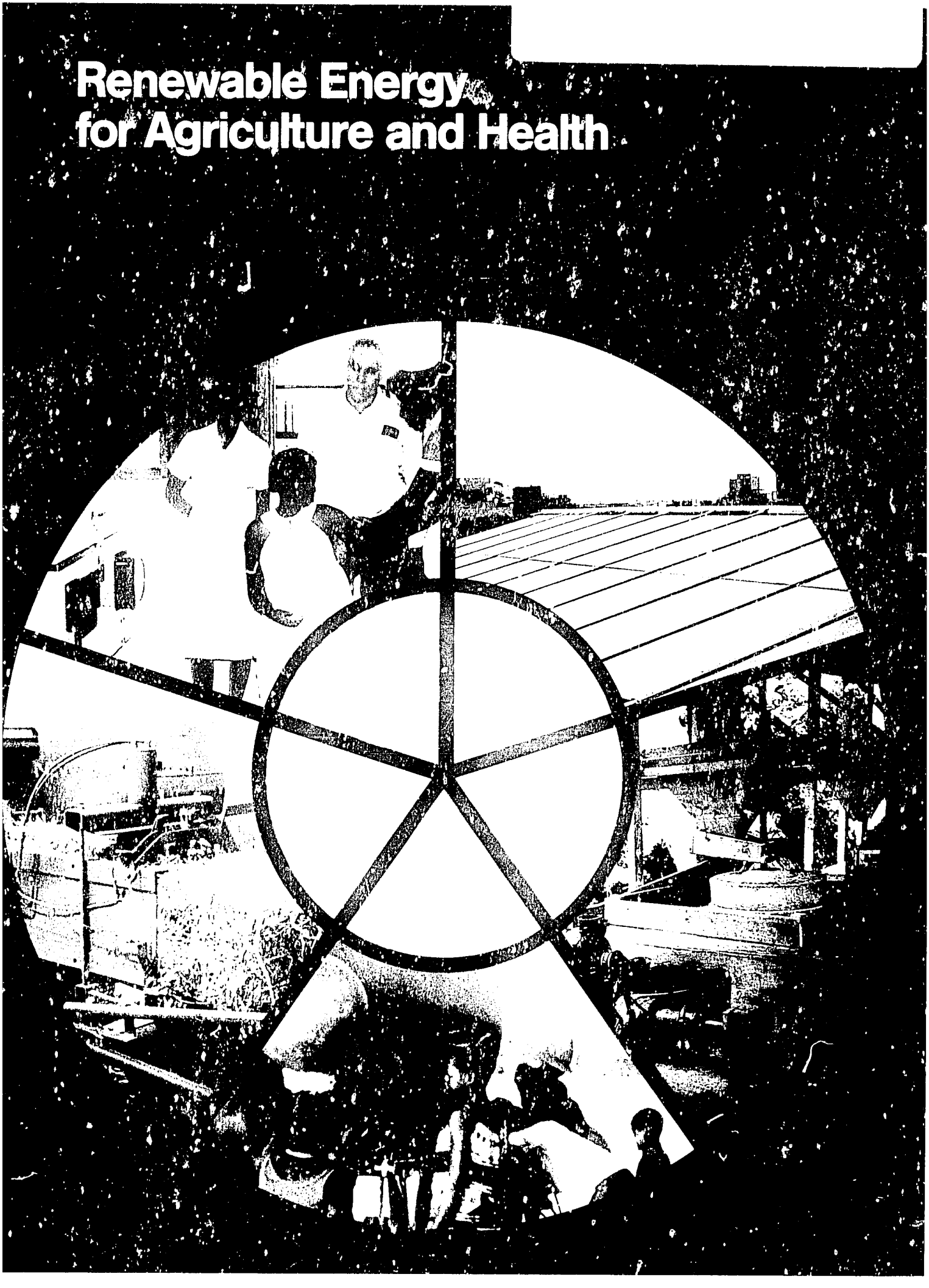
Renewable Energy for Agriculture and Health



To the Reader

For developing countries, an important step on the path to self-sufficiency, social progress, and sustainable development is to find economical, environmentally acceptable, and reliable sources of power. However, in generating this power and supplying it to end-users, particularly in remote areas, development planners face a difficult challenge. Utility grid extensions for many rural areas are expensive and may be difficult to build due to rugged terrain or long distances. Diesel and other conventional power options require reliable fuel supplies and service networks, which are costly to develop and maintain.

Renewable energy provides a way to meet this challenge in a variety of applications. Renewable energy technologies and products are well suited to typical rural conditions, both technically and economically. And, because they rely on the country's own fuel sources, renewables reduce reliance on imported fuels, reducing demand on scarce foreign exchange reserves.

As worldwide leader in the renewable energy industry, the United States is at work adapting these technologies to the needs of both developed and developing countries. With substantial resources and proven experience, the U.S. industry is serving virtually all user requirements, including design, development, installation, maintenance, and management of customized and turnkey projects, systems, and components. In addition, U.S. industry members are working with developing country firms through joint ventures and licensing agreements to encourage local manufacture of U.S. renewable energy equipment and systems.

Renewable technologies can make a particularly valuable contribution in the agricultural and health sectors of developing countries – areas directly affecting social and economic progress. The renewable energy options presented in this brochure, all of which are fully commercialized, offer a cost-effective and reliable source of energy for agricultural needs such as water pumping and processing of agricultural products and for health needs such as immunization programs. With more and improved sources of power, agricultural productivity and health care services can be significantly improved.

The U.S. Agency for International Development (AID) has extensive experience with renewable energy applications, which it is applying to more effectively employ these energy options in rural development efforts. AID, in cooperation with the Committee on Renewable Energy Commerce and Trade (CORECT), believes that renewables should be considered as an alternative to conventional energy options for developing country agricultural and health needs. We are pleased to present this brochure to acquaint planners and users with viable applications for renewable energy technologies and to encourage their use as appropriate.

Sincerely,

Alan Woods
Administrator
Agency for International Development

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Renewable Energy: Improving Agriculture and Health

Daily life in rural areas of developing countries is made more difficult by poor sanitation, inadequate energy supplies, and heavy reliance on human labor. Drinking water is often contaminated, and is retrieved by hand from wells or nearby streams. Crop production, building materials, clothing, and furniture manufacture depend on manual labor, sometimes aided by animals or fossil fuel-powered equipment. The human time and efforts needed to meet basic human health, food, and shelter needs typically leave little opportunity for significant economic and social development.

Renewable energy systems – based on energy sources such as biomass, water, wind and the sun – are designed to help rural residents overcome the barrier of insufficient power. These systems provide energy for many critical needs – from pumping and heating water to vaccine refrigeration and large scale agricultural processing. Communication, education, water heating for sanitation, and many other requirements are also served. Access to power promotes increased agricultural production, improved sanitation, reduced infant mortality, and higher productivity for both workers and local industries. In general, renewables can help contribute to progress and a higher quality of life.

Few rural communities are linked to national utility systems because grid extensions to remote regions with dispersed populations are both expensive and difficult to build. Traditional sources of power – animals and fossil fuels – also have major drawbacks. Animals require food and care and using them as a source of labor ultimately lowers milk and meat production. Gasoline- and diesel-powered engines require costly fuel and spare parts. Using wood and dung for cooking and heating also places an additional burden on humans to collect the fuel, and wood burning contributes to worldwide deforestation.

Because of such problems and the drain on foreign exchange from a dependence on imported fuels, a movement is underway to promote the use of renewable, local sources of energy – biomass, photovoltaics, wind, hydro, and active and passive solar thermal – in applications where they are economically and technically competitive. These renewable energy sources provide reliable, manageable, affordable, and environmentally sound energy that is well suited to sustainable development and the conditions found in rural communities. The primary uses of these technologies in agriculture and health applications are shown in Figure 1. Key characteristics which make renewable energy viable in these applications are described in detail on the following pages and summarized in Figure 2. Overall, renewable energy is an appropriate solution to the basic needs of developing countries for enhanced agricultural production and improved health and sanitation services. Achieving these goals is the first important step for any country on the road to progress.

A decade of experience in renewable energy application and marked improvements in equipment and in-country support give users a valuable new option for supplying power to rural areas. As with any innovation, however, careful economic and technical evaluation of needs and alternatives is essential for successfully meeting high priority rural development needs.

