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# ENERGY PROBLEMS OF DEVELOPING COUNTRIES: IMPLICATIONS FOR U.S. POLICY

by

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of the Overseas Development Council

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# FOREWORD

This is the first of four reports to a project for the Council on Environmental Quality on Energy Problems of Developing Countries: Implications for U.S. Policy conducted by the Overseas Development Council with the collaboration of the Institute for Energy Research of the State University of New York at Stony Brook and José Goldemberg of the Institute of Physics, University of São Paulo. The second report in the series, prepared by the staff of the Overseas Development Council under the direction of James W. Howe, is an analysis of the interdependent nature of the LDCs' energy problems and prospects. It summarizes the general resource and technology situations of the developing countries, focussing specially on the recent and growing interest in their potential for utilizing indigenous, renewable energy resources. The third report, prepared by Dr. Goldemberg while a Visiting Professor at Princeton University, offers, from the perspective of a distinguished Third World physicist, an analysis of the nature of the developing countries' particular energy problems and some of the promising technical alternatives for dealing with those problems. The final report, prepared by Stony Brook under the direction of Dr. Robert Nathans, analyzes existing estimates of the petroleum demand of the developing countries and offers a projection of their minimum oil needs over the next 50 years.

This first report incorporates many of the conclusions of the other three studies, and offers a series of policy recommendations for the U.S. Government. It was prepared by the Overseas Development Council.

The project originated largely out of concern that the U.S. and other industrialized countries were seriously underestimating the significance of the energy problems of the developing countries and the impact that the LDCs' energy needs are beginning to have on the global energy situation.

Although the authors strongly believe that this remains true, there is clearly a rapidly growing recognition on the part of energy analysts and researchers, and from some quarters of the U.S. government -- most notably the Congress -- that the developing countries' energy problems merit the attention of the U.S. This is reflected in the studies mandated by Congress in the 1977 Foreign Assistance Act and the 1978 Nuclear Non-Proliferation Act. It is also evident in the increasing number of studies and articles on the subject occurring in the energy literature and the growing frequency of international meetings involving energy specialists from both the industrialized and developing worlds. In other words, it is a subject that is rapidly gathering interest, and we hope that the reports prepared under this project will help to inform the widening discussions.

## I. Dimensions of the Energy and Development Dilemma: An Overview

The energy plight of the world's poor can no longer be ignored by the rich. There is a collision course between increasing reliance on petroleum-based energy to achieve the world's development goals and the decline in world oil production that most experts agree will begin before the end of the century.

If the wealthy, industrialized countries -- and the wealthy, industrialized sectors of the developing countries -- are to make a smooth transition from petroleum to safe, clean, and inexhaustible energy sources of a sustainable future, the poor must be taken into account for several essential reasons. First, because the energy needs and resources of the developing countries will play a crucial role in the world's transition to a post-petroleum era. Just 15 developing countries -- both OPEC and non-OPEC LDCs -- possess three-quarters of the world's proven petroleum reserves,[1/] and half of the world's remaining undiscovered petroleum resources may be located in non-OPEC LDCs alone.[2/] Furthermore, because their demand for energy is growing more rapidly than that of the industrialized countries, the LDCs' share of consumption of the world's remaining fossil fuels will rise from its present tenth to a full quarter by the end of the century [3/]-- and arguably their need for energy in order to meet even modest development objectives would be equivalent to at least the present entire energy consumption of the OECD countries.[4/]

Even more fundamentally, however, the poor must be taken into account because the global energy transition itself -- its direction, pace and smoothness -- will profoundly affect the ability of individuals and nations to achieve improvements in welfare and quality of life.[5/] Some three billion people -- three quarters of the world's population -- live in the developing world. The World Bank estimates that one billion of them exist in absolute

poverty, having incomes of less that $75 a year,"in an environment of squalor, hunger, and hopelessness... so deprived as to be below any rational definition of human decency." Another billion subsist in conditions of relative poverty that are little better.[6/] Their malnutrition, illiteracy, disease, high fertility and infant mortality, and low life expectancy are a reflection of what has been termed a situation of "energy misery."[7/] Without adequate amounts of energy available in useable forms at prices poor nations and poor people within poor nations can afford, there is little prospect of satisfying basic needs for food, water, shelter, clothing, health care, employment, and dignity for the majority of the world's people, or of ensuring economic and political stability and progress for us all.[8/]

Economic development and the ability to effectively harness increasing amounts of energy to productive purposes are frequently defined as being virtually synomous,[9/] so it is no surprise that there is a strong historical correlation between level of economic development and amount of energy consumption (See Figure 1).[10/] The dilemma for the LDCs is that modern economic and technological development has been predicated largely on a single energy resource, petroleum, that will suddenly be in scarce supply just as their need for it is greatest. Already the LDCs are relatively more dependent on petroleum for their supply than the industrialized countries[11/] and their investment in petroleum-oriented infrastrucures, while still comparatively small, is growing rapidly.[12/] But because the LDCs are just now beginning to be significant oil consumers, they will have been largely by-passed by the economic blessings of petroleum's unique convenience,relative low cost (until recently) and usefulness. (See Figure 2).

Most geologists now estimate that a total of about 2 trillion barrels

FIGURE I

CROSS-COUNTRY COMPARISON OF COMMERCIAL ENERGY USE, PER CAPITA

and the

RELATIVE IMPORTANCE OF OIL, 1975

Scale: Kilograms of Coal Equivalent

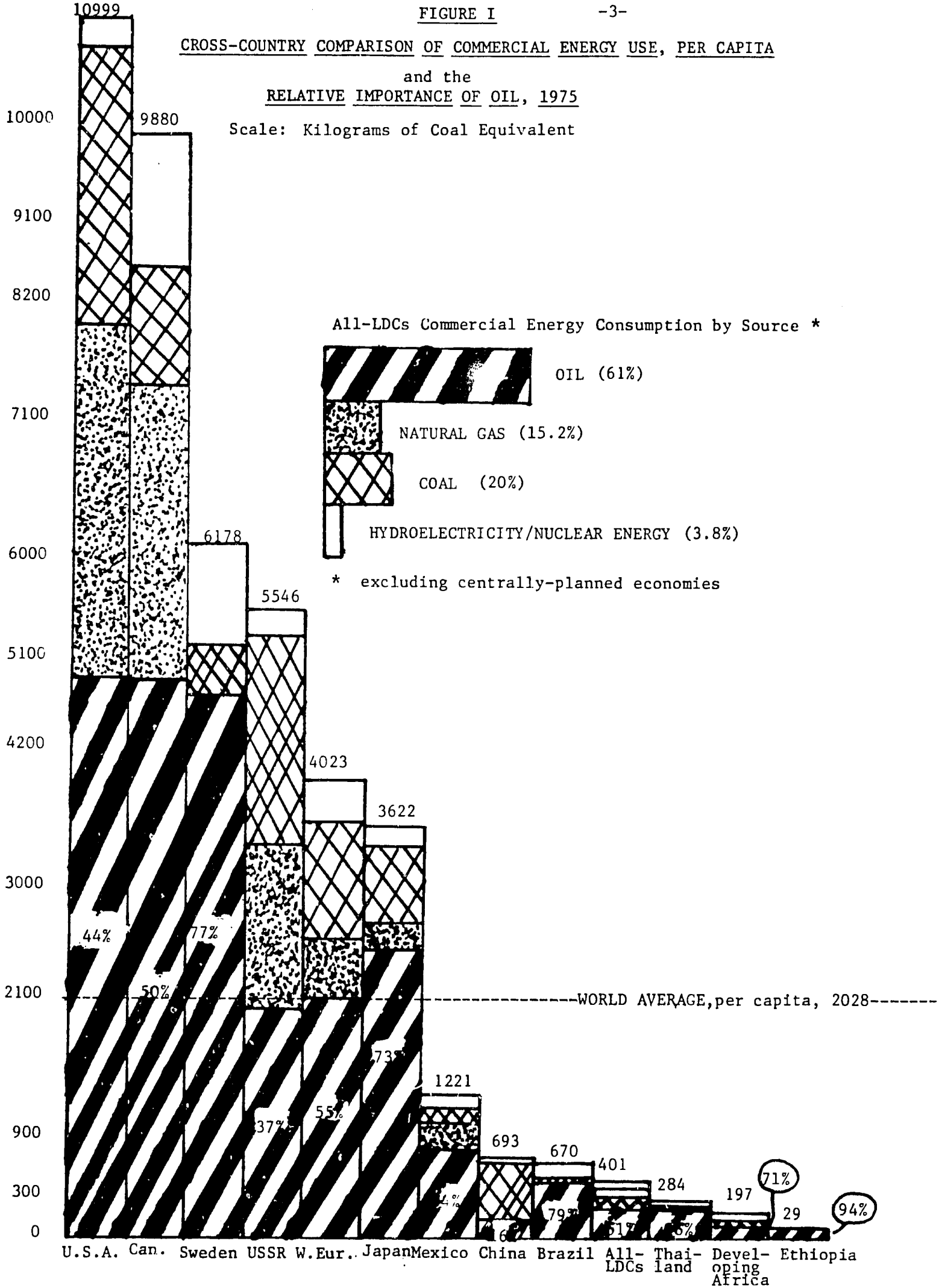
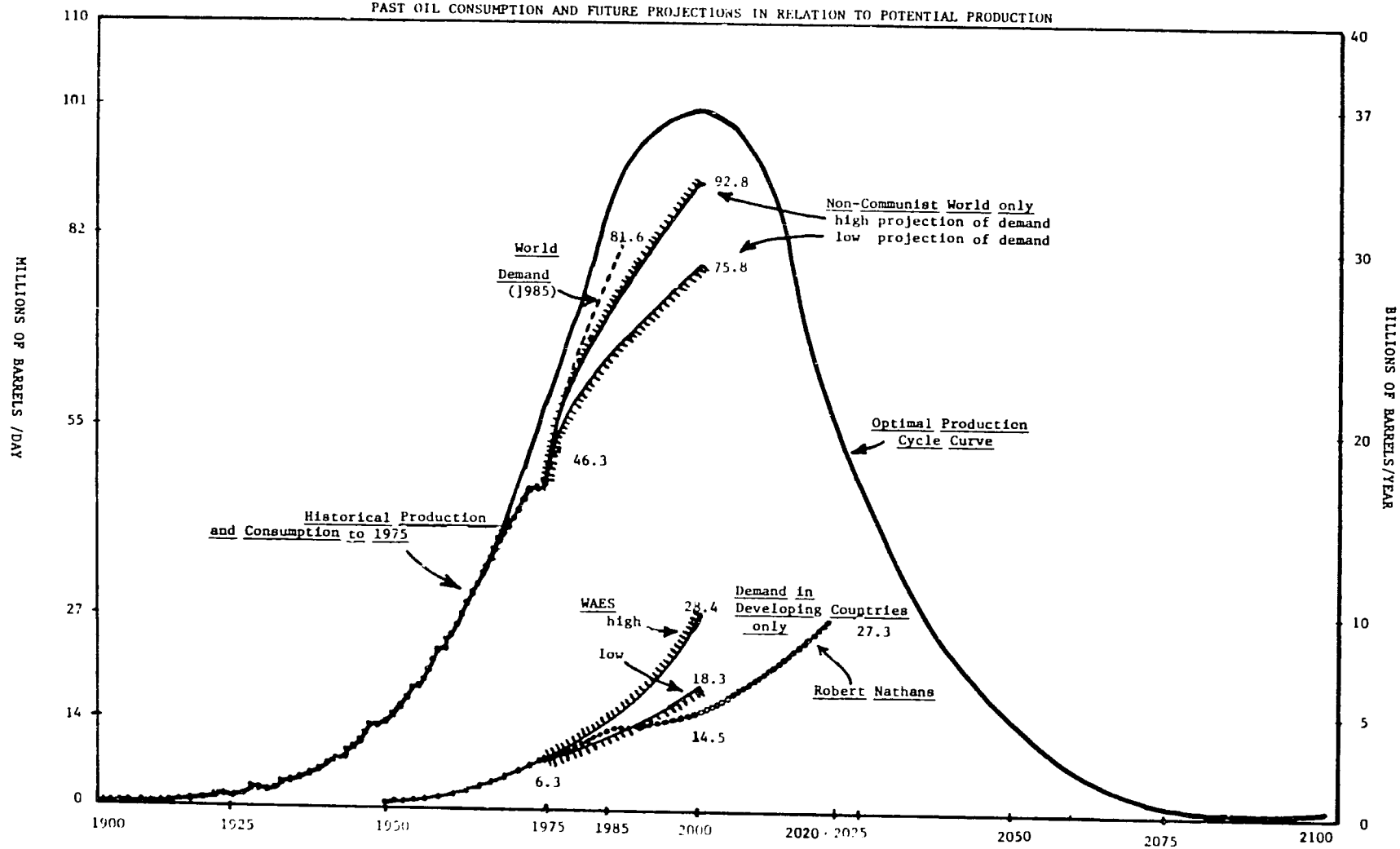


Figure 2




Sources:

World oil production cycle based on Ryman's estimate of ultimately recoverable resources of 2,100 billion barrels. With this cycle, production peaks at 101 million barrels of oil per day in the year 2000. From M. King Hubbert,"Energy Resources" in N.A.S., Resources and Man, San Francisco, 1969. This estimate also conforms to the latest consensus of the World Energy Conference, 1977.

Historical oil consumption disaggregated for world and developing countries. From, U.N. World Energy Supplies, 1971-5, Series J, 1977, and Ibid., 1950-74, 1976.

High and low projections of oil demand to the year 2000 for non-Communist World only from WAES, Energy Global Prospects, 1985-2000, N.Y., 1977.

Projection of world oil consumption including centrally-planned areas for 1985 from, OECD, World Energy Outlook, Paris, 1977.

Developing country projection to the year 2020 , minimum technical oil requirements from, "Energy Demand Projections for the Developing Countries" prepared by Robert Nathans of the Institute for Energy Research, SUNY at Stony Brook, N.Y., March, 1978.

of petroleum will ultimately be recovered from the earth's crust.[13/] Of this amount, only a quarter has already been consumed. During the next two decades, however, the world will consume nearly as much oil as has been consumed in all previous history. In other words, roughly half of the world's total recoverable petroleum resources will have been consumed by the end of this century, and global oil production will peak and begin an inexorable decline sometime during the 1990s.[14/]

Both the industrialized and the developing countries will have to turn increasingly to non-petroleum fuels and power sources. For the world as a whole, there are considerable quantities of coal and unconventional hydrocarbon resources such as oil shales and tar sands. But only a very few LDCs have significant known coal reserves (some three quarters of the world's coal is possessed by the U.S. and the U.S.S.R. alone) or unconventional hydrocarbon resources.[15/] In any event, these are likely to be more expensive to develop, contribute to the worrisome problem of increasing carbon dioxide in the atmosphere, and have considerably higher social and environmental costs than petroleum or natural gas.[16/] Nuclear power has been the primary hope of most energy planners, in both developed and developing countries, for several decades. But nuclear fusion remains years away from practical demonstration, and nuclear fission, although well demonstrated, still has unresolved health, safety, and international security implications, its scale is too large for many developing countries, and its costs also continue to rise.[17/]

If increased energy consumption is essential to meeting basic human needs, increasing productivity, and generally improving human welfare, but the conventional energy sources that have fueled modern economic development will be increasingly scarce or expensive, what are the prospects for the global economy, and particularly for the needs and aspirations of the three quarters of the world's people living in the LDCs? Will they simply be left

to stagnate because they are effectively priced out of the world petroleum market and denied or unable to afford access to nuclear technologies?

