industries that process agricultural and cattle-breeding products to meet local needs as well as those of export;

- The exploitation of other available natural resources (minerals, petroleum, natural gas, etc.) for export and for the local needs;

- The growth of education and health levels to provide the skilled manpower required, to raise the cultural level of the population, to improve their living conditions, and to increase the efficiency of labor.

On the basis of "in the field" qualitative surveys of needs and uses for energy today in the developing countries of West and Central Africa, the following appear to be the fundamental needs and uses for energy:

1. Energy needs and uses, of and by local industries of the modern type

- Mining, fuel, and coal industries
- Minerals-processing industries
- Industries that process agricultural and cattle-breeding products--textile plants, tinned and canned products, leather industries
- Other industries--plastics and glass, brewery and food industries, various workshops

The fraction of the total energy consumption represented by the industries amounts to from 50 to 70 - 80 percent.

2. Energy needs and uses for the development of agriculture and cattle-breeding

- Pumping of water for irrigation
- Pumping of water for cattle
- Workshops of rural craftsmen

The importance for the economy of these needs and uses for energy is evident. However, these needs and uses are very far from being met today at a satisfactory level: the sahelian-zone peasant has 3 months of agricultural labor (corresponding to the only rainy season), and his average annual income of 15 - 20,000 F CFA or $54 - $72 U.S. is in fact gained during this period.

3. Energy needs and uses for public services, communications, and transport

- Of basic importance because of the widespread population, distance to the sea, and other factors; conventional fuel consumption (gasoline, fuel oil, etc.) in the various countries mainly directed to meet these needs

4. Energy needs and uses for public health, education, domestic economy

- For hospitals, dispensaries, nurseries--light, refrigeration, air conditioning, water-heating, distillation, sterilization, etc.

- For cooking (today mainly met by consumption of wood and charcoal), other domestic uses (lighting by kerosene lamps, eventually refrigeration and air conditioning)

- For various educational institutions, radio broadcasting, and educational television

Probable Needs and Uses for Energy in 10 Years and Beyond

About the needs and uses for energy in the developing countries of West and Central Africa for the next 10 years and beyond, the following points seem to be clear:

- The needs and uses identified today will continue and will probably be growing at a rather fast rate.

- It is difficult to make a definite or precise projection, if only because basic surveys are not available. However, on the basis of growth of electrical energy production and consumption, and fuel-products consumption, in the past 10 - 15 years, a 10 - 15 percent annual growth rate in consumption of energy appears to be highly probable. These figures, in the opinion of the author, are only indicative; in fact, the needs for energy in agriculture and cattle-breeding, if they were to be met, could give rise to far more than a 15 percent annual rate of increase. The financial means required have been the main reason why these needs have been met at a very low level.

Priorities for Utilizing Solar Energy in West and Central Africa

These priorities are based on the personal thoughts of the author, based on his experience of the problems in the developing countries concerned.

1. Small engines (0.5 t 10 HP) for pumping water and the functioning of various rural workshops and little industries

2. Hot water for schools, hospitals, nurseries, rural dispensaries

3. Distillation and sterilization of water for hospitals, dispensaries, nurseries; desalination of brackish water

4. Solar thermo and/or photo batteries

- for pumping water

- other uses of electricity (telecommunication educational needs, information, etc.)

5. Solar cookers

Here the question of low prices of the cookers, as well as the necessary complementary equipment, is of critical significance in view

of the above-mentioned low income of the majority of the population. It must be kept in mind that solar cooking cannot be developed on an eliminatory basis, as sociocultural and sociological problems have to be solved before a population will adapt to it. Here the economics is of paramount importance if broad classes of the population are to use solar cookers. Linked with that problem is the fact that any significant impact on the economy of the country, or on the climatic and agricultural consequences (stopping the present wide-scale destruction of vegetation in already destitute regions), can only be attained by mass consumption of this type of solar energy utilization.

As to the important question of why solar energy utilization in developing countries has not reached a reasonably high level, the following seem to be the basic reasons:

1. Perhaps considerable funds have been invested in research and development, but they were, and are, far below the level required (i.e., compared with space programs of the more developed countries of Europe and America).