Figure 1

Renewable Applications in Agriculture and Health

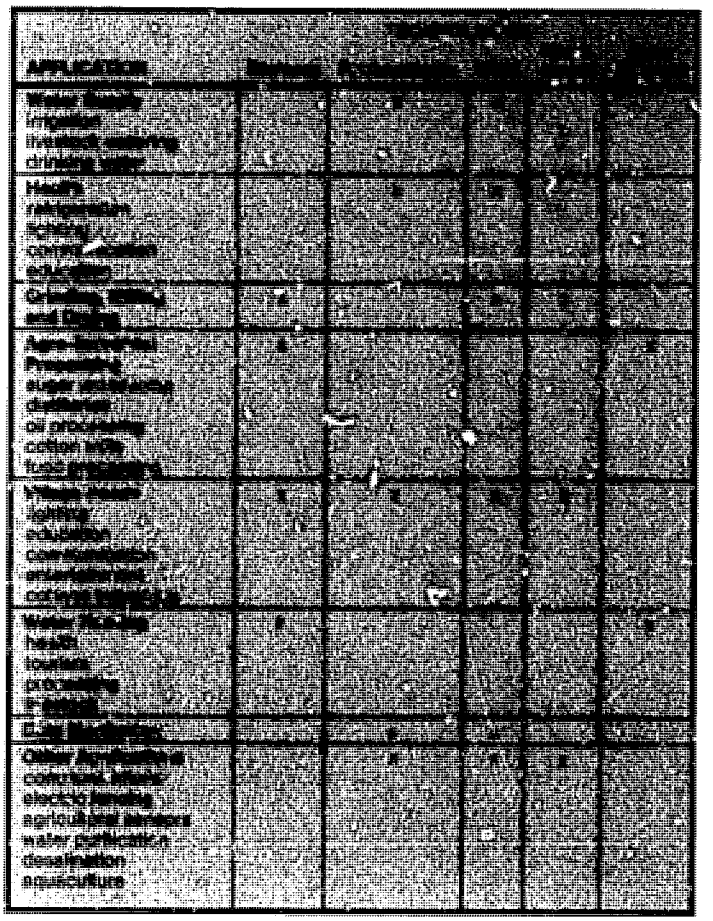


Figure 2

Benefits of Renewable Energy

Water Supply

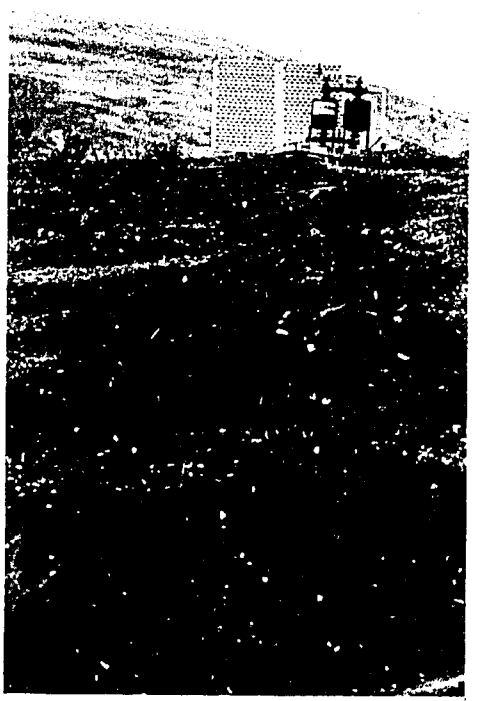
Safe, reliable, and convenient water supplies are essential to health and economic well-being. Unfortunately, nearly a billion people in rural areas of the developing world do not have access to safe sources of water. The result, according to the World Health Organization (WHO), is that 15 million children under 15 years of age die each year due to diseases transmitted through contaminated water. Consequently, WHO has asserted that providing "a safe and convenient water supply is the single most important activity that could be undertaken to improve the health of people living in rural areas."

In spite of technological achievements, much of the world's rural population continues to rely on manual labor to collect water from rainfall, surface sources, and hand-dug wells. This reliance impedes economic development and places a large burden on the populations of these remote areas.

Traditional means of gathering water in remote areas include human power, animal power, and diesels. Human and animal power are limited by how much they can lift, and the resulting costs place a strain on human resources and a loss of animal meat and milk production. These low daily yields also diminish the value of the expensive wells built to tap groundwater sources. Diesel-powered pumps produce greater output but require service and supply networks to work reliably.

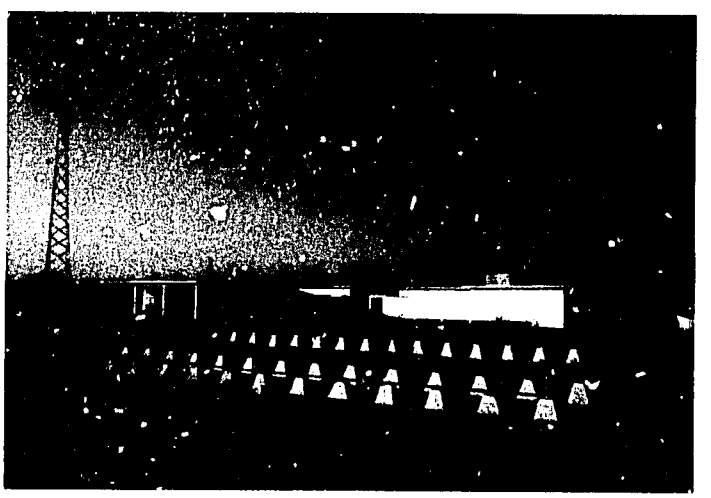
Renewable energy technologies such as photovoltaics (PV) and wind provide cost-effective and reliable alternatives to traditional water pumping techniques. These pumping technologies feature ease of operation, low maintenance, and independence from external fuel sources. They are also designed to be modular, allowing small or large volumes of water to be pumped effectively from a variety of sources. Furthermore, renewable energy pumping systems can easily be used for more efficient irrigation methods, such as drip irrigation on small farms, where diesels are not cost-effective.

As a result of these benefits, thousands of photovoltaic and wind pump systems have been installed worldwide, supplying safe drinking water for human consumption, livestock, and small-scale irrigation. Commercially available and proven renewable energy water pumping systems can supply water from surface sources or wells up to a few hundred meters deep. Daily water output ranges from a few cubic meters to several hundred cubic meters.

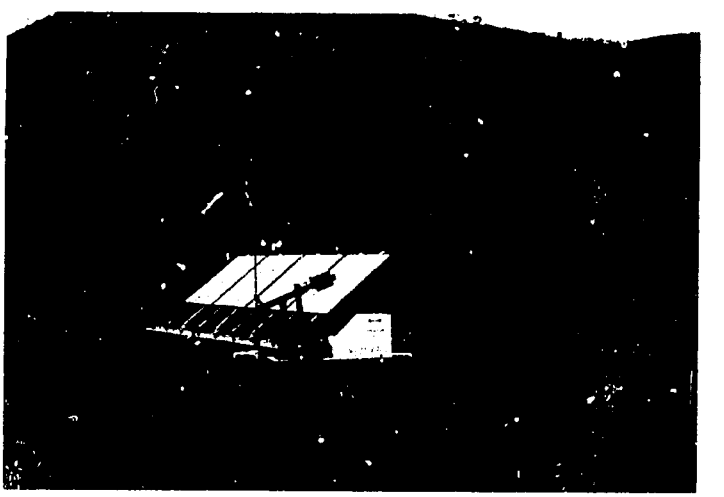


FV DRIP IRRIGATION
A drip irrigation system for an orchard is powered by a 560 watt PV system. This system has shown to be an effective method for conserving water in semi-arid regions such as this location in the state of California, U.S.A.

PV/WIND VILLAGE WATER PUMPING SYSTEM
Water for the village of Khurkera, Pakistan, population 200, is supplied by a 8kW PV and wind hybrid system that pumps up to 1000 gallons of water per hour. Despite operating for less than a year, the availability of water may already be attracting settlers from villages where water is less plentiful.



PV DRINKING WATER SYSTEM
A 600 watt PV system, installed in 1981, pumps up to 5.7 cubic meters daily from a 45 meter well to supply drinking water for an American Indian community in California.



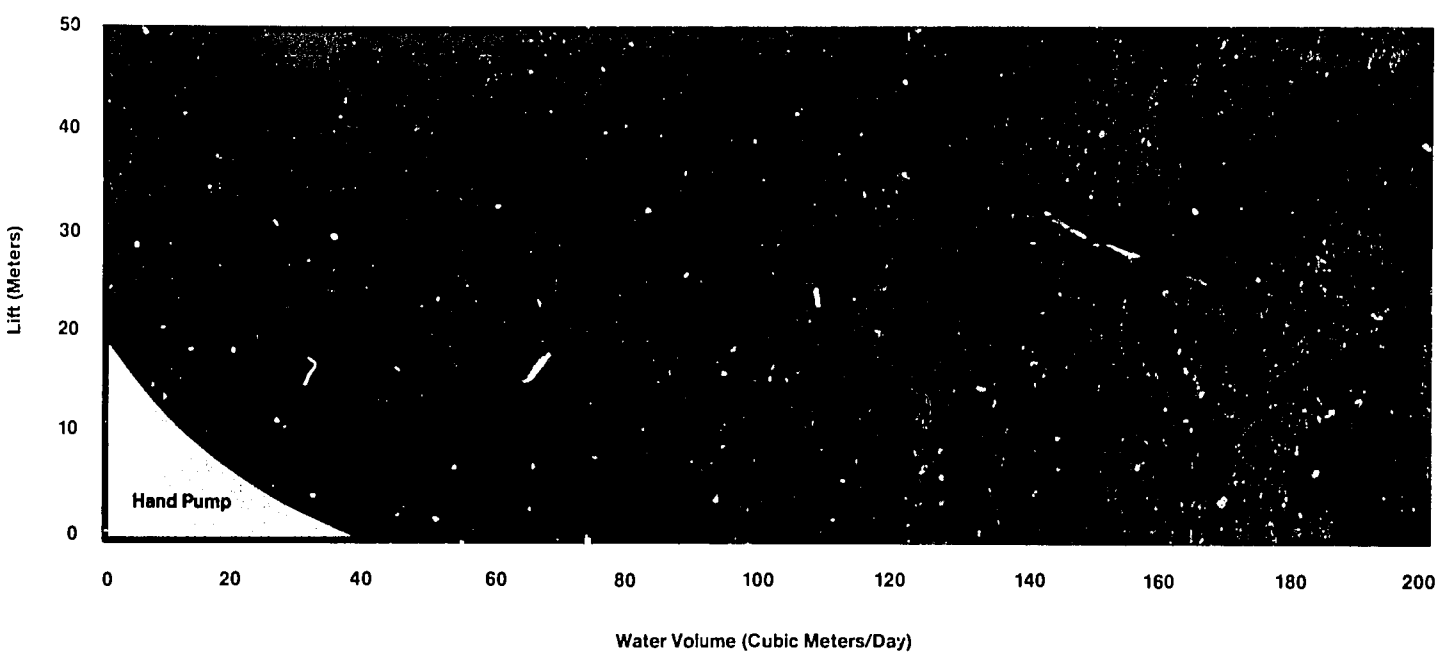
Economics

In rural water supply projects, photovoltaic- and wind-power water pumping is likely to be competitive compared to human- or animal-power water lifting methods in areas where the water table is deep, well costs are high, and each well supplies the daily needs of 100 people or more. These technologies are also economic when compared to diesels in remote areas where fuel supplies and maintenance services are expensive and unreliable and fewer than several thousand people are being served. Photovoltaic water pumping requires at least four hours of bright sunshine each day to be competitive. For shaft-powered wind pumping, an annual average wind speed of greater than three meters per second (m/sec) is required. Electrical wind pumping requires 4 m/sec or better, but, for many situations, has the major advantage that the turbine does not need to be sited at the wellhead. These wind and solar requirements are met in many developing countries. Figure 3 illustrates the regions of daily water volume and lift where photovoltaic and wind pumping are competitive with diesel-powered pumping.

MECHANICAL WIND WATER PUMPING
This mechanical wind water pumping system in Texas, U.S.A., can pump up to 385 gallons of water per hour. Thousands of similar systems using this U.S. design are located around the world.

Figure 3

Range of Competitive Use of Photovoltaic and Wind Water Pumping



Assumptions:
1. Solar insolation: 4-6 kWh/m^2/day.
2. Wind speed: 5 m/sec
3. Fuel prices: U.S. $0.50-1.00/liter.
4. Equipment costs include transport and installation costs in developing country. Costs exclude operating manpower costs.