A growing number of observers, both from the northern industrialized countries (referred to herein as the North) and from the developing countries which frequently lie to the South (referred to herein as the South), have recently been suggesting that a solution to this dilemma may lie in the renewable resources with which most LDCs are especially blessed.[18/] Most developing countries, lying in tropical latitudes, have relatively generous endowments of sunshine.[19/] Africa, Latin America, and developing Asia together have more than two thirds of the world's measured hydropower potential.[20/] Many areas also have promising wind potential or could tap geothermal resources or the power of temperature differentials in tropical ocean currents.[21/] Indeed, most LDCs already derive half or more of their total energy supplies from renewable, solar-related resources -- specifically from firewood, charcoal, animal dung, crop residues, and animal and human draft power.[22/] In fact, even as the world approaches the peak of the petroleum era, it appears that the world's most essential fuel, in terms of numbers of persons who rely upon it for their daily energy needs is still firewood.[23/]

A recent U.S. Government report summarizing a number of government and private studies suggests that the United States could reasonably expect to meet a quarter of its energy needs from solar sources by the turn of the century, and fully half of its needs by the year 2020.[24/] Some private observers suggest that we could have an essentially solar-powered world within 50 years.[25/] If this should occur, the present imbalance in global energy distribution would be largely mitigated. Many of those countries which presently have the least energy and economic potential would have a much more equitable share of the solar energy. The countries of the tropical sunbelt might even be able to exploit a comparative advantage in raw energy resources.

But the solar potential of LDCs has been touted, off and on, for a long time.[26] Solar cookers have been tested in Africa for more than a century [27] and a 50,000 square meter solar still was providing 6,000 gallons of pure drinking water daily to a mining area in northern Chile nearly a hundred years ago.[28] A 50 horsepower solar irrigation pump was operating, successfully, in the Nile Delta in Egypt, before the First World War.[29] During the late 1950s and early 1960s, American foreign assistance agencies, among others, tried developing a number of solar technologies, including solar stoves and a solar-powerd boat.[30]

Solar technologies failed to take off then; why should we be optimistic about their potential now?

It is not hard to understand why many developing countries remain skeptical. Although a number of solar technologies have proven technically feasible, there is still little experience with distributing and maintaining them on a widespread, long-term basis, and the little experience there is in transferring them to LDCs has been generally unsuccessful.[31] The costs of most of them are still quite high compared to some of the conventional energy options.[32] Even if they are cost competitive with other means of energy production over the lifetime of a device, the cost of most renewable energy technologies is concentrated in an initial capital investment, and most LDCs, by definition, are extremely capital poor.* There is also a strong psychological factor: the leaders of the developing world have long been promised the blessings of advanced nuclear energy technologies.[33] They are unlikely to believe that the U.S. and other industrialized countries consider solar technologies to be desirable or modern energy sources until those governments show by R&D budgets

*The same tends to be somewhat true of nuclear technologies which may be even more capital intensive than solar.

and actions, that they consider renewables to be an essential part of their own energy future.[34/]

But there are also some substantial reasons for thinking that solar and renewable energy sources may be a significant part of the future energy solution for the world as a whole, and for the LDCs in particular. First of all, as already noted, the other options have become more problematical, and much more expensive, than was anticipated twenty years ago.[35/] At the same time there have been considerable advances in solar-related technologies. For example, photovoltaic cells are achieving higher conversion efficiences, and as production experience and scale economies advance, their costs are being dramatically reduced. The cost of photovoltaic cells has already been reduced 50-fold since the early days of the space program, and a further reduction of 10-15 fold appears feasible -- which would make them competitive with present conventional means of producing electricity.[36/]

Perhaps of equal importance is the fact that significant shifts have recently begun to occur among LDC policy makers with respect to development philosophy. Until recently, the basic premise of international development strategies has been that if the infrastructure (roads, harbors, factories, power plants, etc.) of the modern industrial sector were expanded, then the benefits of the resulting economic growth would "trickle down" throughout the society.[37/] But cultural and political barriers have more often than not further concentrated rather than dispersed these benefits, with the result that the welfare of poorer classes has in many instances actually worsened.[38/]

During the 1970s it has become increasingly clear that a reorientation of development goals and strategies is needed.[39/] A growing number of experts and policy makers from both the developing and the developed countries now agree that the basic goal of economic development should be nothing less

than elimination of the worst aspects of human poverty, and that this is technically and financially realizable within the next several decades if the developed and developing nations have the political will to accommodate the internal and international adjustments that will be involved.[40]

This will require strategies emphasizing rural development, satisfaction of basic human needs, and increased use of appropriate or intermediate technologies that better utilize domestic resources, especially labor.[41]* It will also require the effective harnessing of a great deal more energy, especially in rural areas.

In view of the difficulty and expense of extending conventional, centralized energy sources beyond urban areas to the majority of people in the LDCs who still live in the countryside.[42], the new solar energy technologies and decentralized energy strategies appear particularly attractive and worthy of further investigation.[43]

## II. The U.S. Role: Policy and Organizational Prescriptions

### Introduction

Part of the rationale for U.S. concern with energy for developing

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* This debate on international economic development strategies has in many respects foreshadowed and paralleled the soft vs. hard paths energy debate presently going on in the U.S. and other industrialized countries.[44] Key words in both debates are equity, self-reliance, and decentralization. The actual experience with the new approaches is still limited, but experiments are gradually getting underway, and both arguments are still evolving.

countries was eloquently expressed by President Carter during his recent visit to Venezuela:

> "...I remember the almost unbelievable change the coming of electric power made in the farm life of my childhood.
> Electricity freed us of the continuing burdens of pumping water, sawing wood and lighting fires in the cooking stove --
>
> "but it did even more: It gave us light by which to read and study at night.
>
> "...I can understand the unfulfilled yearnings of other people in the developing nations to share these blessings of life..."45/

In the pages that follow we discuss several actions that the U.S. Government should take (and some that it should avoid) in order to give substance to its concern for the energy problems of the developing countries.

1. Country by Country

Throughout this paper we refer repeatedly to "developing countries" or "LDCs" as a group. We do this in order to economize on space. However, it is necessary to introduce the complicating fact that for most purposes there is no monolithic group of developing countries. Rather there are about 115 LDCs. Each is fiercely nationalistic, each has its unique energy sources and problems and is determined to make its own decisions. Therefore, the U.S. and other industrialized countries as well as international agencies must deal with each developing country as a separate entity. The generalizations reveal a measure of truth about LDCs as a group but only a strand of truth about any given LDC at any given time.

2. Help LDCs Find and Develop Remaining Oil, Gas, and Coal

LDCs will be hard pressed for time as well as for funds to make a transition to the post petroleum era. Any additional development of fossil fuels will give them more time to make the transition. Moreover, oil is an international commodity which - insofar as the market place is concerned -

knows no national boundaries. Hence, a barrel of oil found anywhere in the world, if not as valuable to us as a barrel found in the U.S.A., is the next best thing. It is in our interest to help find and develop that oil.

Experts estimate that there is as much or more oil in the earth's crust yet to be discovered as has already been discovered. The U.S. Geological Survey estimates that about half of this oil will be found in non-OPEC LDCs. They believe this oil has not yet been found because not much oil prospecting has taken place in these LDCs. For example, for every well drilled in sub-Saharan Africa, some 300 have been drilled in the U.S. on geologically comparable terrain. Of course, one of the reasons international oil companies offer for not having done much exploring in these LDCs is that they cannot get sufficient guarantees for the security of their investments.[46/]

A good subject for study and action by the U.S. and its OECD partners is how to give multinational oil companies the security they need to be willing to invest in exploration and development of oil and gas in these countries. The World Bank has signalled its willingness to participate with private enterprise in making loans to LDCs to discover and develop oil fields. Some experts believe Bank participation would give these private investors the confidence they need to invest. Another approach worth exploring would be for an appropriate international body to sell insurance to such firms against the risk of having their oil and gas property nationalized or their contract abrogated. Still another approach might be to extend technical assistance to help LDCs negotiate satisfactory contracts with oil companies in the hopes this would improve the likelihood such LDCs would honor the contract and to help them confidently monitor the execution of the contracts by foreign companies. Each of these (and possibly other) alternatives warrants careful study before being seriously proposed. Such a study should solicit LDC views

as well as those of multinational oil firms and international financial institutions.

In addition to oil and gas, significant coal deposits are believed to exist in a number of LDCs. Since the size of such deposits is likely to be relatively small and coal is not traded internationally to any great degree, it may be difficult to enlist the interest of foreign private enterprise in making investments in exploration and development of coal deposits. However, industrialized governments should explore ways of encouraging major western coal companies to participate. In addition they should provide technical assistance to LDCs to find and develop any promising coal resources. Such technicians should help LDCs examine specifically how the aid program of the U.S. and other countries might help LDCs to exploit such resources.

3. Clarify U.S. Policy on LDC Nuclear Energy

For the sake of brevity and because detail is not essential to our argument, the following discussion ignores the many technical developments in hand or under way that would alleviate nuclear fuel problems, reduce dangers of weapons proliferation, and solve the waste disposal problem. Our discussion does not distinguish between kinds of nuclear technologies not because they are not important but because they are not important to the topic we discussed here -- how the U.S. effort to prevent weapons proliferation in LDCs is, we believe, having an effect contrary to its very laudable purposes. The applicability of nuclear technologies to the energy needs of developing countries is discussed in Part II.

U.S. policy toward use of nuclear energy in the LDCs is articulated in a number of documents, not all of which are public, including speeches by the President while yet a candidate, a presidential directive, internal governmental program descriptions, a law, congressional views, etc. There

is no time here for a review of these expressions of policy, but, in brief, a conflict appears to exist over whether U.S. policy is to prevent the proliferation of nuclear weapons in LDCs by discouraging (and finding better alternatives to) civilian nuclear energy or merely to discourage weapons proliferation without discouraging use of nuclear energy. Some policy documents make explicit the goal of preventing proliferation by discouraging nuclear energy but other expressions of policy hold that we will help LDCs develop nuclear energy where that makes sense: clearly a conflict.[47/]

We recommend that the U.S. not oppose LDC development of nuclear energy. It is not that we believe nuclear energy makes sense for most LDCs -- indeed we seriously doubt that it does -- but rather that we think U.S. opposition to nuclear energy on the rationale of preventing weapons proliferation is counter-productive. We believe it is resented by LDCs and would result in raising their determination to have nuclear energy facilities for the following reasons:

(1) The U.S. and the U.S.S.R. with thousands of weapons between them focus their worry about proliferation on the LDCs. They show little ability to contain their own expansion of nuclear weapons but are fearful that Pakistan or Brazil might get weapons. This is seen by developing countries as a double standard.

(2) All of the major industrialized countries are pressing ahead with the development of advanced nuclear energy technology. The energy budget of the U.S., among others, still continues to emphasize nuclear. Any U.S. effort to oppose nuclear energy in LDCs surely would sound confused at best and a conspiracy to keep LDCs down at worst.

(3) The juxtaposition of these two U.S. positions (disproportionate fear of LDC weapons and preference for non-nuclear energy for LDCs) is suspicious enough by itself. It is doubly so to the extent the U.S. makes it

clear that it does not want LDCs to have nuclear energy because it might help them get nuclear weapons. In the LDC view this is tantamount to asking LDCs to give up the best (i.e., the one the U.S. prefers) energy choice (nuclear) because they cannot be trusted not to misuse it and make weapons. This is a very demeaning position for LDCs and one quite likely to make them doubt U.S. sincerity when it tells them that it honestly believes nuclear energy is very unwise for them -- quite apart from any concern over weapons proliferation.

(4) It will be acutely resented if the U.S. approaches the LDCs with a "made in Washington" solution for their problems. Instead of offering to help them find the best solution for themselves, the U.S. would be offering to help them install what Washington sees as the best solution. An LDC may be forgiven for wondering why, if Washington has energy policy wisdom in such abundance that it make basic energy strategy decisions for LDCs, it does not use that wisdom to come to some timely decisions about its own energy strategy.

The U.S. policy should recognize that the choice is not whether another country will be permitted to make "bad" decisions (choosing nuclear energy) but rather (1) whether it will restrain itself from the counter productive effect of trying to impose its "good decision," and (2) whether it will help them carry out their decisions safely and efficiently. After the heady years of the 1940s and 1950s, when the U.S. was in a position to impose its views on many foreign countries, it will be difficult for Washington to accept so limited a role, but that is the nature of the world of 1978. Acceptance of a U.S. role consistent with these new realities would be a mark of national maturity.

4. Consolidate U.S. Energy Aid Programs.

If the U.S. does abandon the attempt to stop LDCs from adopting nuclear energy it will have a major organizational problem because there are

two energy development aid programs, one run by the State and DOE and the other by AID. So long as the purpose of the former is not to support development but to discourage proliferation it is conceptually distinguishable from AID's programs. But once that distinction is lost, it finds itself in the same position as to energy assistance that it was during the late 1940s and early 1950s with assistance to health, education, and agriculture. In those days there were three separate aid programs to many Latin American and a few other developing coutnries run by the Office of Public Health, the Office of Education, and the Department of Agriculture. With the advent of the Point Four Program (predecessor to AID) this illogicality was not long tolerated. The Budget Bureau laid down a rather sensible rule: "one country, one U.S. aid program." The rule has served us well in the ensuing decades. There is no reason in the case of energy to have to make the same mistake that was made nearly thirty years ago in health, education, and agriculture. There should only be one U.S. aid program. The Department of Energy and State Department energy program for LDCs should be terminated. DOE activities in LDCs should continue in the following categories: (1) those financed and requested by AID, (2) those wholly financed by host LDCs, and (3) those R&D activities financed and managed by DOE and the host LDC for which DOE can justify its input in terms of getting essential research done at least cost for application in the U.S. rather than in terms of helping the host LDC.*

*A comprehensive discussion of the relationship between AID and DOE, together with detailed recommendation, appears in a report by a panel of the National Academy of Public Administration.[48/] Two of the members of the Overseas Development Council staff who have worked on this report to the CEQ were members of that NAPA panel.

5. Resist the Temptation to Force LDCs to Avoid a Petroleum Path.

We have shown that in most cases it will make little sense for LDCs to plunge down a petroleum based path, and we have expressed concern that most of them are poised to do just that. One reaction of the U.S. Government, when it becomes aware of this problem, may be to enact a policy designed to prevent the LDCs from making this error. A special "non-petroleum energy" program might be designed in Congress or the Executive Branch, and foreign aid legislation might acquire a new stricture (one of more than 100 now in effect), using the "leverage" of foreign aid to reward courntries that eschew the petroleum path and to punish countries that follow it. Such U.S. efforts would be ill-advised. Our view on petroleum is the same as that on nuclear energy. Each country will have to make its own choices right or wrong. Genuinely objective technical assistance (including joint research projects with LDCs to get answers to questions not now answered) could improve the batting average of LDCs as a group. Efforts to prevent LDCs from making errors (given the contrariness of big power - small power relationships) could tip the scales in favor of more errors. Meanwhile, some signs of action by the U.S. to extricate itself from petroleum dependency would not go unnoticed in the LDCs.

## III. An International Solar Energy Partnership

We propose that the President should call for the establishment of an International Solar Energy Partnership. It would be a partnership including both developing and industrialized countries, the goal of which would be to push solar energy technologies to their practical limits, with particular emphasis on its use in developing countries but recognizing that rich countries could well benefit also. It would be concerned with each of the four systems for receiving the current income of energy from the sun: direct

sunshine, flowing water, wind and photosynthesis. (FN Alan Hammond).

A partnership to develop renewable energy resources could have a significant influence on the manner of future international cooperation in science and technology and also contribute to an improvement in the climate of political and economic relations between the industrialized and developing countries. It could be a boon to economic development and would contribute to satisfying basic human needs. It may help speed the development of a major successor to oil. And by contributing to the reduction of costs of environmentally and socially benign alternatives to petroleum energy, and gaining experience with the non-technical costs of these new technologies it would be in the common interest of all nations.

Some of the specific initiatives of an international partnership for solar energy development are enumerated in the paragraphs that follow:

1. Establish an International Solar Energy Development Fund.

This Fund might be financed either through governmental contributions from OECD & OPEC countries as with the International Fund for Agricultural Development, through a mix of governmental and private contributions as with the consultative group on International Agricultural Research, or through a one cent per barrel international tax collected on every barrel of oil traded internationally. This would amount to about $100 million per year.

The Solar Energy Development Fund (SEDF) might be administered by an expanded IFAD or by a special consultative group chaired and staffed as is the CGIAR by either the World Bank or IFAD with such functions as the following:

(1) Building solar energy institutions in developing countries. This would include costs of training personnel, equipment, laboratory buildings, and foreign experts. In a number of countries solar energy research institutes (to use the name given the new Institute in the U.S.) already exist and could

be further strengthened. In other cases such entities would need to be eatablished anew. They would not normally engage in basic research but instead would (a) study what modifications are needed to adapt existing technology to local needs and conditions (b) train a core of people in using such equipment and (c) monitor a series of field tests of such equipment (see #3 below).