2. Efforts have been directed mainly to research and development in developed countries (chiefly Europe, the United States, the Soviet Union); whereas "in the field" developments are, in the opinion of the author, the best and only means of genuinely integrating solar energy utilization (where it is of significance) to economic, social, and cultural development.

3. The process of development is a rather complex one. Developed countries seem to be, or are mainly, interested in broadening their exports at lower costs of investment and lower industrialization of developing countries (c.f., New Delhi Conference). Solar energy utilization cannot,

at the present stage, move without preliminary significant financial means invested in developing countries, for the following purposes:

- To promote research "in the field" for various aspects of solar energy utilization;

- To favor local industries that produce solar energy utilization devices and that produce the basic materials required by this utilization;

- To improve the present situation in which important needs and uses of energy that can be met by solar energy utilization are waiting to be satisfied because of the "vicious circle" aspect of the economy of developing countries (that is, production cannot be undertaken until markets are available, and markets cannot be developed until production is possible); and

4. With the increasingly higher-level training of qualified manpower from developing countries, it becomes more and more difficult for the developed countries to maintain the economic policy of investing in the developing countries only for their own profit or to develop market conquests only on the basis of their own interests.

The effects of the experimental results already attained in the field of solar energy utilization cannot be demonstrated unless regional and subregional institutions are set up, permitting efficient work "in the field" with the participation of interested states, scientists, engineers, and technicians. It is hoped that developed countries will more and more realize that, in view of their own economic interests and with regard to the interests of developing countries, the only feasible and practical way of going ahead is <u>really</u> and <u>efficiently</u> to help the development of research, experimentation, and local manufacturing of solar energy utilization devices.

The above statements refer only to one side of the problem. It must be pointed out that more and more states in West and Central Africa (as in North Africa) are displaying more and more interest in solar energy utilization. Thus in Senegal, Mali, and Niger, national research and development centers have developed a low-temperature solar engine (by Professors Masson and Girardier); in Senegal, produced solar water-heaters; in Niger (started by the author and now at the stage of attracting local and foreign investors in industrial-scale processing) undertaken long-term testing of the Masson-Girardier solar engine. States like Chad, Cameroon, and Upper Volta also show a great interest in solar energy utilization (a small solar engine is operating in Ouagadougou).

This interest is best demonstrated by a Regional Solar Energy Center in West Africa, a project submitted to the U.N. Development Programme, through the Niger River Basin Commission (and backed by all the member states, in particular by Cameroon, Mali, Niger, and Chad). It may be important to recall that, as early as 1964, the Sixth Session of the Economic Commission of Africa backed a resolution in favor of a Regional Solar Energy Center in Niamey, in Niger.

Such a Regional Center could be the first step in implementing a more general Energy Research and Development Center for the sahelian zone; at present, their interest in such a center is not evident to the states concerned.

Anyway, the will and the means of the African states alone cannot solve the financial and other problems related to the implementation of such centers. It is to be hoped that the developed countries' governments, their philanthropic and scientific institutions, and the institutions of the United Nations family will give full support and genuine help, instead

APPENDIX B

SOLAR ENERGY UTILISATION IN DEVELOPING COUNTRIES

R. L. Datta

The developing countries are characterised by quite a few salient features, and their major material needs and problems centre around food, housing, clothing, medical aid, and education. Fulfillment of these needs to at least a minimum level for maintaining a reasonable standard of living is the aim of the developing countries. In attaining these objectives, the most significant requirement is energy. Economic backwardness stands in the way of producing sophisticated power sources, and the peoples there will have to depend on other sources, or forms, of energy. Quite a few of the developing countries are characterised by (a) arid or semi-arid regions, (b) a high percentage of people living in rural areas, (c) high dispersion of people in these rural areas, (d) absence of suitable transport facilities, (e) aversion of rural people to sophisticated technological developments, (f) surplus labour, and (g) availability of other forms of energy.

