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New Directions For A.I.D. Renewable Energy Activities

Final Report

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EXECUTIVE SUMMARY

OVERVIEW

This report responds to the Agency for International Development (A.I.D.) Administrator's call for a critical reassessment of the Agency's experience with renewable energy. It describes today's climate for renewable energy technology in light of lower and unstable world oil prices, declining fuelwood resources, and the present commercial status of various renewable technologies. General lessons learned in developing and applying renewable technology are also described, as well as priority applications and the appropriate role of the private sector. The report then sets out the proposed New Directions for A.I.D. renewable energy activities.

A.I.D.'s focus is on self-sustained economic development. Rural and agricultural development are essential prerequisites to achieving overall economic growth, and special attention is needed to address the energy requirements this development implies.

This report shows that while new renewable energy technologies have not had the far-reaching impact many had hoped in contributing to rural development, specific renewable technologies have demonstrated that they have a valuable role to play. A number of renewable energy technologies are now becoming economically and financially attractive in developing countries. Commercialization of these technologies offers considerable economic benefit to developing countries.

A major finding of this reassessment is that, to mount successful renewable projects, A.I.D. should rely on market forces to select which technology is best for which development application. This represents a significant shift away from past experience, which was too often technology driven and where Government played a large role in renewable energy technology selection and development. A.I.D.'s new direction for renewable energy emphasizes private sector development and assistance programs to stimulate market-driven applications of these energy sources.

WHY HAS RENEWABLE ENERGY BEEN GIVEN A HIGH PRIORITY?

Renewable energy technologies utilize direct solar energy, wind, flowing water, biomass, and/or geothermal energy as alternatives to petroleum or other non-renewable sources of energy. Use of renewable energy sources has been promoted in developing countries for several reasons. These include the following:

- Renewable energy sources are indigenous and available in large quantities in the developing countries.
- Renewable equipment can be small in unit size and fit the need for rural small-scale development applications.
- Renewables utilization has the potential to create rural employment and increase productivity.
- Renewable energy technology often has less severe environmental impacts than conventional alternatives such as fossil fuels.

In most developing countries, rural economies have subsisted by relying on renewable energy sources including traditional biomass and other indigenous sources. Fuelwood scarcity, however, poses a serious problem, requiring that more attention be given to improving the efficiency of utilization and to alternative energy sources. In 1980, it was estimated that of the 2 billion people who depend on biomass fuels, over half could not meet their minimum energy requirements from available sources without reducing the growing stock. It was further estimated that from 2 to 3 billion people may be living in areas of acute fuelwood scarcity by the year 2000.

Renewable energy technologies are sufficiently different from conventional energy systems, in terms of their higher first costs, greater perceived risks, and small scale of individual applications, to require alternative financing approaches (among other incentives and policies) in order to attract investors or buyers.

A number of constraints and problems, however, have been encountered in the effort to deploy new renewable technology. These have included the erratic course of international prices for oil products with which renewables compete, weak institutions for perfecting and promoting renewables, and the inherent difficulty of introducing new technology into an often subsistence-level rural economy. Distortions in energy prices, as well as other policies, have created an environment which stifles private sector initiative and seriously retards the introduction of new alternatives such as renewable technologies.

Given the experience to date and the above constraints and problems, what lessons have been

learned and what New Directions are appropriate for A.I.D. in its strategy to exploit renewable energy sources and technology?

LESSONS LEARNED

The main lessons learned in this reassessment are as follows:

- Large-scale introduction of new renewable energy sources through A.I.D. or other's efforts has not been achieved. This is due primarily to two factors. First, most renewable energy projects were R & D projects and were intended to develop technologies (and institutions), not to directly disseminate commercially mature technologies; and second, institutional weaknesses and unfavorable policy conditions constrained renewable energy implementation.
- While many R & D efforts have not succeeded, a significant number of technical approaches have been demonstrated to be reliable. Several renewable energy technologies such as small hydro, some biomass applications, remote solar applications, and others, have now matured sufficiently for commercial applications to proceed.
- Projects should avoid technology options that are commercially unproven, unless projects are explicitly designed to support technology development as part of an overall commercialization plan.
- Only renewables able to compete in the marketplace with conventional technology in terms of cost, convenience, quality, service delivered, and reliability, will normally be successful.
- Local user or "market" acceptance determines whether a new renewable technology succeeds or fails. User involvement or market testing in project design, implementation, and evaluation should be a project requirement.
- Renewables' market penetration is seriously impeded when other fuels are subsidized or other unfavorable policy conditions exist. Policy conditions require up-front attention in A.I.D. efforts to support renewables introduction.
- Project ideas and designs cannot simply be transplanted from place to place. Applications must be tailored to local market, physical, material, institutional, and economic conditions.
- Lack of attention to "after-sales" service, including maintenance, spare parts, and local skills development, has often proved fatal to both demonstrations and attempts to commercialize a technology.
- Local private sector marketing of technology for commercial purposes is the best way, where possible, to ensure successful dissemination.
- Learning from past experience is severely handicapped by lack of adequate documentation of successes and failures. Improved interchange of results and methods of application could make a major difference in the rate of future success.

ELEMENTS OF A.I.D. RENEWABLE ENERGY STRATEGY

Based on the lessons learned above, it is appropriate for A.I.D. to establish New Directions for its renewable energy strategy. These directions should recognize today's economic and technical realities, and integrate renewable options, where appropriate, as components of rural, agricultural, and other development programs. Long term energy price expectations should be used as a basis for decision making, and a diversified fuel mix that includes renewables should be encouraged. This strategy must be applied within the resource, social, environmental, and institutional situation of particular countries and even sites. Thus, no predetermined technology choice is possible; rather, a better informed judgement and case by case comparative evaluation is called for.

What are the overall objectives of A.I.D.'s New Directions?

First, to ensure the supply of appropriate "least-cost" sources of energy to strengthen rural development efforts, enhance agricultural productivity, and create rural employment opportunities.

Second, to support local and U.S. private sector initiatives to supply necessary energy services, technology, and capital in order to achieve self-sustaining solutions to energy problems.

Third, to place special focus on household energy problems through expanded biomass supply and improved utilization.

Fourth, to create the policy and institutional conditions required for sound energy sector development.

A.I.D.'s renewable energy program will be directed to support the following New Directions:

- **Private Sector Collaboration**

  Expanded cooperation between A.I.D., and U.S. and developing country renewable energy firms and developers to merge A.I.D. knowledge of country constraints and conditions and A.I.D. technical and financial support with private sector skills in design, manufacturing, and marketing.

- **Rural Development and Private Enterprise Support**

  Technical assistance to mission private enterprise and rural development programs will be increased to ensure provision of adequate renewable and other sources of energy for projects requiring new energy sources, to identify energy business opportunities and to provide information and training for A.I.D. staff on energy options for health, agriculture, and other rural development activities.

- **Training in Support of Renewables Commercialization**

  Renewable energy training sponsored by A.I.D. and related initiatives, will be expanded to support the Less Developed Country (LDC) private sector and stimulate the commercial use of renewables in water pumping, health, rural commercial-industrial applications, and decentralized electric power supply, among other rural development applications.

- **Emphasis on Implementation**

  Development of innovative financing schemes to assist in the commercial penetration of renewables into rural and dispersed private markets.

  Expansion of risk-sharing via feasibility study and other explicit support, such as targeted use of the A.I.D. commodity import program to facilitate U.S. and LDC private sector ventures to transfer, adapt, and market cost-effective rural energy systems.

  Further development and adaptation of energy production and utilization technology for selected high priority rural development applications, including adaptation of United States renewable energy equipment.

- **Coordinated Action**

  Reliance on greater donor coordination will be pursued to more effectively utilize and leverage A.I.D. resources and help develop the policy conditions necessary for the introduction of new energy sources

IMPLEMENTATION ACTIVITIES

Implementation Vehicles

The major implementing vehicles for the New Directions proposed above include the Renewable Energy Applications and Training Project (REAT), the Bioenergy Systems and Technology Project (BST), and centrally funded activities in the areas of household fuels, and energy and irrigation. All are ongoing projects or activities.

The Bioenergy Systems and Technology (BST) Project is intended to design, develop, and implement field projects using bioenergy systems. The Renewable Energy Applications and Training Project (REAT) has been responsible for the assessment of A.I.D.'s past experience with renewables and proposals for new initiatives to support rural and agricultural development.

Household fuel activities are another area of emphasis. Current work includes investigation of markets for briquette fuel substitutes made from coal and/or biomass residues, especially in countries experiencing increasing wood scarcities. Household fuel strategy development work, and a review of charcoal stove programs in East Africa are also being pursued.

The energy and irrigation activity is designed to promote the economic utilization of water for irrigation in A.I.D.-assisted countries.

Missions' Lead Role in Implementation. The above projects and activities are the centrally-funded and managed programs available for implementation of the proposed new directions in renewable energy. A.I.D. in-country missions, however, retain the lead implementation role in A.I.D. renewable activities, by virtue of missions' responsibility in the areas of project proposal, design, and implementation. New directions are, in large part, being proposed to stimulate and assist the missions to incorporate energy considerations (including renewable energy where appropriate) more fully into project design and planning. Missions are urged to contact the Office of Energy (S&T/EY) regarding issues or questions concerning renewable energy technologies, either in general or concerning specific applications.

INTRODUCTION

In November 1984, the Administrator of the Agency for International Development (A.I.D.) called for a critical reassessment of A.I.D.'s renewable energy activities. The objectives of the reassessment were outlined in a worldwide cable (State 345387). These were:

- to assess priority applications of renewable energy technologies, with emphasis on productive uses in agriculture and rural industry;
- to recommend development and application of those renewable systems which, when compared with alternatives, are the least-cost and site-specific solutions for supplying energy needs; and
- to suggest means of developing local private sector capability to market, manufacture, and maintain the most promising energy systems; and to involve the private sector at an early stage in A.I.D. projects.

Renewable energy resources first emerged as a major target of development assistance programs after the oil embargo of late 1973. During a time when oil prices were rising rapidly and supplies were insecure, energy suddenly became a high-priority public policy challenge in developing countries. At the same time, a new awareness of the transience of depletable fossil energy sources led to a global wave of enthusiasm for renewable sources, particularly solar energy. Research and development support grew, and donor organizations supported tests and demonstrations worldwide.

Developing countries themselves tended to view indigeaous renewable resources as promising answers to their energy needs, tied to new technology developments and donor interest. Renewable resources were seen as especially appropriate because they could be applied on a variety of scales and skill levels. These related closely to localized energy needs and resources, and offered attractive opportunities for new skills and institutions to be developed.

A consequence of this interest was the initiation of numerous renewable energy projects in developing countries, many of which were supported by A.I.D. A decade later, however, it is difficult to give an account of this experience. The general impression is that only a few of the projects have led to sustained energy supplies in A.I.D.-assisted countries due to concentration on research and demonstration, economic uncompetitiveness, and lack of implementation planning. Moreover, world oil prices have recently dropped, making it more difficult for alternative energy sources to compete economically.

Responding to the Administrator's request to both reassess experience with renewable energy technology and improve the capability of A.I.D. to implement its renewable programs, the Office of Energy, Bureau of Science and Technology, A.I.D., initiated a new Renewable Energy Applications and Training (REAT) Project in July 1985. According to the approved project paper, one of the key project components was to be a "review of lessons learned" from the experience with renewable energy technology applications in the developing countries. An interim report was to be provided to the A.I.D. Administrator by mid-1986, and a final report in 1987.

The Interim Report of the reassessment was prepared in April 1987. Input into the review and revision of the report has been provided by a wide spectrum of interested parties. In addition to the circulation of the Interim Report for input within A.I.D. and to interested outside parties, a two-day workshop was held from September 29 through October 1, 1987 in Annapolis, Maryland. This workshop served as a public forum for the critical review of the Interim Report and an opportunity to share experiences and points of view. This workshop was attended by some 45 participants from the U.S. and international renewable energy and development communities, including representatives from the U.S. renewable energy industry, the World Bank and the Inter-American Development Bank, a developing country government, numerous non-governmental organizations, U.S. Government agencies, several U.S. national laboratories, A.I.D., and private sector consultants. Two sessions were convened at the meeting. The first session critiqued the Interim Report, and the second session involved discussions of major issues, including issues associated with the supply of decentralized energy sources for rural and agricultural development, household fuels supply and demand, and opportunities and constraints for U.S. trade in renewable technology.

This document is the *final* report specified by the Administrator's original request and the REAT project paper. The final report attempts to present a synthesis of lessons learned in the application of

renewable energy technology, to assess renewable technology status and priority applications, and to outline New Directions for A.I.D. renewable energy activities.

THE CHANGING ENERGY SCENE:

IMPLICATIONS FOR RENEWABLES AND OTHER ENERGY ALTERNATIVES

ECONOMIC DEVELOPMENT AND THE ROLE OF ENERGY

The future role of new renewable energy resources and technologies will depend on both the supply of traditional biomass fuels and the cost, scarcity, and security of supply of conventional fuels such as petroleum. At the present time, following the sharp decline of oil prices in 1986 and the subsequent partial price recovery, concerns over price and supply instability have stimulated a serious reevaluation of the nature and scope of all energy programs.

Economic growth and increased agricultural production in developing countries are recognized to be partially dependent on increased direct and indirect commercial energy use and increased energy intensity.[1] Electricity has been particularly important as a stimulus to economic growth in the developed countries, significantly enhancing productivity.[2] Since electricity supply is highly capital and foreign exchange intensive, and frequently generated with imported oil, it is difficult for developing countries to afford. Lower oil prices have, to some extent, mitigated the severe oil cost impacts of the late 1970s and early 1980s. However, as described further below, developing countries still face extremely large oil import burdens, as well as worsening shortages of traditional fuels.

In most developing countries, rural economies have relied on traditional biomass and other indigenous sources of energy. Fuels such as wood and wood waste, animal dung, agricultural residues, and water power have been used for centuries to provide energy requirements for the household, farm, and small productive enterprise. Decreasing fuelwood availability, however, poses a serious problem in many developing countries. In 1980, it was estimated that 2 billion people depend on biomass fuels, and that over half could not meet their minimum energy requirements from available sources without reducing the growing stock. It was further estimated that from 2 to 3 billion people may be living in areas of acute fuelwood scarcity by the year 2000.[3]

WHY HAS RENEWABLE ENERGY BEEN GIVEN A HIGH PRIORITY?

Renewable energy technologies utilize direct solar energy, wind, flowing water, biomass, and/or geothermal energy as alternatives to petroleum or other non-renewable sources of energy. Use of renewable energy sources has been promoted in developing countries for several reasons. These include the following:

- Renewable energy sources are indigenous and available in large quantities in the developing countries.
- Renewable equipment can be small and fit the need for rural small-scale development applications.
- Renewables utilization has the potential to create rural employment and increase productivity.
- Renewable resource use has the potential to save foreign exchange, particularly if renewable

[1] Ramesh Bhatia, "Energy and Agriculture in Developing Countries," **Energy Policy**, August 1985.

[2] Sam Schurr and Joel Darmstadter, **Some Observations on Energy and Economic Growth** (Prepared for Oak Ridge Associated Universities Conference on the Future Strategies for Economic Development, 1976).

[3] M.R. De Montalembert and J. Clement, **Fuelwood Supplies in the Developing Countries**, Forestry Paper No. 42 (Rome: Food and Agricultural Organization, 1983).

technology is manufactured, assembled, and/or maintained locally.

- Renewable energy technology often has less severe environmental impacts than conventional alternatives such as fossil fuels.
- Renewables technology, by being located near demand, reduces the need for costly electrical transmission lines and/or unreliable sources of petroleum supply.

In addition, renewable resources and technology offer an opportunity to stimulate a much wider range of agricultural and small industrial activity. For example, they can be used in rural areas for drying, threshing and winnowing, shelling, hulling and grinding, storage and refrigeration, and canning and related processing. Enhanced biomass conversion systems using a variety of agricultural and forest products can be used for electrical power and thermal loads. Hydro resources can be used in a variety of electrical and mechanical applications. Photovoltaics can be used to provide power for refrigeration equipment and to provide lighting for rural primary health centers.

RENEWABLE ENERGY AND ELECTRIC POWER PRODUCTION

New renewable technologies have also found use in the production of electricity, supplementing conventional sources on utility power grids. Recent experience in the electric power sector in the United States provides an example of the role renewables and/or conservation can play in lowering costs for new capacity additions and stimulating private sector investment. In the mid-1970s, due to an over reliance on oil-fired capacity, U.S. utilities found themselves with uncertain fuel supplies and rapidly escalating fuel prices. At the same time, they faced environmental constraints and falling growth in electricity demand. These uncertainties led to adjustments in resource strategy, perhaps best exemplified by the California experience. In that state there was a strong emphasis on conservation as an alternative to new power plants, as well as a shift to renewable and alternative sources of energy. One major utility, Southern California Edison Company, reduced oil and gas use from 67% in 1973 to 30% in 1984. The utility now relies on nine primary energy sources: oil, natural gas, coal, nuclear, hydro, geothermal, solar, wind, and biomass.[4]

Developers nationwide have also implemented cogeneration and four main types of renewable energy since 1979: biomass, geothermal, small hydro, and wind. A recent report on the 104 leading developers of renewable energy for electric power in the United States reported that by 1985 they had installed 2,236 MW of renewable generating capacity. There were also firm plans for another 5,056 MW by 1987. Between 1981 and 1985, developers in California alone installed 13,373 wind turbines.[5] In addition, some 7,000 MW of cogeneration capacity were added nationally between 1980 and 1985 (almost all fueled by oil and gas).[6]

Several lessons can be drawn from the above developments.

- Renewables such as wind and small hydro were found to be technically sound and readily adaptable to a utility system.
- Incentives were effective in stimulating private sector power development (for example, tax incentives and PURPA).[7]
- Substitution of conservation as an alternative to supply of new power plants was shown to be less costly.
- Smaller increments of new capacity made more sense in the face of demand uncertainties.

LDC experience parallels that of the United States in several prominent examples. In the case of the more conventional alternatives, such as geothermal and hydro, LDC development has been growing rapidly. Examples include China and Thailand for small hydro power, Nepal for hydro-powered mills, and Mexico, Philippines, Central America, and Kenya for geothermal. Other successful new renewable applications can be found with microhydroelectric units in Thailand, microhydro mills in Nepal, wind water pumping in Kenya, and solar photovoltaic (PV) for remote small-scale electricity applications (e.g., 1 kW or below) which have been successful in many countries throughout the world.

CONSTRAINTS FACED BY RENEWABLES

The promise of renewables has been more difficult to realize than many proponents expected. A number of constraints and problems have been encountered in the effort to deploy new renewable technology. These have included the erratic course of international prices for oil products with which

[4] Fereidoon P. Sioshansi, **Alternative/Renewable Sources of Power as Energy Solutions** (New York: New York Society of Securities Analysts, June 20, 1985).

[5] D. Marier and P. Gipe, **Windfarm Update** (August-September 1986), pp. 8–13.

[6] S. Fenn, W. Williams, and D. Cogan, **Power Plays—Profiles of America's Leading Renewable Electricity Developers** (Washington, D.C.: Investor Responsibility Research Center, 1986).

[7] Public Utilities Regulatory Policies Act of 1978, designed to encourage small-scale electric power production, cogeneration, and conservation.

renewables compete, weak institutions for perfecting and promoting renewables, and the inherent difficulty of introducing new technology into an often subsistence-level rural economy.

Oil Prices and the Appropriate Role of Renewables Today

The volatile oil market of the last 15 years, marked by frequent changes in the price of oil and uncertainty about supplies, argues for a flexible A.I.D. energy assistance program. The current oversupply of oil and the accompanying low price may be a short-term phenomenon.

Evidence already suggests that future real prices may rise significantly from current levels. Low oil prices are leading both to higher rates of consumption and much lower rates of investment in oil exploration and development. Non-OPEC production is expected to decline significantly as this reduction in investment hastens the inevitable production decline of oil fields in the United States and elsewhere. These factors have led to widespread expectations of much greater OPEC influence over oil prices in the early to mid-1990s, resulting in higher prices. Projecting oil prices is an imprecise art at best, and most current projections specify wide price ranges or bands. There is, however, a basic consensus among projections regarding the upward movements in prices, the tightening of the market, and the acceleration of price increases in the early to mid-1990s.[8] The recent (December 1987) decline in oil prices does not contradict this scenario; if anything, it will simply further the increased demand and reduced supply expected to eventually cause price increases.