(2) Finance national energy surveys in scores of developing countries to help them to determine what general energy strategy (i.e., centralized or decentralized) and energy sources to pursue.

(3) Finance and help to design field tests of small solar equipment at the village level. The United Nations Development Program has under discussion a project to make tests in perhaps 20 Pakistan villages. AID has initiated programs that may test equipment in a few dozen African villages in the next few years. The SEDF should seek to swell this trickle of tests from dozens into hundreds and eventually thousands. The kinds of testing needed are described more fully in item 8 below. Similarly, SEDF should finance tests of decentralized but larger equipment at the market town level. Such equipment might be large enough not only to generate electricity for the market town but also enough to distribute to surrounding towns. In some instances SEDF may want to finance large scale solar equipment to test its usefulness to the national grid.

(4) Finance the dissimination of the more successful solar energy equipment to points of use throughout developing countries.

As the results of the tests mentioned above become available, a number of countries will want to make the more promising technologies available on a wide scale to villages or market towns throughout their country. SEDF should help to arrange financing for such technology extension including the use of its own funds. The $100 million per year may have accumulated

by that time to a fund large enough to be significant even in the face of demand for funds for widespread application of solar technology.

2. Conduct an International Renewable Energy Evaluation.

The second activity under the International Solar Energy Partnership (ISEP) would be to conduct an international evaluation of renewable energy so that the lessons learned from various field tests such as those conducted by SEDP can be recorded, assembled and made available to energy scholars and policy makers. When SEDF comes into existence it would be the logical agency to take the lead in the evaluation. However, preliminary work needs to be initiated within the next few months before more field tests have been initiated. This would involve bringing together major donors and developing countries active in solar energy testing (e.g., India, Brazil, Iran, and Saudi Arabia) to agree on a common research strategy to guide the field tests of all participants. Thus, when data are generated they can be cumulated to provide answers to an agreed set of questions.

3. Establish RD&D Network on Renewable Energy.

The approach used in the case of food may be instructive in this connection. A formal network has emerged in that field which links the research and development efforts of a number of developed and developing countries on several crops, including corn, wheat, rice, and sorgum. Such linkages include, for example, joint research projects, advisory and training services, and exchanges of information, materials, personnel, and research results.[48/] They focus widely dispersed research activities on a single goal, thus achieving great economy of effort. In the case of corn, for example, an international insitute located in Mexico helps to coordinate the efforts of researchers in more than two hundred agricultural research stations throughout the world in pursuit of greater production of higher-quality corn. Such a network, which would also be useful in the energy

field, permits each participating country to put into the research effort as much as it can afford and to draw from it as much as it is capable of using.

The analogy between food and energy is interesting. Some of the most promising opportunities to produce more food exist in developing countries -- which is also true of energy. The research facilities of the developing countries are not great in either food or energy, but because of natural factors, the optimal location for food research in some cases is in these countries. The same also may prove to be true in thecase of certain energy sources, such as wind, biodigestion and sunshine. Particularly in the tropics, where those forms of energy that depend on sunshine are especially abundant, energy research probably would be especially beneficial. Because of that abundance, together with the relatively low costs of labor in some areas also of land and local building materials, it might be cheaper to locate certain research facilities in the tropics. This would be particularly true if the facilities were operated jointly with the host country, which would put up part of the local costs of the project -- much like the solar energy projects conducted in Niger with French assistance.

Institutions are needed to help coordinate and stimulate activities on given energy topics -- such as wind, biogasification, coal liquefaction, solar heating and cooling, solar electricity, and energy conservation -- either throughout a region or throughout the world. In some cases, existing institutions might undertake such roles either on their own initiative or at the request of a technical conference of experts on particular subjects. In other cases, it might be warranted to create a new international organization -- much as the International Maize and Wheat Improvement Center (CIMMYT) was established by private foundations in Mexico to serve as a research headquarters for corn and wheat and subsequently has come to be recognized as

the leading insitution on these topics. As the network of cooperative energy activities around the world proliferates, a need may arise for additional formal assignments of specific international leadership roles to existing international or globally recognized national institutions.[49/]

Already the amount of R&D on small scale renewable energy throughout the world has grown by leaps and bounds. The files of the ODC contain information on some 325 solar R&D activities in 75 countries outside the United States ranging from lone university researchers to sophisticated solar energy institutes. This includes 175 solar R&D activities in 50 developing countries. This is only a very incomplete listing of the R&D activities actually in operation. However, it demonstrates that energy R&D has proliferated to the point where it might be benefited importantly if it were knit together into a network or series of networks along the lines of the food R&D networks.

A question may arise as to why the OECD countries, with much of the world's research and development capability in energy, should complicate matters for themselves by extending their network to include the rest of the world. Would they not have to give to the extended network more than they get back from it? This would undoubtedly be true while the network is being established and while the new research and analytical institutions of developing countries are gaining experience. But if the experience with the food research network is a reliable guide, there would come a time when the network would begin to pay back handsome dividends to the industrialized and developing countries alike. And even if repayment did not, in every case, justify the investment in terms of the energy research and development budgets of industrialized countries, it would repay them amply when their

wider interests in world development were taken into account — for there can be no adequate development in the poor countries unless their long-term energy needs are met.

In any event, the cost of enabling the developing countries to participate in the global energy research network — by supporting the capacity of their energy research institutions through the provision of technicians, training, and materials — would not be great in comparison with projected developed-country energy research and development outlays. The OECD estimates (on the basis of 1972 prices) that, over the ten years ending in 1985, its member countries will spend between $1.3 and $1.8 trillion, from both private and public sources, on energy research and development.[50] In the context of these expenditures, it probably would be a prudent step to spend the relatively minor amounts needed to include the developing countries in the global energy research network. The socialist countries also should be encouraged to participate — although their financial position should enable them to meet the costs of their own research and development efforts.

A number of "hands on" researchers in both developed and developing countries should be brought together to agree upon a proposed configuration for such networks. For example, should there be one network for solar electric R&D, another for solar thermal, and one for wind? Or should the networks be organized by geographic region? Should there be a lead agency for each? These and other issues should be debated and specific recommendations made by this community of researchers to the U.S. Government and perhaps to other national governments and international bodies for action.

4. Encourage a strengthening of support from bilateral aid programs to solar energy to developing countries.

The U.S. should announce its intention to strengthen its bilateral aid program along the following lines and encourage others to follow suit: (1) help developing countries with energy surveys, (2) help developing countries develop their own institutional strength so that they can conduct surveys, analyze their own macro energy problems, train their own people, and manufacture at least some of the technological equipment they will need to generate and extend to their people the energy needed for development. The U.S. AID program would be directed to provide training, technical advice, and financial support to help establish and build energy related institutions in developing countries. This could be done alone or jointly with SEDF or other bilateral donors, (3) continue and expand its program of supporting on-site tests of various technologies in farms, villages, and urban slums.

5. Announce a Strengthening of U.S. Domestic Solar Work.

The Partnership proposal will not be well received in the developing countries if it consists only of helping developing countries convert to solar energy. There would be widespread concern that solar energy is a second best technology unless the industrialized north signals its earnest intention to convert to solar energy to the maximum extent and at the most rapid pace that is practical. Thus, the U.S. should announce a vigorous strengthening of its internal solar energy program. Other industrialized countries should be encouraged to do likewise. Among other steps this would include increase in government funds devoted to RD&D of solar energy technologies. In conducting such R&D the Department of Energy should, where practical, engage in joint research with developing countries energy researchers. This should be done where it is justifiable purely from the self-interest point of view of economizing on our R&D budget. Otherwise it should be done by AID. In many cases it is likely that developing country institutions and indi-

viduals will be able to perform professional research work at a considerable saving to the Department of Energy.

6. The U.S. should announce that it will place a high priority on existing bilateral agreements for cooperation in solar R&D (such as those with Saudi Arabia) and will seek opportunities for additional international research collaboration. In the same vein the U.S. should encourage the International Energy Agency of the OECD to make further efforts to include developing countries in its program of research on solar energy.

7. Help Developing Countries Get Essential Facts on Solar Energy. An important part of the Partnership would be to help provide essential information that is missing and without which developing country policy makers will be flying partly blind. First, very little is known about the current use in rural and urban slum areas of non-commercial energy such as wood, charcoal, crop residues, dung and animal and human muscle power (all of which are forms of solar energy). Second, little is known about unmet needs for energy in these traditional-energy using areas. Third, little is known about the availability of primary renewable energy (e.g., how much wind and sun for how many months of the year? How much organic waste? How much water flow? How much forest production and potential?) Fourth, there is little information about the physical performance of small scale renewable energy technology (e.g., windmills, photovoltaic cells, bio-digestors) in actual village situations. Fifth, little is known about their costs per unit of work accomplished under actual village conditions. Sixth, there are few data on the acceptability of various small scale renewable technologies by various cultural groups in urban slums and rural areas. Seventh, virtually nothing

is known about the performance, costs and acceptability of decentralized but medium-sized renewable energy technologies in developing countries (e.g., a 10 megawatt wood-fired thermal electric generator designed to serve a small grid that serves a number of nearby villages). Eighth, little is known about the economic and social effects on village or urban slum life of modern energy (e.g., what happens to birth rates, income, migration rates, infant mortality, etc.?)

There are other categories of missing information besides these eight but they illustrate the need for information. The U.S. and other donor countries and, when established, the SEDF should help developing countries answer these questions with major research undertakings in a number of developing countries interested in participating.

8. <u>When Timely, Help Finance the Costs of Small Scale Renewable Energy in Developing Countries</u>

Until information is gained on the kinds of questions outlined in item 7 above, it would be premature to launch a large scale program of installing energy generating technology in the hundreds of thousands of villages, farms and urban slums throughout the developing countries. However, as enough information is developed so that developing countries' energy policy makers can responsibly decide on an energy strategy as well as on the appropriate technologies to implement it, there may arise a need for very large scale financial help to launch such a program. The SEDF, the U.S. and other donor countries, at that time, should establish large scale financing mechanisms to deal with this problem.

Depending upon the kinds of technology that prove most suitable these financing mechanisms might take the form of export credits, stimulation of private investment, soft loans and grants or some combination of these and

other forms.

9. Launching the International Solar Energy Partnership: An International Conference on Renewable Energy.

The U.S. should continue its support for the proposed major international conference on renewable energy sources in 1981. This would be a useful and appropriate commemoration of the 1961 UN Conference on New Sources of Energy that laid the ground work for much of the recent research progress in solar and geothermal energy. Proposals for such a conference are now being discussed within the United Nations.

The U.S. should propose a solar energy partnership at the time it defines further its support for the Conference outlining it in only general terms but promising to make more specific proposals later. It should then commission one or more specific studies which would flesh out detailed recommendations. The U.S.Government should then convene workshops in order to let energy scholars and policy makers debate the recommendations pointing toward issuing a careful U.S. plan for the partnership by the fall of 1979. This would still leave up to two years before the 1981 Conference for international debate of the U.S. plan. If that period of time is well used by those preparing for the Conference, an international consensus among energy policy makers and scholars may have evolved which the 1981 Conference might ratify in the form of an International Solar Energy Partnership.

## I. Dimensions of the Energy and Development Dilemma

### A. The Energy Emergence of the Developing Countries

During the third quarter of this century, from 1950 to 1974, the size of the global economy has trebled.[1/] The world's use of commercial energy has also trebled but commerical energy consumption in the developing countries (LDCs) has more than quintupled at an average rate of 7.1% per year compared with only 4.2% in the industrialized countries.[2/] The industrialized countries are consuming about 430% more petroleum fuels than in 1950; in the developing countries petroleum fuel consumption is up more than 615%. Electricity consumption in the developed countries has risen a little more than 5½ times, while in the developing countries it has risen 11½ times. (See Tables 1-3.) Granted that the developing countries began from a very low base, it is nonetheless impressive that individual LDCs such as Thailand have recently been expanding their electricity consumption and production at 15% and more per year.[3/]

Despite the much more rapid growth in energy consumption in the LDCs, there remains a vast disparity in who consumes how much energy in the world. The United States accounts for 30 per cent of the commerical energy -- the oil, gas, coal, and electricity -- consumed by the entire world. In the industrialized countries the average consumption of commercial energy fuels amounted to the equivalent of 30 barrels of oil per person in 1975. In the LDCs, average consumption was only about 2 barrels of oil equivalent per capita, and in the poorest LDCs, such as Upper Volta or Nepal, per capita consumption amounted to only 4 or 5 gallons of oil equivalent.*

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* 1 barrel = 42 gallons

TABLE 1

Total Commercial Energy Consumption
in millions of metric tons of
coal equivalent

| | World | Developing Countries | Developed Countries | USA |
|---|---|---|---|---|
| 1950 | 2493 | 139 | 1864 | 1146 |
| 1960 | 4243 | 286 | 2461 | 1477 |
| 1970 | 6877 | 578 | 4312 | 2258 |
| 1975 | 8002 | 777 | 4635 | 2350 |

Source: UN Series J. Table 1

TABLE 2

Total Petroleum Energy Consumption
in millions of metric tons

| | World | Developing Countries | Developed Countries | USA |
|---|---|---|---|---|
| 1950 | 433 | 50 | 347 | 279 |
| 1960 | 877 | 109 | 644 | 409 |
| 1970 | 1904 | 231 | 1368 | 606 |
| 1975 | 2284 | 308 | 1502 | 665 |

Source: UN Series J, Table 10

TABLE 3

Total Electricity Consumption
in billions of kilowatt hours

| | World | Developing Countries | Developed Countries | USA |
|---|---|---|---|---|
| 1950 | 960 | 47 | 772 | 391 |
| 1960 | 2301 | 131 | 1695 | 849 |
| 1970 | 4909 | 349 | 3478 | 1642 |
| 1975 | 6437 | 544 | 4360 | 2273 |

Source: UN Series J, Table 21

As examples, the United States uses 65 times as much energy per capita as the developing countries of Asia, or, to take the most extreme contrasts, the U.S. uses 957 times as much as Nepal, 820 times as much as Upper Volta, and 380 times as much as Haiti or Bangladesh.[4/]

But there are also major differences among developing countries. India's per capita energy consumption is some 17 times as much as neighboring Nepal, and 9 times that of Bangladesh. Excluding China, just 16 developing countries consume fully three quarters of all commercial energy in the developing world. Half of all the LDCs' electricity is consumed by just six countries: India, Mexico, Brazil, Argentina, South Korea, and Taiwan.[5/]

Even if it is recognized that much of the energy in developing countries still comes from noncommercial energy sources, such as firewood and draft animals, that are not accounted in national or international energy statistics, the energy gap remains large. In India, total energy consumption including both commercial and noncommercial energy sources is estimated to be about 2 barrels of oil equivalent per capita, still only about one twenty-fifth that of the U.S.[6/] The average American's per capita income is about 50 times greater than that of the average Indian.[7/]

In 1950, the industrialized countries, both those of the OECD and of the Soviet bloc (COMECON), had little reason to include the LDCs in their energy calculations. The developing countries (many of them still colonial territories) then contained almost half of the world's population, but they consumed less than 1% of the world's commerical energy. By 1975 their share of commercial energy consumption had risen to 10%, still inconsequential.[8/] But by 1975, the industrialized countries had become painfully cognizent that just 13 LDCs -- the members of the Organization of Petroleum Exporting Countries (OPEC) -- were sitting on top of more than

half of the world's proven petroleum reserves, and were producing two thirds of the non-Communist world's annual petroleum.[9/] In late 1973, when the Arab members of the OPEC temporarily suspended shipments of petroleum to the U.S. and the Netherlands and quadrupled prices, the result was a devasting shock wave to the international economy that has yet to subside.