A variety of preventable infectious diseases, combined with a lack of adequate health care, has contributed to an infant and child mortality rate in developing countries that is estimated to be about 5 million deaths per year. Poor health has devastating economic and social consequences: the quality of life is diminished, agricultural and industrial development is hindered, and caring for the sick and disabled is difficult, if not impossible.

Vaccination programs have been highly successful in reducing the occurrence of infectious diseases for both humans and livestock. These programs, however, depend on reliable refrigeration systems to maintain vaccine quality and potency. To remain effective most vaccines must be refrigerated between 0- 8 C up to the time of use. The transportation and storage of refrigerated vaccines, known as the cold chain, is a major challenge to health planners.

Today, kerosene- and bottled gas-powered refrigerators are most commonly used in rural areas to keep vaccines at the proper temperature. Developing country experience with these systems, however, has been poor due to the short lifetime of these systems, the need for constant maintenance and spare parts, and, most importantly, the continuous need for uncontaminated fuel to operate them. Examples of vaccine losses attributed to failure of kerosene or bottled gas refrigerators are cited below.

Country	Vaccine Loss From Kerosene/Bottled Gas Refrigerators
Sierra Leone	71%
Peru	52%
Tanzania	45%
Pakistan	30%
Indonesia	26%
Ethiopia	21%
Kenya	20%

Photovoltaics offer a better option for powering remote health refrigerators as recognized by both WHO and the United Nations Children's Fund (UNICEF). Photovoltaic refrigerators, with their reduced maintenance, lower operating costs, greater reliability, and longer working lives, provide a more effective and sustainable cold chain. These systems have undergone laboratory testing and field trials by international agencies, resulting in proven equipment that meets or exceeds the technical requirements of most country health officials. Today, over 1,000 photovoltaic refrigerators have been installed in more than 30 countries worldwide. The Government of Zaire has stated that photovoltaic refrigerators are the *only* solution for vaccine storage and is installing over 100 systems in rural health clinics.

In addition to vaccine refrigeration, there are a number of other remote, health-related uses of electricity where renewable technologies, such as photovoltaics and wind, make sense. These include clinic lighting and radio communications, among others.

The advantages of photovoltaics and wind over expensive batteries, gasoline, or diesel-engine generators for these uses are high reliability, no fuel or maintenance costs, no noise or pollution during operation, and no need to take batteries to electrified areas for recharging. Also, unlike engine generators, renewable power sources provide an ideal match to the low power needs of these applications.

Economics

Although photovoltaic refrigerators are more expensive on a capital cost basis than kerosene and bottled-gas refrigerators, their cost per dose of delivered vaccine is comparable or cheaper in many cases. The high reliability and low operating costs of these systems mean more effective vaccine can be delivered and administered at lower cost.

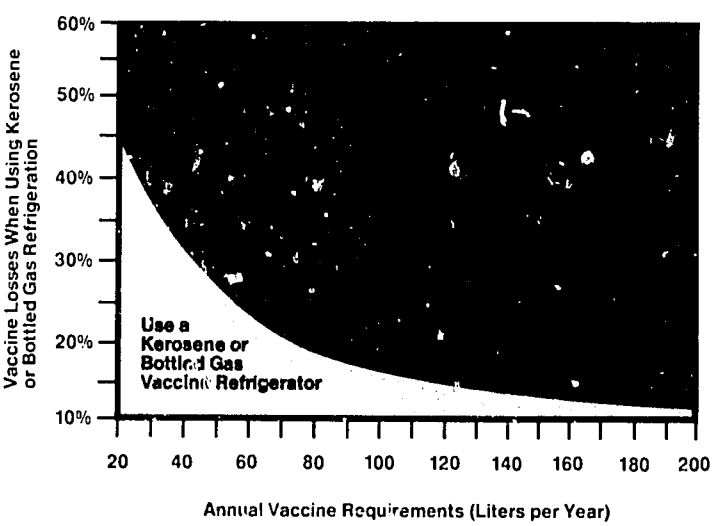
Figure 4 shows that photovoltaic refrigerators are more economic than kerosene or bottled gas refrigerators when vaccine loss is 15% or more and annual vaccine requirements are greater than 130 liters per year. At higher vaccine loss rates, PV becomes competitive at even smaller demand levels. For example, if yearly vaccine requirements are 80 liters and vaccine losses using kerosene refrigeration are more than 20%, then a photovoltaic refrigerator is the preferred option.

Another factor to consider is that the vaccine loss noted above does not reflect the lost health benefits to those who would have received the inoculation. If these benefits were accounted for, photovoltaic systems would be shown to be much more cost effective than the alternatives.

Photovoltaics and wind are also competitive in providing electricity to rural health clinics, which typically have energy requirements of less than 2 kWh per day. Figure 5 compares the equivalent cost of electricity for these small power applications using a variety of alternative sources. As shown, photovoltaic and wind-electric generators can be the least cost alternative for lighting needs when compared to kerosene lanterns and dry cell or lead-acid batteries. Moreover, the renewable energy systems do not require a reliable kerosene or dry-cell battery supply system or a battery charging station.

Figure 4

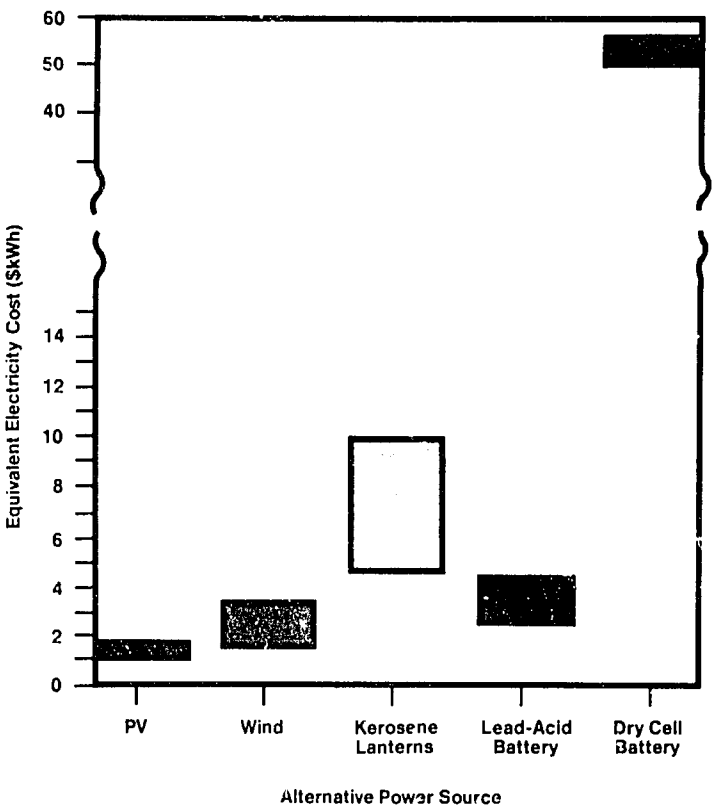
Economically Competitive Conditions for a Vaccine Refrigerator



Assumptions:
1. Based on typical costs of refrigeration reported by WHO/UNICEF and representative kerosene/bottled gas prices.
2. Vaccine losses with a PV refrigerator: 5%

Figure 5

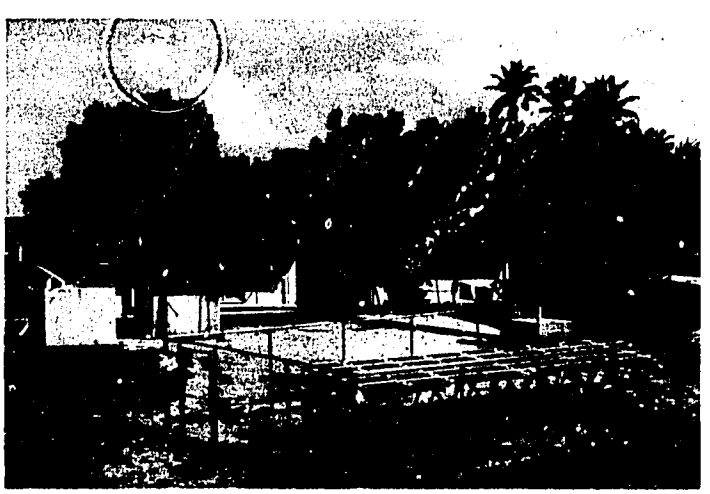
Cost of Electricity for Remote Lighting and Other Small Power Applications



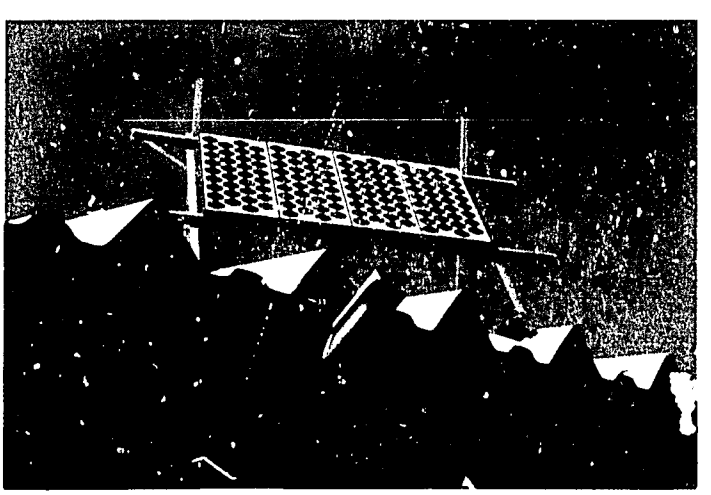
Assumptions:
1. Energy demand less than 2 kWh/day.
2. Kerosene costs $0.50-1.00/liter at site.
3. PV and wind electric generator costs based on costs of currently available small systems.
4. Windspeed: 5m/sec

PV VACCINE REFRIGERATION
A PV system supplies power for vaccine refrigeration at a health clinic in Anse-a-Veau, Haiti.

PV HEALTH CENTER POWER SYSTEM
Operating since January 1983, this PV array at the Waramuri Health Station in Guyana supplies power to a refrigerator/freezer, water pump, 2-way radio, and instrument sterilizer. The 1.5kW system was transported to the site by small river boat.



PV OUTDOOR LIGHTING
Outdoor lighting powered by a 140 watt, roof-mounted PV panel has provided security and storefront illumination for this shop in Maseru, Lesotho, since 1984.



Grinding, Milling, and Drying

The majority of people in the developing world earn their living on the land, primarily through growing and processing (grinding and milling) cereal crops such as rice, wheat, corn, sorghum, and millet. Even in more advanced economies, key crops (e.g., coffee, cocoa, tea, and cassava) need substantial drying and processing before they can be sold.