A significant trend in world oil demand in recent years has been the growth in oil demand of LDCs. The share of free-world oil demand going to Organization for Economic Cooperation and Development (OECD) countries dropped from 86% to 78% between 1970 and 1985, while the share going to LDCs grew from 14% to 22%. LDC (non-OPEC and OPEC members) oil demand is projected by one source to grow by between 12% and 31% by the year 2000, accounting for much of the increase in market-economy oil demand.[9]

[8] Energy Information Administration (EIA), **International Energy Outlook—1986**, 00E EIA-0484-86 (Washington, D.C.: April 1987), pp. 23-26; Anne B. Ashby, **Description of the Global Petroleum Supply Demand Outlook** (Chicago: Gas Research Institute, October 1986); Energy Information Administration, **Impact of Lower World Oil Prices and Energy Tax Proposals on the U.S. Economy** (Washington, D.C.: April 18, 1986); and **Wall Street Journal**, August 21 1987, p. 1.

[9] Energy Information Administration, pp. 23-26.

Impact of Lower Oil Prices on Competitiveness

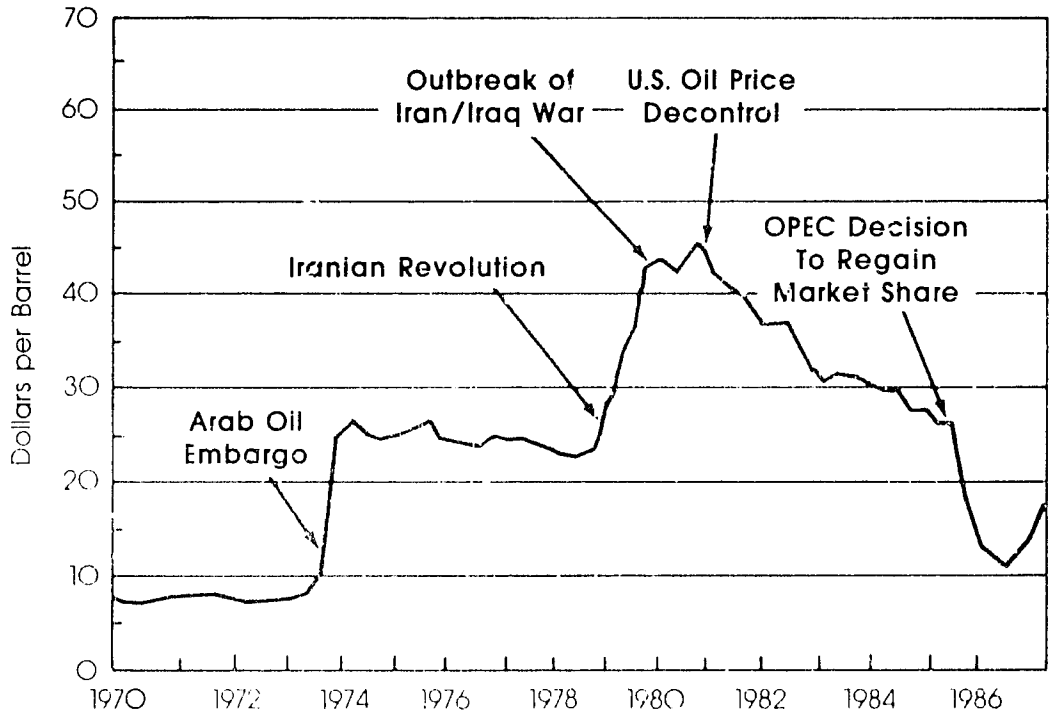
Renewable resources and technologies are actual or potential substitutes for petroleum products, and their economics are significantly affected by oil price levels and uncertainties.[10] This impact varies by application for renewable technology due to differences in relative capital, operating and maintenance costs, and the quality of the renewable resource (e.g., sun, wind, water), among other factors. As Figure 1 shows, the path of international oil prices since 1985 has been anything but stable. *This level of uncertainty argues for a longer term and flexible energy strategy, using long-term price expectations as a basis for decisionmaking and encouraging a diversified fuel mix that includes renewables.*

Another important variable is the extent to which lower international prices actually result in lower domestic prices, particularly prices at rural renewable sites. Lower rates of adjustment or lack of reduction in domestic prices can be an incentive for petroleum substitutes such as renewables. For example, when world oil prices had dropped by about 50%, local currency prices for diesel fuel in Kenya actually dropped by only 17%, and in Pakistan they dropped by only about 9%. During the same period, prices in Ecuador and India increased by 2% and 3%, respectively.[11] Landlocked countries that must transport oil overland, and remote regions in general, often have much higher than world-level prices.

The competitiveness of renewable technologies in commercial markets are directly and substantially affected by lower oil prices. These technologies include power generation via biomass, wind electric generators, solar water heating, and fuel alcohol. On the other hand, rural and small-scale applications such as wind water pumping, PV remote power for telecommunications and health, grain milling via microhydro mills, and off-grid minihydro are likely to be much less affected. The same applies to the rural use of fuelwood, crop residues, and animal wastes. Generalizations about the impact of lower oil prices, therefore, can be misleading. For further discussion of the impact of oil

[10] The review of relative costs in Section IV provides the quantitative background for this discussion. Due to lack of consistent data, the report uses *financial* comparisons except where clearly defined as *economic*. Comparisons of the relative merits of renewable and petroleum alternatives from a social perspective should normally be based on "economic," as opposed to "financial" costs. Economic costs more closely reflect international prices by incorporating an adjustment to account for the scarcity of foreign exchange and the surplus of local labor, among other things. Financial costs are those actually incurred by an investor, that is, market prices including local taxes, etc.

[11] Russell deLucia and deLucia and Associates, Inc., **Lower Oil Prices: Implications for Household Fuel Strategies** (Cambridge, Mass.: December 1986).



* Average quarterly cost of crude oil imported by U.S. refiners

Figure 1. Recent World Crude Oil Prices

Source: U.S. Department of Energy, 1987

prices on renewable energy competitiveness, see Appendix D.

The Policy and Institutional Environment

Properly functioning energy markets are essential to ensure efficient allocation of resources in the energy sector for economic development. Distortions in energy prices, as well as other policies, create an environment that can both stifle private sector initiative and seriously retard the introduction of new alternatives to conventional fuels and technology. A.I.D. has increasingly been focusing on the elimination of distortions such as subsidized petroleum product and electricity prices, tax systems that inhibit new investment, and the presence of government monopolies that stifle the role of the private sector.

The economics of renewable energy alternatives are particularly affected by policies which unequally subsidize or favor conventional alternatives. In addition, weak institutions make it difficult to implement new technology programs, requiring prior investment in training, and new program and technology development capability. Other constraints include government procurement bias toward low first-cost rather than low life-cycle cost, as well as simple lack of knowledge of the availability and reliability of renewables.

Financing of Renewables

Renewable energy technologies are sufficiently different from conventional energy systems in terms of their higher first costs, greater perceived risks, and small scale of individual applications, to require alternative financing approaches (among other incentives and policies) in order to attract investors or buyers. Among the characteristics that constrain renewable systems in their competition with conventional oil and electricity systems are the following:

- *Higher first cost* is a characteristic of most renewable energy technologies. Although fuel costs are non-existent or small, the capital costs per unit of output are typically much higher than those of oil or electric systems.
- *Perceived technical and financial risks* associated with renewable energy technologies (their manufacture or their purchase and use) are generally higher than for more conventional technologies. Although many renewable energy systems are now reliable and warranted by their

manufacturers, perception of this has lagged in LDCs.

- *Large numbers of dispersed applications make purchaser financing difficult and expensive.* Conventional bank financing of large commercial lending institutions is not designed to support a large number of small investments in individual installations.
- *Import of renewable technology requires scarce foreign currency.* In addition, purchasers of equipment generate savings in fuel and electricity payments which are in local currency and which do not offset foreign exchange used to purchase systems.[12]

[12] Meridian Corporation and I.T. Power, **Report to the Financing Task Force, Committee on Renewable Energy Commerce and Trade** (U.S. Department of Energy, April 30, 1987).

Financing strategies will be needed to stimulate the introduction of both energy supply and production equipment into the rural economy. Similar schemes for basic agriculture development have been widely implemented. Credit Institutions' lack of familiarity with renewables applications, cost, and performance is a serious related constraint.

What are the implications of these uncertainties and constraints for A.I.D. programs and the level of support which is appropriate to give to renewable energy alternatives? The discussion below attempts to shed light on some of these uncertainties and their impacts on renewable alternatives. The remainder of this report will provide an assessment of past experience, technology status, and New Directions for A.I.D.

LESSONS LEARNED FROM RENEWABLE ENERGY EXPERIENCES

INTRODUCTION

Over the past decade, there have been a large number of renewable energy projects and installations in the developing countries. Many of these have been part of A.I.D. projects or of similar activities supported by international development agencies and the developing countries themselves. These projects were intended to lead to a reduction in oil imports, augment domestic fuelwood resources, increase energy self-reliance, and assist in meeting important basic human needs, among other goals. A.I.D. has been involved in over 200 programs which contain significant renewable energy components in Asia, Africa, the Caribbean, and Latin America. Many smaller-scale systems have been installed and demonstrated in LDCs using A.I.D. funds.

OVERVIEW OF A.I.D. RENEWABLE ENERGY ACTIVITIES

Bilateral energy programs are administered by A.I.D. resident missions within three regional areas: Africa, Asia/Near East, and Latin America and the Caribbean. The A.I.D. Office of Energy (S&T/EY), part of the Science and Technology Bureau's Directorate for Energy and Natural Resources, has been involved in support to small hydro development, renewable energy training, biofuels research and development, photovoltaics development and demonstration, decentralized energy systems, and improved energy systems for agriculture. S&T/EY also provides information and support to missions active or interested in renewable energy activity.

Renewable Energy Project Data Base. During the course of this reassessment, the need for a comprehensive set of project reports became apparent. A.I.D. requested Volunteers in Technical Assistance (VITA) to compile a data base of A.I.D.-financed renewable energy projects in order to provide A.I.D. staff, missions, contractors, and others with a centralized source of detailed information on the development and dissemination of renewable energy technologies within the A.I.D. network. VITA identified and assembled detailed information on over 170 renewable energy projects financed by A.I.D. since 1975. VITA also produced detailed summaries of 74 projects and brief summaries of 110 other projects. Additional information on the A.I.D. Renewable Energy Data Base is contained in Appendix A. A.I.D. project spending on projects involving renewable energy is summarized in Table 1, organized by country (or region) and specific technology. Technology-specific figures are only approximate, due to the lack of budgeting and/or accounting by technology.

In Asia, A.I.D. has been heavily involved in renewable energy technology development, including human and institutional development to provide local capabilities in renewable energy analysis and development. Projects in India, Thailand, Philippines, Nepal, Egypt, Tunisia, and Morocco have tested solar, wind, biomass, biogas, and small hydro systems for meeting rural and village energy needs. Specific technologies have included solar crop dryers, anaerobic digesters, biomass gasifiers, wind water pumpers, micro- and minihydroelectric generators, low cost stoves, and agricultural waste-fired process heat boilers.

A.I.D. woodfuel activities in Asia have included communal and private forestry, agro-forestry utilizing multi-purpose trees, and improved charcoal stoves. Significant forestry projects were conducted in Pakistan, India and Nepal; the major improved stove activity was in Thailand.

Africa-based renewable energy activities have had two major areas of emphasis: first, small-scale renewable energy technologies for decentralized application; and second, increased fuelwood production and efficiency in use. Technologies involved included charcoal and wood stoves, wind water pumpers and electrical generators, minihydroelectric, biogas, gasification, animal power, and solar electric and thermal technology applications.

A.I.D. efforts to increase fuelwood production in Africa have included a variety of communal and private forestry projects, with more recent efforts focused on agro-forestry using multipurpose trees. More efficient charcoal stove activities have been pursued in East Africa in particular, where local

manufacturers are now manufacturing improved stoves developed with A.I.D. assistance.

A.I.D. renewable energy activities in Latin America and the Caribbean have generally been components of larger energy projects either multi-technology research and demonstration projects, or policy analysis and planning projects whose primary goals were to create effective centers of energy policy analysis and planning through institutional and human development. There have also been a large number of natural resource management projects with fuelwood components, and, more recently, agro-forestry projects have been undertaken in Haiti and Central America. Examples of renewable energy activities include geothermal exploration in Central America, rural electrification in Central America using existing large hydro capacity, and the construction of small hydroelectric plants and local electrical grids in Peru. Multi-technology research, development, and pilot projects involving wind, solar, small hydro, and biomass conversion have been pursued in the Dominican Republic and in Central America, with the Central American Industrial Research Institute (ICAITI).

Table 1. A.I.D. Renewable Energy Projects In Major Recipient Countries

[Funding (U.S. $) by type of energy*]

Country or region of projects	Animal traction	Biomass	Cookstoves	Forestry	Geothermal	Hydro	Solar	Wind	Renewable not specified	Total
Egypt		922,000							449,100	1,371,100
Near East Regional							365,300			365,300
Bangladesh		925,737								925,737
India		41,081,800	1,700,000	47,500,000	329,000	540,800	975,000		87,000	92,213,600
Pakistan				12,500,000					60,000	12,560,000
Philippines		15,020,000			6,204,000				7,150,000	28,374,000
Thailand		610,231	208,000	554,000		8,550,000	169,200	7,900	2,630,669	12,730,000
Indonesia		848,353			50,000	44,308	50,000	44,308	3,347,631	4,384,600
Asia Regional									109,000	109,000
Guatemala				500,000					171,000	671,000
Honduras				807,600			190,000	215,000	1,800,000	3,012,600
Costa Rica		490,000	490,000						550,000	1,530,000
Ecuador									4,000,000	4,000,000
Peru						10,000,000				10,000,000
Dominican Republic				8,890,000		4,166,000			76,400	13,132,400
Jamaica				310,000			4,181,000	45,000	1,744,000	6,280,000
Caribbean Regional									300,000	300,000
Djibouti									660,000	660,000
Somalia			539,000	2,730,500						3,269,500
Sudan				2,275,000					6,022,000	8,297,000
Kenya		503,050	1,096,950							1,600,000
Tunisia							1,200,000	51,074	296,926	1,548,000
Morocco							36,000		9,600,000	9,636,000
Senegal	2,248,067	110,800	317,700	1,885,615			740,000		131,500	5,434,282
Mali									4,517,000	4,517,000
Niger	4,761,900			2,279,400			500,000			7,541,300
West Africa Regional								500,000		500,000
Zaire							800,000			800,000
Botswana									3,304,000	3,304,000
Lesothe									1,600,000	1,600,000
Africa Regional			200,000	250,000		150,000	15,000		312,500	927,500
Centrally Funded									350,000	350,000
Total	7,010,567	60,511,971	4,551,650	80,482,115	6,583,000	23,451,108	9,221,500	863,282	49,268,726	241,943,919

*Funding data are often unavailable or ambiguous on specific renewable energy technologies, particularly if one project covers a variety of technologies. The table shows the Life-of-Project (LOP) funding for the eighty projects and subprojects contained in the A.I.D. Renewable Energy Data Base (See Appendix A). Funding allocations are only approximations.

Source: Volunteers in Technical Assistance (VITA), September 1987.

EVALUATION CRITERIA FOR RENEWABLES ASSESSMENT

Comparison and evaluation of the experience with different renewable energy technologies involved in the diverse group of projects described above is made difficult by a number of factors. These include:

- lack of consistency in project objectives (institution building, field testing, technology development and/or dissemination) and lack of adequate documentation of projects, particularly follow-up after completion;[1]
- differing site-specific resource endowments and local energy policies, including relative energy price subsidies;
- difference in management performance by contractors, A.I.D., governments, and other local factors, such as economic performance.

The basic goals of the introduction of new energy sources have been to produce savings in scarce resources (e.g. capital, time, land and natural resources, labor, etc.), to further rural development to assist the rural poor, to increase the quality and value of products produced, and to increase levels of output. Evaluation of A.I.D.'s experience with renewable energy needs to take into account, to the extent possible, these broad goals, differing specific project objectives, and site-specific and institutional conditions.

The evaluation which follows is not of specific projects; rather it is a *programmatic assessment* which attempts to draw out overall lessons from project experience and apply these to the establishment of guidelines for further project design and implementation and overall New Directions for A.I.D. renewable activities. The evaluation which follows focuses on several major questions or criteria listed below.

1. Was the renewable application appropriate for the development need addressed?
2. Is there significant potential for substantive impact?
3. Is the innovation or technology replicable and likely to lead to self-sustaining implementation?
4. Is the renewable application consistent with institutional and economic constraints, and were constraints addressed?
5. Did the renewable technology perform well and reliably?
6. Is the renewable likely to be economical and financially competitive?
7. Are the environmental consequences beneficial or at least acceptable?

This report relies heavily for its evaluation information on the previous mid-term and final evaluation work of A.I.D. for specific projects and regional evaluations undertaken for Asia, Latin America and the Caribbean, and Africa. The review of projects undertaken by VITA for A.I.D.[2] and the Renewable Energy Data Base have also been used. In addition, substantial outside review of the Interim Report of this reassessment has been accomplished through both solicitation of written comments and via a workshop help in September-October 1987.[3]

LESSONS LEARNED

The body of experience so far shows a great deal of variation in degrees of success and failure for virtually every renewable energy source and technology. Therefore, any broad statements concerning "lessons learned" should be viewed with care. To every statement there are exceptions, and all statements embody assumptions which must be understood.

Technology Application Results

In the past dozen years of experience with renewable energy applications in developing countries, the technical and economic uncertainties have been considerably reduced. The major lessons learned are the following:

- Large-scale introduction of new renewable energy sources through A.I.D., or others efforts, has not been achieved. This is due primarily to two factors. First, most renewable energy projects were R & D projects and intended to develop technologies (and institutions), not to directly disseminate commercially mature technologies; and second, institutional weaknesses and unfavorable policy conditions constrained renewable energy implementation.

Renewable energy projects have had many diverse goals, including technology research, development, and demonstration; and institutional development related to energy analysis or resource and technology appraisal. Widespread dissemination of technology often was not an explicit part of

[1] John H. Ashworth, **Comparison of Data Across Renewable Energy Technologies** (Burlington, VT: Associates in Rural Development, Inc., September 8, 1983).

[2] William Ramsay and Michael Zink, **An Assessment of Evaluations of A.I.D. Renewable Energy Projects**, Draft (Arlington, VA: VITA, July 20, 1986), p. 8.

[3] Mike Jones, et al., **New Directions for A.I.D.'s Renewable Energy Activities: Workshop Summary** (Washington, D.C.: Office of Energy, U.S. A.I.D., September 29-October 1, 1987).

projects. Renewables were often hindered by negative policy conditions such as subsidized prices of petroleum products and electricity, prohibitions against private sector involvement in certain energy activities, and a lack of the financing needed to cover higher capital costs. There is often a lack of government and private sector institutions capable of leading implementation; with several notable exceptions, government agencies and parastatals have not been very successful at developing and disseminating new renewable technologies. Finally, some technologies, such as photovoltaics, presently are only cost-effective for specialized, high-value end uses such as communication, medical power, and refrigeration.

Projects in the household fuels area have been more commonly aimed at producing new energy supply or conserving existing resources than have wind, solar, or biomass conversion projects. Success in the household fuels area has been slow to develop for both technical and institutional reasons. For reforestation efforts, many years are required to show tangible results, and therefore it is premature to assess the ultimate impact of many of A.I.D.'s efforts in this area. Fuelwood and charcoal conservation via stove improvement programs have been achieving success only recently since there has been a major learning curve to follow. Success of recent projects and experience gained, however, indicate that substantial success in both fuelwood supply and improved efficiency of use are possible.

- While many R & D efforts have not succeeded, a significant number of technical approaches have been demonstrated to be reliable. Several renewable energy technologies such as small hydro, some biomass applications, remote solar applications and others, have now matured sufficiently for commercial applications to proceed.

Most renewable energy sources (solar, wind, biomass, and hydro) can now be utilized through some technology that can perform well in the field. A positive result of the research and development activity of the past is that many renewable technologies are now commercially available, and their ability to produce energy in usable forms has been demonstrated, such as small-scale remote photovoltaic electricity production for pumping, refrigeration, and communications; wind water pumping and electric generation (small and large scale); and solar water heating. These are also experiencing vigorous private sector promotion.