But the greatest energy impact of the LDCs is yet to come. While the U.S. and other industrialized countries become increasingly reliant on Mid-East OPEC suppliers -- and there is concern that the Soviet bloc may soon begin turning to Mid-East imports as well -- the non-OPEC LDCs become more important for two reasons. First, because they contain the last large areas of potentially oil-bearing sedimentary basins that are still unexplored and undeveloped. Some geologists estimate that half of all the petroleum resources yet to be discovered are located in the non-OPEC LDCs.[10/]

Second, and just as crucial, the LDCs' need for energy continues to grow at a faster rate than the rest of the world -- and petroleum remains the only fuel that they can turn to meet those needs. By the year 2000 the non-OPEC LDCs will require nearly 20 million barrels per day and only be producing half of that amount.[11/] By 2025, even with vigorous attempts to substitute other energy fuels, their economies might still require a minimum of 20-30 million of barrels per day.[12/]

Most geologists now agree that global petroleum production will peak sometime between 1985 and the year 2000.[13/] If the LDCs need for petroleum continues to rise, however, especially if their needs continue to rise after global production has peaked and begun to decline (See Figure 1) no matter how vigorously the industrialized countries cut back on their fuel consumption and introduce new sources, the economic implications appear straightforward and ominous. In the face of increasing scarcity and

increasing need, prices will have to rise to balance demand.

B. Global Petroleum Crises: Past and Future

Once the global petroleum supply situation becomes "tight" it is almost inevitable prices will rise. Unlike the price increase that occurred during 1973-74, when the OPEC cartel first flexed its muscles and the Arab OPEC members invoked an oil embargo against the U.S. and the Netherlands, the future portends an actual shortfall in desired supplies. The inevitable result, if global demand for oil is rising while the supply is peaking and beginning its decline, is that prices will rise. While those who can afford it will pay the higher prices, those who cannot afford to do so will be squeezed out of the marketplace. By and large, this means the poorest of the developing countries, and especially the poor majority living in rural areas and urban slums of the developing countries.

If the oil suppliers, perhaps together with the international community, should decide that a certain portion of the declining petroleum supply should be specifically allocated to the poorest countries, the result may actually be to worsen even further both the position of the poorest countries and of the world economy.

By artificially subsidizing the dependence of the poorest countries on petroleum, the global community would be perpetuating an economic distortion. In effect they would be encouraging the poor countries to become further "hooked" on petroleum during a period when the global petroleum supply situation can only get worse.

Many energy analysts argue that this is what is already occurring for the world as a whole.[14/] Because petroleum is such a concentrated and convenient fuel, it has been possilbe to find and locate it at a production cost of only several dollars per barrel or even less. As the most concentrated and accessible supplies have been depleted it has been necessary to spend relatively more time and effort in locating additional deposits, and most of these additional deposits have been either deeper in the earth's surface, farther from market centers, or in areas where adverse conditions all combine to raise production costs. By not basing petroleum prices on the marginal cost of adding new supplies (i.e., the amount of additional cost to go farther offshore, drill deeper, or develop new technology to exploit alternative fuels) the world's recent economic growth has been founded on an artifically cheap energy source. Once it runs out, or even runs low, its prices will jump. Even if the new price stimulates production of adequate amounts of additional or alternative sources, the suddenness of the price adjustment means a sudden and major discontinuity in prices for consumers.

The 1973-74 oil price rises gave some taste of what may be in store for the LDCs. The immediate, direct effect was a precipitous rise in the cost of their oil imports, and in the share of scarce foreign exchange that they had to spend to maintain those imports.

In the early 1970s, non-OPEC developing countries were importing

about one third of their total oil consumption.[15/] Before global oil prices quadrupled in 1973, the oil importing developing countries imported about $3.7 billion worth of petroleum -- some 5.3% of their total imports. In 1974, however, their oil import bill jumped to $13 billion and accounted for about 11.6% of their total imports.[16/]

The situation in different countries varied, of course. As examples:[17/]

| | Net Petroleum Imports | | Petroleum as Share of Total Imports | |
|---|---|---|---|---|
| | 1973 | 1974 | 1973 | 1974 |
| | (In millions of U. S. dollars) | | | |
| Tanzania | 34 | 118 | 7.5 | 15.5 |
| Kenya | 30 | 134 | 5.0 | 13.5 |
| Sudan | 25 | 38 | 5.1 | 5.8 |
| India | 401 | 1,426 | 12.8 | 27.6 |
| Philippines | 201 | 651 | 11.2 | 18.8 |
| Brazil | 803 | 2,887 | 11.5 | 20.5 |
| Mexico | 177 | 286 | 4.3 | 4.7 |
| Cuba | 177 | 648 | 12.3 | 26.5 |
| Guinea | 6 | 24 | 9.0 | 29.6 |

Price increases during 1975 and since have raised the annual petroleum imports bill of all LDCs together to about $16 billion.[18/]

The developing countries' needs for foreign exchange to pay for the petroleum imports have increased accordingly At the same time, however, the international recession has reduced the industrialized countries' demand for the raw materials which are the LDCs' normal source of foreign earnings, and the costs to them of food and manufactured goods from the U.S. and other industrialized countries have also increased significantly.[19/]

The prices of manufactured products have generally risen faster than the raw materials and other primary exports of the LDCs. As a result, the

terms of trade (relative value of imports vs. exports) have deteriorated for at least 50 LDCs since the 1973-74 price increases.[20/]

Furthermore, most of the foreign capital investments made by the OPEC countries have gone to the industrialized countries rather than to the LDCs.[21/]

In part, the increased costs to the non-oil-producing developing countries have been offset by increased loans and grants from OPEC and from the industrialized countries.[22/]

Both the developed and the developing countries now find themselves in a difficult dilemma. So long as their economies remain sluggish, with low output and high unemployment, the day of reckoning when the ultimate oil price crisis occurs will be delayed. But as they strive to improve their economic performance, their petroleum demand increases accordingly, hastening the day when oil prices will rise. The higher and more sharply they rise, the more likely they are to trigger off a new round of inflation and recession.[23/]

Two things seem certain at this point. First of all, unless decisive actions are taken now, the next oil crisis, whether it comes in 1985 or 1995, will be worse than that of the early 1970s. And secondly, it is extremely unlikely that the world, including the developing countries, will ever again have access to such a cheap and convenient form of energy -- petroleum at $2.00 or $3.00 per barrel -- as was available to fuel the rapid industrial recovery and growth of America and Europe from the close of the Second World War through the boom of the 1960s and early 1970s.

The crisis of a world in which demand for petroleum is pushing against the physical limits of supply, as may occur before the end of the century, directly links the energy problems of the LDCs and the industrialized countries. But there is another energy crisis that is specific to LDCs: the need to locate and distribute adequate supplies of energy to enable the satisfaction of essential human needs and the fulfillment of goals

for economic development.

## C. The Continuing Crisis: Energy for Development

### 1. Non-Commercial Energy, An Energy Iceberg

Economists and government policy makers have usually considered energy narrowly, signifying only measurable commercial energy fuels and primary electric power sources. This limited perspective distorts a number of energy issues, especially in the developing countries.

In the U.S. petroleum is conventionally estimated to supply about 44% of all energy. In the developing countries, on the average it officially counts for 61% of all energy.[24/] But these figures are in reality only the visible tip of an energy iceberg. Although firewood and other non-commercial energy sources are no longer of much significance in the U.S. or other industrialized countries, they are still very important in most developing countries. But since they are non-commercial fuels or power sources (i.e., they are usually utilized by the person who finds them and are seldom sold in a market where they could be measured or assigned value), they are generally ignored or their importance grossly underestimated.

The case of India, where there are relatively good data on non-commercial fuel consumption, is indicative of the general situation. A conventional energy budget for India appears roughly like this:[25/]

| | millions of tons of coal equivalent (mtce) | percentage |
|---|---|---|
| Coal | 51.35 | 39.5% |
| Oil | 29.90 | 23.0% |
| Electricity | 48.65 | 37.5% |
| Total | 129.90 | 100.0% |

Only the commercial sources -- fossil fuels, and hydropower -- are included. But in fact, firewood and animal dung still probably account for very nearly half of all the fuels consumed in India, changing the picture considerably:[26/]

| | mtce | % |
|---|---|---|
| Commerical energy | 129.9 | 42.0% |
| Non-commerical fuels | 179.4 | 58.0% |
| Total | 309.3 | 100% |

An even more accurate picture of India's actual energy situation is gained by also considering the role of animal draft power. In 1972, India's 130,000 tractors provided less than 3 billion horsepower; 86 million draft animals provided an estimated 34 million horsepower.[27/]

| | mtce | % |
|---|---|---|
| Commercial energy | 129.9 | 33.0% |
| Non-commercial energy | 179.4 | 46.3% |
| Animal draft energy | 77.8 | 20.1% |

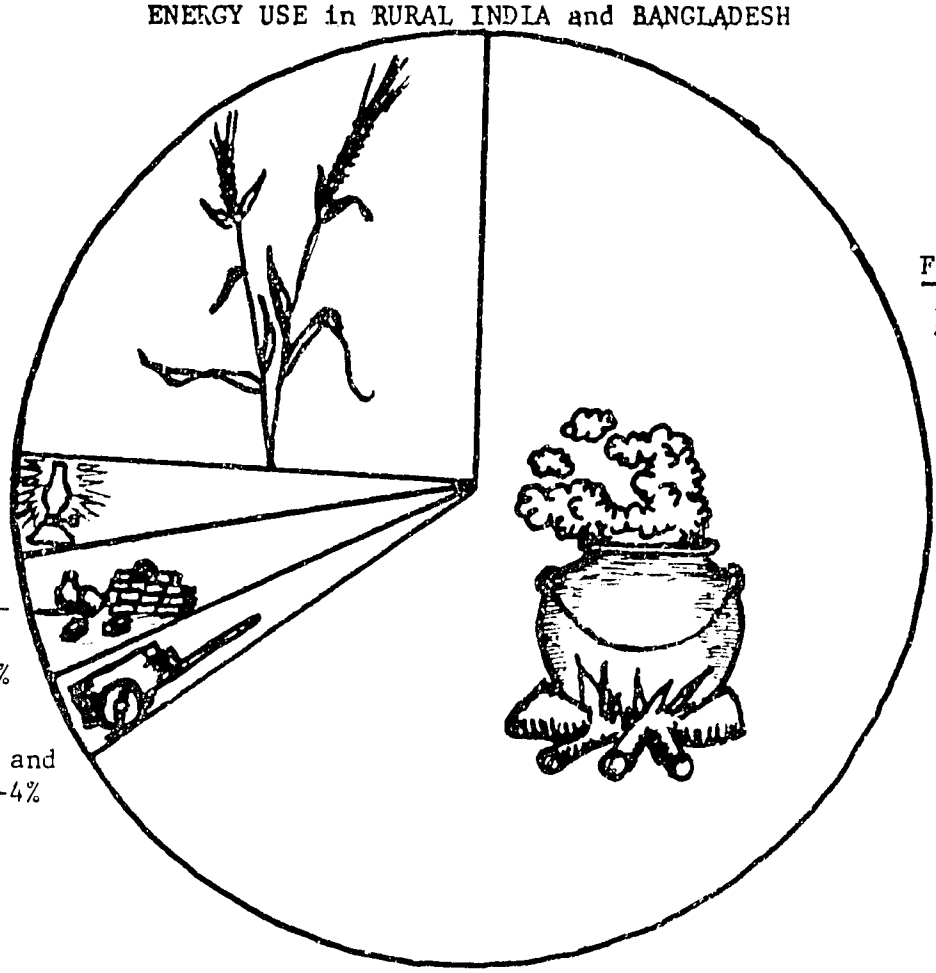
If human labor were included the picture would change even further.

Clearly, any analysis of India's energy situation, or any policies formulated for energy in India, would be incomplete if only the conventional energy budget were relied on. In India, there is a substantial effort made to determine non-commercial energy consumption. But in many LDCs non-commercial energy sources are still essentially ignored.

The picture of total energy sources would be similar for most other LDCs, although in most of Latin America the ratio of commercial fuels to non-commercial fuels would be higher while in most African LDCs the ratio of noncommercial fuels would be even greater -- nine to one in several countries.[28/]

Figure 2

ENERGY USE in RURAL INDIA and BANGLADESH




| | India* | | Bangladesh** | |
|---|---|---|---|---|
| | Daily per capita $10^3$ Keal | % | Daily per capita $10^3$ Keal | % |
| Agriculture | 1.57 | 22% | 1.32 | 26% |
| Domestic Activities and Food Processing | 4.55 | 64% | 3.38 | 65% |
| Lighting | .30 | 4% | .20 | 3% |
| Pottery, Brickmaking & Metal Work | .47 | 7% | .06 | 2% |
| Transportation & other use | .22 | 3% | .22 | 4% |
| TOTAL | 7.11 | 100% | 5.18 | 100% |

Adopted from Roger Revelle, 1978.

*R. Revelle, Science, 192,969 (1976)

** R. Tyers, Energy in Rural Bangladesh, (Harvard Center for Population Studies, 1976) Mimeograph.

Any comprehensive energy policy in these countries cannot be limited merely to conventional commercial energy success.

2. Energy Use in Developing Countries

a. Energy Use in Rural Areas

Although most people in LDCs live in rural areas, rural areas account for only a small share of total commercial energy consumption. According to World Bank estimates, only 12% of the people in developing countries live in areas that have access to electricity (23% in Latin America; 15% in Asia, the Middle East, and North Africa; and only 4% in sub-Saharan Africa).[29/] The figures for gasoline and diesel fuels would probably not be much higher. But even where electricity is available, usually less than half the population can afford to purchase any of it, even when it is heavily subsidized by the government.[30/] At the present rate of expansion, about 1% per year, by the end of the century only one out of four rural inhabitants will live in an area with electricity -- and fewer than half of those people will be able to afford to make use of any of it.[31/]

Nearly two-thirds of all energy consumed in a typical LDC village may go to cooking and food preparation alone. (See Figure 2). Most of the remaining energy goes to agriculture.[32/] Where the green revolution of modern agriculture has taken hold, significant amounts of fossil fuel inputs are also necessary for mechanized cultivation, irrigation, and chemical fertilizers and pesticides. But most of the energy consumed in rural areas still comes from noncommercial or traditional sources: firewood, charcoal, crop residues, dried animal dung, animal draft power, and human labor. Estimates by Revelle and Makhijani for seven LDCs suggest that non-commercial energy sources typically provide 5-10 times the commercial energy used in rural areas.[33/] In addition, solar energy is used directly for crop drying and heating (passive solar techniques are common in traditional architecture)[34/] and wind is traditionally used in such tasks as separating grain

chaff. But it is firewood that is most important. "Wood is the poor man's oil."[35/] For the 90% of a country's population that relies on woodfuels, either firewood or charcoal (which is easier to transport and burns more cleanly) each individual may consume a ton or more each year. In cooler climates such as South Korea where wood is necessary for warmth as well, per capita consumption may amount to four tons annually.[36/]

Wood and other traditional or non-commercial fuels may never enter a market, but their costs may be quite high both to those who use them and to society in general.* In Nepal and other areas, where woodfuels are scarce, a family may have to devote several man-days** each week to gathering sufficient quantities of wood for cooking fuel.[37/] In many areas of the developing world, animal dung is also collected and dried for cooking fuel. In either case, exposure to the smoke of open fires or partially enclosed stoves undoubtedly has a detrimental impact on the health of those who do the cooking.[38/] Consumption of traditional fuels also means that their value as organic matter for regeneration and sustenance of soils is lost.

As rural and urban populations*** have multiplied, wood fuels have begun to be consumed faster than they can regrow in many areas. The result is a worsening cycle of overcutting, deforestation, erosion, and loss of vital agricultural land that is reaching crisis proportions in parts of

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* In most areas, traditional fuels are still common property resources. Their overuse provides a classic example of the tragedy of the commons.[39/]

** Usually woman-days, since in Nepal, as in most cultures, it is the women and children who gather the firewood.

*** Firewood shortages are an urban-industrial problem also. In Bamako, Mali, the average manual laborer may spend up to one third of his income to purchase firewood for his family.[40/] The quest for firewood has left a virtually treeless landscape of 70 kilometers radius around Ougadougou, Upper Volta.[41/] "At present rates of deforestation, Senegal will be bare of trees in 30 years, Ethiopia in 20, Burundi in eleven."[42/]

South Asia, African countries bordering the Sahara from Senegal to Ethiopia, the Andean countries, Central America, and the Caribbean.[43]

In order to alleviate this devastating pressure on their dwindling forest resources, and in an attempt to improve their people's quality of life, some LDC governments in recent years have chosen to subsidize kerosene and other commercial fuels to make them affordable for domestic cooking. But this immediately increases the country's need for petroleum imports.