Traditionally, grains are harvested, dried, and separated from the stalks and chaff by the farmer, then hand- or machine-milled. Traditional methods of agricultural processing are often wasteful, measured by lost grain and lost farm labor. Open-air drying invites losses from birds, insects, and rodents, while uneven drying can drastically reduce the sale value of the product. Hand-milled grain kernels are often broken, lowering their sale and food value. Human- and animal-powered grinding is typically inefficient, requiring large inputs of food and fodder per unit of flour and meal produced.

Grain grinding is one of the most energy-intensive aspects of the traditional agricultural production cycle and one of the first to be mechanized. Animal- and human-powered mills have been used in South Asia for centuries. Small diesel mills are found in mountain villages in the Himalayas and in market towns in sub-Saharan Africa. The alternative, however, has been large diesel-powered units which require costly fuel, maintenance, and support back-up networks.

Renewable energy technologies, including solar, biomass, and micro-hydro, offer efficient and cost-effective techniques for drying and processing agricultural commodities. For example, compared with traditional drying techniques, solar and biomass-fired dryers can significantly reduce crop losses from uneven drying and/or scavenging by animals. This has been demonstrated in the successful use of U.S.-designed commercial rice dryers in the Philippines which have reduced losses and greatly lengthened storage life.

Micro-hydro powered grinding units have been used in Nepal for hundreds of years, and now new modern metal turbines are being installed throughout the country on a commercial basis. Micro-hydro units are less costly than diesel-powered mills because they use a free fuel, need less servicing, and are more reliable. They also require less farm labor input, are better scaled to typical processing volumes than hand grinding, and do not cause any damage to the grain product.

Economics

Renewable energy mills have proven to be highly profitable commercial replacements for diesel units, particularly for remote installations. These mills typically repay capital investments in 2-3 years from savings previously spent on diesel fuel. In Nepal, seven-year loans at 12% for micro-hydro mills are often repaid in 3-4 years because of the high stream of income generated through the grinding and milling of rice and wheat with these units.

As discussed above, the renewable energy technology most suitable for grinding and milling applications is micro-hydro. A micro-hydro plant is higher in initial cost but is a superior alternative if reasonable commercial lending and an adequate, year-round stream flow are available.

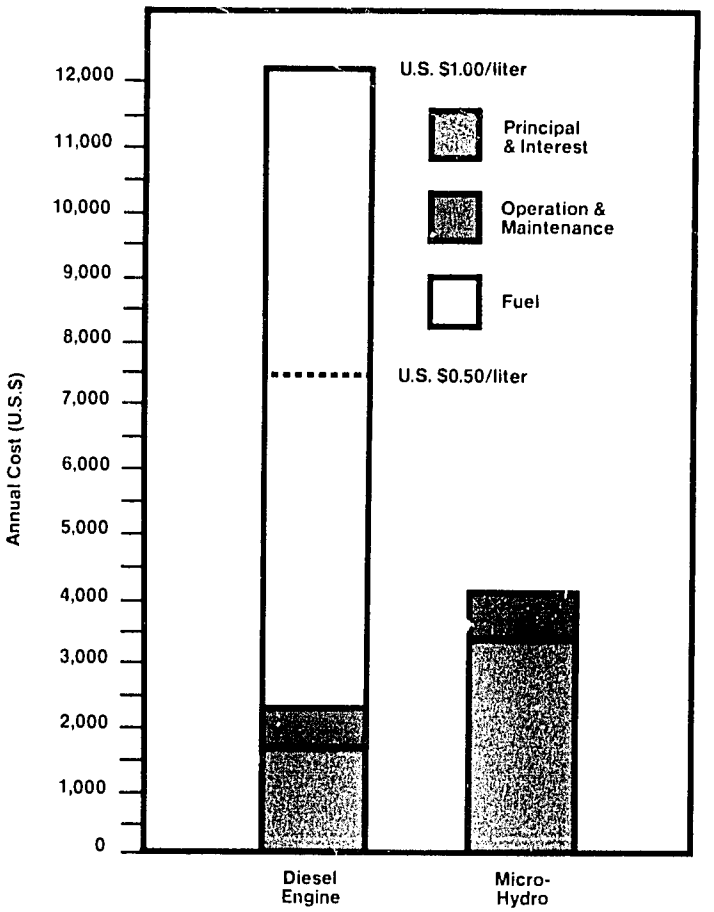
Figure 6 demonstrates the cost-effectiveness of renewable energy systems for providing 5 kilowatts of mechanical shaft power for remote grain mills. The costs are based on 24-hour mill operation for six months of the year, a typical situation in agricultural areas with multiple cropping.

As shown, the high operating costs of the diesel unit more than offset the higher initial capital cost of the micro-hydro plant. In addition, the micro-hydro unit is more reliable (diesel fuel is often in short supply in rural areas), requires less maintenance, and has very low operating costs. High quality, U.S. micro-hydroelectric units also typically last for 20 years, while diesel engines routinely have to be replaced every 3-5 years.

SOLAR RICE DRYER
Serving a commercial rice mill in Chidibarum, this solar rice dryer can handle 75 tons of rice per day. It has been operating since 1984.

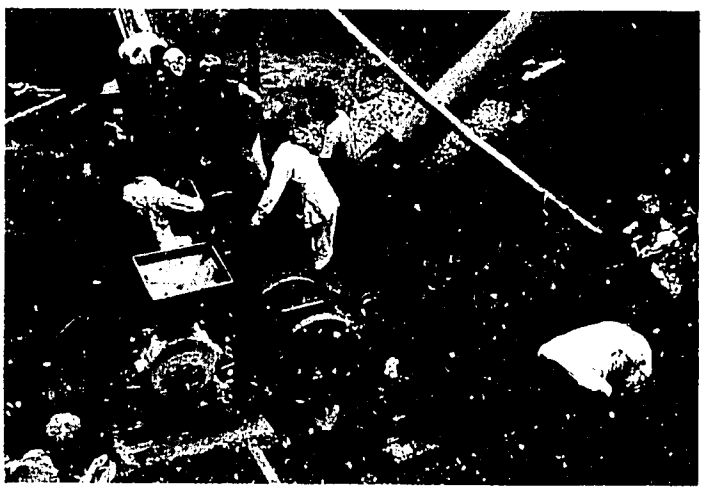
Figure 6

Annual Costs of Providing Power to a Small Grain Mill



Assumptions:
1. 4380 operating hours/year for each system.
2. Delivered diesel fuel costs of U.S. $0.50-1.00/liter
3. Lifetimes – micro-hydro unit – 20 years, diesel engine – 5 years.
4. Micro-hydro turbine costs: U.S. $5,000/kW installed.

MICRO-HYDRO GRAIN MILLING OPERATION
Several grain grinding mills are operated through direct shaft power from one micro-hydro turbine in this installation in Nepal.



GRAIN GRINDING WITH MICRO-HYDRO
Even traditional grain grinding methods can be improved with the use of modern micro-hydro technologies, as demonstrated in this Nepalese grinding operation that uses direct shaft power.

Agro-Industrial Processing

Agricultural processing is a key economic activity in most developing countries. Processed agricultural commodities are a major source of foreign exchange, employment, and industrial development. Agricultural processing industries, however, are also a major consumer of imported fuels. As energy costs begin to dominate production costs, these industries are turning to previously unused or underutilized agricultural residues to replace traditional fuels.

Agricultural residues such as bagasse, groundnut shells, cotton lint, coconut husks, and palm oil residues are already used for certain applications. However, great quantities remain for energy utilization and the efficiency of current energy production methods can be greatly increased. Other residues, including rice hulls, olive pits, coffee husks, cocoa cabosse, and oil-palm ears, currently remain virtually unused. These residues, which often constitute a major disposal problem, can produce energy through technologies such as direct combustion, anaerobic digestion, gasification, briqueting, pelletizing, and charring. These techniques produce fuels that can be used in homes, commercial establishments, and industries; they can also be exported.

Sugar factories, distilleries, oil expelling and processing plants, cotton mills, and food processors, among others, are all evaluating the use of biomass combustion boilers to generate heat and/or electrical power and biomass gasification units and solar thermal collectors for heat. All of the heat and much of the electrical power are generally used directly in the business' processing activities. However, where excess electric power is generated, it can be sold to utilities or other firms. Such systems can help the sponsoring firms to generate revenue, expand off-season employment, dispose of accumulated residues or unwanted products, and increase the supply and reliability of local power.

U.S. firms have already installed over 4 10,000 kW of agricultural-based electric power generating capacity that includes:

- a 900 kW electric generator at a dairy fueled by cow manure biogas.
- a 5,500 kW electric generator fueled by walnut and almond shells, peach and olive pits, orchard prunings, rice hulls, rice straw and wood waste.
- a 7,500 kW power plant fueled by groundnut shells and woodchips.
- a 9,600 kW electricity and steam generator fueled by sunflower seed hulls.
- a 20,000 kW electricity and steam generation sugar processing plant fueled by bagasse.
- a 50,000 kW process steam and electricity generator fueled by sugar sorghum waste.
- a 10,600 kW electricity generator fueled by rice residues.

In addition, U.S. firms produce over 1.5 million liters of ethanol per year for blending with gasoline. Currently, over 700 million liters of ethanol capacity is either planned or under construction. These technologies can be used in developing countries to reduce energy costs and increase the competitiveness of agricultural processors.

Economics

A number of energy conversion systems are commercially available from U.S. manufacturers which use agricultural residues as feedstocks. Available technologies include direct combustion, anaerobic digestion, and biomass gasification. These units are normally inexpensive sources of thermal energy and/or electricity on a life-cycle basis. As Figure 7 demonstrates, agro-fired cogeneration systems, boilers, and power plants can produce both electricity and/or process heat at a cost lower than conventional fired plants using fuels such as residue fuel oil. The initial cost of the agro-residue fired plants is slightly higher than conventional plants. However, they generally produce lower cost process heat than fossil-fuel fired boilers even if the biomass fuel stock has to be dried or pre-treated before being used as a fuel, unless the price of fossil fuels is heavily subsidized. One important consideration that affects the economic viability of an agro-residue fired installation is whether the feedstock is produced year-round or whether it will have to be stored during certain periods of the year to provide a constant fuel supply.

BIOMASS ENERGY FOR AGRO-PROCESSING
For the last 20 years, the Central Romano Sugar Factory at La Romano, Dominican Republic, has been supplying power for its own needs as well as excess power to the nearby Casa de Campo resort complex. One of the largest sugar factories in the world, it burns plant residue in processing 18,000 metric tons of cane per day.