Several positive cases of renewable application can also be cited. In India, annual photovoltaic module production capacity was 250–300 kilowatts in 1984 and will exceed 1 megawatt in late 1987 or early 1988; in Zaire, transceivers and aircraft beacons powered by PV are operating; and in Botswana, PV units are serving effectively in schools and clinics and for street lighting.[4] Biomass fuel conservation, via introduction of improved cooking stoves, has been successful in Kenya with a portable metal-ceramic *charcoal* stove. (see case study below) Results of A.I.D. and other donor woodstove (as opposed to charcoal stoves) projects have been generally poor.[5]

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[4] John H. Ashworth, **Renewable Energy Systems Installed in Asia** (Burlington, Vermont: Associates for Rural Development, Inc., 1985), pp. 2-5—2-12.; John H. Ashworth, personal communication, December 14, 1987; Ramsay and Zink, p. 7.

[5] H. Mike Jones, **Final Report: Energy Conservation and Planning, Kenya Renewable Energy Development Project** (July 1985).

CASE STUDY 1

HOUSEHOLD FUEL CONSERVATION: THE CASE OF IMPROVED CHARCOAL STOVES IN KENYA

BACKGROUND: *Declining Wood Supply and Rapid Growth of Charcoal Demand.* Declining supply of biomass is a major environmental and social problem throughout Africa. Agricultural clearing of woodlands and wood use as fuel and for charcoal production are main contributors. Urbanization exacerbates this problem by stimulating imported energy use. It also increases wood requirements by shifting households to charcoal fuel due to energy losses incurred in converting wood into charcoal.

Types of Traditional Cooking Devices and Efficiency. It is estimated that there are about 1 million charcoal stoves in use in Kenya. Household energy use comprises about 77% of national wood energy demand. The traditional charcoal stove is made by artisans from scrap metal in workshops in major urban centers. The efficiency of the traditional stove is only about 20%.

Efforts to Conserve Woodfuel. In 1981, U.S.A.I.D. initiated its Kenya Renewable Energy Development Project (KREDP) to provide technical assistance, minor funding for evaluation and testing, and initial improved stove demonstration.

TECHNOLOGY SELECTION AND DEVELOPMENT: Early in the project, it was decided to adopt a pragmatic approach to selection and a private sector-oriented approach to stove promotion. Stoves were to:

1. only be an incremental step in technology;
2. involve only a moderate cost increase;
3. use primarily existing production and marketing systems;
4. be adapted to traditional cooking methods and foods;
5. represent a clear improvement for the consumer;
6. use readily available materials and skills;
7. offer significant profits and ease of manufacture for producers;
8. offer potential for large-scale introduction and fuel savings; and
9. maintain acceptable levels of carbon-monoxide production.

Laboratory and Field Tests. A variety of different stove innovations were tested by the KREDP. The Thai bucket type stove proved to best meet the above criteria. The lead role for testing and development rested with the A.I.D. contractor assisted by the Intermediate Technology Development Group (ITDG), the Kenyatta University College (KUC), and the Kenya Energy Non-Governmental Organization (KENGO).

DISSEMINATION AND MANUFACTURING: *Dissemination Strategy.* The KREDP program required the production and sale of only 5,000 stoves. It did not define a dissemination program.

Technical/Financial support. Technical support was provided to numerous prospective private manufacturers. A study tour was also sponsored to Thailand to observe stove production and marketing.

Training. Once the Kenya Ceramic Jiko (KCJ) was shown to save charcoal and meet with user acceptance, the activities at government agroforestry centers were expanded. These activities suffered from a number of problems, however, including the lack of staff experience in production methods, ceramics, and kiln design.

The KREDP supported several small-ceramics producers by providing limited financing. However, the greatest production occurred at one manufacturer, Jerri International, which had its own finances and a skilled potter.

Market Development and Marketing. Only limited promotion and marketing assistance was provided for the improved stove. Non-governmental organizations, particularly KENGO, became very active along with KUC, in both further testing and evaluating improved stoves, and training. Limited assistance was, however, enough to gradually generate a significant demand and interest on the part of the public.

RESULTS: *Production and Marketing.* It has been estimated that there were 30 commercial production units for jikos by 1986, with production between 6,000–8,000 per month. Total units produced were estimated to have been about 125,000 by mid-1986. Quality of the ceramic liners for improved stoves remains a problem.

Post-KREDP Projects. Alternative Technology International, with A.I.D. funding, designed and implemented a production expansion project in 1985. The project was to establish 20 additional improved stove production centers. This project was prematurely halted in 1986. Another project has been initiated by CARE in Kenya and has succeeded in the introduction of a partially automated clay liner production technique.

LESSONS LEARNED: *Institutional Setting.* The KREDP was implemented within the Ministry of Energy by a U.S. contractor and a largely African staff. The Government contributed policy support, and legitimized the program with private artisans and local Government. Government financial and staff support to the program was very limited. Unrealistic plans of the Ministry of Energy for Regional Government production centers to compete with the private sector never materialized. Government intentions to improve quality control and develop a training program were also largely unrealized due to staff and funds constraints.

The private sector and non-governmental organizations played a critical role in gaining public support for surveys, training seminars, and providing staff for extension work. NGOs proved less capable in stimulating commercial production. Trained artisans were insufficiently skilled and usually unable to operate a business.

Technology Selection, Evaluation and Development. The selection of sound private sector-oriented criteria for improved stoves was critical to success. Early inputs from technical experts in testing and design by ITDG and innovations of the project advisor were also essential.

Expansion of a Mature Program. The success of this project is evident in the self-sustaining commercial production of improved stoves. However, A.I.D., in not following through on its efforts, left many problems unresolved. The Government, for its part, even after years of technical and financial assistance, has been unable to mount an effective program. Clearly, the local private sector (assisted by A.I.D. contractors) played the most dynamic and successful role in this story.

Small hydro technology is well known, competitively priced, and widely promoted, and hydro equipment is being manufactured by several LDCs (particularly in Asia). In Thailand, the National Energy Administration (NEA) has an ambitious program of micro- and minihydro promotion, with approximately 30 units installed and 20 under construction. Capital costs are low, and reliability has been demonstrated.[6] Ten small hydroelectric systems, ranging in capacity from 230 to 1,200 kilowatts, and associated local grids are being constructed in Peru; four systems were installed as of September, 1987, and the remaining six are expected to be completed by late 1988. Despite being beset by administrative difficulties and construction delays, the hydroelectric plants are being built at moderate cost (approximately $1,700–2,100/kW, not including the cost of the local distribution system), and will provide electricity to communities not served by the electric grid.[7]

As noted elsewhere, however, there is still substantial variability in the competitiveness and degree of success of renewables in different cases. In addition, deployment for some renewables has been more difficult, even though it is feasible with good technology and project management. Biogas, biomass, gasification, solar drying, and dendrothermal electricity all have been difficult to apply due to technical, economic, and/or institutional factors.

- Projects should avoid technology options that are commercially unproven unless projects are explicitly designed to support technology development as part of an overall commercialization plan.

In Nepal, firms that manufacture traditional water-driven grinding wheels were assisted by A.I.D. and other donors (United Mission to Nepal, Swiss Association for Technical Assistance and the Asian Development Bank) in converting production to modern, efficient designs. These designs represented only a minor increase in complexity and cost. A.I.D.'s assistance accelerated introduction of this technology. Similarly, in Thailand, the micro- and minihydroelectric systems the NEA is installing are based on improved, locally manufactured equipment of simple and well proven design.[8]

Kenya's improved charcoal stove program is a case where minor design changes and new materials applied to local designs produced a product which was affordable and easily accepted. The stove is manufactured and distributed largely through existing groups of artisans and sales outlets. This has led to rapid introduction of the stove in the market, with prospects for major replacement of traditional charcoal stoves (some estimates indicate up to 80%–90% replacement in 10 years).[9] Thailand also has had positive experience with im-

[6] Ashworth, **Renewable Energy Systems** . . ., pp. 2-5—2-12; John H. Ashworth, personal communication, December 14, 1987.

[7] United States Agency for International Development (U.S.A.I.D.), **A.I.D. Renewable Energy Data Base**, Summary of Project No. 5270226 Peru Small Hydro Development; James Hester, personal communication, December 10, 1987.

[8] Ashworth, **Renewable Energy Systems** . . ., pp. 5-1—5-15.

[9] H. Mike Jones, **Fuelwood and Charcoal Conservation** (unpublished), for a World Bank, Peri-Urban Fuelwood and Charcoal Preparation Mission-Kenya (June 1986).

proved stoves, although large scale dissemination has not yet occurred.

- Only renewables able to compete in the marketplace with conventional technology in terms of cost, convenience, quality, service delivered, and reliability, will succeed.

The importance of careful analysis of economics and competitiveness is illustrated by the case of biogas. Biogas has been technically demonstrated in Asia, with 1400 units installed in Nepal by 1985 and a large national program underway in India. That experience, however, has now shown the technology to be uneconomical at the household level in relation to alternatives, although valued for high quality lighting for household use. No major impact on household use is thus foreseen without continued subsidies and reduction of technical complexity.[10] Greatest attention with biogas projects has generally been given to these less economical household uses versus the more cost-effective larger scale uses such as energy for dairies or agricultural processing plants, facilities that generate large amounts of biomass wastes.

In contrast, small hydro has demonstrated both reliability and cost effectiveness, leading to a significant introduction of this technology, particularly in Thailand, and Nepal. Use of local designs, materials, and fabrication has been a key to holding down costs to an affordable local level, about ⅕ to 1/10 of the imported equipment capital cost in Nepal. These hydropower activities are proceeding well with largely local resources due to their economic attractiveness to their customers. Photovoltaics in remote area communications and health facilities have also proven to be very reliable and cost competitive with alternatives. A.I.D. projects in Burkina Faso, Zaire, India, and Guyana attest to this fact.[11]

The competitiveness of renewable energy technology depends on the quality of renewable resources available, local skills, nature of the end-use, demand, alternative fuel availability, and local energy prices, among other factors. Therefore, relative economic determinations need to be made on a case by case basis.

Conditions for Successful Projects and Innovation

One of the most striking lessons learned from the experience with renewable energy applications is that remarkably few technology/end use combinations can always be said to be appropriate. In fact, the key to technology application success is usually how well the renewable energy application is designed and implemented. The major lessons learned about how to better develop and manage future A.I.D. or other renewable application projects are as follows:

- Local user or "market" acceptance determines whether a new renewable technology succeeds or fails. User involvement or market testing in project design, implementation, and evaluation should be a project requirement.

If a project is to have a reasonable probability of succeeding, it must involve the prospective local users of the resource/technology system. This has often not been the case. Involvement should begin before needs are defined and project directions are laid out. Participation in all phases of the project, through construction and operation, helps to ensure motivation and a transfer of technology. This also prepares potential users for the new option.

In the Thai village hydroelectric program, villages are organized into electric cooperatives. The local cooperatives must assist in the construction of the plants; in return, they receive an equity stake equal to the value of their labor/materials contribution, and are entitled to a share of the revenues from electricity sales (in proportion to the equity stake). These cooperatives are not intended to be profit making entities, but they are "private sector" in that their revenue depends on their performance (delivery, bill collection), and they can invest revenues in other activities. Thus, there are fiscal incentives of sorts to encourage efficiency. The fact that cooperative members are the customers also encourages attention to maintenance and upkeep.

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[10] Ashworth, Renewable Energy Systems . . ., pp. 2-11—2-12, 5-1—5-15; Ramsay and Zink, p. 10.

[11] Ramsay and Zink, p. 7.

CASE STUDY 2

RENEWABLE ENERGY TECHNOLOGIES FOR CONSERVING FUELWOOD: CENTRAL AMERICA

Background. The Fuelwood and Alternative Energy (FWAE) Project sponsored by A.I.D. in Guatemala, El Salvador, Honduras, Costa Rica, and Panama provides a number of lessons regarding the dissemination of energy efficient designs and renewable energy alternatives in rural areas. Begun in 1979, a major theme of the FWAE Project was to assist in alleviating the critical problem of deforestation occurring in Central America. The two components of the project were development of improved fuelwood supplies and dissemination of suitable renewable energy technologies and more efficient means to utilize fuelwood.

Implementation. Responsibility for development or modification, demonstration, and dissemination of energy technologies was given to the Central American Industrial Research Institute (ICAITI), a regional institute that conducts research and development for industry. In addition to technology development and demonstration, ICAITI conducted training sessions and seminars, published reports, and provided technical assistance to commercial applications. The project included combustion technologies (domestic wood stoves, industrial kilns and ovens, and charcoal kilns), solar energy technologies (fuelwood and agricultural dryers, salt evaporators, and hot water systems), and domestic and industrial scale biogas.

Many other organizations were involved in dissemination of technologies developed by ICAITI, and in some cases provided important feedback on technology design. The importance of listening to people in the field was borne out in a number of cases. ICAITI was amenable to mid-course corrections, such as occurred with the household stove program. In this case, the initiative (to switch from promotion of Lorena-type stoves to pre-fabricated ceramic stoves) came from within ICAITI and resulted in commercial dissemination of artisan-produced stoves in rural areas.

Technology Experiences. A recent evaluation of the FWAE project found that nearly all of the technologies that have received a high level of acceptance had significant local input in design and adaptation and significant private sector participation in their promotion.[12] Several technologies primarily built and promoted by entities other than ICAITI (including PVOs and NGOs) included charcoal kilns, solar salt evaporators, Lorena-type and pre-fabricated ceramic stoves for households, batch bread ovens, and institutional stoves. Private sector individuals were involved in all of these except the Lorena-type stoves. Many attempts were made by different organizations to initiate small, private businesses based upon Lorena stove construction, but none endured very long once donor intervention terminated.

The solar salt evaporator has been the most successful technology in terms of fuelwood savings, environmental impacts, and generation of employment and small industries. ICAITI testing of a simple, inexpensive black plastic design in Guatemala and collaboration with government programs (including incentives) has resulted in a whole new industry for coastal inhabitants. ICAITI originally developed an improved fuelwood salt evaporator, but before testing was complete, the decision was made to concentrate entirely on the promotion of solar alternatives. The initiative for this change came from a Honduran organization. The main rationale for introduction of the technology, which required hardly any promotion beyond the initial demonstration of the designs, was to help the small producers become more competitive. In Honduras, ICAITI promoted successful interchange between small local salt producers and Guatemalan counterparts. The solar salt patio design has quickly become the predominant mode of production, replacing the cooked salt process that required wood.

Other technologies have met with low acceptance. These include solar fish and agricultural dryers, biogas digesters, and continuous bread ovens. The project was successful in increasing awareness of solar agricultural dryers and demonstrating the technology in a variety of designs, but the demonstration units were small and cheap and not market-oriented. Those with the initiative and imagination necessary to adapt the demonstration models to their needs went on to successful application, however.

Lessons Learned. The most successfully implemented technologies were those that incorporated the highest degree of local user input in technology design and adaptation and the greatest involvement of the local private sector in dissemination. In general, the project appears to have predefined a wide range of technologies based on quite limited market analysis. There was a bias toward a narrow engineering approach rather than a market-oriented one and an emphasis was placed on technical design and demonstration rather than practical field evaluations with the consistent incorporation of feedback. In many cases there was premature demonstration and dissemination with little follow-up and numerous abandoned units.

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[12] [illegible] and Associates, **Evaluation of ICAITI, Fuelwood and Alternative Energy Sources Project, and Regional Industrial Energy Efficiency Project**, Sept. 1987.

Despite these problems, the project has succeeded in disseminating several renewable technologies for productive use, three of which have proven sustainable through the private sector (solar salt dryers, batch bread ovens, and pre-fabricated ceramic cooking stoves). In several cases (brick and tile kiln, ceramic cooking stoves), initially inappropriate designs were modified incorporating critiques and suggestions of artisans and other users, resulting in vastly improved designs.

Lack of participation can be fatal to a project. For an Indian integrated village energy system, the villagers were supposed to feed dung into the biogas digesters and use the residue as fertilizer. However, the local farmers used dung directly as fertilizer, not believing that the residues of the digester would be as effective. As a result, dung had to be trucked in from a considerable distance to keep the digester running.[13]

- Project ideas and designs cannot simply be transplanted from place to place. Applications must be tailored to local market, physical, material, institutional, and economic conditions.

Failure of projects which have not been matched appropriately to local needs and social customs include solar cooking projects in Africa and a non-A.I.D. solar cooking project in Mexico. These were technically effective, but unacceptable to local recipients, and demonstrated the importance of matching appropriate interventions with needs.[14] On the other hand, the successful application of microhydropower in Nepal is in part the result of the technology being well matched to local conditions and to a needed end use. The Nepalese have long exploited hydropower and have extensive experience in dam and canal engineering. The hydro equipment is sold as part of an integrated package of mill equipment that includes grain-grinders, oil expellers, and dehullers. The mill package is well suited to the local market in size and complexity, and loans are available to mill owners who wish to purchase the equipment.[15] Similarly, use of photovoltaic cells for remote village power supply in various islands of the South Pacific is proving to be attractive with a reported 2000 small PV systems installed.[16]

Project design should factor in the availability and nature of local renewable energy resources, local human resources, and institutional capabilities. This means that project design requires a considerable amount of relatively detailed information. Design should also not start with preconceptions about which technology to apply. For example, in Honduras, 25 wind units were planned for an A.I.D. project, but only two units were installed after local energy requirements, wind availability, and the local water table were later tested.[17]

- Lack of attention to "after-sales" service (maintenance, spare parts, and local skills development) has often proved fatal to both demonstrations and attempts to commercialize a technology.

If an application is to be sustainable, it needs to be backed by a reliable system for maintenance and spare parts supply. Also, it must not be too complex and should include training. This will ensure that continued operation does not depend on continued foreign technical assistance or on one or two local individuals who may move on to other activities.

Biogas projects have frequently failed because they were inherently too complex and capital intensive for the rural household. This has been demonstrated in many cases, notably in African projects in Rwanda and Lesotho, and also in Guatemala and in the Pacific Island of Saipan. On the other hand, for larger-scale nonhousehold biogas applications, a supporting system is much more feasible using the greater funds and labor available.[18]

The successful experience of the Kijito wind machine in Kenya also illustrates the need for a support system. In this case, a local entrepreneur was

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[13] **India: Technologies for the Rural Poor**, various evaluations (August 1986).

[14] Mark Ward, John Ashworth, and George Burrell, et al., **Renewable Energy Technologies in Africa** (Washington, D.C.: U.S.A.I.D., April 1984), pp. B-27–B-28; Norman L. Brown, ed. "Solar Energy in the Less Developed Countries," **Renewable Energy Resources and Rural Applications in the Developing World** (Boulder, CO: Westview Press, 1978), p. 41.

[15] Ashworth, **Renewable Energy Systems**, pp. 4-2, 5-6, 5-8.

[16] World Health Organization, **The Cold Chain Product Information Sheets** (SCPDIR 55 IT5).

[17] Ramsay and Zink, p. 8.

[18] *Ibid.*, p. 10.

provided with a technology design and continuing technical assistance by the Intermediate Technology Development Group, funded by the British Overseas Development Administration. In combination with the entrepreneur's attention to the production of reliable equipment and willingness to provide exceptional service, a high quality and reliable wind machine evolved. The choice of an entrepreneur with sufficient capital, a reputation for service, and good technical capability was critical, because the design itself was unproven in Kenya. Numerous customers bought this equipment on the strength of the service/repair guarantee, and the revenues and experience these sales provided allowed for further development and refinement of the design. The equipment now has an excellent reputation and is being used not only in Kenya but is exported elsewhere in Africa.[19]

- Local private sector marketing of technology for commercial purposes is the best way, where possible, to ensure successful dissemination.

If an application is to be sustained without continuing external assistance, it must be made the responsibility of an institution with a strong motivation to make it work. By far, the most promising incentives for this purpose are economic, which ideally means giving private sector organizations the central role. Another strong factor can be the involvement of nongovernmental organizations which provide local input and a support system where market forces may be weak or undeveloped, for example, in fuelwood supply or rural stove programs. Local cooperatives have been shown to be effective in managing electric systems, because members are concerned about the reliability and cost of service and often have an equity stake in the system.