The further tragedy of deforestation from firewood cutting is that most of the wood so tediously gathered is then burned in inefficient open fires or stoves. Most non-commercial fuels are probably consumed with an overall efficiency of only about 5-10%.*[44] This means that relatively little productivity or benefit is derived from the heat energy that is used.* Similarly, the mechanical efficiencies of hand tools or animal drawn carts are generally very low.

To a lesser extent this low efficiency use is also true in use of commercial energy in rural areas. (See Table 4). If buses or trucks are available, for instance, they are also likely to be older and less efficient models than those used in urban areas. The same is true for diesel electric generators, and the low load factors of electrification projects in rural areas, (either diesel autogenerators or extensions of central grids) is a continuing problem for electrification programs. The problem seems to be similar to that of poor income groups everywhere: while they can least afford to consume energy wastefully, they can also least afford the capital

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* It should be noted, however, that in many cultures, cooking fires also have other values - they may be used for warmth and for protection from wild animals, and they may be essential to regular religious customs (e.g., offering the first morsel of cooked food to the gods) or special ceremonies.[45]

investments (in more efficient tools, stoves, etc.) that would enable more productive energy use.

**TABLE 4**

**Summary of Makhijani's Rough Calculations of Energy Use in Some Rural Areas of Third World 46/**

(in billions of Joules/year per capita)

| | NON-COMMERCIAL ENERGY | | COMMERCIAL ENERGY | | TOTAL ENERGY | |
|---|---|---|---|---|---|---|
| | Energy Input | Useful Energy | Energy Input | Useful Energy | Energy Input | Useful Energy |
| India (East Gangetic Plain) | 15.1 | 0.8 | 1.5 | 0.5 | 17.2 | 1.3 |
| China (Hunan) | 32.5 | 2.5 | 8 | 1.6 | 39.5 | 4.1 |
| Tanzania | 25.0 | 1.2 | 1 | 0.2 | 26 | 1.4 |
| Nigeria | 18.3 | 0.9 | 0.7 | 0.14 | 19.2 | 1.14 |
| Mexico (North) | 61.6 | 15.2 | 15 | 3.0 | 75.6 | 19.2 |

b. Energy Use in Urban Areas

Most cities in the developing world are rapidly expanding in population. In the last ten years, more than 200 million people in developing countries moved from rural to urban areas.[47/] In many of these cities, the population is doubling every 10-15 years. But while the cities are growing at a rate of 5-8% a year compared to less than half that for the countryside, within the city itself, the slum sections, the barrios and favelas are growing at twice the rate of the city as a whole.[48/]

These slum areas seldom have basic energy services for household use, transportation, or business. The capital requirements for electrification, pumped water supply, sewage disposal, roads, and decent housing are an enormous financial burden for developing countries. The World Bank

estimates that 190 million urban dwellers lack access to basic services, of that group between one-fifth and one-quarter could afford to pay for the services if they were available.[49/]

In lieu of these services, or even in competition with some, an informal sector has emerged. This sector can be divided roughly into two groups: the traditional small businessmen and traders on the one hand, and a heterogeneous mixture of domestic servants, day laborers and "backyard" craftsmen. This last group is primarily composed of small entrepreneurs who utilize both indigenous, traditional resources and technologies as well as resources and technologies from the more modern sector. The informal sector seldom contributes little to national income economic accounts (as with non-commercial fuels, its activities are inherently difficult to record). Yet it is a very important part of the economy. A World Bank study of informal sector surveys in four countries (India, Indonesia, Brazil and Peru) found that jobs in this sector employed between 50% amd 69% of the total labor force in the 96 cities surveyed.[50/] This informal sector uses relatively little conventional energy[51/] and, in fact, some of its employment is required to make up for the lack of utilities, public transportation, or other energy-dependent services.[52/]

Not surprisingly, the economies of urban areas of developing countries display a wide range of technological and organizational modes of economic activity. An urban building project may employ advanced earthmoving equipment, bricks supplied by a small kiln, and day-labor contracted from the informal sector. A wrecked automobile, a classic example of modern industry, may find its way into an open-air blacksmith's shop where its steel is handcrafted into bicycle parts. Delivery vans compete alongside pushcarts; and imported pressure lamps are sold alongside locally-made kerosene lamps made from tin cans.

The small businessman uses little energy and is careful about what he uses. This is in part because he is small but also because he is unprotected by government and open to intensive competition, forcing him to keep his costs low. Nevertheless, still greater savings might be possible if more efficient tools, construction materials and processes were available to him.

The backyard craftsman is connected both to the modern and traditional energy economies. The backyard urban blacksmith may fuel his fires with traditional charcoal, firewood, or coal. He may use both energy-intensive raw materials from the modern sector such as an oil drum or car body to produce a charcoal brazier which in turn uses a traditional fuel for heat. The same is true of the tinsmith making keorsene lamps or the fabricator using cast-off plastic containers. Such activities are beneficial in terms of recycling materials through a labor-intensive, employment gathering process. These informal activities are dependent upon the modern sector for their supply of raw materials, and part of the informal sector also services modern products directly, by repairing automobiles and appliances, for instance. The key distinction between the modern and informal sectors is that the latter emphasizes repair and improvisation, while the formal sector favors technical innovation leading to the production of new products that are later discarded (to be reused by the informal sector).[53/]

Commercial energy forms, usually fossil fuels, are playing an increasingly important role in the industrial and modern service sectors of the economies of developing countries. This is especially true for energy intensive industries such as iron and steel, cement and construction, paper, fertilizer, and mining.[54/] Fossil fuels are also indispensable to rapid, long-distance and mass transportation systems. And, of course all petrochemical products, including plastics, most pharmaceuticals

and synthetic fibers are dependent on fossil fuels for their feedstock.

In many modern industries, however, it may be possible to substitute labor for energy inputs. Both multinational and domestic corporations have tended to be more capital intensive, and therefore commercial energy intensive, than may be necessary. In the early 1970s, investment per worker in the rubber industries of the Philippines and Japan amounted to about $2,600 and $1,800 respectively. But in Korea and Taiwan, the comparable capital investments were only $630 and $760. The major difference appears to be that the governments of Korea and Taiwan consciously made capital expensive by maintaining interest rates of 25-30%, so that multinationals and local firms would use more labor.[55/] In doing so, they also reduced their need to import the petroleum that would have substituted for energy of the laborers employed.

Most developing nations, however, particularly those with large modern sectors, have what amounts to an energy-intensive outlook. In Brazil and Mexico, multinational corporations constitute about a third of total investments, but they employ less than 10% of the manufacturing work force.[56/] State-owned industrial corporations, whether financed domestically, or internationally, have tended to develop along technologically similar lines with similar employment effects. The result has been to develop a modern urban economy that may, at least for the oil-importing developing countries, be unsustainable without constantly increasing foreign exchange earnings to pay for the increasing amounts of oil that must be improted.

Although very little study has yet been given to the particular patterns of energy use in urban areas of LDCs, it appears that the energy use of the affluent minorities is very comparable to that of urbanites in Western Europe or even in the United States.[57/] Similar patterns of energy waste have also developed, and there are promising opportunities for

conservation in residential and commercial use.

For example, in the small island nation of St. Lucia, a great deal of excitement has recently been stirred by the assessment of a significant geothermal energy potential for the island. Plans have been drawn for a geothermal power plant of 1 megawatt capacity. Since the island's total electric power capacity is presently only about 10 megawatts, this would be a considerable addition to energy supplies. But in St. Lucia, where tourism is the primary industry, nearly 60% of all the island's electricity is consumed by modern, air-conditioned and brightly lit hotels. With insulation and other improvements sufficient to increase the efficiency of the hotel industry's energy use by 16%, a full megawatt of power would be freed for other purposes, effectively increasing the island's power supply as much as the most costly geothermal project.[58]

Similarly, transportation appears to be a promising area in most LDC urban areas for improvements in energy efficiency, and therefore also in economic performance. Most LDCs share the haphazard design patterns that are characteristic of most cities of the developed countries. As a consequence, production, markets, and customers are located at considerable distances from one another, requiring a great deal of transportation that might be avoided by conscious planning of city and regional layouts.

### 3. Energy and Development

Human technological and economic development has been largely a matter of harnessing increasing amounts of energy to productive or useful purposes.[59] Although energy consumption itself is not wealth, it is obvious that rich countries are those which either have substantial energy resources of their own or the ability to purchase them from those who do,

while poor countries have neither substantial energy resources or the technology to fully exploit those they do have, nor the ability to purchase significant energy supplies from others. The same is true for individuals or groups of people within countries.

Each individual developing country is unique, with its own particular endowments of geography and human history. But there are several generalizations that encompass most of them, with significant portents for their energy situation.

Most LDCs lie in tropical latitudes. Sunshine is therefore generally in relatively plentiful supply, and they have a natural advantage for plant or biomass growth, at least where water is available.

Most LDCs are former colonies of European powers and have practiced self-government and participated in modern economic development for only the past 1-3 decades. In most instances, this means not only that energy per se is a new topic for them, but also that there is less industrial and other economic infrastructure that is already established and committed to petroleum fuels. In general, the Latin American countries have been independent longest, and are considered to be most developed, while the African countries are generally newest and least developed.

This is reflected also in the degree to which each of these regions has been urbanized. In Latin America, roughly 50% of the population dwells in urban areas; in Asia, only 25%; and in Africa, all but about 10% of the people still live in rural areas, mostly in villages or small towns.[60] This is rapidly changing, however. (Most of the major cities of the developing countries are growing at rates of 5-8% annually, literally doubling in population every decade.)[61]

This rapid urbanization is the result of two major phenomena that most developing countries have in common. First, they are presently

going through a demographic transition in which their death rates have been drastically reduced in recent years through the availability of modern medical drugs and the eradication of a number of formerly prevalent diseases but without a corresponding decline in birth rates. The result is that total populations of many countries are doubling in only two to three decades, requiring a doubling of production of goods and services during that time merely to maintain a constant standard of living.

The second phenomenon is a rapid rise in economic expectations on the part of the leaders and peoples of these countries. They have a growing awareness of the potential of modern technologies to improve human welfare, and they desire a share in that potential, both for themselves and for their children. Since cities are both symbolically and in fact the places where economic opprotunity is most concentrated, one of the corollaries of rising economic aspirations is an increasing flow of people from rural to urban areas.

Many development experts and demographers now suggest that these two phenomena are closely interrelated, that the basis of the global population explosion is the clear-headed recognition on the part of poor individuals that they need to produce large families to accomplish farm and household chores, to earn money and provide security for their old age. In other words, the demographic transition will not be completed until these people have achieved a minimum share of the world's potential wealth: when they have relatively secure access to food, shelter, and health care adequate to prevent those children they do have from dying at an early age.[62/]

Rapid population growth and rising expectations also exacerbate what may be considered the lowest common denominator of the developing countries: their relative and absolute poverty. Compared to the U.S., Canada, Japan, Australia, New Zealand, the Western European countries, and the countries of

the Soviet bloc, they are relatively poor. And large portions of their populations, totalling a billion persons, or one of every four people on the planet, are still absolutely poor. In the words of the World Bank, these are:

> "individuals (who) subsist on incomes of less than $75 a year in an environment of squalor, hunger, and hopelessness. They are the absolute poor, living in situations so deprived as to be below any rational definition of human decency. Absolute poverty is a condition of life so limited by illiteracy, malnutrition, disease, high infant mortality, and low life expentancy as to deny its victims the very potential of the genes with which they are born. In effect, it is life at the margin of existence." 63/

Two clear trends have dominated the energy consumption picture in LDCs during recent decades. First, there has been a tremendous increase in the total amount of energy consumed. This total growth has been greatly stimulated by the second trend, the rapid transition from traditional non-commercial energy fuels to commercial energy, especially to petroleum and electricity.

The U.S. and most West European countries underwent a transition from almost total reliance on non-commercial biomass fuels to heavy reliance on coal as part of the Industrial Revolution a hundred years ago. Petroleum fuels then began to supplement coal in large quantities in the early part of this century. Most LDCs have begun a similar but more rapid transition during this century.64/ But because the LDCs have relatively small (known) coal resources, and because petroleum has been, until recently inexpensive and conveniently available on the international market, most LDCs are making their transition directly from biomass fuels to petroleum.

Although the developing countries presently consume barely 15% of the world's total commercial energy, the rate of growth of their energy consumption has recently been considerably higher than that of the developed countries.65/ By the turn of the century they may account for a full

quarter of global commercial energy demand.[66/]

When only commercial energy sources are considered, petroleum is now more dominant in the energy supply picture of most developing countries than it is in the developed countries. (See Figure 1) Petroleum has become the fuel of choice because it is the easiest fuel to transport, to store, and use. And until recently, it has been generally the cheapest energy form, even when transported over long distances.

Compared to oil, human labor, for example, is woefully expensive. The labor of a healthy adult working 12 hours can be performed by a mere 2.5¢ worth of gasoline, even at today's prices. It would take a human 7 days of hard labor to perform the same work accomplished by a one horsepower internal combustion engine burning just one liter of gasoline.[67/]

This raises a potentially serious conflict: since the lack of jobs is a critical problem in almost all LDCs -- especially for the poorest people -- how can the conditions of unskilled people be improved by finding substitutes for their manual labor? Agriculture provides a good example of how additional non-human energy inputs can increase both productivity and employment. A majority of the workers in an LDC's labor force may be farmers or agricultural laborers. But the agricultural labor force comes into full play only at critical points during the crop cycle: during plowing, planting, and harvesting. During the remainder of the year most farmers and laborers are essentially unproductively idle, or unemployed. But during those few weeks just before periods of rain when plowing, planting, and harvesting must be accomplished, they are hard pressed to get everything done. Bottlenecks in production result.[68/]

But if mechanization were carefully introduced to relieve these bottlenecks, it would be possible in many instances to allow cultivation of a larger area or even of an additional crop. This would mean that the

annual demand for labor would be both increased and evened out. Additional jobs would be created within the agricultural support industry -- those which produce and distribute fertilizers, irrigation systems, farm machinery, and the fuels that go with them.

The problem is that increased energy inputs are frequently allowed to substitute for labor, rather than enchance it. The labor freed by introduction of small tractors or threshers is a resource that should be put into more productive work, perhaps public works or small industries.

As with all technologies, there is a danger that the ability to tap new energy resources may tend to strengthen the strongest. For example, in India, only those relatively well off farmers who possess at least 3 or 4 cattle can make effective use of gobar, or cow dung, biogas digestors. Those families no longer have to devote hours each day to gathering firewood or collecting and drying cow dung for cooking fuel. But the poorest people in the area, the landless peasants, who formerly could freely gather the otherwise worthless cow dung for their own cooking fuel, are now denied their only source of heat and light.[69/]

In Mauritania, a costly French solar pump was installed by the French development assistance agency to provide fresh water for a rural village. The two richest inhabitants of the village took control of the pipeline soon after it was installed, and began selling the water to their neighbors -- water that had previously been free to anyone who went to the well for it.[70/] Such examples have occurred ever since entrepreneurial individuals first set up residence by promising streams, and then harnessed the water power with a mill to grind their neighbors' grain.

The problem of rich-prone technologies is a real one. The experience of rural electrification in the United States may offer some helpful lessons. Since electricity would have been too expensive for individuals to pay its

full costs, federal and local governments encouraged the formation of co-operatives by making credit available to them at modest terms. Many of these electric cooperatives carried over into other areas, enabling farmers to store grain and purchase fertilizers and feed for livestock together. Arjun Makhijani has suggested that similar rural cooperative associations could be formed in many Indian and other villages of the developing world. The benefits of a technology such as a gobar biodigestor could thereby be extended to an entire village on a basis established by the villagers themselves.[71]

As an example of this approach, a small Peruvian village, remotely isolated in the Andes, recently began producing electricity from their own turbines and generator on a nearby stream. Since little cash is available or used in the area, villagers pay for their electricity with their work in constructing the power lines and maintaining the facilities. The village will pay off a loan it received from the central electrification authority for part of the equipment by using the surplus power to grind the grain of other villages nearby.[72] Similar examples could be cited from both developed and developing countries around the world. Unfortunately, they are still only examples. and not common or normal practice in most areas.