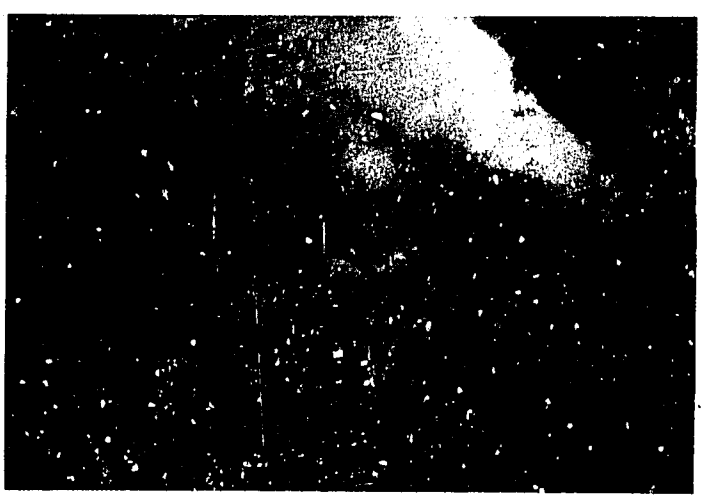
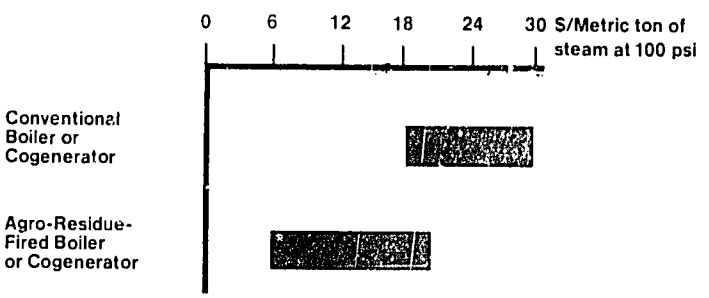
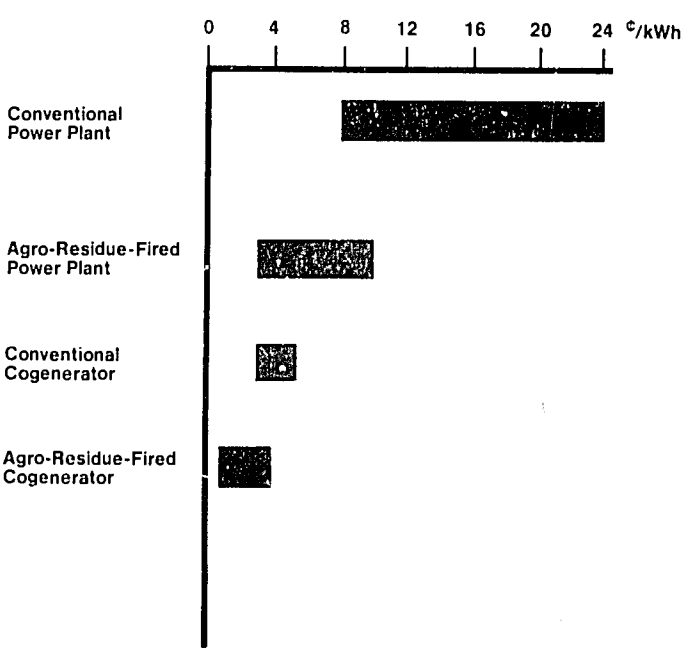


Figure 7

Total Capital and Operating Cost of Producing Process Heat



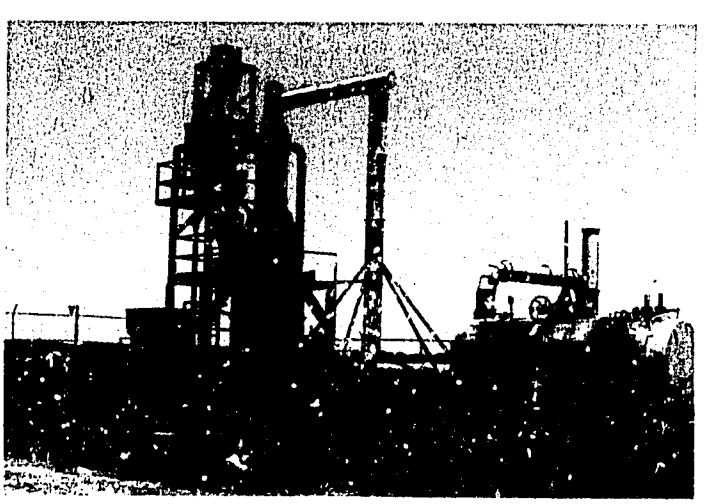
Total Capital and Operating Cost of On-Site Electricity Generation



Assumptions:
1. Plant size: 250 kW to 40 MW
2. Capital costs: U.S. $1,000-3,000/kW
3. No cost for feedstock.

COLLECTING BIOMASS FEEDSTOCKS
Agricultural residues must often be collected from the fields where crops are grown. This chopper harvester collects from 6-8 tons of toppings per acre from sugar cane fields for use in the Central Romano Sugar Factory at La Romano, Dominican Republic.

GASIFIER FOR AGRICULTURAL PROCESSING
This large-scale gasifier burns several different types of agricultural wastes, including rice hulls, coco husks, and bagasse. The unit produces up to 11 million Btu per hour depending on the feedstock for use in crop drying, food processing, and other agricultural processing.



Village Power

Rural communities require power for lighting, water supplies, health care, education, communication, entertainment, agricultural processing, and cottage industries. However, the high cost of utility grid extensions and the low initial power demand in communities prohibits economical delivery of electric power to many rural populations. Stand-alone diesel generation provides an energy option but these systems require a complex service network to provide reliable fuel supplies, spare parts, and maintenance services. Many countries are now realizing that the social need to provide electric power to rural areas must be balanced against the reality of limited resources. Renewable energy technologies offer a feasible and decentralized alternative for economically meeting these social commitments and development needs.

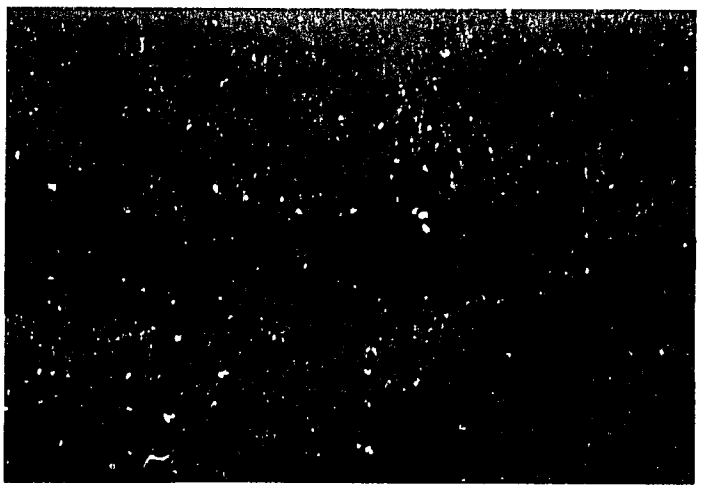
Renewable energy technologies such as micro-hydro power plants, wind electric generators, and photovoltaics can supply electric power to many rural communities more reliably and economically than conventional alternatives. These technologies can also be used in a "hybrid" configuration where two or more technologies are combined to take advantage of the best characteristics of each power system. Renewable energy rural electric grids can be easily scaled to serve the needs of one farm, several hospitals and schools, or even a whole group of villages. There are thousands of communities in isolated regions of the world that are being supplied with reliable electric power using renewable energy technologies.

Renewable energy power systems for rural electric applications offer key advantages:

- Fuel, if required, comes from local sources, such as a stream (micro-hydro), agricultural or wood residues (biomass), sunlight (photovoltaics), or wind.
- Only a local distribution grid is required.
- System reliability is high and maintenance needs are minimal. Local villagers can be easily trained to do system servicing.
- Resources are retained within the community since payments are not made to outside organizations for fuel or specialized maintenance services.
- Power can be economically matched to local load conditions.
- The modular nature of these power systems allows them to be expanded over time, reducing planning time and initial capital costs.

MICRO-HYDRO FOR VILLAGE ELECTRICITY
The village of Khun Khong, Thailand receives electricity from this micro-hydro installation.

WIND POWER FOR REMOTE VILLAGE
Residential power is supplied by five 8kW wind turbines to the remote village of Sheldon Point, located on the west coast of Alaska. Despite extreme climatic conditions, the turbines, installed in 1983, can operate year-round.



Economics

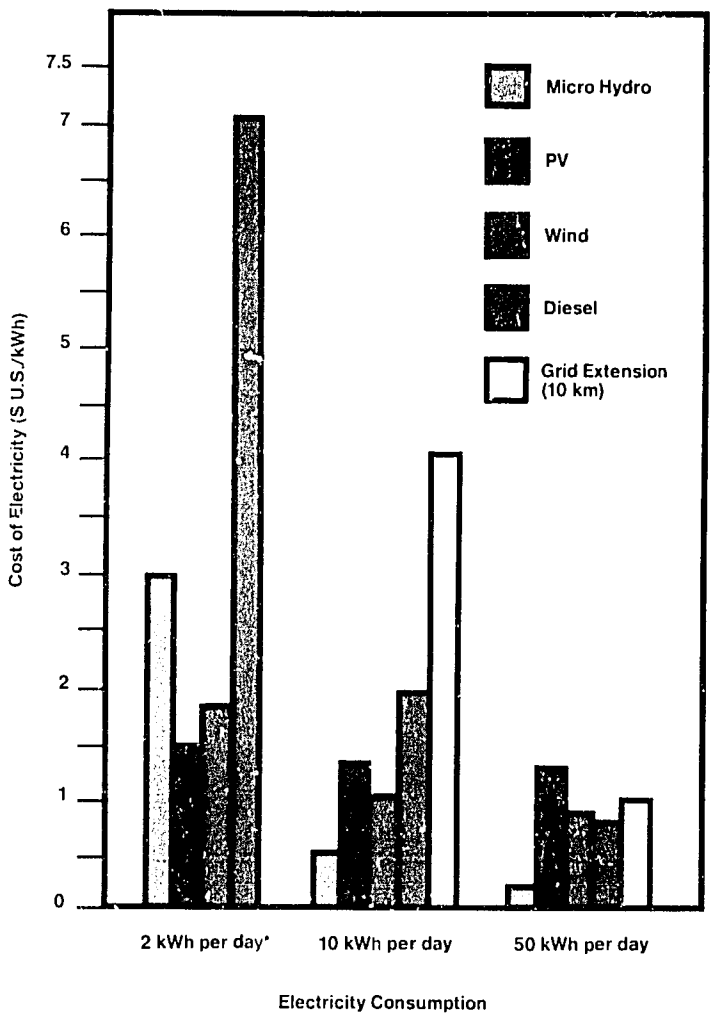
Depending on the amount of electricity required, photovoltaic, wind, and micro-hydroelectric technologies can be economical sources of power where the renewable resource base exists. Figure 8 shows the costs of providing electricity to remote communities using renewable energy systems, diesel generators, and grid extension for consumption levels of 2, 10, and 50 kWh/day. These levels represent the approximate needs of 1, 5, and 25 rural families, respectively.