Participation of an appropriate private sector entity is important for widespread application of most renewables. The case of the Kijito wind machine in Kenya also illustrates this lesson. Starting with essentially the same technology and technical assistance, the only major success of six applications with the ITDG wind machine design was with the small entrepreneur in Kenya. Progress was much slower with a parastatal in Botswana, and unsuccessful with a research institute in Egypt and a very large commercial firm in India.[20]

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[19] U.S.A.I.D., Bureau for Africa, **Renewable Energy Technologies in Africa** (Washington, D.C.: April 1984), p. B-5. Countries exported to include Tanzania, Sudan, Nigeria, Uganda, Niger, Botswana, and Comoros. Company Information, April 10, 1985 (**A History of Kijito Windpumps**).

[20] Associates in Rural Development, Inc., **Technical Findings on the Performance of Renewable Technologies in Africa: Results form 55 Projects in Seven Sample Countries** (Burlington, VT.: 1987), pp. V-1—V-34; and personal communication with Bernard McNelis, IT Power, Reading, Bershire, U.K., February 19, 1987.

CASE STUDY 3

PHILIPPINE DENDROTHERMAL AND GASIFIER EXPERIENCE

Background. Use of biomass energy resources was given a major priority by the Philippine Government in the late 1970s and early 1980s in response to the need for reliable and economic rural fuel supplies. Two programs were sponsored focusing on providing fuelwood for conversion into electricity via direct combustion (the dendrothermal program) and into fuel for internal combustion engines using a gasification process.

Program Descriptions. The dendrothermal program was to establish tree plantations to provide fuel to electrical plants producing 3-5 MW each. The program called for 72 individual power plants throughout the country. The program was managed by the National Electrification Authority (a government agency attached to the Ministry of Human Settlements) in conjunction with an association of rural electric cooperatives. NEA provided technical and financial assistance to the cooperatives and coordinated program implementation on a national scale. NEA was also responsible for coordination of tree species trials and establishing a network of fuelwood plantations for the dendrothermal power plants. Plants were to be owned and operated by rural electric cooperatives, supplementing the power purchased from the National Power Corporation. Tree plantations were established in close proximity to the power plants to satisfy the fuel requirements of the wood-fired boilers. The plantations were operated by local farmers on marginal land and were intended to provide supplemental income to rural households.

In a second similar activity, a gasification program was developed to provide power for irrigation pumps and small commercial vehicles by converting biomass to gaseous fuel. This program was managed and implemented by the Farm Systems Development Corporation (FSDC), a government-owned corporation also attached to the Ministry of Human Settlements. To implement this activity, FSDC established the Gasifier Manufacturing Corporation (GEMCOR). FSDC purchased and installed the gasifiers at selected irrigation cooperatives and on a fleet of FSDC-owned service vehicles and provided user support and training, as well as fuelwood production assistance.

The common element of both programs was rural tree farming associations. Farmers wishing to participate received land, materials, and technical assistance in growing trees. Seedlings were provided at cost, with financial assistance for other necessary inputs. The harvested trees were to be either sold directly to the power plants or converted to charcoal for gasifiers.

Implementation. There were numerous problems with implementation of the programs. Tree species trials were incomplete, leading to a low overall survival rate after four years, approximately 32%. The technology selected for use in the gasification program had not been field proven and, in most cases, operator training was insufficient. Furthermore, FSDC did not have the technical capability to resolve gasifier problems. In addition, charcoal and fuelwood prices grew much more rapidly than expected.

The wood-fired power plants also experienced a host of technical and management problems. In order to be economically viable, these plants had to be base-loaded, but in most regions loads were insufficient. Also, the National Power Corporation was not involved in the planning and implementation, to the detriment of the project.

Status. By 1984, only two of the projected 72 dendrothermal power plants had been fully constructed, and those plants enjoyed intermittent use only. Construction had been started on seven other plants, and equipment was on order for an additional eight plants. Contracts for additional sites were indefinitely suspended until an acceptable level of progress was made at the existing project sites. In the gasifier program, more than 1000 gasifiers had been sold by the end of 1985. However, as few as five percent were operational, and these were installed in stationary (irrigation pump) applications. Those sold to private individuals and companies enjoyed the greatest level of success.

Lessons Learned. The common problem throughout both the above programs seemed to be emphasis on rapid widespread introduction of technologies (tree plantations, gasifiers, and wood-fired power plants) without proper preparation of the host country institutions and adaptation of the technologies to suit local conditions. Tree species trials were inadequate for different sites. The gasifiers needed better technical and training support programs, including a full-time staff of well-qualified engineers. The dendrothermal program suffered from the introduction of equipment prior to pilot plant testing. There was also insufficient field support by the equipment manufacturer and NEA. In some cases, failure of plantations planted close to the power plants required purchase of fuel from commercial sources at much higher prices.

In retrospect, it appears that the social benefits of establishing tree plantations managed by small holders were overestimated and complexity of management was underestimated. When matched with the technology related problems encountered with the gasifiers and wood-fired power plants, the problems proved too complex to overcome.

Contrasting experiences with gasifiers in Brazil and the Philippines are also relevant. Gasifiers in the Philippines were manufactured by a parastatal organization (GEMCOR) and sold to end-users through a sister agency (FSDC), which provided financing and was to provide technical support. Neither FSDC nor GEMCOR provided sufficient training and support to the end-users, which led to significant operating problems and near total abandonment of the systems (See case study). In Brazil, on the other hand, there is an active gasifier industry that has widely disseminated gasifiers for decentralized direct heat applications. Some members of the Brazilian industry have been successful in training to gasifier operators, which has contributed to a much better operating record in Brazil.[21]

The micro-hydro mills in Nepal mentioned above are a product of the private sector. There are over 25,000 traditional waterwheel-driven grain grinding wheels in use in Nepal. The new equipment builds on this existing demand, familiarity with water-power, and existing dam works; waterwheels are replaced by simple crossflow turbines, and modern milling equipment replaces stone wheels. A commercial industry has sprung up with four or five domestic turbine manufacturers (four purely private, one PVO affiliated); several of the manufacturers have implemented over 100 hydro mills apiece. The turbines are direct-drive, with a variety of agroprocessing equipment running off a common power shaft (belt-driven). The agroprocessing equipment and small generators includes grinders, dehullers, and oil expellers. The turbine manufacturers generally assemble entire milling packages of turbine plus processing equipment, and install the entire package. All the packages are sold, to private millers. These mills are much less expensive to operate than diesel driven mills (including capital costs) and are much more reliable. They earn their owners substantial profits, which results both in growing demand for the mills and in the owners taking good care of the equipment. This is a good example of private sector implementation, with the private sector on both sides of the transaction, economic incentives for producers to buy the equipment, and strong competition and marketing among the turbine manufacturers.[22]

- Renewables' market penetration is seriously impeded when other fuels are subsidized or other unfavorable policy conditions exist. Policy conditions require up-front attention in A.I.D. efforts to support renewables introduction.

Governments play the primary role in setting the energy and economic policy environment within which the private sector must operate and within which renewables must compete. Even in a country with relatively free private markets, the government influences private sector decisions through such actions as tax and import policies, capital allocation and pricing, energy price controls, and by the purchase of equipment for government projects. Frequently, the government also intervenes in markets by establishing limits on institutional roles and rights and other constraints on free market forces.

A prominent example of the importance of government policy regarding the introduction of energy resources is the promotion of electricity use by subsidizing rates. These subsidies often become disincentives to the introduction of competing renewable electricity systems. Access to the grid and sales to utilities on reasonable terms are important for alternative power supply projects. This approach has greatly stimulated small-scale power generation in the United States, for example, from small hydro, wind, and cogeneration plants. Similarly, subsidized diesel adversely affects the decision to install PV systems in many countries, and subsidized kerosene contributes to the uncompetitiveness of biogas.

- Learning from past experience is severely handicapped by lack of adequate documentation of successes and failures. Improved interchange of results and methods of application could make a major difference in the rate of future success.

Generally speaking, evaluation reports prepared for A.I.D. renewables projects have been well-designed to address task accomplishment. However, they are deficient in evaluating costs, competitiveness with alternatives, degree of appropriateness for the targeted need, or prospective sustainability. These limitations can be overcome if, in the future, projects themselves pay greater attention to cost and other documentation, and evaluations focus less on task and more on overall goal accomplishment. Another serious problem is the lack of systematic collection of information on project success and system performance. This information is also not reaching program and project managers adequately to affect management and technical decisions. Projects also have been observed to be too

[21] Gerald Foley and Geoffrey Barnard, **Biomass Gasification in Developing Countries** (Earthscan/IIED London), 1983 pps. 82-88; Gerald Foley, **Charcoal Making in Developing Countries** (Earthscan/IIED London), 1986 pps. 34-36. Matthew Mendis (World Bank), personal communication, December 11, 1987. The World Bank Energy Department recently conducted an assessment of gasifier status, report forthcoming.

[22] Allan Inversin, **Microhydropower Sourcebook** (National Rural Electric Cooperative Association International Foundation Washington, D.C.), 1986 pps. 225-247.

short to achieve desired objectives in some cases, and lack of maintenance support and follow-through at project end is a frequent problem with A.I.D.-sponsored projects. There also remains a lack of central coordination, or adequate central support, to assist missions and ensure that lessons learned are transferred to missions designing projects.

It is hard to judge the overall success of fuelwood projects for two primary reasons: the long growth periods for trees and the limited availability of appropriate evaluations. Many projects have provided some quantitative information, for example, indicating numbers of seedlings produced and hectares planted, and some make survival rate "guesstimates." However, the potential overall impact of the projects in the intermediate to long-term, which is more relevant, is not determinable without long-term monitoring.[23]

Projects appear to have the greatest chance of success where they are introduced through a local institution, where cash income is generated via related construction and wood sales, or where strong economic interest exists, for example, in fruit, shade, and fodder trees.[24] This is exemplified by an A.I.D. project in Senegal where the Forest Service and village self-help groups collaborated effectively. Another case is found in Tanzania, where the project's success is attributed to institutionalization as part of local school and church activities. A.I.D. project experience also tends to support the view that seedlings produced in government nurseries are high in cost, and supply is not likely to be substantially expanded or be sustained without outside support.

Problems with projects in several African countries demonstrate the importance of good project management and careful selection of species, among other things. In Senegal (in a different project than that cited above) inappropriate selection of species to fit the local environment led to the planting of a particular eucalyptus species which resulted in very low yields.

In Mali, problems in management led to project delays in construction and reduced production from woodlots. In the Gambia, problems were encountered with the management of harvesting, resulting in unnecessary replanting.[25]

Reported results from World Bank forestry projects, reinforced by A.I.D. experience, have highlighted the following fuelwood project-specific "lessons learned":

1. Local support is essential and is generated where there is realization of the importance of fuelwood and trees and a recognition of growing scarcity.
2. Few LDCs have the infrastructure to support large-scale fuelwood planting.
3. People tend to favor food or fodder crops over fuelwood production.
4. Fuelwood can be produced on private farms much more cheaply than in government-owned plantations, provided the farmers perceive the need and benefits from this production.
5. Availability of land for plantations or allocation of farmland in agroforestry systems are important constraints to fuelwood production.
6. Adequate infrastructure in terms of seedlings, nurseries, and a distribution system is required. Supplemental systems which are not dependent on government, such as commercial-private sector activities, are essential.
7. Effective outreach and extension should be designed into a project at the beginning.
8. Well-developed commercial markets for poles and demand for fruit and fodder trees are very important in stimulating interest in tree planting.[26]

GENERAL LESSONS

Private Sector

The private sector direction proposed and discussed below under New Directions for A.I.D. Renewable Energy Activities, is based on several findings from the review and evaluation in this report.[27] There is increasingly clear evidence that there are higher rates of economic growth in developing countries which rely on market forces and the private sector. A 1985 World Bank Report found that LDCs whose private sectors utilized more than half the available credit had average per

[23] Ramsay and Zink, pp. 26–29.

[24] USDA, **Mid-Term Evaluation: Sudan Eastern Refugee Reforestation Project** (Project 6500064, Oct.–Nov. 1985); **Evaluation: Madhya Pradesh Social Forestry Project, India,** Project 3860475, 1981–87 (Washington, D.C.).

[25] Ramsay and Zink, pp. 26–29.

[26] United Nations Development/World Bank, Energy Sector Assessment Program, Energy Sector Management Assistance Program, **Quarterly Information Brief;** and UNDP/WB, **Annual Report of the UNDP/WB Energy Sector Programs: Achievements and Future Directions** (Washington, D.C.; April 1985).

[27] "Private sector" is taken here to mean individual entrepreneurs and privately-owned, for-profit firms in industry, agriculture, and services. This term also refers to other entities which operate with commercial characteristics, such as cooperatives or even some parastatals which operate in a for-profit, market-conscious manner. This private sector emphasis recognizes the possible contributions to be made by government agencies, not-for-profit non-government organizations (NGOs), and private voluntary organizations (PVOs). It does propose, however, that the desired goal be the development of local private sector production, installation, maintenance and repair capabilities.

capita GNP growth rates of 4.5%; LDCs whose public sectors utilized more than half the available credit had GNP growth rates of under 1%, with many of the countries having negative growth rates.[28] Another important factor is the nature of the rural energy market, which consists of a large number of heterogeneous and dispersed applications. The rural renewables market appears best served by a dispersed and competitive private sector. Finally, experience to date casts doubt on the ability of public sector entities in most LDCs to deliver reliable energy supplies to rural areas; common constraints include shortages of financing and skilled managerial and technical personnel and bias in allocation of energy investment to urban areas.

Another factor favoring a private sector emphasis in renewable energy technology application is the example of the United States, where implementation of private power production and sales has been a major success story. This success is due in part to favorable legal/regulatory environments, government incentives, and subsidies.

The private sector emphasis in renewable energy activities is also consistent with the broad themes of A.I.D. policy and with current and planned development activities. A.I.D. launched the Private Enterprise Initiative in 1981. The purpose of the initiative was to help developing countries rely more upon private enterprise, individual entrepreneurship, competition, and market forces to foster broadly-based self-sustained economic growth. Private sector activities common to the three regional bureaus include policy dialogue efforts to improve business conditions, technical assistance and training, technology transfer, and various credit related activities.[29]

While A.I.D.'s private sector initiatives are concerned primarily with the development of LDCs' private sectors, the U.S. private sector can be a valuable part of the strategy to help achieve this goal. The use or involvement of U.S. firms is another increasingly relevant goal of the private sector emphasis, and U.S. industry has a legitimate role to play in A.I.D. energy programs. For example, some U.S. firms' renewable technologies are currently more competitive in off-grid situations common in LDCs than in on-grid applications in developed countries. U.S. technology transfer and entrepreneurial skills can also play a valuable role in stimulating LDC private enterprise. U.S. private sector involvement is in the long-term interest of the United States since it will help stimulate trade and commerce in general. LDC sales can also be valuable to U.S. industry in order to help production volume reach levels necessary to lower production costs and allow investment in further product and production research and development.

[28] Keith Marsden, "Private Enterprise Boosts Growth," World Bank Report (1985).

[29] Kaaren Christopherson, Agency for International Development: Current Activity in Private Enterprise Development 1985-1988, PPC/CDIE/DI.

STATUS OF RENEWABLE ENERGY TECHNOLOGY AND APPLICATIONS FOR ECONOMIC DEVELOPMENT

INTRODUCTION

Renewable energy technologies must compete in terms of performance and cost against more traditional means of delivering energy services. The actual choice of energy technology must be site-specific, reflecting the varying mix of material and human resources and availability of renewable resources. This section contains four major parts dealing with the status of renewable technologies and their uses: first, a generalized summary of the technology status and applications; second, a description of opportunities for further technology development; third, a review of some of the major environmental benefits and problems with renewables and competing alternatives; and fourth, a description of the potential role of renewable energy sources and technology in assisting rural development.

STATUS OF RENEWABLE ENERGY TECHNOLOGIES

The discussion below provides an overview of the current (late 1987) status and competitiveness of the various technologies. The discussion provides a guide to the general applicability and competitiveness of different major renewable alternatives, using the experience of the past decade as a base. A brief synopsis of the status and competitiveness of renewable energy technologies is presented in Table 2. This summary material is elaborated on in the body of this section.

In comparing renewables with various conventional alternatives for delivering energy services, it is important to keep the following general points in mind. Renewable energy technologies make use of energy available on or near the site of application; thus the cost of energy from them varies considerably depending on where they are employed. Further, when one speaks of cost-effectiveness of renewable energy technologies, which usually have low operating costs but high capital costs, it is important to remember that this often depends on financing terms. In many cases, it will also depend on the path of oil prices over the next 10–15 years. Finally, where use of renewable energy technologies results in generation of local employment, saving of foreign exchange, and environmental benefits, an application that is financially marginal may be attractive from an economic or social point of view.

DESCRIPTION OF RENEWABLE ENERGY TECHNOLOGY STATUS

Photovoltaic Electricity Generation

Photovoltaic (PV) technology involves conversion of solar radiation into electricity. The modular nature of the technology allows systems to be scaled to meet a range of energy demands. PV systems have proven reliable in a variety of developing-country applications, including small-scale water pumping, communications, and refrigeration and lighting for rural health clinics. Technological innovation and increased scale of production have resulted in a decrease in the cost of a PV module from $100 to $5–6 per peak watt in the past 15 years, and further decline is expected as technological advances are incorporated into commercial products.

Although PV costs have declined considerably in the past five years, the high capital cost remains a barrier to dissemination. On a life-cycle basis, however, PV systems are often cost-effective for off-grid loads under 1 kW where alternative fuels are expensive and/or supplies are unreliable. (Note: Diesel engines, often the alternative to PV systems, are not available below about 2.5 kW for use in LDCs.) [1] The high reliability, low maintenance requirements, and long life of PV systems are factors in their favor. For vaccine refrigeration, for example, the greater reliability and longer life of PV refrigerators, contrasted with problems of kerosene availability and refrigerator performance, make PV units attractive despite much higher initial cost. It

[1] D. Eskenazi, D. Kerner, and L. Slominski, **Evaluation of International Photovoltaic Projects**, Vol. I and II (Falls Church, VA: Meridian Corporation, September 1986).

TABLE 2. SUMMARY OF TECHNOLOGY STATUS AND APPLICATIONS

PHOTOVOLTAICS. Photovoltaics (PV) have proven to be reliable in developing country applications, in remote areas, and when power requirements are small but important—for example, for communications, refrigeration, and for remote health facilities. At very small volumes (10–20 cubic meters) and in favorable solar conditions, photovoltaics are competitive with diesel for water pumping.

WIND MECHANICAL PUMPING. The main applications of wind mechanical pumping are for village water supply and livestock watering. Wind pumping competes favorably with diesel for water pumping when wind speeds are good and where water volumes are low.

WIND ELECTRIC GENERATORS. Wind electric power generation for small loads is generally competitive with PV or diesel where wind speeds are good. Wind also is technically proven for larger grid-connected systems under appropriate conditions. Viability, however, is extremely sensitive to wind conditions at specific sites and alternative fuel costs.

BIOMASS FUELS—DIRECT COMBUSTION. Direct combustion of wood or other biomass for steam-raising can be cost-effective, though further scaling down of currently available systems is necessary to serve the small size (25–200 kW) of many developing country applications. For electricity generation, the competitiveness of biomass combustion depends heavily on the relative cost of biomass fuel versus other alternatives, achieving minimum economic plant size and fuel collection cost. Promising applications include use of wastes at sugar mills, wood product industries, and larger rice mills.

BIOMASS FUELS—GASIFIERS. Gasifiers are coming into fairly common use for direct heat applications with a variety of fuels in a number of developing countries. Experience with gasifiers with internal combustion engines has been mostly unfavorable, though use of homogenous feedstocks and competent maintenance can result in cost-effective power production where diesel costs are high.

BIOMASS FUELS—BIOGAS. Success with biogas has been achieved with commercial-scale systems where biomass feedstock is available on-site. Household systems have frequently been found to be uncompetitive with other fuels, hard to maintain, and difficult to manage.

ALCOHOL FROM BIOMASS. The viability of ethanol production, from sources such as sugar cane, as a substitute for gasoline depends upon the domestic cost of oil and the value that is placed on other factors such as foreign exchange savings and employment generation. Although ethanol production is not generally competitive at current oil prices, there are circumstances where it may be economically viable.

SOLAR WATER HEATING. Solar water heating is a well-developed commercial technology for urban residential and commercial purposes. It is often competitive with electricity for water heating. Industrial solar water heating is not generally attractive at current oil prices.