In most parts of the developing world, it is the women and children who do many of the most onerous of tasks such as gathering fuelwood or dung, hauling water, and grinding grain. These are some of the easiest tasks to mechanize, and doing so greatly increases the time that children might be able to devote to school or that women could use for other productive activities including handicrafts or cottage industries. In at least one West African village where the women had been accustomed to walking several kilometers each day to a water well, a horse drawn cart is now being used to haul

the water. But the cart is being driven by men.[73/] A World Bank rural development project several years ago almost foundered because it was to include bicycle-powered grain grinders. But in that particular region grain grinding was only done by women, and only men rode bicycles. Fortunately, this cultural mistake was recognized before the project actually got underway and another energy device was used.

New sources of energy can also have either benign or harmful effects on local environmental quality. Introduction of fast-growing tree varieties or more efficient cooking devices might relieve deforestation and desertification pressures,[74/] and introduction of solar substitutes would reduce pollution problems associated with fossil fuels. But such changes should be introduced carefully. Unless special measures are taken, for instance, dam reservoirs may facilitate the spread of water-borne diseases such as schistosomiasis.[75/] And the establishment of diesel powered wells for watering cattle in West Africa is credited with encouraging the build-up and concentration of cattle herds beyond the carrying capacity of the land, greatly exacerbating the effects of the recent Sahelian drought.[76/]

## 4. Future Energy Use

### a. Projections of Future Energy Consumption

All of the usual problems inherent in making projections are compounded in any attempt to assess future levels of energy consumption in LDCs. Data on the present energy consumption situation are inadequate, the dynamics of energy growth are only poorly understood, and key variables affecting energy consumption, such as population and economic growth rates and energy prices, are uncertain.[77/]

The quintupling of oil prices in 1973-74 made all existing estimates of future energy demand for both rich and the poor countries obsolete.[78/]

Several projections of commercial energy consumption in the LDCs to the year 2000 have been published during the last several years, however. These are summarized in Table 5a. Because of its special significance, the future of oil consumption for the world has also been assessed in several recent studies. Consumption and estimates of petroleum imports and projections from these studies are presented in Tables 5b and 5c.

But even these post-1974 studies do not adequately take into account the LDCs' energy needs. Most important, none of the studies addressed non-commercial energy, even though non-commercial energy sources probably account for over half of all the energy used in the developing world. The reason non-commercial energy is neglected in these studies is that, as we have stressed, there are few data on non-commercial consumption and resource availability. One of the results of ignoring non-commercial energy sources, however, is that much of the apparent increase in official energy consumption statistics may be simply a shift from non-commercial to commercial energy sources rather than an actual increase in total energy consumption.

In some areas, the rising cost of petroleum products has resulted in a return to traditional fuels. For instance, in much of Kenya and East Africa, people in cities and towns who have begun to rely on kerosene for cooking fuel in recent years have recently switched back to charcoal. Although few of the people seem to consider this a serious hardship, their official energy consumption has declined considerably. Of more concern, however, is that the pressure on East African forests to provide wood for charcoal has been intensified.[79/] Finally, projections of primary commercial energy or oil consumption indicate gross rather than net, or end-use energy. Losses in conversion or wasteful uses are not identified, nor do they consider how alternative patterns of development within the developing

Table 5a

LDC Commercial Energy Consumption
(in millions of barrels per day of oil)

| Country Category | 1975 | 1985 | 2000 |
|---|---|---|---|
| Source of Projection | | | |
| OPEC | | | |
| WAES 3/ | 1.7 | 18.5 - 23.5 | 8.4 - 13.10 |
| Non-OPEC LDCs | | | |
| BNL 1/ | 9.1 | | 25.9 |
| IER 2/ | | | 28.4 - 41.0 |
| WAES 3/ | | 14.9 - 18.2 | 26.5 - 35.6 |
| Strout 4/ | | | 38.7 |
| All LDCs | | | |
| WAES 3/ | 9.5 | 19.10-23.10 | 34.9 - 48.7 |
| ODC 5/ | | 18.5 - 23.5 | 41.1 - 63.6 |

Table 5b

Comparison of Recent Projections of LDC Petroleum Consumption
(in millions of barrels per day)

| | 1975 | 1980 | 1985 | 2000 |
|---|---|---|---|---|
| OPEC | 2.0 | | | |
| OECD 6/ | | 2.9 | 4.1-4.2 | |
| CIA 7/ | | 3.0 | 2.8-3.3 | 3.9-9.8 |
| Non-OPEC LDCs | 6.9 | | | |
| OECD 6/ | | 5.3 | 6.2 | |
| CIA 7/ | | 8.5 | 12.0 | |
| WAES 3/ | | | 8.9-10.7 | 14.6-20.9 |
| CRS 8/ | | | | |
| IER 2/ | | | | 15.2-21.9 |
| BNL 1/ | | | | 14.4 |
| All LDCs | | | | |
| OECD 6/ | 6.9 | 8.2 | 10.3-10.4 | |
| CIA 7/ | 8.8 | 11.5 | 1.6 | |
| WAES 3/ | | | 11.7-14 | 18.5-28.7 |
| CRS 8/ | | | | |
| IER 2/ | | | | 15.2-21.9 |

Table 5c

Comparison of Recent Projections of LDC
Petroleum Imports (Exports)
(in millions of barrels per day)

| | 1975 | 1980 | 1985 | 2000 |
|---|---|---|---|---|
| OPEC | 28.8* | | | |
| OECD 6/ | | (30.6) | (24.5-35.1) | |
| CIA 7/ | | (29.9-31.7) | (42.7-47.2) | |
| WAES 3/ | | (33.2-36.7) | (35.2-38.7) | |
| CRS 8/ | | | | |
| Non-OPEC LDCs | | | | |
| OECD 6/ (1974) | 2.3 | (negl.) | (0.8) | |
| CIA 7/ | 3.0 | 2.4 | 3.0-4.0 | |
| WAES 3/ | | | 3.8-4.0 | 7.6-9.4 |

* 1974

countries could affect these countries' use of energy, particularly their use of petroleum, which in turn can have very different impacts on world oil economy. Therefore, it is difficult to assess how a change in commercial or petroleum consumption will affect overall welfare.

Nevertheless, it is interesting to note that most of the projections come out fairly close to one another. The consensus seems to be that if apparent trends continue to the end of the century, total primary energy consumption in the LDCs will at least triple and probably quadruple. (See Table 5a). If this occurs, it means that by the end of the century, the non-OPEC LDCs will be in roughly the same petroleum supply position that the U.S. is in today. Out of a total petroleum consumption of something like 20 million barrels per day, nearly half, or about 8-9 million barrels per day will need to be imported.

b. Future Energy Needs

The projections of energy consumption discussed in the previous section are the present answer to the first step of the question, how much energy will be needed for economic growth? Since the projections of energy consumption, or energy demand, have been based on historical relationships between energy and economic growth, the projections give an indication of how much energy would be needed, if those historical trends are continued, to meet anticipated (although perhaps not desired) economic growth rates. There is reat deal of uncertainty, however, as to how economic growth and energy relationships will change in a period of relatively higher energy prices or a period of uncertainty about future supplies of petroleum, the dominant conventional fuel. It seems probable that economic growth rates can be maintained at much less than the energy intensity of recent years.[80/]

References to Tables 5 a,b,c

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3/ WAES, Energy, Global Prospects, 1985-2000.

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7/ CIA, The International Energy Situation: Outlook to 1985, (Washington: CIA, April, 1977)

8/ CRS, Project Interdependence: U.S. and World Energy Outlook Through 1990, (Washington: U.S.G.P.O., Congressional Research Service, July 1977).

But there is also concern that rising energy prices may bring about a severe reduction or even a reversal of economic growth.

The second part of the question: how much energy will be necessary to meet basic human needs, such as adequate supplies of food, water, shelter, clothing, and health care is even more difficult. Even if a firm agreement is reached about what constitutes an adequate amount of any of these essentials, there will be tremendous difficulties in calculating the the energy inputs necessary to achieve them.

For example, the energy (petroleum)-intensive agricultural methods used in the U.S. today require energy inputs amounting to about 8 barrels of oil equivalent to produce enough food for one person per year. If food production were similarly energy-intensive throughout the world, global agriculture alone would consume all global petroleum reserves within only 13 years. The U.S. agricultural model would certainly not have to be duplicated everywhere to produce an adequate supply of food for the world, however. A more reasonable estimate of how much energy will be needed for agriculture in the developing countries has been made by David Pimentel, of Cornell University. Pimentel estimates that to make significant reductions in global malnourishment will require a 3-fold increase in food supplies by the end of the century which in turn will require a 4-fold increase in total quantity of energy used in the food systems of developing countries.[81]

## II. The Conventional, Depletable Energy Options

### A. Introduction

Our conception of a conventional resource is subject to change. A hundred or so years ago, the list of conventional energy resources would have included firewood, coal, whale oil, animal draft power, wind for sailing, watermills, and some new-fangled gooey black stuff called "rock

oil", or petroleum. Electricity was still something a few scientists and inventors played with in their laboratories. Perhaps a century from now the mix of conventional energy sources will be equally as different from those we have today.

Today, when people in the U.S. or elite groups in the LDCs, including government policymakers, think of energy, a few specific sources come to mind: petroleum, including a large variety of petroleum fuel products such as gasoline, diesel fuel, aviation fuel, etc.; natural gas and natural gas liquids (which are usually combined with liquid petroleum and refined into other end products); coal, including hard coals (anthracites) and a variety of softer (bituminous) coals, including those with the special properties desirable for cooking, and lignites and lower grade coals including peat; nuclear power from the fission of uranium atoms; and hydropower, from falling water. Hydropower is almost always converted directly into electricity because it is a relatively inexpensive electric power source and the electricity can be conveniently transmitted to the site of its use. Similarly, nuclear power is used exclusively for production of electricity, although at least a portion of the waste heat from nuclear theoretically could be siphoned off and used for direct heating purposes.

With the exception of hydropower, none of these conventional energy sources is renewable. The line between a renewable and a nonrenewable resource is admittedly an arbitrary one, however. For instance, the lifetime of uranium fuel could theoretically be multiplied 70-fold if it were utilized in a successful breeder reactor cycle. A given hydro site is not indefinitely renewable if, over the course of decades or centuries, the reservoir fills with silt. Fossil fuels technically are renewable, since they are believed to originate from decayed plant matter that was produced from photosynthesis. But the fossil fuel formation process takes millenia to complete, so for all

practical purposes they are an exhaustible resource. On the other hand, even biomass resources such as trees and forests can be exhausted. If they are cut faster than they regrow, they are being depleted, or literally mined. Even the sun, the basic renewable energy resource, and the one that drives the water cycle and the winds and provides the energy for photosynthesis by green plants, will exhaust itself within another 3 billion years or so.

But the point is that modern economic civilization has been based on a few resources (with the exception of hydropower) that are all depleteable and being depleted. Therefore, when we speak here of the conventional resources we will restrict ourselves to meaning those resources that are commonly perceived as the "modern" energy fuels: fossil fuels of all kinds plus fissile fuels.

The new and renewable energy sources include both conventional hydro and small stream or low head hydro resources. Geothermal, tidal, and ocean thermal resources are both new and renewable. The technologies for tapping wind, biomass, and direct insolation are both old and new, but the resources themselves are renewable.

## B. Resources and Technologies

### 1. Petroleum and Natural Gas

Nearly thirty non-OPEC developing countries are oil producers*, and more than a dozen of them are oil exporters.**

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* The OPEC countries possess more than two thirds of the world's petroleum and nearly 40% of the world's natural gas reserves. They presently account for more than half of global oil production but only 5.6% of global production of natural gas.[82/]

** Angola, Bolivia, Brunei, China, the Congo, Egypt, Malaysia, Mexico, Syria, Trinidad and Tobago, and Tunisia, and Zaire.[83/]

Prospects for future production are uncertain, of course. Global proven reserves stand at 646 billion barrels and most geologists anticipate that an amount equivalent to total past production and present proved reserves may ultimately be discovered and extracted from the earth's surface.[84] A large proportion of this amount is likely to come from non-OPEC LDCs -- perhaps as much as half of all future discoveries.[85]

The non-OPEC LDCs and their adjacent costal areas, contain most of the world's potentially oil-bearing sedimentary basins that are still unexplored. Drilling density (number of wells per square mile of geologically promising territory) in the non-OPEC LDCs is less than 1% that of the United States. Some fifty times more wells have been drilled in geologically comparable terrain in the U.S. than in Latin America, and nearly a thousand times more than in developing countries of Africa.[86]

Although most of the wells in a mature drilling area such as the U.S. are to develop previously developed fields, it is clear that the oil potential of most LDCs is still largely under-explored.

Since oil and gas exploration remain largely dependent on the international oil corporations and drilling companies, some promising LDC areas may have been neglected either because of fear of foreign exploitation on the part of the governments involved (or fear of contract abrogation or expropriation on the part of the companies) or because deposits are too small to offer the companies a reasonable likelihood of an exportable surplus.[87]

Even if an LDC discovers new or additional supplies of petroleum, it may decide that selling on the international market would be even more beneficial than consuming the oil domestically. Such a decision would not necessarily be contributing to a conspiracy by the rich countries to continue to hoard the world's petroleum to themselves. Rather, it may simply be of

greater value to an LDC to export its crude oil at the high prevailing petroleum prices rather than to invest in costly refining and distribution systems for itself. Similarly, the country is almost certain to be better off if it applies the foreign exchange earnings for such sales to developing a less petroleum-intensive or alternative energy system based on sustainable domestic resources, such as available hydro sites or even of natural gas, which cannot be as readily exported as petroleum.*

Several non-OPEC countries are already minor exporters of natural gas (Afghanistan, Bolivia, and Brunei),[88] and several others (e.g., Bangladesh)[89] possess considerable resources that could be developed. The primary barrier to utilization of natural gas is the investment required for pipeline systems to transport the gas from production areas to individual consumers.

Natural gas reserves are usually discovered in the course of exploration for petroleum. But, unlike oil, without a pipeline transportation system the gas is virtually worthless, so it is usually flared, or burned off during oil production. For the world as whole, about one eighth of annual production is flared.[90] The proportion of gas flared in the LDCs is probably much higher.

2. Coal

Global coal reserves are generally considered to be vast, probably 9-10 times more than known or anticipated petroleum and gas resources.[91] But of this amount the LDCs are presently known to have only 10%, and nearly 94% of these are in India and China.[92] In contrast, Latin America and Africa combined possess less than 1%.[93] It should be noted, however,

* China has about 20% of the world's population but produces less than 3% of the world's oil production. Nevertheless, China manages to export 30 million barrels per year.[94]

that most LDCs that have begun significant industrialization (that would normally have stimulated efforts at coal exploration) have done so in the post World War II era of cheap petroleum, so many countries have never even seriously examined their coal potential before and large areas of the LDC remain totally unexplored for coal.

Also, with the notable exception of China,[95] small and lower grade deposits have generally been ignored. But in view of rising petroleum prices, such deposits may now be very attractive for local and regional markets. Even if there are no industrial grade deposits in a country or region, it may be worthwhile to develop low-grade deposits for domestic use (e.g., coal briquettes for domestic heating and cooking) as an alternative to scarce firewood or imported kerosene.

3. Oil Shales and Tar Sands

Tar sand deposits have been identified in only ten countries, most notably in Canada, the Soviet Union, Romania, Albania, and Trinidad. Recovery of oil from tar sands has been attempted in each of these countries, but without commercial success. Among LDCs, areas with known but unexploited deposits are Venezuela, Colombia, Malagasy Republic, the Middle East, and West Africa.[96]

Oil shale deposits have been identified in a number of LDCs: Costa Rica, Cuba, Cyprus, Israel, the Malagasy Republic, Mali, Morocco, Syria, Lebanon, Jordan, Somalia, Thailand, and China. Brazil and Morocco both have sizeable resources, and both are building commercial scale shale oil extraction facilities.[97]

The $CO_2$ Question

A number of tests and continuous readings since 1958 have demonstrated

a marked rise in the carbon dioxide ($CO_2$) content of the atmosphere, mostly due to combustion of fossil fuels.[98/] It has been estimated that, at present fossil fuel consumption rates, average global temperatures could rise one degree by the turn of the century.[99/] The effect of such a temperature rise is still uncertain; it could lead to a dramatic change in rainfall or wind and temperature patterns.[100/]

The climatic effects of shifts in $CO_2$ balance will be felt across national and continental boundaries; both industrialized and developing countries have an interest in monitoring $CO_2$ effects and moderating $CO_2$ production.