As shown, wind, photovoltaic, and micro-hydro systems are cheaper than diesels when energy demand is low (less than 50 kWh/day). This occurs because the renewable system can be more easily sized to meet small electrical loads than can diesel generators. In particular, photovoltaic and wind systems are the least cost alternatives at consumptions levels of 2 kWh/day, while micro-hydro is the most competitive option at loads of 10 kWh/ day.

At higher consumption levels (up to 50 kWh/day), micro-hydroelectric systems continue to be the least cost solution. Photovoltaic and wind technologies have electricity costs comparable to diesel generation and electric grid extension at this scale.

Figure 8

Cost of Electricity for Multiple Uses



Assumptions:
1. Solar insolation: 4-6 kWh/m^2/day.
2. Fuel costs: U.S. $0.50-1.00/liter.
3. Micro-hydro analysis assumes that the flow rate is adequate year-round and the diesel analysis assumes that fuel and maintenance services are supplied reliably year-round.
4. Discount rate: 10%
5. Windspeed: 5 m/sec
6. *Grid extension not considered at 2 kWh per day.

MICRO-HYDRO RESIDENTIAL LIGHTING
Lighting is a key requirement for local village development for cottage industries, for evening educational programs, and for health facilities. Electricity for lighting in this Thai village is generated by a local micro-hydro installation.

Water Heating

As nations develop, demand for hot water increases dramatically. In part, this is due to greater awareness of personal hygiene and sanitation, along with higher levels of disposable income. Hot water usage reduces diseases spread by contaminated food and water. Hospitals, clinics, schools, and hotels need hot water for cleaning, sterilization, food preparation, laundry, and bathing. Industrialization also increases hot water demand. Processing industries such as dyeworks, spinning and weaving factories, and canning and food processing plants need large quantities of hot water to produce finished goods.

In most rural areas, domestic and commercial hot water is produced by burning firewood or dung, which adds to deforestation and land depletion problems. In industrial and tourist facilities, the typical fuels used for water heating are electricity, an expensive option, or liquefied propane gas (LPG) and fuel oil, which are costly and often imported.

Proven and cost-effective renewable energy technologies can be used for water heating. They have little or no operating costs and use free, locally available fuels. Having no moving parts, thermosyphon flat-plate solar water heaters use natural convection to move the heated water to the storage tank. Solar water heaters are ideally matched to businesses such as laundries that have substantial daytime hot water needs, but little or no demand in the evening. Solar collectors operating in the 75-150 C range are commercially available, reliable, and cost-effective for large installations or for industrial applications requiring low pressure steam.

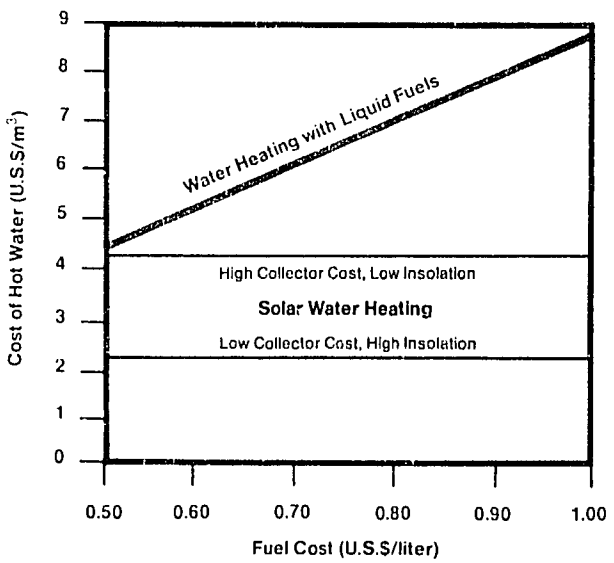
Biogas produced by anaerobic digestion can also be used to fuel water heaters designed to run on natural gas, LPG, or propane. In dairies, biogas is used for pasteurizing milk and heating wash water. In agricultural processing plants, surpluses of agricultural residues are used to fire boilers or gasifiers to produce hot water.

Economics

Figure 9 shows the life cycle costs of producing hot water (60°C) from a flat plate solar collector versus LPG or oil burners. As shown, solar systems are more economical even in moderate solar regimes if the cost of liquid fossil fuel is greater than U.S. $0.40 per liter. In areas of excellent solar insolation, where more than 4-6 hours of sunlight are available, solar hot water heaters are good investments even if the cost of conventional liquid fuels is as low as U.S. $0.20-0.40 per liter. In urban areas, solar systems are normally a low-cost solution when compared to inefficient electric water heaters, unless subsidized utility rates give electric water heating an advantage.

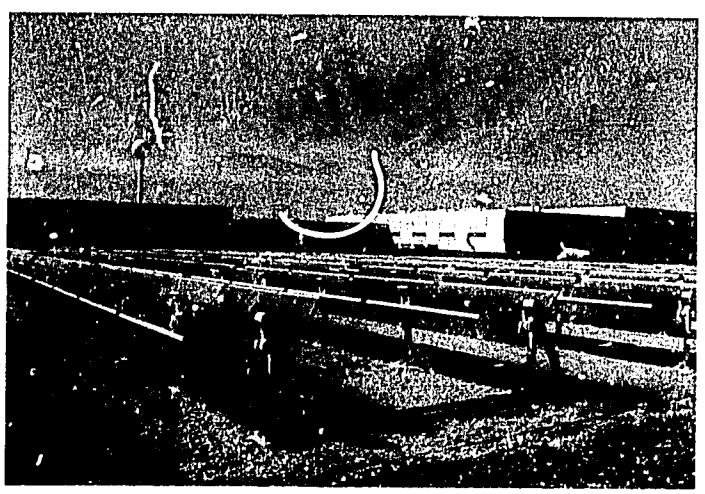
Figure 9

Cost of Hot Water (60°C) – Solar vs. Liquid Fuels

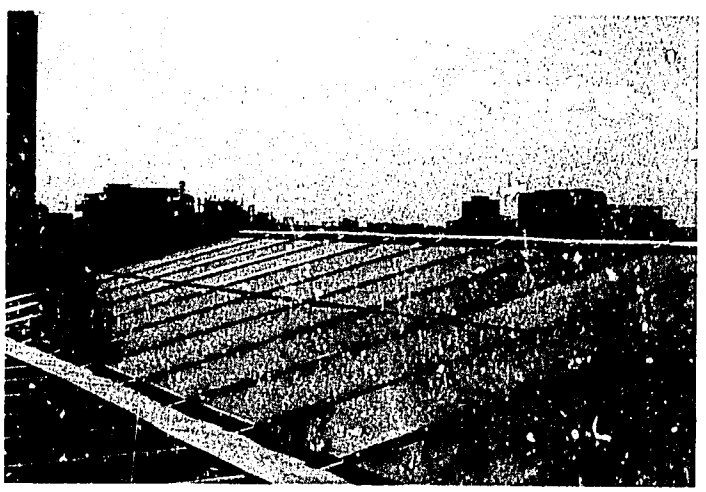


Assumptions:
1. Solar Collector Costs. U.S. $100-200/m²
2. Solar Insolation: 4-6 kWh/m²/day of collector surface.

SOLAR STEAM FOR MEDICAL MANUFACTURING
A large-scale solar concentrator system, installed in 1980, provides steam for use in cleaning medical gauzes at this Johnson & Johnson manufacturing plant in Texas.



SOLAR HOT WATER FOR HOTEL
Mounted on a hotel in Thailand, this large-scale solar flat-plate collector provides hot water for guests and hotel services, such as laundry. Installed in 1979, it provides thousands of liters of hot water per hour.



Additional Applications

In agriculture and health, renewable energy sources have their largest impact on the six application areas previously discussed. Many other applications for renewables also exist which may make small or indirect contributions to agriculture or health, or help rural development efforts in other ways. Some of these are listed in Figure 10.

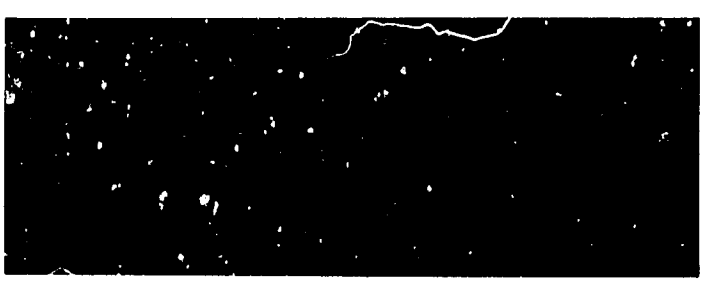
In agriculture, wind and photovoltaics (PV) are useful for applications such as electric fences for livestock and crop protection. In the U.S., PV is now the technology of choice for electric fences when conventional power sources are lacking, as it eliminates the frequent replacement of relatively expensive batteries and increases reliability. In health, water purification and desalination systems are important for providing potable drinking water where existing sources are contaminated or contain too much salt. Where utility grid power is not available, wind, PV, and micro-hydro are often viable alternatives.

Telecommunications is vital for both the formal and the informal education of rural families. Radio and television (TV) systems broadcast educational programs and introduce communities to events and changes happening outside their region. PV, wind, and micro-hydro sources can power microwave repeater stations and satellite ground stations which broadcast to even the most remote area. The modularity of these sources makes them suitable for TVs and radios in community centers and even individual homes. Where batteries are the primary source of power for TVs and radios, PV-powered battery chargers can eliminate the need to buy replacement batteries or to pay to have automobile batteries recharged at a service station.