SOLAR DRYING. Solar drying by newly developed systems is feasible technically for agricultural drying, but it has not been widely used due to relatively higher cost compared with traditional systems. The energy and costs saved by solar dryers is normally relatively small, though the improvement in product quality is likely to be significant.

SMALL HYDROPOWER. Small-scale hydropower is a proven and common technology in the developing world for the production of off-grid electricity and the delivery of shaft power. Low capital costs (for example, from domestic manufacture and engineering), good water conditions, and high load factors are necessary for small hydropower to compete with other resources in electrical applications.

GEOTHERMAL. Geothermal reservoirs can be tapped to provide steam for electrical power production at a range of scales. Geothermal resources have been successfully tapped in many developing countries and represent a proven and normally attractive means of using domestic resources for power generation. The main constraints are availability of geothermal resources and location versus electrical loads. Lower temperature reservoirs which are more widely distributed can provide direct heat for industrial processes.

SOLAR THERMAL ELECTRIC. Solar thermal electricity generation is in small-scale commercial use in California, where favorable conditions exist.

has been reported that at least 1000 PV medical refrigerators have been installed worldwide.[2]

Use of PV systems for *water pumping* is often competitive with alternatives for small-scale water demands of 10–20 m^3/day in locations with a good solar resource. PV pumps are available to pump from boreholes, open wells, rivers and canals; 3000 to 5000 systems are in worldwide operation today. In the last 3 to 4 years the technology has matured to the stage where the majority of systems available may be considered technically reliable.[3] A portable PV pump for livestock watering to pump 60 m^3/day through 2 m head now costs \$3,000–\$5,500 in the United States. A typical system to pump 20 m^3/day through 20 m head to supply a small village costs about \$9,000 in the United States.

In remote areas, use of PV technology for small building electricity loads may be less costly on a life-cycle basis and can be more reliable than grid extension or diesel electricity generation, depending on the distance from the grid, the price of grid power, and diesel fuel prices. A PV system to supply a load averaging 3 kWh/day, such as for a school or health clinic, costs \$8,000–\$9,000 installed.[4]

Wind Mechanical Pumping

Wind mechanical pumping is an old and well-proven technology. A wide variety of wind pumps are currently manufactured in developed and some developing countries. Commercial designs are between 2 and 8 m in diameter, and installed costs vary from around \$250 to \$500/m^2 of rotor. Installed costs for a typical 5 m machine is between \$5,000 (in-country production) and \$10,000 (imported).[5] The main applications for wind pumping are water supply for people and livestock. Wind pumping for irrigation is not likely to be economical due to the variation in month to month water requirements and the need to size the system for the maximum water demand.

The cost-effectiveness of wind pumps is site-dependent. The cost of water from a wind system drops sharply as mean wind speed increases. With wind speed of 4 m/s, a wind system can be competitive with diesel for applications requiring 40–50 m^3/day. A recent global review of wind resources found that many LDCs have significant proportions of their land areas with mean wind speeds greater than 3.5 m/sec.[6]

Wind Electricity Generation

The past five years have seen considerable experience with wind turbines for stand-alone and grid-connected electricity generation. Over 13,000 micro wind turbine generators for central battery charging have been installed in Mongolia,[7] and California has some 15,000 turbines of 50–500 kW size in grid-connected operation. Small turbines in the 0.1 to 10 kW range now cost between \$1000 (for 100 watt machines built in large number in China) and \$2000 per kW installed. Installed cost for the machines in California wind "farms" have fallen to \$1000–\$1200 per kW.[8]

The output from a wind turbine depends on several factors, the most important of which are average windspeed and machine efficiency and reliability. Energy cost is also sensitive to the duration of calm periods at the site and the amount of electric storage required. For small turbines, cost of electricity in a good wind location ranges from \$0.10 to \$0.80 per kWh, depending on the scale of output and the power quality required.[9] Economics appear favorable for small loads such as those required for small-scale lighting, telecommunications, and navigation where mean wind speeds are above 4 m/s. In some places wind machines may be economically competitive with grid extension.

Small-scale wind-electric water pumping is a nearly commercial technology that offers higher system efficiency and reliability than wind mechanical pumping. Along with a reduction in delivered water cost over mechanical pumping, such systems, which have fewer moving parts, offer greater reliability and perhaps lower maintenance. Because of the higher efficiency, these systems may be competitive with diesels at good wind sites even for quite large water demands.[10]

The competitiveness of grid-connected wind systems depends on the wind resource and the cost of electricity from alternative sources. Construction and operation of wind "farms" for selling electricity to the grid has become a major industry in California, with total installed capacity of nearly 1300 MW. Experience has been progressively improv-

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[2] A. Derrick, **Vaccine Cold Chains With Solar Powered Refrigerators** (Washington, D.C.: I.T. Power, 1987).

[3] Bernard McNelis, **PV Water Pumping** (Washington, D.C.: I.T. Power, 1987).

[4] Matthew Buresch, **Strategies for Rural Electrification: An Economic Comparison Between Grid Extension and Diesel Power and Photovoltaic Power**, Proceedings from Photovoltaics: Investing in Developing (New Orleans, LA: I.T. Power, May 4–6, 1987).

[5] Alan Wyatt, **Problems and Prospects of Meeting the Basic Energy Needs of Rural Communities in Developing Countries Through the Utilization of Wind and Solar Energy Systems** (Research Triangle Institute, 1987).

[6] IT Power, Ltd., **Wind Technology Assessment Study**, Vol. I, UNDP, ITP/82041, UNDP # GLO/80/003 (Reading and Swindon, U.K.: February 1983), pp. ix–8.

[7] **Wind Energy News Digest** (June 15, 1986).

[8] R. Lynette and Associates, Inc., **The Lessons of the California Windfarms** (1987).

[9] M. Bergey, Bergey Windpower, personal communication.

[10] Alan Wyatt, Research Triangle Institute, personal communication.

ing. Many earlier machines produced less energy than expected, and problems of poor design, siting, and maintenance created difficulties. The technology has improved, however, and costs have declined. Newer machines are able to produce electricity at a cost of $0.07 to 0.08 per kWh.[11] Wind farms are also installed or are planned in Europe, Israel, Australia, and India. Five separate wind farms with total capacity of 3.3 MW have been installed in India, and there are plans for an additional 25 MW.

Water pumping systems operating from diesel engines have substantially lower first costs than wind and PV pumping systems, but have much higher operating costs. Diesel systems are also vulnerable to increases in fuel costs, shortages, and the need for imported spare parts. They also require more human intervention for supervision, maintenance, and refueling.

For small water demands, wind and PV pumping systems are often cheaper on a life-cycle basis than diesel. Figures 2 and 3 illustrate water cost (pumped through a 40 m head) for the different systems under a variety of conditions. The analysis indicates that a wind pumping system costing $500/m^2, utilizing a wind resource averaging 4m/s, is competitive even with low cost diesel at a daily water demand below 25 m^3. (Diesel fuel costs are assumed to be $0.60/liter in the high case, $0.30/liter in the low case.) Against higher cost diesel, the wind system is competitive at much higher water volumes. A PV system costing $14 per peak watt, at a site with daily insolation averaging 5 kWh/m^2, is competitive with diesel in the high case at volumes less than 10–20 m^3/day. If the head is less, wind and PV may be competitive at somewhat higher volumes.

The comparison in Figures 2 and 3 illustrates that both wind and PV are cost-effective under favorable resource conditions where transport costs for diesel are relatively high. Cost from wind systems is especially sensitive to wind speed. System size has a substantial impact on cost, particularly for diesel. For larger diesel engines, capital and operating cost per unit output decreases substantially. This effect also occurs with wind, but the influence of size is more modest. The ability to size PV systems for almost any load is an advantage, but there is also no significant lowering of equipment cost per unit output for larger PV systems.[12] Because of the high capital cost of PV and wind systems, it is important that they not be oversized. If output is halved from 80 to 40 m^3 for a system sized for 80 m^3, the cost of water doubles.

Wind and solar pumps have differing advantages and disadvantages.[13] PV systems are higher in cost, but should be very reliable. Wind pumps are less expensive, but demand more maintenance. Day-to-day output of PV units will be more consistent than wind pumps in many areas, reducing required storage volumes. Wind pumps are well suited to LDC production, while PV components will probably need to continue to be imported for most countries.

Biomass Fuels: Direct Combustion for Heat and Electricity

Direct combustion of wood wastes or crop residues for process heat and/or electricity generation is common in wood products and some agroprocessing industries. Wood from dedicated plantations is also used for heat in applications such as tea and tobacco drying. Much of the technology currently employed in LDCs to utilize biomass residues such as sugar cane bagasse or rice husks is of old design and low efficiency. Since the rapid increases in the prices of fossil fuels in the 1970s, many new systems for the handling and combustion of biomass fuels have come on the market in the U.S. and Europe. These include boilers for applications of the several MW scale.

With improved system efficiency, some systems which utilize biomass residues for on-site electricity demands can allow generation of more electricity than can be used on-site. If this electricity can be sold to the central grid or to other nearby users, it can be a source of revenue for wood products and agroprocessing industries. Particularly attractive for some applications are cogeneration systems where high pressure steam is used to generate electricity in a turbine and the lower pressure exhaust steam is used as industrial process heat. Bio-energy systems also can alleviate disposal problems associated with some biomass residues (such as rice husks).

In LDCs, application of biomass-electricity technology at sugar mills, larger rice mills and wood product facilities for on-site use and off-site sale is economically promising. During the last decade, sugar producers in Hawaii have installed efficient, high-pressure boilers in order to sell electricity to public utility grids. A.I.D. is supporting assessment of this option in Jamaica, Thailand, and the Dominican Republic. Researchers in a number of locations have identified cane varieties which, while

[11] R. Lynette and Associates, Inc., personal communication.

[12] Economics of Small Renewable Systems for Developing Countries, UNDP Background Paper, Symposium (Sophia-Antipolis, France: May 31–June 6, 1986), p. 37.

[13] Alan Wyatt, Problems and Prospects...

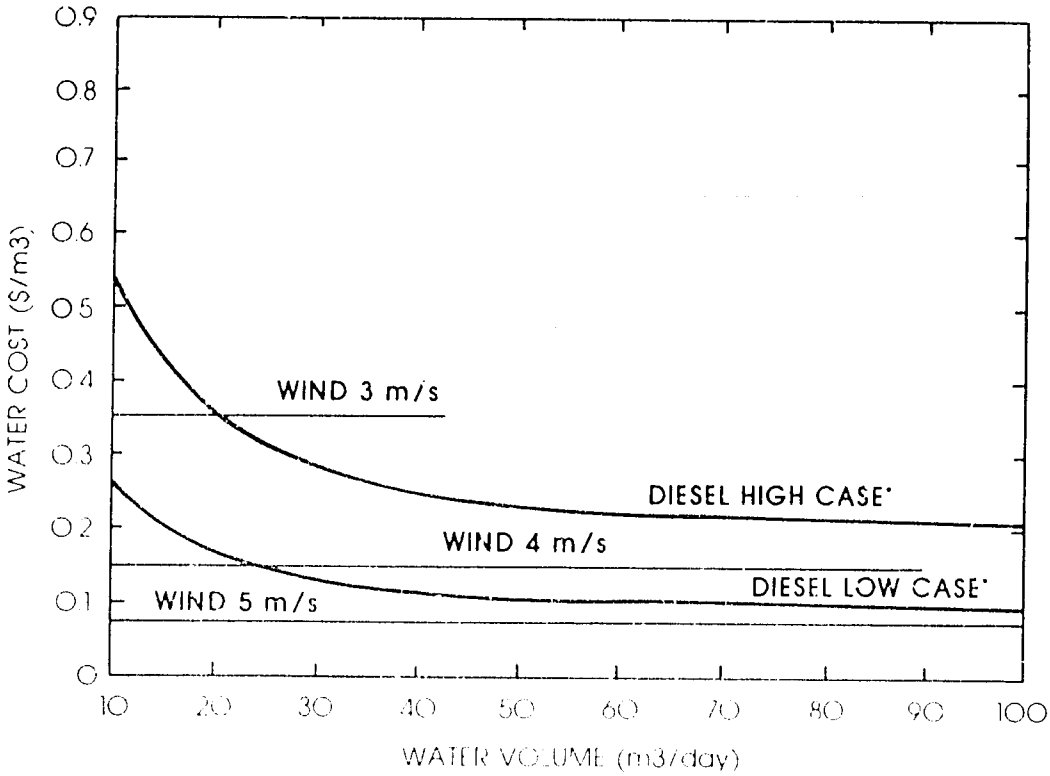

Figure 2. Comparative Cost for Water Pumping
(Diesel versus Wind)

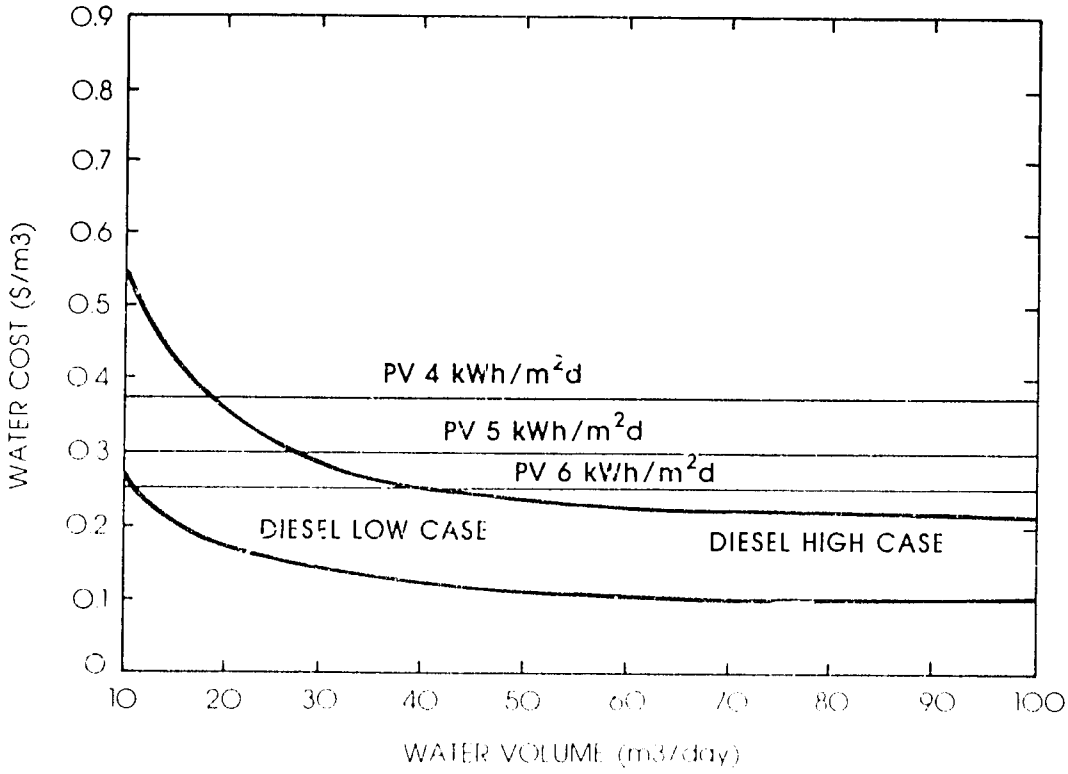

Figure 3. Comparative Cost for Water Pumping
(Diesel versus PV)

***Source:** G. Samuels, Oak Ridge National Laboratory, Analysis Assumptions in Appendix B.*

unattractive to conventional sugar growers, offer promise as "energy canes."

Rice-producing developing countries have been exploring more efficient ways to utilize rice husks. Several new mills in Burma cogenerate electricity using husks, and research in India is exploring both direct combustion and fluidized bed combustion of husks for electricity production. New approaches for using rice husks as a fuel source are also being implemented in the U.S. In Louisiana, an 11 MW power plant utilizing rice husks cost $1,000/kW. It is selling electricity to the grid and ash residue to steel the industry.[14]

Power generation with wood waste for on-site use is common at plywood factories and some sawmills in LDCs. The waste produced at sawmills is often considerably greater than required for on-site process steam and electricity needs, allowing the sawmills to become a source of rural power. Electricity cost for a large number of 3 MW wood waste-fired power plants to be installed in Indonesia were recently estimated to range between $0.03 and $0.05 per kWh.[15] The estimated capital cost per installation of large numbers of such plants was $2.5 million, or $830 per kW.

Another potential source of fuel for a biomass electricity system is wood from a dedicated tree plantation. In the Philippines, two plants of 3 MW size were completed and are in limited operation. Tree production was problematic due to use of inappropriate species and overall plantation management. In some areas, however, tree plantations have been very productive. A 1985 World Bank assessment of this so-called dendrothermal system concluded that such systems are likely to be competitive only at 10MW size or greater, at 1985 oil prices.[16] An A.I.D.-sponsored study in the Philippines concluded that a 2 MW power plant operating with a high utilization rate and fueled with wood from a 1500 hectare tree plantation was economical when compared to versus diesel generation.[17] Where fuel costs are high or supplies unreliable and sufficient electricity demand exists, the economics of smaller-scale dendrothermal systems may be favorable.

Another potential source of fuel for a biomass-electricity system is municipal solid waste (MSW). MSW systems have become increasingly sophisticated over the past 15 years, and research is continuing to minimize emissions and improve system economics. Capital costs for these systems are high, however, and materials recovery may be more important than energy production in many LDCs.

Biomass Fuels: Gasification for Heat and Electricity

Biomass materials may be converted through partial burning into combustible gases in a gasifier. These gases may be burned directly for heat applications (such as drying) or used in an engine for electricity generation, water pumping, or transportation. Gasifiers are coming into fairly common use for direct heat applications in a number of developing countries, and are quite cost-effective in many cases, particularly where retrofit of oil-fired equipment is possible. Since cleanliness of the gas is not a concern, as it is when using gasifiers with diesel engines, reliability of these systems appears to be good. Direct heat gasifiers are also able to use feedstocks with higher moisture content than gasifier-engine sets. Gasifiers for this purpose can be built in larger sizes, for example, up to about 10 million Btu/hour and take advantage of economies of scale which tend to make the financial and economic benefits more attractive.

The use of gasifiers with diesel engines has produced more failures than successes, in part due to the use of difficult feedstocks and the lack of careful operation and maintenance. Tars and contaminants in the producer gas condense and accumulate within the combustion chamber of internal combustion engines, which can cause severe damage if a rigorous decarbonization schedule is not followed. Long-term engine life is reduced regardless of maintenance scheduling, and users must devote a greater level of attention to the operation of these power systems. Of around 1000 gasifiers put into service in the Philippines, few are still working. In Brazil, on the other hand, gasifiers have been successful in many cases due to use of high quality charcoal and the ability of local industry to manufacture and service the hardware. Carefully-designed systems using wood chips, rice husks, and coconut shell and husk have been successful elsewhere, though there have been many more systems that have not worked well.

The decline in diesel prices has shrunk the niche where gasifiers for electricity generation are cost-effective. Where the cost of transporting diesel is high, loads fairly constant, and homogenous feedstocks and competent maintenance applied, a gasifier can be a reliable and cost-effective system. Brazilian-made gasifier-engine sets currently cost about

[14] B. Amin-Arsala, Office of Energy, Bioenergy Systems and Technology Project, A.I.D., personal communication.

[15] Peter Jezek, P., S. Schweitzer, and J. Weingart, **Small Power Systems for Economic Development in Rural Indonesia: New Opportunities for the Private Sector**, Draft (March 1987).

[16] World Bank, Energy Department, **Technical and Cost Characteristics of Dendrothermal Power Systems** (Washington, D.C.: December 1985).

[17] Associates in Rural Development, **Feasibility Reassessment . . .**, p. IV-69.

$500/kW, a price well below that of imported systems.[18]

Biogas

Biogas is a combustible gas produced as a result of biological conversion of organic material in an oxygen-free enclosure. A biogas system includes a digester container, piping to transfer gas to the device using the gas, and a means for using the sludge remaining after fermentation is complete. Uses of biogas are water heating, room lighting, cooking, and sometimes, running an engine.