4. Nuclear Fission

Nuclear power offers LDCs the promise of large amounts of relatively inexpensive electricity and the prestige of possession and use of the most advanced technologies. Unfortunately, in the LDCs -- as elsewhere -- these promised benefits are becoming increasingly problematic. Even more so than other energy technologies, the benefits of nuclear power are complicated by a number of serious economic, environmental,public safety, and political and security problems.

By mid-1977 the LDCs had installed capacity of nuclear power plants amounting to about 2,000 megawatts (MW) or about the equivalent of two ordinary size reactors in the U.S. The International Atomic Energy Agency (IAEA), however, expects that amount to be increased by 100 or even 200 fold by the turn of the century.* [101/]

Only Pakistan, India, Argentina, and Taiwan presently have operating nuclear

*293,000MW - 437,000MW

power reactors, but they will be joined during the next several years by a dozen other LDCs: Brazil, Iran, Mexico, South Korea, Cuba, the Philippines, Indonesia, Kuwait, Turkey, Egypt, and Libya. The International Atomic Energy Agency (IAEA) estimates that an additional 17 LDCs may be generating nuclear electricity by the year 2000.[102/]

There is a basic electrical engineering rule of thumb that major power grids should receive no more than 10%-15% 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 technical and economic reasons), a grid should be at least 7000 megawatts in capacity to make use of one.[103/] This, theoretically, eliminates all but the largest LDCs and those smaller countries that interconnect their grid systems.

There has been a continuous trend toward ever-tighter safety and operating standards for nuclear power plants in the developed countries. There is some concern, however, that perhaps because of the cost of "marginal" safety improvement, both reactor vendors and the LDCs themselves may not be ensuring that the most up-to-date safety devices and procedures are deployed on nuclear plants in the LDCs.[104/]

Politically, nuclear energy poses two broad problems. One is the question of dependence. For the foreseeable future, most developing countries would have to rely on costly imported technology, materials, training and supervision, from the industrialized countries. Processed uranium fuels also are available only from the U.S. and several other industrialized countries. In short, many LDCs face the prospect of trading dependence on imported oil for dependence on imported nuclear fuel and technology. A second problem is that the increase in international safeguards against diversion or theft of plutonium or enriched uranium, gives

rise to very sensitive questions of political sovereignty.

The future of nuclear power in the developing countries will depend largely on development of new fuel cycle and reactor systems, (especially of smaller more "appropriate" reactor sizes) and on the resolution of major technical issues (safety, waste disposal, decommissioning, etc.) and related political questions by the industrialized countries in their own nuclear program.[105]

## III. The Renewables

### A. Resources and Technologies

#### 1. Introduction

The conventional energy sources all have the disadvantage of being depletable, and of becoming steadily more expensive as they become depleted. The renewable energy resources, the incoming energy resources that are constantly replenished by the sun or geophysical forces have their share of disadvantages also; they are diffuse, requiring expensive capital investments to tap substantial quantities, they are also generally intermittent, varying according to diurnal and seasonal cycles. But a basic question is whether or not they would be adequate to sustain large energy conversions inherent in modern economies. The answer theoretically is yes, because their total quantities are vast.

#### 2. (Direct) Solar Potential

Under optimum conditions, i.e., on a clear day near the Equator, each square meter of the earth's surface receives about 6-8 kilowatt hours (kwh) of solar radiation.[106] Virtually all of the land areas occupied by the developing countries lies between the latitudes of 40° north and 40° south, for which a conservative average would be about 4 (kwh) per

square meter per day. Since the developing countries (including China) total about 79 million hectares of land surface, it can be calculated that they annually receive some 7.2 terawatt hours ($10^{12}$kwh or 890 billion tons of coal equivalent) worth of solar energy. This is more than 600 times greater than 1.4 billion tons of coal equivalent of commercial energy that LDCs presently consume. If only two percent of this incoming solar radiation were converted at 20% efficiency, some 3.6 billion tons of coal equivalent of energy could be produced, or nearly three times more than their present total commercial energy consumption.

Solar radiation is, of course, a periodic energy resource that varies according to daily and annual cycles and according to local atmospheric and weather conditions. There may be considerable differences in average quantities and patterns of solar radiation received at sites that are close geographically, so local measurement is helpful in maximizing efficient equipment.

Solar cooking, distillation and drying techniques all involve low temperature heat. Most solar cookers have been technical successes and cultural failures. Work is underway on several new approaches that permit solar cooking indoors, away from the sun. Hot water or steam can be routed into an oven or used in conjunction with other fuels to shorten cooking times. Cooking directly in the sun may prove useful to small urban enterprises such as beer brewing and bread making.[107] Solar distillation of dirty or brackish water has been used for many years. For stills producing 25,000 to 50,000 gal/day in remote areas solar is usually competitive with conventional thermal stills today. Solar crop and timber drying is relatively simple and effective, and is beginning to receive widespread attention.[108]

Solar water heaters are a rapidly growing industry in many countries: Japan, Israel, Australia, and the United States. One of every five homes in Israel now has a solar water heater, and in the Northern Territories of Australia, solar water heaters are required by law on all new government buildings. Japan has over two million units in operation, with several hundred thousand being sold annually. Solar water heaters are also produced and used in a growing number of LDCs, most notably in Malaysia and Niger.[109]

Higher temperatures -- 100° to 300° C -- suitable for most industrial applications -- can be produced by concentrating the sun's rays on a single point or along a narrow axis. Solar furnaces of several thousand degrees provide temperatures adequate even for specialized metallurgical procedures.

Virtually any industry that needs heat could use the sun as a heat source. But the higher the temperature that is needed, the more solar energy that must be converted, and the higher its cost. Therefore, it often makes most sense to use relatively inexpensive low concentrations of solar heat to partially or pre-heat hot water or steam. For example, at the Kaira Amul dairy's pasturization plant in India, hot water for dehydrating milk is preheated by a simple solar collection system, to 80° C, and then further heated to 210° C by fuel oil. But the solar preheating means that they have reduced their total oil consumption by more than 1350 barrels of oil per year.[110]

In the U.S., industrial process heat is being provided by solar concentrating collector systems for a soup canning plant in California, a concrete block factory in Pennsylvania, and a fabric-drying facility in South Carolina, The potential for industrial applications is almost certainly even greater in most developing countries, however, where sun-

light is more consistent and plentiful and where the costs of conventional fuels are considerably greater already.[111]

Solar cooling techniques can also range from the simple to the highly sophisticated. In hot, dry climates, the cooling action of evaporation can be used simply by running water over the container of items to be cooled. Solar absorptive air conditioners and refrigerator units are also becoming practical. They work best when the sun is hottest, i.e., when cooling is most important.

Photovoltaic cells are expected by many researchers to ultimately prove the least expensive of all technologies for producing electricity. They are already being used in a few instances in LDCs: to power educational television sets in remote classrooms in Niger and India, to power radios in the Andean region of South America, and for a few irrigation pumps in West Africa.

Deterioration of the photocells encapsulations and diminished power performances have been reported from some of the African installations, but these appear to be only minor technical problems.[112] The major barrier to widespread use of photocells in LDCs appears to be simply their initial capital cost -- and this is rapidly declining. If the present U.S. Department of Energy (DOE) cost target of $0.50 per peak watt by 1986 is met, as it appears it will be, this barrier will have been largely removed.[113] If total system cost can be brought down to 40-60 mils/kwh by 1990 (in 1975 dollars) -- also a DOE target -- it will be possible to produce electricity even in remote rural areas of LDCs for less than it costs for electricity in most LDC urban centers today. Caution is in order, however, To date there has been only limited testing of photovoltaic cells under the physical, social, and economic conditions actually found in the villages of LDCs.

Photocells are probably already economically attractive for many applications where small amounts of electricity are needed in areas remote from other power sources. World Bank experts have calculated that photovoltaic cells with battery storage would be less expensive than diesel generators or primary batteries for powering educational televisions in rural villages in the Ivory Coast.[114] Similarly, a Massachusetts Institute of Technology study concludes that even at today's prices photocells would be a cost competitive power source for shallow irrigation pumps in Chad.[115]

3. Wind

Globally, the average wind velocity in the lower atmosphere is roughly 9 meters per second, or the equivalent of about 1/2 kilowatt per square meter of "windmill area".[116] Total windpower available at the surface of the earth has been estimated to amount to roughly 20 billion kilowatts.[117] Unfortunately, there are no comprehensive estimates available of wind power potential in the developing countries.

Equatorial regions (between 20°N and 20°S latitude) generally have relatively modest wind regimes, although there are many local exceptions. Within the latitudes of 30°N to 40°N and 30°S to 40° S, however, normal geoclimatic conditions produce two belts of high atmospheric pressure. Wind currents in these regions are usually strong and reasonably constant. They were dependable enough to be relied upon by sailing ships as "trade winds."

Generally speaking, wind is an even more variable energy source than direct sunshine. Since it results largely from temperature differentials on the earth's surface and within air masses, it varies considerably according to general diurnal and seasonal patterns. But it is also significantly affected by surface terrain: mountains and hills, valleys,

even individual trees and buildings. Because of this, any measurements of wind resources must be highly specific to the site on which the wind-powered machine will be located.

## 4. Biomass Resources and Potential

### a. Woodfuels

Data for woodfuel resources in the LDCs are grossly imprecise. Estimates of tropical forest area -- the basic source of the resource -- vary from less than 1.5 billion hectares[118] to more than 3 billion hectares.[119] UN statistics show that more than five sixths (86%) of all wood consumed in LDCs is used for fuel. (See Table 6).[120]

UN statistics are based on data from national governments. In most countries wood consumption is not carefully monitored, and woodfuel figures may at best be estimates based on a small sample of areas from within the country. In one country where the UN Food and Agriculture Organization (FAO) sponsored a fairly comprehensive woodfuel consumption survey, the government figures were found to be less than 2% of the actual amount.[121] This is hopefully a worst case, but the official UN figures should be considered to be minimum estimates.

Just as petroleum is valued as a feedstock for the chemical industry, wood has important non-fuel uses as well. It, too, can be used as a raw material for cellophane and other synthetic materials. It is also essential for paper and pulp, and lumber remains the world's leading building material. The global timber industry competes with fuel needs for the world's forest resources. Forests are also destroyed by clearing for agriculture. Large areas of tropical South America, Africa, and Southeast Asia have long been subject to slash and burn agriculture.[122] But until recent years, when

rapid population growth has increased the need for agricultural production, neither agricultural clearing nor firewood consumption adversely affected the global forest balance.

Some experts are now concerned that total consumption of firewood and other forest products is approaching the natural increment, or annual growth rate, of the world's forests. Even if human consumption of wood is only a fraction of annual growth for the world as a whole, for an increasing number of localities it is clear that human demands are exceeding natural supply. For example, at present rates of wood removal and deforestation, Senegal's forests will have entirely disappeared in 30 years, Ethiopia's in 20, and Burundi's in 7.[123] By the turn of the century, the world's tropical forests will survive only in a few permanent parks and sanctuaries.[124]

Ironically, if a large portion of the annual growth were removed in a manner consistent with sound forestry or silvicultural techniques, the growth rate and annual yield of most forests could be increased, Productivity of natural forest areas varies tremendously. In dry and savannah forest areas, the annual yield may be only 2-10 cubic meters per hectare. In moist and rain forests, natural yields average anywhere form 10-30 cubic meters per hectare per annum. But with plantations of fast growing varieties such as eucalyptus, grown under favorable conditions, annual yields of up to 50 and 60 cubic meters per hectare have been recorded over short rotations (6-8 years).[125] Even if just the unproductive "overstock" were removed from standing forests, productivity could be significantly increased.

As it is, Derek Earl has calculated that the developing countries alone are presently losing an equivalent of 3.5 millions tons of coal by not fully exploiting the potential of natural incremental growth.[126]

Keith Openshaw, of the University of Tanzania, has suggested that

natural forests and plantations covering only about one tenth of the world's land area (they presently occupy approximately one fifth) producing an average of 10 cubic meters of roundwood per hectare per annum could readily satisfy anticipated demand for all forest products in the year 2000.[127/]

Deforestation results not only in the loss of woodfuels, but affects energy supply in other ways also. The loss of forest area deprives draft animals of an important element of their forage in many areas. Erosion and siltation reduce productivity on adjacent agricultural lands. The silt washed down from hillsides and into waterways often ends up settling behind the first dam it comes to, thereby reducing the power and water storage potential of hydroelectric reservoirs. Finally, loss of forest cover leads to reduced retention of groundwater. As a result, local water tables may decline, meaning that wells must be sunk deeper and the water pumped up from lower levels.[128/]

Reforestation projects might well be the single most important portion of any LDCs energy development program. In addition to a high net energy return, reforestation projects are labor intensive, require relatively little capital, and produce numerous side benefits: food and fiber production, cash crops in some instances, forage for livestock, and environmental protection for water and soil. For people of the highlands of Tanzania, for example, where each person would have to replant eight trees to replace the woodfuel that they consume during a year,[129/] reforestation projects combined with the widespread introduction of more efficient wood stoves, may be an essential energy policy.

b. Crop Residues

Although reasonably good data are available on crop production, residues are seldom measured. Estimations of total residue amounts are difficult because stem, stalk, and leaf quantities can vary significantly

Table 7

**ESTIMATES OF ANNUAL CONSUMPTION OF AGRICULTURE RESIDUES AS FUEL**

(including bagasse, rice straw, hay, cotton, sticks, etc.)

| Source of Estimate | Country or Region | Millions of tons | Millions of tons of Coal Equivalent (MTCE) |
|---|---|---|---|
| 1 | world | | 10 |
| 2 | China | 70 | 33 |
| 3 | India | 40 | 19 |

Source:

1. D. F Earl, Forest Energy and Economic Development, Clarendon Press, Oxford, 1975.

2. V. Smil, China's Energy: Achievement, Problems, Prospects, Praeger, New York, 1976.

3. R. Revelle, "Energy Use in Rural India," Science, Vol. 192, June 4, 1976.

from field to field even for a particular crop. Perhaps the greatest difficulty in determining crop residue availability for fuel purposes is that residues have other, perhaps "higher", values for non-fuel purposes: as construction and industrial materials, as fodder for livestock, and for regeneration of soil quality and protection against erosion.

The few available estimates of present crop residue use are shown in Table 7. (Earl's figures for the world are clearly out of line with what are probably fairly accurate estimates for China and India.)

c. Animal Waste and Biogas

The only available estimates of consumption of cattle dung for fuel are compiled in Table 8. Cow dung has traditionally been burned in an open fire as a fuel in the Asian subcontinent, and in parts of the Middle East, Africa, and Latin America. Consumption of cattle dung for fuel appears to be growing in most of these areas due to woodfuel scarcities.[130/]

India began extensive work with the possibilities of cow dung, or gobar gas, biogasification in the 1940s. About 46,000 gobar biogas digestors are presently operating in small farms (having 4 or more cattle) and villages in India.[131/] Conversion efficiency of the gobar's energy content when converted to biogas is as high as 60% compared with about 5% when the dung is dried and burned directly in cooking over an open flame. Furthermore, the residue from biogasification retains the full value of the original dung as an organic fertilizer. In direct burning of the dung this value is lost.

A few thousand biogas units are also in use in Taiwan on individual family owned pig farms. The most impressive use of biogas, however, is in mainland China, where nearly 5 million family and community biogestors have been installed since the early 1970s.[132/] The Chinese have developed a

TABLE 8

ESTIMATES OF ANNUAL CONSUMPTION
OF COW DUNG AS FUEL

| Source of Estimate | Country or region | Millions of tons | Millions of tons of coal equivalent (MTCE) | Millions of barrels of oil equivalent (MBOE) |
|---|---|---|---|---|
| 1 | India | 100 | 58.0 | 37.7 |
| 2 | Pakistan | 11 | 6.3 | 4.1 |
| 3 | Turkey | 14 | 8.1 | 5.3 |
| 4 | World | 150 | 90 | 58.5 |

SOURCES

1. National Commission on Agriculture, Interim Report on Production Forestry -- Man-made Forests, Government of India, New Delhi, 1972. (cited in Earl, reference 4 below).