Considering this background, it is pertinent to mention the structure of energy requirements for India, which is typical of the developing countries and has a wide range of environmental conditions. India accounts for 15 percent of world population and only 1.5 percent of the energy consumption of the world. One third of this energy is in animate form, in-

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cluding human labour; the same amount is accounted for by noncommercial energy in the form of firewood, dung, etc.; the remaining amount is shared by commercial energy sources like coal, oil, hydroelectricity, nuclear energy, etc. (See Tables 1 and 2.)

A few significant facts emerge from Tables 1 and 2:

1. Noncommercial forms of energy constitute more than half the total inanimate energy supply.

2. The average growth rate per annum for coal is 5 percent; oil, 10; hydropower, 14. The total for commercial energy is 7.5 percent.

3. The average growth rate per annum for dung is 0.4 percent; firewood, 3.4; vegetable waste, 1.75. The total for noncommercial energy is 2.75 percent.

4. Commercial forms of energy are gaining at a faster rate, although the consumption of noncommercial fuels is increasing at more or less the same speed as population growth.

In order to increase the standard of living of the country, the favourable ratio of commercial to noncommercial sources of energy has to be increased. Apart from this, to bring about a rapid growth in the agricultural sector, control soil erosion, and stop denudation of forests, the noncommercial sources of energy should be replaced as speedily as possible by either commercial sources (comparatively more difficult for a developing country) or other sources of energy. Here solar energy can play a great role.

Another pertinent fact in the case of India is that within the commercial energy sector there is a trend toward more and more dependence on oil as a source of energy. Such a trend may lead either to attempts

Table 1. Energy Consumption, India, 1953 - 1969

	Commercial Energy				Noncommercial Energy		
	Coal	Lignite	Oil	Hydro power	Dung	Firewood	Vegetable Waste
	(ton x 10^{-6})			(KWH x 10^{-10})		(ton x 10^{-6})	
1953-54	34.1	-	3.5	2.9	46.4	86.3	26.4
1955-56	35.1	-	4.4	3.7	48.8	88.8	27.7
1960-61	49.9	-	6.7	7.8	54.0	100.0	30.7
1962-63	59.6	-	8.5	11.8	54.9	101.6	31.1
1965-66	67.7	2.5	10.7	15.2	44.06	126.4	32.5
1968-69	69.5	3.4	14.8	20.8	49.40	142.0	34.2

Table 2. Forms of Energy in Total Commercial and Noncommercial Consumption, India (Percent)

	Commercial					Noncommercial			
	Coal	Lignite	Oil	Hydro Power	Total	Dung	Firewood	Vegetable Waste	Total
1953-54	18.5	-	11.9	1.4	31.8	-	-	-	68.2
1955-56	18.1	-	13.2	1.7	33.0	-	-	-	67.0
1960-61	20.6	-	16.2	2.6	39.6	-	-	-	60.4
1962-63	22.2	-	18.9	3.9	45.0	-	-	-	53.0
1965-66	21.6	0.5	20.0	4.1	46.2	5.6	38.3	9.9	53.9
1968-69	19.4	0.6	23.5	4.2	47.7	5.5	37.7	9.1	52.3[a]

a/The coal-equivalent for the last of above indicated years is 358.65 million tons of coal.

to discover more indigenous sources or to more imports. The transport and domestic sectors will be the maximum consumers.

Kerosene is the universal illuminant, particularly in rural areas, and a source of domestic heat in towns. The demand for kerosene has been maintained at a high level and is steadily increasing. There is not enough indigenous production of kerosene to meet this demand; about 0.7 million tons had to be imported in 1969 - 1970. This is another field for solar energy.

This typical picture of a developing country leads one to examine further the conditions in the rural areas where the people are very much scattered, with few transport facilities; and requirements for energy are localised. In arid and semi-arid zones, the intensity of solar energy is fairly high (higher than 650/cal/cm^2/day) for a long period of the year. Brackish water sources have been known in many of the areas, and the ground-water is known to exist at high depth. High temperatures prevent people from working outside their dwellings for long periods. Firewood, dung, vegetable waste, and oil are the main sources of energy for cooking and lighting. Salt is an essential article of food as much as water. Commercial sources of energy in the rural areas of many developing countries will continue to be only a very long-term expectation.