Large numbers of residential-scale biogas digesters are in use in China and India, with much lesser numbers in some other LDCs. A significant number of units are reportedly not operational at any given time. Financial analyses of biogas have generally produced unfavorable results at the household scale. The major technical problems have been difficulty in ensuring proper operation and inadequate supply of fuel and water. The programs in Asia, e.g., Nepal, India, and China, have been notably more successful than in Africa. The African setting has been less amenable to handling the system's complexity, relatively high capital cost, and the need for daily inputs of water and dung.[19]

For industrial-scale applications where biomass feedstock is available on-site, biogas may be economical. Such facilities include distilleries, feed lots, and piggeries. The main factor is the competence of system design and capital cost, as well as availability of adequate feedstock. In some cases biogas systems can help alleviate waste disposal problems, thereby adding to their value. An A.I.D. evaluation in Nepal found that, at current diesel prices, a system with biogas providing 50% diesel substitution would just break even. Since substitution observed in Nepal was averaging about 65%–75%, commercial biogas applications appeared at least financially competitive.[20]

Alcohol from Biomass

Biomass-derived ethanol can be used to substitute partially or completely for gasoline in internal combustion engines. Ethanol can be produced from three main types of raw materials: sugar-bearing materials such as molasses and sweet sorghum, starches such as cassava and corn, and cellulosic material such as wood or agricultural residues. The basic technology for the production of ethanol (most commonly from sugarcane molasses in LDCs) is commercial except for cellulosic materials. Despite today's lower gasoline prices, ethanol production may be economically viable for landlocked countries where delivered gasoline is costly and/or for countries where prices received for sugar exports are less than production costs. The economic feasibility of ethanol production depends on whether there is a market for fermentation byproducts and the cost of feedstock and process steam and power. An integrated plant with byproduct markets can produce ethanol for around $0.25/liter. Depending on the circumstances, costs generally range between $0.25 and 0.35 per liter. In most cases, the minimum size for a cost-effective facility is around 60,000 liters per day.[21]

Solar Water Heating

Solar water heating with flat-plate or other type of collectors can be used to displace electricity or fuel oil for providing hot water. Water for residential and commercial purposes heated to temperatures of about 55–85°C is a commercial technology, and local manufacture of solar water heating systems exists in many developing countries. Providing higher temperatures for process heat for industry is a relatively well-developed technology, but requires more expensive collector systems.

The economic feasibility of solar water heating depends on the type of system, the type of application, the amount of solar insulation, and the cost of alternative fuels. For residential use, electric water heating is common in middle and upper income households. Economic analyses in a recent UNDP/World Bank study of solar water heating in Kenya found that residential and commercial applications displacing electricity were quite cost-effective in economic terms while the applications saving fuel oil in industry were not cost-effective under the criteria considered.[22] (Electricity in Kenya is mostly generated from hydro.) The economics in other countries depend on the local cost of electricity and other fuels, but the Kenya findings suggest that solar water heating for residential and commercial applications (hotels, hospitals, etc.) will often be cost-effective.

Solar Dryers

Solar dryers utilize the sun's energy to heat air to dry a wide variety of agricultural and other products. They can increase the value of products by better controlling the rate of moisture migra-

[18] M. Mendis, Energy Sector Management Assistance Program, World Bank, personal communication.

[19] U.S.A.I.D., Renewable Energy Technologies in Africa (Washington, D.C.: April 1984), p. B-5.

[20] Ashworth, Renewable Energy Systems . . ., pp. 5-8 to 5-10.

[21] W. Klausmeier, Sylvatex Corp., personal communication.

[22] UNDP/World Bank, Kenya Solar Water-Heating Study (February 1987).

tion. Where this adds significantly to the value of the product and higher revenue can be received, solar dryers may be cost-effective.

Solar dryers that have been built (mostly by research institutions) exhibit great variety in forms, construction materials used, types of products dried, performance obtained, and costs. Small passive solar dryers have been used with fruits, vegetables, cacao, and fish; large solar dryers (capacities of several hundred kilograms) have been developed to dry paddy in the wet season in Thailand and the Philippines. In comparison with ambient-air drying systems, solar drying presents several advantages. These include more rapid drying (often approaching that of fueled dryers), higher quality of dried products (due to controlled rate of moisture removal and insulation of the product from external agents), much lower operating costs than in fueled drying, and possibility of use in remote areas where conventionally fueled energy sources are scarce.

Performance of solar dryers has varied considerably, depending on the climate, the design, and rate of utilization of the unit. Positive results have been achieved in all Mediterranean and dry or humid tropical climates. Costs for finished products, on the basis of a "turnkey" installation assembled on site, have been estimated at between $60 and $400/m² of collector or $15 to $300 per kg of water evaporated per day. For best performance, units must be custom-made. Operating costs are comparable to those involved in natural drying. For farm and intermediate-scale applications (such as in cooperatives) solar dryers appear competitive with artificial dryers where there is a hot and relatively dry climate, availability of inexpensive labor, products whose moisture content must be reduced drastically, and regular availability of products to be dried throughout the year.[23]

Hydro Power

The harnessing of the energy in falling water for mechanical purposes and electricity generation has been common practice for decades. Large dams for electricity generation of hundreds or even thousands of megawatts have received the most attention, but smaller water flows can provide cost-effective power for the grid and for productive rural uses away from the grid. Small-scale hydropower (generally defined as less than 15 MW) is in use in around 20 LDCs, and equipment is now being manufactured in several developing countries. In many cases, small hydropower sites primarily serve a local demand such as power for an industrial plant or for irrigation.

[23] Fetter, A. Drying Food Products in the Developing Countries (Brussels: Commission of the European Communities, 1985).

Micro-hydropower generally refers to sites of less than 100 kW that can provide either electrical or mechanical power to serve small loads such as agroprocessing and milling. In many parts of the world, the technical expertise necessary to successfully implement micro-hydropower projects is locally available. Projects generally use simple, inexpensive equipment that often can be fabricated in-country. Entrepreneurs in Nepal, Pakistan, India, and elsewhere have begun manufacturing turbines, generators, and end-use equipment, and can provide "turnkey package" service to rural customers.

Costs and operating characteristics of small-scale hydropower are dependent on parameters such as the water head, flow rate, and the civil works required, as well as the capacity utilization factor in operation, which depends on power demand and flow variation. Local innovation has reduced the completed cost of some small-scale hydro projects from the $3,000 to $6,000/kW typical of heavily-engineered overseas systems to as low as $1,000 to $2,000/kW.[24] At $3,000/kW, the levelized cost from mini-hydropower ranges from around $0.15/kWh at 30% capacity factor to less than $0.10/kWh at 50% capacity factor.[25] Thus, a good site matched with an appropriate demand will often provide cheaper power than diesel generation.

Geothermal Energy

Geothermal energy provides heat and base-load electricity in many countries. Geothermal electric capacity in developing countries as of 1986 was 894 MW in the Philippines, 645 MW in Mexico, 95 MW in El Salvador, and a total of 147 MW distributed among Kenya, Nicaragua, Indonesia, Turkey, and China. About 50 other developing countries have been identified as having potential for geothermal development.[26] Some field development had occurred in seven of these as of 1986, and some degree of exploration had been done in 30 other countries.

Electric power can be generated economically with relatively low-temperature geothermal fluid (about 120° to 180°C). Due to the cost of exploring and developing the resource, geothermal power plants have mostly been of large (tens of megawatts) size. In the past five years, however, smaller systems have come into commercial use. Ready-to-install turbo-generator packages in the 1 to 1.5 MW range have been operating reliably in

[24] NRECA, Decentralized Hydropower in A.I.D.'s Development Assistance Program (1985).

[25] Strategies Unlimited, Small-Scale Hydropower Market Analysis, Draft (1987).

[26] Meridian Corporation, Foreign Geothermal Energy Market Analysis (1987).

the U.S. since 1983. Their small size allows for incremental development of a geothermal well-field or for use at isolated or off-grid sites. Use of Rankine cycle engines allows utilization of lower temperature resources (down to 120°C) than was previously economical. Cost in 1987 for a 1200 kW power plant (delivered in the U.S.) was $800/kW.[27]

Solar Thermal Electricity Generation

Electricity production from solar thermal systems has been demonstrated for a variety of large-scale technologies. These include parabolic dish and trough systems, central receiver systems, and solar thermal ponds, which are operating in Israel. Privately-financed power stations using parabolic troughs are now producing electricity for utilities in Southern California under very favorable utility purchase arrangements. At the end of 1987 the total installed capacity of six stations was 138 MW.

PRIORITIES FOR TECHNOLOGY DEVELOPMENT

Substantial progress has been made in the last 10 years in the design, testing, and commercialization of many renewable energy technologies. Some of these technologies represent export opportunities for the developed countries, for example, wind electric systems, photovoltaics, large biomass combustion systems, alcohol production technology and equipment, and geothermal technology and equipment. Others, such as wind mechanical pumping equipment, biogas, solar drying, small hydro power, and traditional biomass utilization, are more likely to remain locally manufactured. In both areas however, the review conducted for this report has identified: (a) market opportunities which have been missed, (b) incomplete technology development for major productive applications, and (c) inadequate pursuit of potential for technology cooperation between the United States and LDCs.

The development, manufacture, and sales of renewable energy technology presents a major opportunity both for developing countries and for U.S. industry. Developing countries are in a position to exploit the opportunities identified in past projects, but still must further develop some technologies and establish further local production capability. For its part, the U.S. renewable industry faces stiff foreign competition in many renewable technology areas, and in some LDC markets its technology may be too complex, costly, and large-scale. In order for both LDC development and U.S. market opportunities be exploited, further effort is necessary to:

1. support LDC institution-building and training in order to expand technology transfer and contribute to future trade opportunities in the medium to long-term;
2. identify and develop further small-scale applications of renewable technology, such as PV and wind electric, for rural productive enterprises and social uses;
3. assist U.S. industry in adapting technology to adjust to appropriate LDC requirements in scale, complexity, costs, and maintenance environment; and
4. work with U.S. industry in reassessing foreign trade opportunities for renewables and factoring in the plans and supporting programs, and the developing countries' goals for greater self-sufficiency.

It is not possible or appropriate in this report to attempt to present a complete list of either the needs for renewable energy technology adaptation or future export opportunities for U.S. industry. Nor is it possible to give a complete list of other renewable technology development needs. The type of adaptation will, of course, also vary in each case. For example, in some cases only reliability testing may be necessary to insure users that a device can be used successfully. With other technologies, local manufacturing and materials problems, alternative fuel combinations, and selection of more durable system components to facilitate on-site servicing is necessary. A preliminary and partial discussion of some of the major opportunities and needs is presented below.

Agricultural/Food Processing

In many intermediate scale agricultural and food processing facilities, either biomass residue or effluent waste streams exist which could be successfully converted for on-site energy use. A large market exists for systems appropriately sized for smaller scale applications.

Prime movers in the range of 25 to 200 kW need to be built to provide energy sources for systems for threshing, grinding and milling applications. Technologies such as steam engines or small turbines can be used for remote power where biomass and water are available. However, equipment sized to meet these loads is not currently available off-the-shelf. Systems which could be retrofitted to oil-fired equipment could also be highly useful, for example, equipment allowing tree-plantation fuels to be used for tea drying or industrial process steam. Direct conversion of solid biomass to a gaseous

[27] D. Schochet, Ormat, Inc., personal communication.

form for drying, curing, and kiln firing operations also presents a major opportunity if systems currently in use can be modified to increase thermal efficiency and reduce cost.

Digester systems in larger-scale and commercial applications are needed to process effluent from distilleries, canneries, slaughter houses and feedlots. Digesters may offer both environmental and economic benefits in systems which have significant on-site energy demands. Downscaling and modular packages would greatly enhance use of this technology with the major impediment being the higher cost associated with custom designed systems.

Many rural areas require refrigeration or ice-making to preserve fish, dairy products, and fresh produce. Small-scale biomass systems for absorption refrigeration or, in smaller applications, wind or PV electricity based systems could be very beneficial.

Water Pumping

Small water systems (< 10 kW) are presently served frequently by either hand pumps, wind, or small internal combustion engines. Recent studies have shown that smaller, electrically-driven wind systems offer attractive advantages over more traditional mechanically-driven systems. These systems, if they are to see wide-scale acceptance by the market, will require funding to demonstrate their reliability. Optimization of components is also desirable to provide the most cost-effective system compatible with rural area requirements.

Domestic Fuel Substitution and Conservation

Densification or briquetting of biomass fuels can be an effective means of enhancing the usefulness of agricultural processing residues and making use of wasted materials. Technologies exist to economically briquette fuels, but cost reduction and greater reliability of systems are needed, as well as improved equipment for utilizing these fuels in conventional energy-using equipment.

Recent studies in Pakistan to determine the acceptability of using briquetted biomass/coal mixture for domestic cooking also have yielded encouraging results. Further effort is required to establish markets, study health effects, and support initial commercialization.

ENVIRONMENTAL AND HEALTH ISSUES AND RENEWABLES

In addition to supporting rural economic development, successful use of the renewable energy technologies discussed in this section may have a number of environmental and health benefits. These may include improvements in human health resulting from clean drinking water supply and, in the case of improved stoves, reduction in exposure of women to harmful smoke or emissions. Renewable alternatives to conventional fuels for electricity can reduce air and water pollution and other impacts associated with conventional electricity generation. Though obviously the impact of these technologies in the near-term will not be large, their adoption sets a direction that could lead to significant benefits (and help avoid serious problems) in the long run.

Supply of energy for rural health centers and for drinking water systems is potentially a major contribution of renewable energy to improved rural health. Of the roughly one billion people in the world without safe drinking water, about 100 million could be economically served by solar PVs or other renewables, according to a recent study.[28]

Another important health benefit is the potential of improved cookstoves and introduction of alternative fuels to reduce exposure of women and children to smoke and burns. Though further research is needed to better understand the health impact of cookstove smoke exposure, studies suggest that such exposure is connected with acute respiratory infections, chronic obstructive lung diseases, blindness and other eye problems, and low infant birthweights. High levels of potentially cancer-causing compounds have been found in wood cookstove smoke.

Another group of renewable energy technologies are those that improve the supply and use of traditional renewable energy resources used by households and small industry. Projects that contribute to fuelwood supply, methods for more efficient charcoal production, and improved end-use technologies can lessen the pressure on natural forests and/or reduce the demand for crop residues and animal dung that may have soil replenishment uses. General clearing for agricultural use and, in many areas, gathering of wood for energy purposes are the major causes of deforestation and associated desertification, erosion, and loss of soil fertility. By enhancing wood supply and reducing the amount combusted, the above technologies also lessen CO_2 buildup.

Air pollution in urban areas from transport fuel use and stationary energy production is also a cause of respiratory problems in some countries. Use of ethanol from renewable biomass resources

[28] Meridian Corp., A Comparative Assessment of Photovoltaics, Handpumps and Diesels for Rural Water Supply (May 1987)

instead of gasoline leads to the reduction of most vehicle emissions.

Many renewable energy technologies also displace other means of generating electricity. In the near term, many of the systems displaced will be off-grid diesel generators, though over time many of these units would otherwise be replaced by grid electricity. Renewable energy technologies can also feed into the central grid. The long-run potential for electricity generation from renewable sources such as biomass, wind, solar energy, small hydro, and geothermal energy is on a cumulative basis quite large in many LDC's. By substituting for other conventional sources of grid electricity, which include combustion of oil, natural gas, and coal, as well as large hydro and nuclear energy, renewables can bring considerable environmental benefits.

The environmental impacts of the different means of generating electricity vary with many factors. These include energy source, scale of use, type of technology used in energy collection and transformation, location of the facility relative to sensitive natural environments and human populations, and degree of attention given to mitigating impacts. Renewable energy technologies, in contrast to many conventional systems, offer the potential for relatively low environmental impact. In contrast to fossil fuel technologies, renewables generate electricity with little or no pollution of air and water. With the exception of some bio-energy technologies, they do not contribute to atmospheric CO_2 buildup. Some technologies such as anaerobic digestion make use of residues whose disposal may have detrimental environmental impacts.

It should be recognized, however, that certain large-scale renewables used for producing electricity entail severe environmental problems. The most well-known are large hydro projects, which utilize a renewable resource but often cause considerable loss of land, bring major ecological changes, and may create a breeding ground for undesirable insects and water-borne diseases. Depending on the site and design, small hydro dams can also have some of the negative ecological impacts of large dams. Other potentially negative effects of renewables are associated with geothermal resources development and use; for biomass fuels, alternative use of crop residues that may be necessary for soil replenishment; and, in the case of energy plantations, competition for arable land with food production.

RENEWABLE ENERGY IN RURAL DEVELOPMENT

Development efforts are intended to provide access to resources and services such as water, food, health care, education, shelter and economic opportunity. The availability of capital and other inputs such as energy is fundamental to a rural economic development program.

Renewable energy resources and traditional technology have played a leading role in satisfying rural energy demands. Fuels such as wood and wood waste, agricultural residues and water power, have been used for centuries to provide energy requirements for households, farms, and small productive enterprises. These traditional energy resources often comprise a surprisingly large percentage of developing country energy consumption. In many cases, traditional energy use accounts for well over one-half of total national energy consumption.

In addition to traditional sources of energy, there are other rural renewable energy resources which have as yet gone largely unexploited. Today, many technologies are commercially available which could use these untapped renewable resources. For example, photovoltaics can be used to provide power to refrigeration equipment and to provide lighting for rural primary health centers. Enhanced biomass conversion systems using a variety of agricultural and forest products can be used for power and thermal loads. Hydro resources can be used in a variety of small electrical and mechanical applications ranging from under 50 kW to over 100 MW. In most developing countries, however, resource assessment and market surveys have not been undertaken to provide the necessary level of information required for renewables implementation. This represents a major constraint to the introduction of renewable technology alternatives.

The following brief discussion describes some of the roles renewable resources can play in providing energy to rural areas.

Household and Public Services

Household Uses. Traditional energy resources are used extensively in most countries to satisfy needs for cooking and household space heating. Food preservation, including both drying and in some cases refrigeration, can also be satisfied by renewable resources. Most agricultural and home drying practices are accomplished by direct solar drying techniques (most often performed pre-harvest); in some cases, when higher grade thermal requirements are necessary, agricultural residues or fuelwood may be employed.

Energy use for domestic cooking constitutes the major demand for declining traditional resources such as fuelwood. Estimates in various countries suggest that cooking consumes from 62% to 80% of total energy used in rural areas.[29] One major attempt to apply simple renewable technology has been improvement in the efficiency of cooking devices. These have been promoted successfully in the case of commercial fuels such as charcoal, but this success has not been repeated in reducing use of user-gathered wood or other biomass. Neither fuel substitutes such as briquetted biomass nor conservation are likely to have major impacts except where fuels are commercial.

Water. Water is necessary for household purposes, for agricultural production, health services, and some processes such as refrigeration (ice is often used for preservation of seafood). Water lifting and pumping is an energy intensive process, and, if large quantities are pumped, conventional fuels will usually be required. However, for village or small enterprise activities, photovoltaics and wind can and have been used to service demands of 10-20 m^3/day and 10-50 m^3/day, respectively. Photovoltaics have been used to provide water supply for villages with remote water services. In most cases, when water is available on site, manually operated hand pumps are used to deliver water to a central distribution point. Wind driven-pumps have been employed in some locations which have acceptable wind regimes, and are meeting demand for potable water and livestock watering. These systems, however, require relatively large capital outlays for appropriately sized equipment, which often is beyond the reach of a single user.

Health. Rural health clinics provide primary care to rural populations which do not have ready access to hospitals and medical technicians. These primary care facilities require electric and thermal energy for refrigeration equipment, lighting, and, in some cases, sterilization equipment.

Refrigeration is required to extend the shelf life of vaccines and medicinal supplies. It may also be required to extend the life of specimens for laboratory analysis to be performed in more sophisticated medical centers located in urban areas. Refrigeration demands can be met by photovoltaic arrays with battery back-up units. Photovoltaic arrays can also be used to service lighting demands. These power requirements are relatively small (less than 1 kW), but are of a very high social value.

Thermal energy is needed to provide hot water for sterilization and cleaning other supplies and instruments. This may be provided by using solar thermal collector systems or by using a biomass-fueled combustion system. Typical fuels for combustion systems would include fuelwood or an agricultural residue, such as coconut shell, rice husks, or corn cobs.

Agroprocessing and Small Industry

Renewable resources are able to effectively service a wide range of agricultural and small industrial demands. These include drying, biomass combustion, hydro power, and others for threshing and winnowing, shelling, hulling, grinding, storage and refrigeration, canning and related processing, and actual harvesting practices. They are also used for field operations in crop production, such as cultivation and planting, pest control and harvesting.