2. C. Lerche, and A. S. Khan, An Estimate of Timber Trends in West Pakistan, U.N. Food and Agriculture Organization, Rome, 1970. (cited in Earl, reference 4 below)

3. T.T.K.C., Turkiyede yakit problemi ve hal careleri, Turkiye Tabiatini Koruma Cemiyeti Yayinlari, Ankara, 1962. (cited in Earl, reference 4 below).

4. D. E. Earl, Forest Energy and Economic Development, Clarendon Press, Oxford, 1975.

simple and very inexpensive system that utilizes readily available dung, human night soil, crop residues and other organic wastes. The units seem to be highly successful even if not of high efficiency or sophistication.[133/] The rapid development of biogas technology in China is largely a reflection of the tremendous ability of the government to mobilize its rural population, but an even more significant key to China's success is probably simply that in China (unlike much of India and most other developing regions) it is customary to keep livestock in family community court yards. This greatly facilitates the collection of dung and bedding for biodigestion.[134/]

d. Animal Draft Power

Draft animals are a time-tested energy technology applicable for a variety of heavy agricultural tasks and transport. Presently there is roughly one draft animal per 10 people in the LDCs, but their distribution is highly skewed toward parts of Asia, Latin America, and a few areas of Africa.[135/] Draft animal power is allocated roughly 75% for farm work and 25% for transportaion and domestic use.[136/] They provide not only energy but meat, milk, hides, body warmth in winter, and dung for fertilizer and cooking.

The cost of draft animals depends primarily on the amount of land available to feed them over and above human needs. For every acre cultivated by draft animals, roughly a third of an acre must be reserved for producing fodder.[137/]

Draft animals are a fairly sophisticated technology, requiring careful husbandry, training, vaccinations, and specialized equipment. Animal diseases, especially trypanosomiasis (sleeping sickness) are a major limitation on draft animal use, especially in large sections of Africa.

A regional estimate of total cattle and horse draft animal populations is presented in Table 9. One authority has calculated that if an

Table 9

**DRAFT ANIMAL POPULATIONS OF DEVELOPING COUNTRIES, BY REGION**

All figures in millions or heads in 1975

| | TOTAL POPULATION (1) | | ESTIMATED NUMBER USED FOR DRAFT (2) | |
|---|---|---|---|---|
| | Cattle | Horses | Cattle | Horses |
| Africa | 143.3 | 16.3 | 42.9 | 9.7 |
| South America | 215.1 | 27.9 | 64.5 | 16.7 |
| Asia | 351.9 | - | 105.6 | - |
| Oceania | .7 | .7 | 0.1 | .04 |
| TOTAL | | | | |

Source:

(1) United Nations, Statistical Yearbook 1976, New York, 1977.

(2) Calculated as 30% of total cattle population and 60% of total horse population.

Note: Horses includes mules, asses, and donkeys.

average draft animal (bullock or horse) generates 500 watts of power harnessed at 10% efficiency for 8 hours a day, 250 days of the year, the average draft animal would produce about 100 kilowatt hours[138/] annually. The total estimated draft animal population of LDCs would thus produce nearly 25 million megawatt hours of energy or the equivalent of one tenth of all their hydro electricity.

5. Hydropower Resources and Potential

Nearly a quarter of global electric power capacity is hydropower. Annual production from this capacity makes up about 44% of LDC electricity production.[139/]

Because hydropower is directly related to the volume of water flow and the vertical height it falls, many of the world's largest hydro sites are found in mountainous areas with heavy tropical rainfalls. But because these areas are generally remote from population and industrial centers, transmission costs, alone, may be greater than the cost of the dam and generating facilities combined. A number of prime hydro sites are located along rivers that are also international boundaries, so their development requires bilateral or even multilateral cooperation on joint facilities and sharing of produciton. Regional or downstream effects of the dam (displacement of settlements in the reservoir area, changes in water flow patterns downstream, etc.) must also be shared. Most hydro projects in LDCs have been constructed with financing (usually long-term, low interest loans) from international banks and development assistance agencies. Construction costs are typically about $600/KW, and since most hydro projects are multipurpose, providing flood control and water stopage for irrigation as well as electric power generation, they are generally an attractive investment.

In terms of power generation, exploitation of larger power sites poses some particular problems for LDCs. For example the fact that completion of new hydro facilities means a very large and sudden increase in power availability makes it difficult to bring about an orderly evolution of electric power use in smaller countries, or in regions just gaining electricity for the first time. Either the generating capacity is significantly under-utilized until local demand gradually expands or it is channeled to a few large individual power consumers -- new mines, fertilizer plants, or heavy industry. Moreover, costs may often be underestimated: in addition to the cost of constructing the hydropower installation itself an equivalent or greater amount must usually be invested in transmission and distribution equipment.

These and other (environmental and social) problems associated with large scale hydropower development might be largely mitigated through use of small- and miniscale hydropower plants where they are suitable. Small-scale hydropower has been virtually ignored as a major source of energy supply since the early part of this century, but recent reexaminations of its potential sparked largely by the apparently tremendously successful experience of the Chinese suggest that it now has significant potential, both in the developed countries and in LDCs.[140/]

A recent workshop in Tanzania sponsored by the U.S. National Academy of Sciences concluded that mini-hydro units would be cheaper than diesel autogeneration in small Tanzanian villages. It appears that it would also be less expensive than electricity from large scale (centralized) hydro installations (including transmission costs) with virtually none of the environmental and social costs associated with the large units. Equally as interesting was the workshop finding that in Tanzania, considered to be

essentially a dry or even an arid country, a majority of the rural population lives adjacent to year-round streams that might be suitable for small-scale hydro development.[141/]

Another recent workshop in Nepal found that in the hill area of that country -- which suffers perhaps the severest deforestation and erosion of any region in the world -- there is an exploitable power potential of more than 3½ kw per person from mountain streams and rivers. One of the most interesting ideas considered was the feasibility of producing nitrogen fertilizer through electrolysis or electric arc processes powered by mini-hydro stations. Compared to the cost of importing and transporting nitrogen fertilizers to remote hill areas, these processes seem very promising economically. The electric arc processes would also produce substantial amounts of heat that could be put to productive use. The workshop concluded that "small scale hydropower development is considered essential when coupled with a program of afforestation" to increase agricultural productivity and to prevent further environmental degradation in Nepal. "For a typical hill village of 250 persons, a 16-18 kw hydropower plant and a 30-40 hectare managed woodlot can provide significant irrigation, fertilizer, domestic water supply, lighting, and small industry returns while having enormous social benefits."[142/]

6. Geothermal and Tidal Potential

a. Geothermal

Not surprisingly, geothermal resources have been most carefully examined in areas where their presence was obvious, especially in areas of recent volcanic activity. But as Table 10 indicates, exploration is very

Table 10

## GEOTHERMAL RESOURCES

| REGIONS AND COUNTRIES WITH SIGNIFICANT RESOURCES | GEOTHERMAL (Description of Resource) |
|---|---|
| Latin America | |
| Argentina | Surface manifestations |
| Chile | Antofagasta: 14 MW potential (2 wells); wet steam |
| Mexico | Cerro Preto: 75MW current production (since 1973) 355 MW by 1981; wet steam; Pathe, exploration of dry steam potential |
| El Salvador | Ahuachapan: 30MW production (since 1975); wet steam 60MW by 1977 and 90MW upon completion |
| Nicaragua | Central Volcanic Province: exploration and evaluation |
| Costa Rica and Guatelama | under exploration |
| Panama | 4 joint Panama/U.N. exploration & assessment projects |
| Other South America | surface manifestations |
| Asia | |
| Central & South Asia except India | surface manifestations |
| India | Ladakh: exploration of wet steam, 1973 |
| Turkey | Kizildere: 30 MW wet steam planned (1977) ;space heating for Afyon city |
| China | Kwantung: commercial production from 1958 |
| Taiwan | Tatun: 100MW wet steam planned as of 1974 |
| Philippines | Albay and Los Banos (Luzon) 50MW expected on line, Leyte, 100 MW potential |
| Indonesia | Central Java and Bali, exploration W. Java, 30MW under construction |
| Korea | |
| Oceania | surface manifestations |
| Africa | |
| Ethiopia | South Central Lakes district: 100MW production (1975) to Addis Ababa;A-far Region: perhaps enough potential for all current African electricity production |
| Kenya | several areas of good potential |
| S. and other E. Africa | surface manifestations |
| Zaire | Kuabukwa, Shaba Province: 220 kw capacity; steam electric; on stream |
| N. Africa and Middle East | surface manifestations |

Source: Knight, Kathleen and Robert E. Bowen, "Geothermal Energy as a Potential Alternative Energy Source for Less-Developed Countries," paper delivered to Annual Convention of the International Studies Association, March 17, 1972, pp. 9-13, except Zaire entry, from, U.N.E.C.A., "Energy Resources in Africa" prepared for Second Africa Meeting on Energy, Accra, Ghana, 1-2 March, 1976, p. 29.

preliminary at this point even in these countries. Most of the actual development is being tailored toward meeting urban demand for electricity (e.g., in Ethiopia, Philippines, and El Salvador). Interestingly, some of the largest potential producers are those that have been generally energy-resource poor countries (e.g., East Africa and Central America).

b. Tidal Resources

Information on known exploitable tidal power sites in developing countries is summarized in Table 11. Tidal resources are much easier to estimate than many other resources. But since an exploitable site requires a tidal range of 15 feet or more, (which would mean about 10 megawatts per square kilometer of storage area), the number of sites in the world is very limited.

B. Renewable Strategies

Perhaps the ultimate attractiveness of the renewable energy sources is that for all but those few countries blessed with large fossil or fissile fuel endowments, renewable sources are the only energy alternative likely to meet urgent needs for development.

In the United States and Western Europe, a great deal of debate has recently arisen about the goals and names of energy strategies.

In October of 1976, an article by a physicist in the journal Foreign Affairs, catalyzed what might best be characterized as a "religious war" among energy researchers and government planners. In this article, Amory Lovins sketched out what he perceives to be an essential energy choice confronting the U.S. and the world as whole. As petroleum production peaks and then begins to decline during the next two-three decades, Lovins suggests that we can either choose to develop increasingly large and centralized, hard technologies, such as synthetic fuels from coal and oil shales or nuclear breeder reactors, or we can begin to develop decentralized, soft energy

Table 11

## TIDAL RESOURCES

| Countries with Significant Resources | Resources: Tidal amptitude in feet and/or potential energy |
|---|---|
| Latin America | |
| Argentina | San José Gulf Region: 12 x $10^9$ kwh/yr. Production potential |
| Chile | Magellan Archipelago: 20 + feet |
| Mexico | Rio Colorado entrance of: 36 + feet |
| Brazil | Maraca Island: 27 + feet |
| Asia | |
| Burma | Rangoon: (mean range) 13 + feet |
| India | Sunderbaus and Gulfs of Canbay and Kutch: total 300 mw capacity |
| Republic of Korea | Seoul River, entrance of: 29 + |

Sources: Arthur D. Little, Inc., An Overview of Alternative Energy Sources for LDCs, Report of A.I.D. #C-77105, 1974, pI-B-6; Considine, Douglas M., ed., Energy Technology Handbook, (McGraw-Hill: New York), 1977, p. 8-40; U.N. Department of Economic and Social Affairs, New Sources of Energy and Economic Development, 1957, p. 68.

technologies, such as the various forms of solar energy that are already distributed near to consumers and can readily be scaled to match the immediate level of energy needed. 143/

The energy establishment, including the large oil companies and the electric utilities, are clearly on track toward "hard" energy technologies. They know that the technologies that they presently work with, large grids and pipelines or related delivery systems, have been proven by experience -- experience the soft technologies lack. Proponents of the "soft path" suggest, however, that by increasing the scale and centralization of hard facilities, the costs are also rising. They urge that costs of investment and rising fuel costs be considered, as well as the impact on social systems and the environment, including risks from possible accidents. 144/

The arguments in many respects are largely philosophical rather than technical. And they parallel very closely the arguments that have evolved over the past decade about economic development strategies -- whether the focus should be on developing centralized industrial infrastructures or on building up from the grassroots. It seems likely that if the soft technologies prove to be practical for application in rural LDCs, soft, or "appropriate" technology approach to energy development would have many attractions to an LDC government interested in a development strategy based on rural and agricultural development and focussing on the welfare of the ordinary citizen.

A good example of the difference between a soft and a hard type of energy development strategy for rural fertilizer production has been calculated by A.K.N. Reddy of the Indian Institute. Reddy has calculated the advantages of fertilizer production through use of decentralized biogas plants rather than conventional coal-fueled plants. A single large coal-fueled fertilizer factory would produce 230,000 tons of nitrogen fertilizer

per year. But all of the biogas plants would cost $15 million less to build, and all of the money invested would remain within India, whereas some $70 millions would have to be spent on imported technologies and materials for the conventional plant. Some 130 times as many jobs would be provided by the biogas strategy, and those jobs would be scattered throughout the countryside, where employment is desperately needed. Transportation costs would be insignificant with the biogas-produced fertilizer, because it is produced where it will be used. Last but not least, the conventional coal-fueled plant would consume a tremendous amount of energy, enough to meet the present needs of 550 Indian villages. The biogas plants, however, would produce enough fuel to meet most of the energy needs of all the 26,000 villages in which they are located.[145/]

While we are sympathetic to most of the arguments made for soft energy technologies, our argument here is focussed on the particular value of renewable energy resources. Most LDCs already have economies largely based on renewable energy resources. Many LDC leaders might note disparagingly that they are already "stuck" in such a situation; up to 90% of their people are still dependent on firewood for cooking.

But far more effective use could be made of these resources, even of "primitive" firewood resources. The efficiency of cooking stoves could at least be doubled, as could the efficiency with which wood is traditionally converted into charcoal. The growth rates of existing forests could be vastly increased, and large areas could be reforested. At the same time technologies for capturing and harnessing local solar, water, wind and water energy could be put in place to the extent they prove to be practical. The result would be improvements in welfare and productivity, including the increased time that would be available for pursuits other than fetching firewood and water, grinding grain, etc. For the poorest people -- the

three quarters of the LDCs' rural population that will still live without access even to electricity by the turn of the century, this may be the only energy policy strategy that is possible. It can also be used as a basis for increasing agricultural productivity, and developing new rural industries.

For the market towns, small cities and even in the urban areas, medium and large scale applications of renewable technologies may prove equally promising . Hydropower is usually the least expensive means of producing electric power on any scale. Some solar technologies show promise of being competitive with any of the conventional fossil fuel technologies within the next decade, even in the largest port cities, where fossil fuels are least expensive.

The fact that conventional fuels presently are less expensive in urban areas has some significant effects and limitations on industrial development. The price differential, due to transportation and distribution costs between large urban areas, particularly port cities where fossil fuels are imported, and the countryside or interior regions of a country may be considerable. If locally available renewable energy sources can be economically tapped, however, there would be virtually no difference between the price of power in the large cities and the interior areas. As a result, one of the greatest biases toward uneven, concentrated urban development would be eliminated. Small industries and productive activities could more readily be established closer to raw materials and domestic markets. This would make truly decentralized development strategies feasible for the first time in the developing countries.

In terms of resource availability and technologies, renewable energy resources could readily satisfy the world's energy needs. The key questions remain economics and timing. How soon can costs be brought down to levels competitive with conventional energy sources? How rapidly can the

industries that produce, distribute, install, and maintain new solar technologies be developed? How rapidly can individuals, firms, and governments afford to "roll over" capital stock -- housing, factories, and power generation equipment -- to be replaced by the new sources. How readily can the new technologies be integrated with existing conventional energy systems?

For the LDCs, some particular questions arise: How can the new energy technologies be successfully introduced into traditional societies; i.e., how long will it take, what effects will result from introducing new energy technologies in traditional rural villages? And how can it be effectively done?

These questions are comparable in importance to the questions presently being asked about the feasibility of developing new synthetic fuels or new nuclear fuel cycles. Their answer deserves a similar level of study.

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