Data monitoring is a specialized application for renewable energy technologies that requires trained technicians. However, the information it can provide can directly benefit rural populations. For agriculture, monitoring instruments provide data on precipitation levels and intensity, river levels, humidity, soil moisture, leaf wetness, and many other factors. This data helps farmers properly plan for planting, harvesting, and irrigating crops. Monitoring is also key to determining a country's renewable energy resources. Instruments can monitor wind speeds and directions, solar insolation, and river flow to identify the best resources for a particular region. As monitoring equipment must often be located in inaccessible or remote areas, technologies such as wind and PV are valuable power options. Since year-round data collection is common, these technologies can reduce or eliminate the need for regular battery replacement.

Renewables are directly contributing to the commercialization of many more agriculture and health applications. As awareness of renewable energy increases, additional applications will no doubt be developed.

Figure 10
Additional Applications



PV-POWERED EDUCATIONAL TV
Since 1981, a 68 Wp educational TV system has provided training and entertainment for the 35 inhabitants of a rural village in Oman.

REMOTE CLIMATE MONITORING SYSTEM
This remote weather station monitors wind speed, wind direction, solar radiation, temperature, humidity, and precipitation. Powered by a small PV panel or batteries, it is a critical tool for conducting energy resource assessments.

Biomass

Biomass is a term that broadly encompasses plant matter used for energy production. Biomass may be used in a number of ways to produce energy, the most common of which are combustion, gasification, fermentation, and anaerobic digestion, as illustrated in Figure 11.

Biomass combustion is the direct burning of any plant matter. It can produce direct heat for cooking, crop drying, forges, kilns, and heating water, or raise steam in a boiler for electric power production or industrial process heat. Biomass combustion can displace fossil fuels directly. It also burns existing biomass resources (wood, charcoal, and agricultural residues) more efficiently than traditional methods. The U.S. biomass industry builds and exports high-quality biomass direct combustion systems to generate hot water, steam or electricity for the forest products industry, food processing plants, electric utilities, and specialized markets such as sugar and rice mills.

In gasification, biomass products are heated in an oxygen-starved environment and decompose without burning, while producing a volatile gas, called producer gas. This gas may be used in a furnace (direct heat gasification) or in an internal combustion engine. Biomass direct heat gasification may be added to an existing fossil fuel boiler. Thousands of such systems have already been installed at sites ranging from pulp and paper mills to community colleges and post offices.

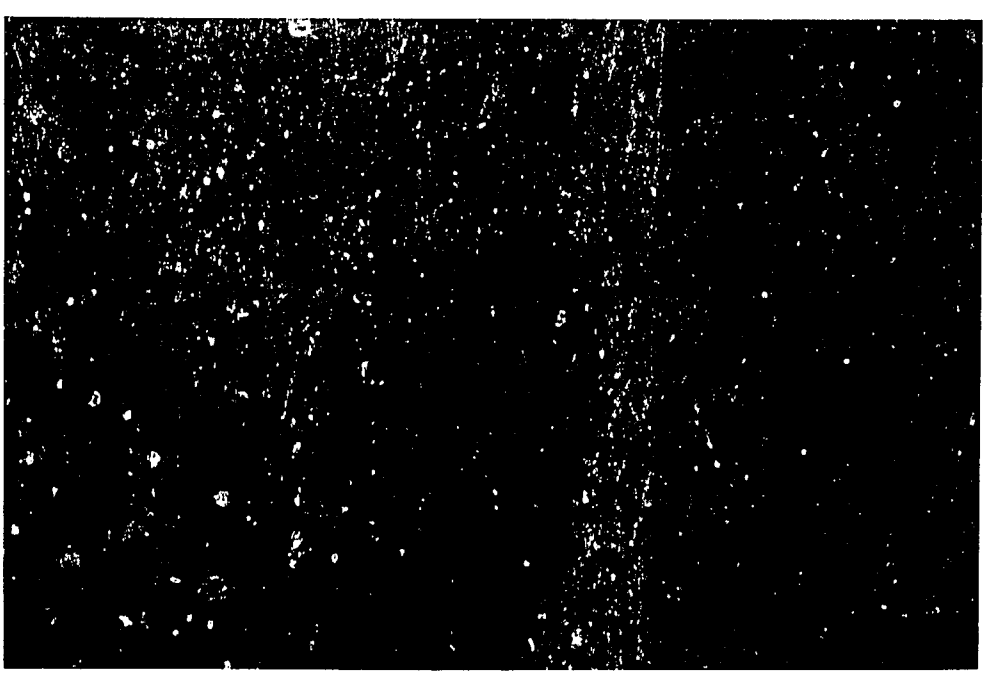
Biomass feedstocks can also be converted into valuable energy products through fermentation. Starch and sugar feedstocks are treated to produce a sugar solution, which is then exposed to yeast or bacteria which convert the sugar into ethanol (ethyl alcohol) and carbon dioxide. The ethanol is generally removed from the fermented liquid by a distillation process. Ethanol can be used as a fuel for modified internal combustion engines, as an octane enhancer, or as a displacement for 10-20% of gasoline in existing vehicle engines.

A fourth biomass energy conversion system is anaerobic digestion. In this process, manures, agricultural residues, or specially grown crops are fed into a sealed container called an anaerobic digester or biogas plant, where they are broken down by special bacteria, producing a gas that is 50-60% methane.

Because of their specialized expertise in the technology development and design of all types of biomass systems, U.S. firms have been called upon to supply such systems throughout the world. Users include the food processing industry, large dairies and feedlots, and the forest products industry, as well as a number of other facilities requiring industrial or commercial heat, hot water, or steam. U.S. hardware and engines can be provided as a part of an overall plant construction or system upgrading. These technologies are well proven, economical, and reliable. The U.S. biomass industry, a worldwide leader, can provide a complete range of biomass products and services for direct use and/or local manufacturing and sale.

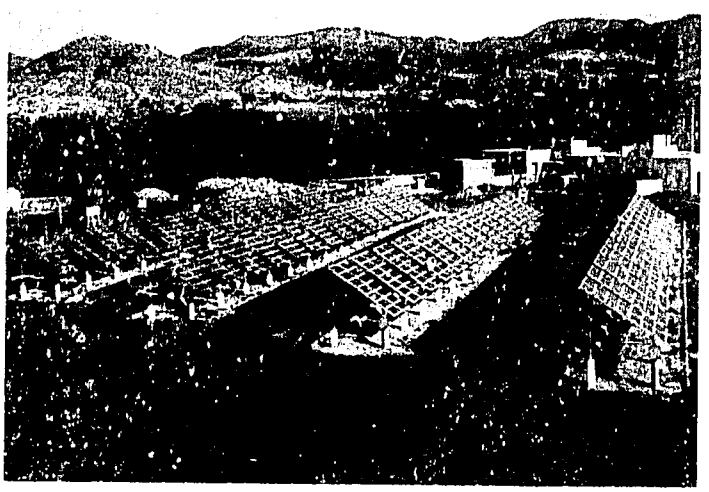
RICE HUSK FUELED ELECTRICAL GENERATOR
A rice milling operation in Louisiana, U.S.A., has received all its power needs since 1984 from this 11.5 megawatt rice husk fueled power plant. In addition, 84% of the electricity generated is sold to the public utility grid.

Figure 11
Biomass Power



Photovoltaics (PV), a form of solar energy, uses semiconductor solar cells to generate direct current (DC) electricity directly from sunlight. This can be used to supply power for any electrical application. Photovoltaics were first used in space in the 1960s to provide power for satellites. Since 1970, the U.S. photovoltaic industry has further developed the technology, and today is providing commercial systems and components for a variety of applications worldwide.

Photovoltaics has numerous benefits, particularly for remote power needs. PV is a proven source of high quality electrical power, and the PV system is simple, clean, flexible, and reliable in operation. PV systems have no moving parts, require minimal maintenance, and the fuel source – sunlight – is free. PV systems are operating in a variety of environments ranging from deserts to the Arctic Circle, to harsh, corrosive marine environments. Furthermore, its modularity enables end users to operate small systems for individual applications (e.g., lights, vaccine refrigerators, and water pumps) or to add on additional systems as demand increases (e.g., hospitals and village power systems). Thousands of these systems have been installed from Botswana and Mali to the Caribbean and South Pacific. Figure 12 shows how PV systems operate in various agricultural and health sector uses.



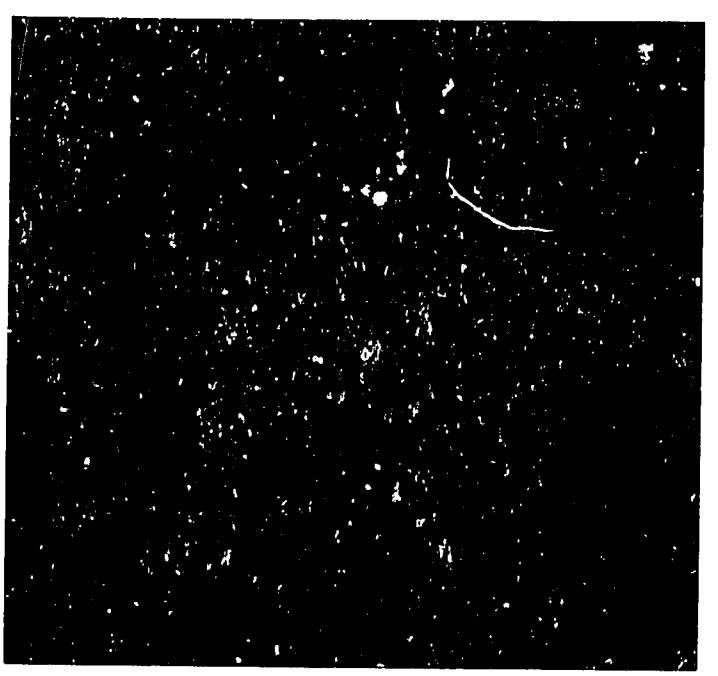
PV POWER FOR LOCAL UTILITY GRID
Village electrical power has been provided by ths 28 kW PV installation since 1983. It is located in Hamman Biadha, Tunisia, a village of about 150 households.

PV is based on the use of solar cells that are connected together to form a module. Depending on the application, a number of modules can be combined to form a PV array. Through this grouping technique, systems can easily be constructed to generate power in practical forms tailored to the exact needs of any application. PV output is measured in terms of watts peak (Wp), which is the electrical output of the system at approximately noontime, or when the sun's intensity reaches its peak. System outputs can range from a few milli (one thousandth) Wp, such as used in a solar watch, to several mega (million) Wp, as used in a large electric utility power plant.