Several crops require processing after harvest to either improve storage characteristics or to enhance the value of the product to suit consumer/market requirements. Grain is dried to extend storage life, milled, and, in some cases, par-boiled or polished to suit a particular consumer preference. Nuts are shelled, dried, and sometimes roasted to add value to the raw product. Oil seeds are subjected to a thermal process to extract the oil. Milk is pasteurized, separated into various constituents, and in some cases heat-treated and refrigerated to extend storage life. All these processes have the effect of extending storage life and/or adding value (through quality improvement) to the end product. Table 3 provides a summary of the renewable energy technologies used to satisfy these various demands. Some of the more important rural production applications are described below.

Drying. In most countries, grain is dried through simple exposure to the sun, either in the field or on a drying pad. However, when harvest occurs during a wet season, mechanical drying becomes necessary to insure that losses due to spoilage are minimized. This can be accomplished using conventional fuels (e.g., kerosene) or by using biomass fuels. Experience has shown that solar dryers are often less effective than other alternatives, mostly due to the fact that the demand occurs during periods of low solar insolation. However, agricultural residues have been used quite effectively to provide the thermal energy for drying purposes.

Milling and Grinding. Small mills vary from larger commercial facilities in capacity and usually milling efficiency, but specific energy required is equivalent for most mills. Energy used in grain mills has been provided by small water turbines, electric motors, or by diesel engines. In some appli-

[29] Roger Revelle, Energy Use in Rural India, **Science** 192 (June 4, 1976), pp. 969-975; and J.D. Walton, Jr., *et al.*, **A State-of-the-Art Survey of Solar-Powered Irrigation Pumps, Solar Cookers, and Wood-Burning Stoves for Use in Sub-Saharan Africa** (Georgia Institute of Technology, 1978).

Table 3. Renewable Resources and Examples of Their Applications in Rural Development

	Applications							
	Electric generation	Milling	Drying	Refrigerated storage/ ice-making	Water supply	Communications	Cooking	Lighting
Biomass (e.g., wood, bagasse, coconuts, shell husk, coffee grounds, etc.)	X	X	X	X			X	
Wind	X	X		X	X			X
Solar:								
Thermal			X					
PV	X			X	X	X		X
Hydro	X	X		X				
Geothermal	X		X				X	

Source: D. Waddle, Oak Ridge National Laboratory, December 1987.

cations, such as sugar mills, steam systems have been employed to provide shaft power for the mill and to provide electricity to drive other auxiliary loads. Where and when available, hydro resources have been used to provide shaft power for grinding and milling.

Opportunities to expand the use of biomass fuels and hydro facilities to power mechanical loads exist in many developing countries. In many cases, this requires matching a suitably sized technology to a specific application. For example, by far the greatest number of rice mills are very small scale, requiring 5 kW prime movers to supply shaft power. A significant number of intermediate-sized mills (25–200 kW) are in use, and are presently powered by grid-powered electric motors or direct diesel drives. A very small fraction of mills exist in the large category (over 500 kW). However, commercially proven biomass conversion systems are available for only very large systems. Systems in the small and intermediate ranges are available from limited sources and by and large have yet to prove themselves under continual field use. There is a need to develop biomass conversion systems capable of operating under adverse field conditions in the small and intermediate size range.

Other Thermal Applications

Rural enterprises usually have relatively few needs for thermal energy. Some of these, however, present attractive opportunities for conversion of renewable energy forms to service these thermal loads. The two major opportunities to exploit renewable resources in using these processes appear to be in food processing and in the building materials industry.

Food Processing. Various important food processing activities are able to make use of renewable resources, including biomass and small-hydro. Canning plants consume vast quantities of steam in the processes of sterilization, pasteurization and the bottling process itself. Ice making is very important in areas where fishing is a major industry. Very often, these areas are located far from population centers where the larger markets exist. In order to preserve the catch to insure quality upon delivery, the fish must be iced at the landing point or on the vessel itself. Refrigeration is also necessary in areas with delicate vegetable, or cut flower industries. With the introduction of smaller biomass-fueled absorption refrigeration equipment and yet, through use of wind and photovoltaic-electric technologies, these loads can be met through use of renewables.

Building Materials. Ceramic kilns require continual high grade thermal input to maintain temperatures during the firing process. Brick making requires thermal energy to fire the clay. Lumber must be dried after milling, and production of plywood consumes large quantities of process steam. All these processes can and in some cases are being satisfied with biomass conversion systems. Some of them, if large enough to justify the capital expenditure, could be met by use of low temperature geothermal energy. In larger plant sites, some of these loads might be serviced by biomass-powered cogeneration systems.

Summary

Much potential remains for introduction of renewable energy resources and technologies to serve productive, value-added processes, which would provide increased income, opportunity, and community development for rural areas. These also often present opportunities for local and U.S. companies willing to develop technologies appropriately designed to suit the local conditions and market demand.

NEW DIRECTIONS FOR A.I.D.'S RENEWABLE ENERGY ACTIVITIES

OVERVIEW

In this report we have briefly examined some of the major economic and energy problems facing the developing countries. We have shown that while renewable energy sources have not had the far-reaching impact many had hoped they would, specific renewable technologies have demonstrated that they have a valuable role to play. Certain renewable options are more appropriate in scale for rural energy end-uses, have lower operating and maintenance costs than engine-based systems, offer opportunities for local manufacture, and utilize local natural resources as their source of energy. The choice of energy source must be based on more than potential benefits, however; it must be based on a site-specific economic, technical, and institutional assessment of what is in the best interest of the user, community or industry to be served. Furthermore, productive rural and social uses must exist or be developed simultaneously for the new energy source to realize its potential.

ELEMENTS OF A.I.D. RENEWABLE ENERGY STRATEGY

It is appropriate at this time for A.I.D. to establish New Directions for its renewable energy activities. These directions should recognize today's economic and technical realities and integrate renewable options where appropriate as a complement to rural, agricultural, and other development programs. These activities also must be pursued within the resource, social, environmental, and institutional situation of particular countries and even sites. Thus, no predetermined technology choice is possible; instead, informed judgement and case by case comparative evaluation is called for.

What are the overall objectives of A.I.D.'s New Directions?

- *First*, to ensure the supply of appropriate "least-cost" sources of energy to complement rural development efforts, enhance agricultural productivity, and create rural employment opportunities.
- *Second*, to support local and U.S. private sector initiatives to supply necessary energy services, technology, and capital, in order to achieve self-sustaining solutions to energy problems.
- *Third*, to mitigate household energy problems through expanded biomass supply and improved utilization.
- *Fourth*, to create the policy and institutional conditions required for sound energy sector development.

Constraints to Achieving A.I.D.'s Objectives. Realizing the above objectives requires a continuation of efforts to create the necessary country-level policy and institutional framework. Pricing (including taxes and subsidies), institutional conditions, and institutional development, are the three primary issues which must be addressed. Pricing policies which subsidize conventional petroleum fuels or electricity create incentives for the excessive use of these fuels and reduce the incentives for considering renewable alternatives. Institutional conditions such as the traditional government procurement bias favoring low first-cost equipment versus low life-cycle cost seriously impedes the introduction of renewables. Similarly detrimental is the commitment of renewable research and development funding primarily to R&D institutions without parallel support for commercialization. Finally, further institutional development is needed to create strong intermediate rural institutions or systems, such as technical assistance and extension services, to stimulate the market for commercial uses for renewables.

Lack of credit programs to provide financing is another serious constraint to the introduction of renewable technology, given high capital costs and, in some cases, a substantial foreign exchange component. Lack of adequate funds constrain the private sector in its attempts to develop technologies for introduction and in the establishment of production and marketing systems. Similarly, consumers are constrained by the lack of financing required to defray the higher initial costs of renewable systems.

THE ROLE OF ECONOMIC GROWTH AND THE PRIVATE SECTOR

Within the general development program of A.I.D., economic growth is considered the primary driving force for self-sustained development. Rural and agricultural development are essential prerequisites for achieving overall economic growth, and for increasing employment, retarding migration to urban areas, and permitting more rational use of limited natural resources. Special attention to the energy requirements of rural and agricultural production systems is therefore essential. The "Strategic Plan" for A.I.D. recognizes the importance of the private sector in achieving development goals and states, "We encourage governments to place greater reliance on free market forces and the indigenous private sector as the principal engines of sustainable development." [1]

The review of experiences with renewable energy applications suggests that if renewables are to make a sustained and widespread contribution to a developing country's energy system, private sector production, marketing, sales, and service must be the primary implementing vehicles. A.I.D. inputs can be of valuable assistance in promoting private sector involvement. For example, assistance can be provided by helping to develop local maintenance and repair capability or by stimulating the establishment of appropriate local energy companies. Even when the buyers and project developers are public sector organizations, as in the health, water supply, or communications areas, the private sector plays a major role as an source of equipment, spare parts supplier, and provider of maintenance services.

At the same time, LDC governments have a necessary role to play in establishing the institutional conditions necessary for new energy supply. Nongovernmental organizations also serve as important supplemental vehicles for implementation of alternative energy sources in certain cases. For example, where a market may not exist or when the market is weak (e.g., where fuels are noncommercial).

Table 4, on the next page, enumerates important potential roles for the local and U.S. private sector, nongovernmental organizations and developing country governments in the renewable energy area.

IMPORTANCE OF RURAL AND DECENTRALIZED ENERGY SUPPLY

In the past, insufficient attention has been given to providing the energy infrastructure and power required for rural agricultural, industrial and social development. Examples of major losses in agricultural output in recent years due to insufficient or unreliable oil or electricity supply in the Sudan, Somalia, Sri Lanka, and Madagascar are examples of a widespread problem.[2] In recognition of this problem, A.I.D.'s Energy Policy Paper stated, "A.I.D. will give special attention to providing cost-effective energy supplies for the rural economy...." [3]

An emphasis on decentralized power supply via the application of renewables supports broad A.I.D. policies of promoting small-scale private enterprises, especially those in rural areas and small towns.[4] It has been increasingly recognized that these small-scale enterprises play a much larger role in LDC economies than previously thought, often accounting for more than half of industrial production. The lack of reliable or affordable energy supplies could be a serious constraint to the further expansion of such small industries or to the more extensive utilization of existing businesses. Such areas are often good sites for renewable energy applications, such as power generation from small hydro or biomass.

Allowing private firms and individuals to generate and sell electricity, either to neighboring people and companies or to the grid, is potentially an effective way of adding system capacity or providing decentralized electricity while minimizing the demand on public sector financial resources. Many firms in the mineral and agro-processing industries (especially sugar factories and paper mills), have generated electricity and process heat from bagasse or wood waste to serve their own needs and have often provided power to employees' dwellings or neighbors. Expanding and replicating this model is a logical means of improving energy delivery to rural areas.

Renewable energy technologies are not uniquely suited to private power production. In many cases fossil fuel systems would be the least-cost, logical choice; in others, depending on renewable resource endowments and fuel prices, renewables are more appropriate. Assisting profit-motivated firms and entrepreneurs and providing a broad choice of generating technology, within environmental and other policy guidelines, appears to be the most appropriate means of promoting least-cost solutions.

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[1] U.S.A.I.D., **Blueprint for Development** (Washington, D.C.: undated).

[2] U.S.A.I.D., Office of Energy, Bureau for Science and Technology, **Small Power Systems for Economic Development in Rural Areas: A Strategy** (Washington, D.C.: U.S.A.I.D., November 1986)

[3] U.S.A.I.D., **A.I.D. Policy Paper Energy** (Washington, D.C.: July 1984)

[4] U.S.A.I.D., Office of Energy, **Energy and the Private Sector**, Energy for Development Paper No. 3 (Washington, D.C.: U.S.A.I.D., October 1985).

TABLE 4. POSSIBLE FORMS OF PRIVATE SECTOR, GOVERNMENT AND NONGOVERNMENT ORGANIZATION INVOLVEMENT IN RENEWABLE ENERGY DISSEMINATION

Local Private Sector

- Equipment design or adaptation
- Equipment manufacture
- Equipment assembly
- Distribution and sales
- Facility construction
- Maintenance and spare parts supply

U.S. Private Sector

- Equipment licensing and joint ventures
- Equipment design or adaptation
- Equipment manufacture and sales
- Establishment of local outlets
- Investment in projects
- Services such as management assistance and spare parts supply
- Preparation of feasibility studies

Nongovernment Organizations

- Training and extension
- Needs assessment
- Public education
- Small-scale production promotion

Government

- Institutional and policy framework
- Extension

NEW DIRECTIONS IN RENEWABLE ENERGY ACTIVITIES

New Directions for A.I.D.'s renewable energy activities (and associated programs) are required in order to more effectively develop the renewable and indigenous energy resources needed for rural economic development. The following describes these New Directions, as well as selected current activities which support these directions.

A.I.D.'s renewable energy activities program will be directed to support the following New Directions:

- **Private Sector Collaboration**
  Expanded cooperation between A.I.D., and U.S. and developing country renewable energy firms and developers, to merge A.I.D. knowledge of country constraints and conditions and A.I.D. technical and financial support with private sector skills in design, manufacture, and marketing.

- **Rural Development and Private Enterprise Support**
  Technical assistance to mission private enterprise and rural development programs will be increased to ensure provision of adequate renewable and other sources of energy for projects requiring new energy sources to identify energy business opportunities, and to provide information and training for A.I.D. staff on energy options for health, agriculture, and other rural development activities.

- **Training in Support of Renewables Commercialization**
  Renewable energy training sponsored by A.I.D. and related initiatives will be expanded to support the LDC private sector and stimulate the commercial use of renewables in water pumping, health, rural commercial-industrial applications, and decentralized electric power supply, among other rural development applications.

- **Emphasis on Implementation**
  Development of innovative financing schemes to assist in the commercial penetration of renewables into rural and dispersed private markets.
  Expansion of risk-sharing via feasibility study and other explicit support, such as targeted use of the A.I.D. commodity import program to facilitate U.S. and LDC private sector ventures to transfer, adapt, and market cost-effective rural energy systems.
  Further development and adaptation of energy production and utilization technology for selected high priority rural development applications, in-

cluding adaptation of United States renewable energy equipment.

- **Coordinated Action**
  Reliance on greater donor coordination (for example, with the Energy Sector Management Assistance Program of the World Bank, among others) will be pursued to more effectively utilize A.I.D. resources and help develop policy conditions necessary for the introduction of new energy sources.

CURRENT RENEWABLE ENERGY ACTIVITIES

Biomass Energy Systems

The Bioenergy Systems and Technology (BST) Project is intended to design, develop, and implement field projects using bioenergy systems. The project is presently funded to do work in three primary sectors: sugarcane bagasse, rice residue, and wood products utilization. These materials represent resources of significant importance to developing countries. This project provides support for prefeasibility studies, limited research in biomass utilization systems, field testing of new equipment, and promotion of private sector investment in energy systems utilizing the above biomass resources.

As an example of BST activities, A.I.D. has begun a Cane/Energy Assessment Program which evaluates the use of sugar cane crops to produce electricity for year-round baseload applications and, potentially, fuel alcohol for transport. This initiative is particularly important as it serves to mitigate the poor economic condition of the sugar industry, a major employer and income generator in the agricultural sector of many developing countries. U.S.A.I.D. Kingston-Jamaica, for example, in cooperation with the A.I.D. Office of Energy, the Trade and Development Program, and the U.S. and Jamaican private sectors, is conducting a pilot cane energy program. Studies of cane energy potential in Honduras, the Philippines, and Thailand have also been undertaken, among others.[5]

Renewable Energy Applications

Another centrally funded program is the Renewable Energy Applications and Training Project (REAT). This project is responsible for the assessment of A.I.D.'s past experience with renewables, recommendation of new initiatives in renewable energy technology for rural and agricultural development, and coordination and support of A.I.D. programs to identify markets and commercialize renewable technologies.

The REAT project seeks to achieve these objectives in cooperation with A.I.D.'s missions and regional bureaus through the following activities:

- Assistance to the LDC and U.S. private sector in identifying development oriented applications of renewables and support of the design and implementation of commercially oriented projects.
- Training of LDC nationals from the private and public sectors in identification of productive uses of renewable technology, design of applications, and commercialization of technology.
- Provision of information on past and future renewables applications and status and results of renewables technology research and demonstration to the LDC and U.S. private sectors, LDC governments, and NGO's, among others.
- Development of an "A.I.D.-Industry Partnership" to facilitate comment on, and adaptation of, A.I.D. projects to ensure sound private sector oriented design and to ensure that demonstration leads to commercialization. This includes an informal "A.I.D.-industry forum" to exchange information on doing business successfully in LDCs between experienced U.S. business and the renewable industry members committed to export development and technology adaptation.
- Support to the Inter-agency Committee on Renewable Energy Commerce and Trade (CORECT), including adaptation of A.I.D. programs in training and commodity exports to better meet U.S. industry export goals and support overall education activities for developing countries on renewable energy.
- Support to applied research and development on renewables technology to further develop certain priority applications, adapt the scale and complexity of available equipment to LDC markets, and assist in identifying innovative, productive, and consumer markets. One option under consideration would be to sponsor competitive proposals for technology adaptation to LDC markets, with awards to support development and commercialization.

Household Fuels

Energy Supply. The strategy for meeting household energy needs in rural areas is emphasizing new mechanisms for the supply of traditional fuels. These include agroforestry-type initiatives to produce wood fuel (normally in a multipurpose

[5] U.S.A.I.D., **Cane Production for Sugar and Electric Production in Jamaica,** Bioenergy Systems and Technology Project (Washington, D.C.: U.S.A.I.D., October 1984).

system) and other efforts to substitute or use alternative fuels, including petroleum and electricity, as well as the use of agricultural processing residues and coal-biomass residue mixtures as supplements. A greater understanding of traditional fuel markets is required to assist in planning and executing interventions, particularly pricing policy.

Fuel Utilization/Conservation. Studies show that conservation in most cases follows scarcity and/or higher prices. This means that it is extremely difficult to introduce innovations to conserve biomass resources before resources are already threatened. Recognizing the difficulty of attempting to conserve fuels, resources are being targeted to those areas with the greatest chance of success. A.I.D. strategy will be to expand support to stove conservation efforts when they deal with commercial fuels, use the private sector as the basis for production and marketing, and offer significant potential for self-sustaining and large-scale production. Finally, since inadequate attention has been devoted to understanding the fuel saving and health and environmental impacts of improved cooking devices, greater attention is being given to these issues.

Energy and Irrigation

This centrally funded activity is designed to promote the economic utilization of water for irrigation in A.I.D.-assisted countries. The program supports improvements in the performance of existing small water pumping systems, development of a methodology for selecting small pumping systems, promotion of integrated small-systems for water supply for irrigation, and dissemination of information on commercially available options for water pumping and energy systems and equipment. While this is not primarily a renewable energy-oriented program, it does serve to identify appropriate roles for renewables and supports objective review of pumping options.[6]

[6] U.S.A.I.D., Office of Energy, **Draft Program Plan—1988-89** (Washington, D.C.: U.S.A.I.D., December 1987)

APPENDICES

APPENDIX A

A.I.D. RENEWABLE ENERGY DATABASE

The Agency for International Development (A.I.D.) Renewable Energy Database is a compilation of detailed technical and financial data on renewable energy activities in selected A.I.D.-funded projects. At present, the database contains information on 80 projects and subprojects implemented since 1975.

For each project, the database contains the project number and title, country, years of operation, status, length of project funding, appropriation category, project purpose, renewable energy outputs, project inputs, a summary of renewable energy activities, key words, descriptions of technical applications, annotations of project technical reports, evaluation findings, key persons, detailed funding data, project revisions, and follow-on activities.