The future community development centres in these areas will also require that small-scale industrial centres be developed. The transportation sector is to be cared for in these centres, which will also have to take care of the health and training of the people. Problems encountered, therefore, centre around (a) water shortage, (b) fuel shortage, (c) lighting, (d) power shortage, (e) water lifting and irrigation, (f) comfort of people, and (g) food and salt. The overall picture in re-

spect to energy consumption is that the requirements for energy of a small rural community of 40 to 50 families may be about 3,000 KWh per family per year.

In view of the conditions existing in these regions and the requirements of the people, the known technologies in the harnessing of solar energy have immense possibilities.

Some possible applications of the scientific principle and technologies to meet the needs of rural, developing areas are listed:

Needs	Scientific Principle and Technology
Solar salt	Design of salt farm based on relationship between solar evaporation rate of brine and vapour pressure of brine, wind velocity, and other ambient conditions. Enhancement is effected by addition of green dyes.
Fresh water	Water desalination by solar distillation and humidification-dehumidification techniques. Technology has been developed, and needs extension.
Water heating	Water heating by use of solar energy collectors, which can be introduced in any developing country now.
Water Lifting	(1) Pump driven by semiconductor solar generator. (2) Pumping by the use of solar engine using methyl chloride or synthetic fluids of freon group as working fluid.

Comfort of people, food storage	Solar-operated refrigeration and air-conditioning plant. By the use of ammonia absorption system, or other system.
Drying of agricultural products, and dehydration	Solar air-heaters corrugated or meshed type, temperature more than 30°C above ambient, controllable.
Cooking	Solar cooker of parabaloidal mirror or other design, and incorporating heat storage for kitchen cooking.
Lighting	Silicon solar cell with battery.
Small power	(1) Solar heat engines. (2) Thermoelectric and thermoionic conversion. (3) Photovoltaic conversion. (4) Photochemical conversion.
Food (green vegetables)	Controlled-environment agriculture using desalinized water to provide arid zones with fresh fruit and vegetables.

This list is not intended to be comprehensive but only to indicate that the solar scientists have the scientific principles/technologies, a few of which are already being applied and others which require further development.

A close examination of research and development activities over the world indicates that the greatest advances have been, are being, and are likely to be made in utilising solar energy in relatively small units, mainly because the diffuse nature of solar radiation means that larger devices will necessitate much higher capital investment. This factor is

is particularly important to the needs of rural people, and it fits into the pattern of rural economics.

The total solar energy reaching the earth is estimated to be much greater than that required by world's population, and, technically, can replace the conventional sources like fuel and electricity. But, because of the limitations set by the higher cost of collecting solar energy and the higher investment cost for solar devices, due to the diffuse nature of this energy, it is used at present only for some special cases. The changing direction and the intermittent nature of solar energy have brought problems of storing solar energy devices, along with increased cost. Searches for cheaper materials in solar devices have not always brought results on account of the varying radiative properties of materials. Even a complete picture of solar insolation is not available in most parts of India.

In order, therefore, to ultimately evolve technologically sound and economically acceptable solar devices, a systematically planned approach by scientists and engineers is necessary. It is, therefore, essential that such planned investigations should cover fields relating to

1. The preparation of a world solar-energy map, for which the cheaper, portable type of bimetallic pyranograph may be used;

2. Radiative properties of the comparatively cheaper solar materials, specially those available in different regions of the world, particularly rural areas; and

3. Trapping devices that work by using either selective materials or indigenous design or both; and also a storage system for solar energy--which amounts to a substantial investment cost for solar devices.

APPENDIX C

MAJOR PUBLICATIONS ON SOLAR ENERGY

This bibliography includes most of the major books, collected papers, symposia proceedings, bibliographies, and journals dealing with solar energy applications.

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6. U.S. Training Opportunities for Management and Senior Researchers of Industrial Research Institutes in Developing Countries

7. The Role of U.S. Firms in the Development of Industrial Research/Development/Engineering Capabilities in Developing Countries

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