The Renewable Energy Database was prepared by Volunteers in Technical Assistance (VITA) under A.I.D. contract number LAC-5701-C-00-5057-00. Data were gathered from project documents available in the A.I.D. central document depository and from numerous reports provided by contractors, evaluators, and missions. The preparers make no claim that the database is complete; it reflects solely the documents reviewed. If the reader has relevant technical or economic documents that augment or update project descriptions in the database, please forward those documents to:

James Sullivan
Director
Office of Energy
Bureau for Science and Technology
Agency for International Development
Washington, D.C. 20523

All project documents cited in the Renewable Energy Database are available for review on microfiche at the A.I.D. Library. The reports may be viewed Monday through Friday from 10:00 A.M. to 5:00 P.M. at:

A.I.D. Library
Room 105
1601 North Kent St. (SA-18)
Rosslyn, Virginia

Please note that the mailing address for the A.I.D. Library is in Washington, D.C.:

A.I.D. Library
SA-18, Room 105
Agency for International Development
Washington, D.C. 20523

The database is available in hardcopy or on diskette for Wang or IBM-compatible computers. A.I.D. staff can obtain copies from the Office of Energy (S&T/EY); outside users may purchase copies of the database from:

Information Services
Volunteers in Technical Assistance (VITA)
1815 N. Lynn St., Suite 200
Arlington, Virginia 22209
(703) 276-1800

The database is also available on-line as a file linked to the A.I.D. Development Information System Projects Database. For access to that file, please contact

Training Office
Document and Information Handling Facility
Agency for International Development
7222 47th St.
Chevy Chase, Maryland 20815
(301) 951-7191

APPENDIX B

SUMMARY OF OTHER DONOR EXPERIENCE IN RESPONSE TO A.I.D. REQUEST FOR INFORMATION

In order to broaden the range of experience for assessing renewable energy experience, preliminary inquiries were made to the major international development assistance agencies. The following briefly summarizes the responses received.

World Bank

The World Bank has a large, ongoing energy assistance project involving lending for major projects ($3.4 billion in FY 1982). The World Bank provides assistance to member countries on project selection, implementation, and overall energy sector assessment, and supports institutional strengthening.

The Bank has given more attention to traditional sources of energy such as forestry-woodfuel and small and large hydro, while considerably less emphasis has been placed on other renewable and nonconventional energy sources and technology. Recent renewable projects have included peat utilization in Burundi, biomass utilization in Ethiopia, solar water heat and PV in the Gambia, sawmill residues in Ghana, and fuelwood and forestry in Malawi, Sudan, Tanzania, Thailand, and Uganda.

World Bank findings regarding prerequisites for successful *fuelwood projects* include

- need for an awareness of the need for reforestation;
- a strong cash market for fuelwood;
- availability of land near population;
- an effective extension service;
- necessary infrastructure and adequate recognition of the scope of the problem by government.

Technology-specific results on technical and economic viability include the following:

1. Solar water heating, wind water pumping, wind electricity, small-scale hydro and ethanol are all technically proven and may be economical
2. Technologies with economic promise, but for which various obstacles remain, are biogas for commercial operations, large-scale power production from wood and wind, concentrating solar collectors for industrial process heat, and gasification.[1]

United Nations Development Program (UNDP)

The UNDP has undertaken a large number of energy projects throughout the world during the last five years. Expenditures for renewable energy programs were estimated at about $134 million from 1982-1985. Approximately 52% of UNDP energy resources have gone to programs involving renewable sources, particularly forestry, fuelwood, geothermal energy and hydropower. Most UNDP assistance is in the form of grants and direct technical assistance.[2]

United Kingdom—Overseas Development Administration (ODA)

ODA has supported many renewable energy technologies, including fuel-efficient stoves, wind pumps and wind generators, biomass-fueled engines, and improved charcoal production. Financial support has been provided largely through the Intermediate Technology Development Group, the Commonwealth Science Council, and the Tropical Products Development and Research Institute. Projects have included wood resource surveys and woodfuel supply projects in Somalia, Lesotho, Kenya, Zimbabwe, India, and Nepal; wood-fired thermal power stations and charcoal production improvement in the Philippines; fuel-efficient stoves in Sri Lanka, Kenya, Nepal, and the Gambia; and wind pumps in Kenya and Pakistan, among others

ODA has identified three principal roles for renewables in LDCs: a replacement for conventional fuels, an energy source for rural development, and fuels for domestic cooking and space heat.

Lessons learned on technology applications by ODA included:

[1] **Energy Transition in Developing Countries** (Washington, D.C.: World Bank, 1983), Doc. #0-8213-0225-6; see also, UNDP/World Bank, Energy Sector Assessment Program, Energy Sector Management Assistance Program, **Quarterly Information Brief** (Washington, D.C., April 1986), and UNDP/World Bank, **Annual Report of the UNDP/World Bank Energy Sector Programs: Achievements and Future Directions** (Washington, D.C., April 1985)

[2] *Ibid*

1. remote communities are usually not the best place for trials of new technology due to logistics and lack of local skills;
2. biomass technologies have the most promise for widespread impact;
3. ethanol technology from cane or molasses is known, but economics are very site-specific and dependent on the cost of alternatives;
4. a good market exists for small-scale steam engines using biomass as well as a technology for briquetting wastes into commercial fuels;
5. wind-diesel standby packages of less than 100 kW should have a good market once proven while grid-connected wind generators will probably not have a major market until oil prices rise significantly;
6. wind pumps are an attractive technology for water pumping where wind resources are good. Local manufacture may prove necessary to make them affordable and to ensure a supply of spare parts.[3]

GTZ and German Appropriate Technology Exchange (GATE)

Renewable energy recently has had considerable support under the GATE Special Energy Program (SEP). Technologies included have been hydropower, wind pumping and electricity generation, biogas, gasification, photovoltaics, solar dryers, energy conserving wood stoves, and hand pumps, among others. The expenditure of the SEP appears to have been approximately $30.5 million for 42 projects. The SEP concentrates on nine countries: Sudan, Kenya, Tanzania, Mali, Niger, Burkina Faso, the Philippines, Peru, and Colombia. GATE reports the greatest success has been achieved through local private executing agencies operating close to target groups.

German experience with renewable technology included the following lessons:

1. Renewable technology from developed countries, in many cases, has been too complicated and insufficiently adapted to local conditions to be used, produced, or marketed in LDC's.
2. Economic viability depends very much on site-specific conditions and is difficult to generalize.
3. Sociocultural factors play a significant role in acceptance of renewables

With regard to specific technologies, findings included the following:

1. Fuel-conserving stoves can be developed and successfully disseminated, as done by GATE in Burkina Faso and Niger.
2. Small-scale hydro for electric power and hand-pumps for small-scale water supply, respectively, are both well-proven and available technologies with significant (but different) markets. Hydro requires more transfer of planning and production expertise as well as development of new financing schemes.
3. GATE reported lack of confidence in technology and/or probably low potential impacts for biomass gasifiers and solar cookers and indicated that PV pumping, lighting, and solar thermal systems were not yet self-sustaining without external financial support.[4]

Canada-International Development and Research Center (IDRC) and Canadian International Development Agency (CIDA)

IDRC is a research-oriented element of Canada's aid program. IDRC has been active in the energy area and has funded research in energy policy, fuelwood and fuelwood conservation and solar drying energy. Support is channeled to LDC research institutions and/or other LDC groups. Approximately 16 million Canadian dollars have been spent on energy-related projects from 1970 to date, with about 40% spent in Africa for projects largely related to fuelwood. The Canadian International Development Agency also has a large energy program which has been involved in a variety of substantial energy and electricity planning and instruction projects, among others.[5]

Organization of American States (OAS)

The OAS performs prefeasibility and feasibility studies, prepares analyses of development needs of member states, and provides limited technical assistance. Projects have included feasibility studies of an alcohol plant, solar dryers, wood gasifiers, solar refrigerators, a wood gasifier demonstration project (Costa Rica), and a wood-fired power plan.

[3] Letter from J.D.L. Harrison to Steve Hirsch, VITA, July 22, 1986, with various notes and discussion transcripts attached.

[4] Letter to Steve Hirsch from Dr. Pilz, July 18, 1986. Attachment: "Improvement of the Energy Supply Situation in Developing Countries by the Use of Renewable Energy Resources and Conservation of Energy." **Special Energy Program: Development Policy Cooperation in the Sector,** to date.

[5] Letter from Joseph H. Hulse, Vice President-Research Programs, IDRC, various attachments, June 20, 1986.

The OAS appears to have a limited renewable energy program.[6]

[6] Personal Communication, Wayne R. Park, Senior Energy Specialist, Department of Regional Development, Organization of American States, October 2, 1986.

Finnish International Development Agency (FINNIDA)

FINNIDA's renewable energy activities have been oriented toward forestry and fuelwood conservation and have included micro-hydro feasibility studies. The value of ongoing energy projects was indicated to be approximately $29 million.[7]

[7] Letter from Kari Karanko, Assistant Director, Finnida, July 1, 1986.

APPENDIX C

SUMMARY OF A WORKSHOP ON: NEW DIRECTIONS FOR A.I.D. RENEWABLE ENERGY ACTIVITIES

EXECUTIVE SUMMARY

The Office of Energy, Bureau for Science and Technology, is conducting a reassessment of renewable energy under the Renewable Energy Applications and Training (REAT) project. As part of REAT, an Interim Report, "New Directions for A.I.D.'s Renewable Energy Activities," was completed in February 1987 that reviewed past projects, described the lessons learned, evaluated the status of different renewable technologies, and recommended new directions for A.I.D. renewable policy.

A two-day workshop, held September 29 through October 1, 1987 in Annapolis, Maryland, served as a public forum for the critical review of the Interim Report and an opportunity to share experience and points of view on renewable energy. Two sessions were convened at the meeting. The first session critiqued the Interim Report prepared by the Office of Energy and its contractor, Oak Ridge National Laboratory. The second session included three areas: (1) renewable energy and U.S. trade in renewable technology; (2) decentralized energy sources and rural and agricultural development; and (3) household fuels supply and demand. The following executive summary represents the concensus views of workshop participants on a number of topics addressed.

Interim Report Review

Renewable Energy Technology. The Interim Report had proposed a priority ranking of renewable technologies for A.I.D. to concentrate on. Many participants felt that a global priority ranking of technologies is inappropriate given varying national resource mixes, energy prices, and human and material factors. However, A.I.D. still needs to provide explicit guidance to the field on the viability of different renewables. The technology and project evaluation criteria of the report should be broadened to include social and environmental considerations. The basis for evaluation should be clarified. Is success to be based on original objectives (which may have been research and demonstration, *not* dissemination) or on present priorities, including energy supply and replication. More attention should be given in the final assessment report to institutional problems in implementation and A.I.D.'s internal constraints in project design, management, and funding.

Household Fuels. Household fuel conservation efforts can succeed when fuels are commercial and stove programs are implemented through the private sector. Where these conditions are not met, as is frequently the case with wood stoves, substantial savings are not likely. Health, social, and environmental benefits are important additional justifications for improved stove programs.

New Directions

Private Sector. The Interim Report proposed a strong private sector emphasis in A.I.D.'s future renewable activities. There was general agreement with the report's contention that reliance on the private sector, in appropriate circumstances, provides the greatest chance of success in implementation of renewables. It was recognized, however, that in many cases the lead role of government in providing social end uses (e.g., health care), setting appropriate policy conditions, and supporting research or demonstration still requires significant support.

Trade and Development. The role of A.I.D. in renewable energy trade was a subject of much debate. It became readily apparent that there was a significant lack of understanding on the part of the renewable industry regarding both what A.I.D. can do to help the industry and what the general A.I.D. policy on assisting the U.S. private sector is. A.I.D. was urged to do more to explicitly assist the U.S. industry to compete internationally, particularly by providing information on markets and local contacts, financing feasibility studies, and by ensuring that renewable alternatives be fairly considered in procurement decisions. It was recommended that A.I.D. also technically involve industry in projects and allow for participation in renewable program planning. A.I.D. was also urged to remain an objective evaluator of technology options for LDCs. The divergence of perspectives on the role of the U.S. industry versus the roles of LDC governments and private sectors needs to be

reconciled, as regards the issues of export sales versus transfer of technology, types of systems chosen, and long-term industry commitment to these markets.

Household Fuels. Strong support was expressed for commercial fuelwood supply solutions, including agroforestry, in order to improve the rate of success in supply programs and mitigate the problem of inadequate public resources. Improved stove programs emphasizing the private sector deserve further support in circumstances where either conservation of fuel or social and environmental benefits are likely to be achieved. Further support of health and environmental research and impact evaluation of stove programs is needed.

Rural Development. Renewables are particularly well suited, due to their scale and reliance on indigenous energy sources, to rural development, including rural electrification. There was a strong consensus that credit availability is a major constraint to the implementation of renewables in rural areas and better credit options should be developed and supported by A.I.D. Grain drying and storage, milling and grinding, "cold-chain" health equipment, and potable water supply were cited as priority applications of renewables. For future technology applications, "bankability" should not always be insisted upon since some important development applications may be economically or socially attractive but still not commercially viable.

Information and Institutional Development. Participants urged that A.I.D. continue its role as a major builder of LDC institutions and expertise via support for training. Better flow of information on technology application results would benefit A.I.D. missions, and others interested in renewable implementation in the field, and simple comparative evaluation information for conventional and renewable energy sources would also be beneficial.

APPENDIX D

IMPACT OF LOWER OIL PRICES ON COMPETITIVENESS OF RENEWABLES

The impact of lower oil prices on renewable energy options with reference to LDC markets is discussed below. Two areas are differentiated in the discussion. The first pertains to renewable technologies competing in commercial markets with oil which are directly affected by lower oil prices. Second, a discussion is provided on rural and small-scale renewable energy applications which may or may not directly compete with oil products and which are less readily served by oil.

Commercial Applications of Renewables

Wind electric generation. Recent lower oil costs have a negative impact on wind electric by lowering utility average generation costs from oil-fired power stations. In the United States, these oil price reductions result in lower purchased power rates and decrease the competitive advantage of wind generation. This same impact could occur in grid-connected LDC wind electric projects. In remote locations in LDCs and in non-grid connected power sites where wind speeds are good (e.g., a mean speed of over 4.5 m/s), wind may still be attractive due to the high cost and unreliability of oil transport. Actual economics will be dependent on the site itself, and the size and nature of the demand, i.e., intermittent or constant.[1]

Biomass combustion systems. Where biomass fuels are inexpensive, such as in rural areas or where factory site industrial residues exist, biomass-fueled processes are likely to remain competitive. However, in urban areas where oil prices are at their lowest and biomass most costly, cost-effectiveness of biomass-fired systems has been significantly reduced by lower oil prices.

Wood based systems, such as those implemented recently in the Philippines, can be competitive in certain circumstances for example, where substantial capacity is required and high rates of capacity utilization are achieved. Lower oil prices, however, significantly affect viability. Based on data from a recent report for A.I.D. in the Philippines, two dendrothermal[2] proposals were competitive at 1985 oil prices with diesel generation (at future assumed 60% load factors) but become uncompetitive at 10% and 35% reduction in oil prices, respectively.[3] Results from a recent World Bank report are even less favorable.[4]

Solar water heating. The influence of lower oil prices on solar versus domestic electrical water heating depends on the fraction of oil used in electricity generation. It is likely that domestic solar water heating will be less affected by lower oil prices due to the variety of fuel sources. Probably more important in determining whether or not solar water heating is actually used will be the extent to which high initial capital costs are financed by future solar promotion programs.[5]

Alcohol fuels are very strongly and negatively affected by lower oil prices, as ethanol is a direct substitute for gasoline in the modern sector. Ethanol costs were recently estimated at roughly U.S.$ 0.22 per liter (based on a new plant proposed for East Africa). International prices for imported gasoline, varied greatly in 1986, ranging from about U.S.$ 0.11–0.13/liter for most of the year versus over $ 0.24/liter in mid-1985. These relative price changes result in a substantial elimination of ethanol's cost advantage, making current, lower oil prices a severe disincentive.[6]

Rural Small-Scale Applications

Wind and photovoltaics, prior to oil price reductions, showed favorable financial returns for remote small-scale applications in instances where good wind and solar resources existed. There is substantial field experience with both to support these results. Small-scale applications include furnishing village water supply and livestock watering. Wind

[1] Economics of Small Renewable Systems ..., p. 53. Also S. Fenn, et al., p. 155.

[2] Biomass combustion for electricity generation via woodfuel from a dedicated plantation

[3] Associates in Rural Development, Inc., Feasibility Reassessment of the Philippines..., p. IV-69.

[4] World Bank, Technical and Cost Characteristics of Dendrothermal Power Systems, Energy Department Paper No. 31, (Washington, D.C.: December 1985). The relative economics of dendrothermal is highly site and alternative-specific, and should consider present and future oil prices. New dendrothermal projects clearly will be harder to justify in the future with lower oil prices.

[5] Petro-Sun International, *et al.* A National Solar Program for Kenya (1985).

[6] OECD, Biomass for Energy, (Paris: 1984), p. 51. Also H. Geller, "Ethanol Fuel From Sugar Cane in Brazil," Annual Review of Energy, (Palo Alto: 1985); and Oil and Gas Journal, (November 17, 1986).

appears to remain competitive with lower priced diesel at good wind speeds (>4 m/s) and small water volumes (<25 m^3/day). Photovoltaics can also still compete under the same price assumptions, but only at very low daily volumes (in the range of 15 m^3 per day at moderate depths) and high insolation levels (greater than 5 kWh/m^2 d).[7]

Fuelwood Needs, Resource Availability and Oil Substitution

Fuelwood is the primary energy resource for the world's poor. Recent studies indicate a continuing overexploitation of fuelwood resources and a significant loss due to clearing of forested land for agricultural purposes. The World Bank has estimated that even with a 20–30% improvement in efficiency in the use of fuelwood, some 50 million hectares of additional land devoted to trees would need to be planted by the year 2000 to roughly balance supply and demand.[8]

Options to address these problems include fuel substitution via petroleum, energy conservation, and additional fuelwood supply.[9] Rising woodfuel and charcoal costs have made such fuels as kerosene competitive in some urban areas (even before the recent decrease in oil prices). However, additional oil substitution in rural areas where wood is normally a "free" good, would have enormous foreign exchange consequences.

Energy conservation still offers the opportunity for improving the fuelwood supply-demand picture. However, experience has indicated that gains, for example, from improved woodstoves, are much less than originally hoped for. This results from the poor past success rates of woodstove programs and the related realization that conservation *follows* scarcity and commercialization of fuels. Increasing success is being achieved with redesigned approaches based on experience gained, particularly for charcoal. The desirable level of additional fuelwood supply and conservation are likely to be independent of the price of oil where oil derived fuels are not primary substitutes for fuelwood or charcoal. This is usually the case in non-commercial rural uses.

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[7] IT Power, Ltd., Wind Technology Assessment Study, Vol. I, UNDP, ITP/82041, (UNDP # GLO/80/003) (Reading and Swindon, UK, February 1983). At this scale minimum feasible diesel engine sizes cause diesel costs to be high.

[8] World Bank, **The Energy Transition in Developing Countries**, (Washington, D.C., August 1983), pp. 46–49.

[9] Means of addressing supply requirements are addressed in the Fuelwood Research Implementation Plan (FRIP) and Forestry/Fuelwood Research and Development Project.

APPENDIX E

WIND, PV, AND DIESEL WATER PUMPING ASSUMPTIONS

General

Pumping head is 40 m for all water volumes. Two cases are examined. Figures 2 and 3 show the comparative costs per m3 for water delivered for wind and PV systems, respectively sized for that output, versus diesel. This represents a minimum cost as systems will usually deliver less than maximum output. Costs at each pumping volume are shown for each technology.

Basic System Assumptions

Discount Rate = 10%
Period of Analysis = 20 years
Central Recovery Factor = 0.11746
Total Head = 40 m
Daily Volumes Analyzed = 10, 20, 40, 60, 80, 100 m3

Water Pumping System

Hydraulic energy required
E (joules) = 9810 Q (m^3) H(m) or for 40 m
E (kW hr) = 0.109 Q (m^3)

Diesel

Engine size	2.5 kW
System cost	$2,500–$5,000
Engine life	10,000 hours or five years
Pump life	five years
Replacement cost:	
Engine	75% of initial system cost
Pump	35% of initial system cost
Maintenance	$0.30/hr to $0.50/hr
Pump efficiency	40%
Engine efficiency	15% to 20%
Overall efficiency	6% to 8%
Fuel cost:	
Low	$0.30/lt
High	$0.60/lt

Solar Pump

Capital cost	$14 per peak watt
Array life	20 years
Pump life	five years
Pump replacement cost	$1.5 per peak watt
Annual maintenance cost	1% of initial capital cost

Windpumps [1]

Capital cost	$500/$m^2$
Windmachine life	20 years
Pump life	five years
Pump replacement cost	10% of initial capital cost
Annual maintenance cost	2% of initial capital cost

Note: Costs for wells and storage systems not included.

[1] Large windpumps have diameters of about 9 m, 65 m2. At low wind speeds, a single pump will not supply 100 m3/day. The maximum output for larger units constrains output at windspeeds 3 and 4 m/s in Figure 2.

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