PV power systems consist of the PV array, supporting structure, control electronics, a DC-AC inverter if alternating current (such as normal household current) is required, and a storage device if one is needed. A storage device, usually a rechargeable battery, is incorporated in the system to supply power at night and during cloudy periods.

The U.S. PV industry is the acknowledged worldwide leader in both technology development and products. In 1985, the U.S. shipped 7.5 MWp of PV equipment, which represents nearly 40% of total worldwide shipments. Components, subsystems, complete systems, design services, installation, and service support are all available from a large number of experienced U.S. suppliers. The U.S. industry has also supported many licensing and joint venture arrangements worldwide to serve any application or product requirements that may arise.

Figure 12
Photovoltaic Power



Wind

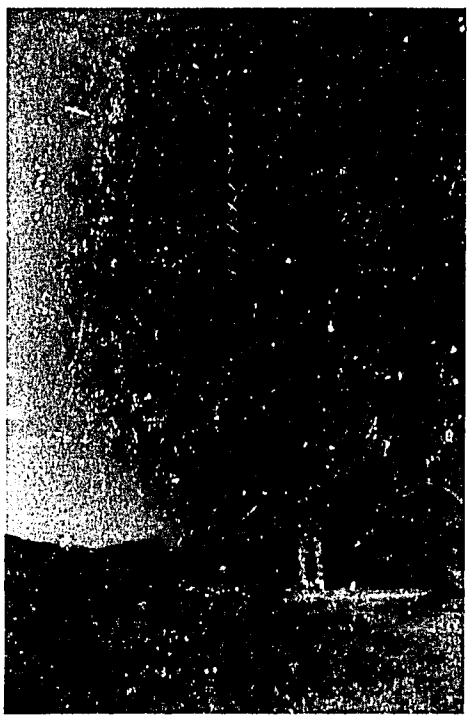
Man has been using wind energy for thousands of years. The first recorded use of wind machines was in Persia in 200 B.C. where simple windmills were used to grind grain. In the first half of this century, over 6 million small wind turbines were pumping water and generating electricity in the midwestern United States alone. Compared to these early machines, the technology has improved tremendously. Current wind system products are more durable, efficient, cost-effective, and reliable. They have been used around the world in a wide variety of operating conditions and environments.

The main wind energy conversion device is the wind turbine. This converts the energy in the wind to rotary motion, which in turn powers a generator to directly produce electricity or a drive shaft to mechanically pump water, grind grain, or heat water. The two major types of wind turbines are vertical and horizontal axis. The key subsystem components include a blade or rotor which converts the energy in the wind, a drive train which includes a gear box or generator, a tower, and other supporting equipment.

Wind energy provides an excellent power source for non-grid connected sites where a wind resource exists. Wind turbines are produced in a variety of sizes to meet remote energy needs. Very small direct current systems are available in sizes that produce a few hundred watts, most often used in battery charging. Larger sized turbines of up to 20 kilowatts are used as stand-alone, alternating current generators for agricultural and remote residence needs. Figure 13 shows a typical stand-alone configuration.

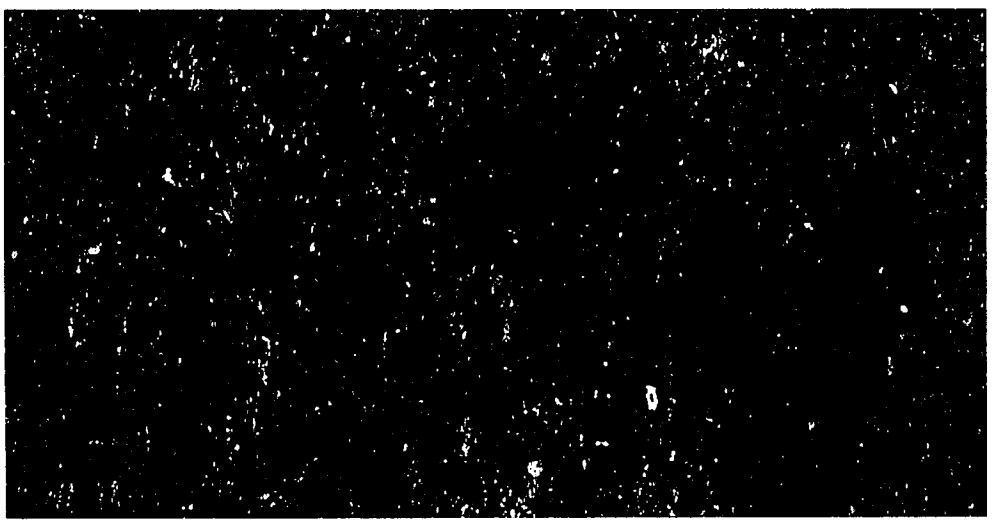
The advantages of wind turbines are many. They do not need fuel, their maintenance needs are minimal, their operation is simple, and they are rugged and reliable with adequate local maintenance. Their modularity allows them to be sized to match the energy needs of the application and then expanded as the energy requirements of an application grow. In addition, the power available from wind, and therefore the economic attractiveness of a project, increases dramatically as average windspeeds increase.

The U.S. wind industry is ideally suited to support agricultural and health needs in regions of the world where proper wind resources are available. The industry manufactures and supplies system and subsystem components, complete systems, and can also provide design, installation, and service support. Joint ventures and licensing agreements have been established by the industry in many countries. Overall, thousands of successful systems in a large number of countries demonstrate that the U.S. wind industry and its technology are viable, economic, and reliable solutions to the energy needs of developing countries.



WIND VILLAGE WATER PUMPING
This recently implemented U.N. water supply project utilizes a 12kW wind turbine to pump up to 1000 gallons of water per hour for the village of Malmari, Pakistan. The availability of water, which has been in short supply, may help stop migration out of the village.

Figure 13
Wind Power



Micro and Small-Scale Hydro

In a hydro power system, falling water is directed against a turbine, which is rotated by the force of the water. The spinning turbine is then either coupled directly to a load such as a grinding mill or more commonly, connected to an electrical generator set to supply electricity. A micro-hydro system is illustrated in Figure 14.

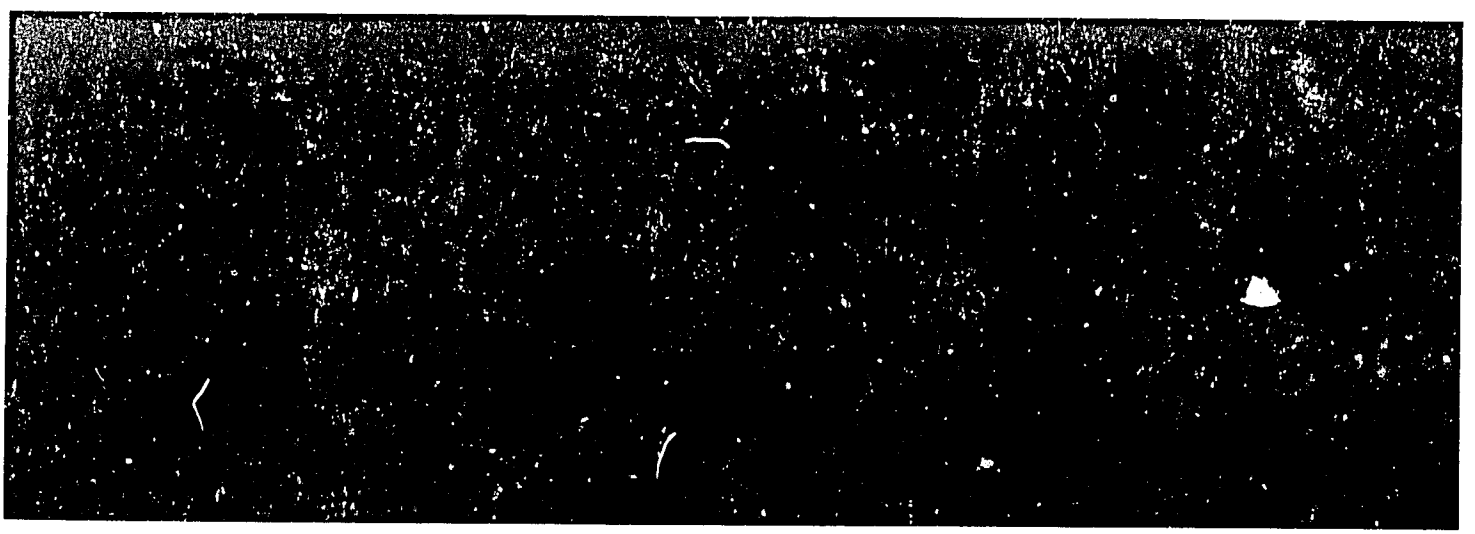
Through the 1970s, hydro systems in the developing world were primarily large dams used for the production of power for the national grid. Smaller sites were not developed. In the past two decades however, increased attention has been given to micro and small-scale hydroelectric plants to serve rural communities. This has proven to be cheaper than spending large amounts of money to extend existing grids to small towns and villages. U.S. firms have been key to the design, development, installation, operation, and financing of micro (less than 50 kilowatts) and small-scale (50 kilowatts to 10 megawatts) systems and components (turbines, governors, generators) worldwide.

Micro and small-scale hydro systems provide a number of major benefits. They are reliable and proven in thousands of installations. They have no fuel costs, are non-polluting, and typically have little or no harmful environmental impacts. Operation and maintenance can be performed by local maintenance staff. If properly maintained, they have a lifetime of more than 20 years. They provide continuous 24-hour power as long as the water resource is sufficient and can be used for either shaft power or electricity production.

Hydroelectric systems designed and built by U.S. contractors have been major contributors to the electrical power mix of both developed and developing countries. U.S. firms offer complete micro and small-scale hydro services, ranging from site analysis to design to construction supervision, and U.S. turbines are among the world's technology and reliability leaders. Today, U.S.-designed and constructed micro and small-scale hydro systems are helping to provide reliable, low-cost power for remote mountainous sites in locations ranging from Malaysia and the Philippines to Nepal and Ecuador.

MICRO-HYDRO ELECTRICAL GENERATOR
A villager adjusts the intake valve for the turbine on this micro-hydro genset in Nepal.

Figure 14
Small-Scale Hydro



Solar thermal energy systems capture the sun's free energy and convert it into heat. The most common applications in developing countries are heating water, food processing, crop drying, and space heating in colder climates.

There are two major types of solar thermal energy systems – active and passive. Active systems use a pump or blower to circulate water, air, or a heat exchange fluid in a collector, where it is heated by the sun's rays. Active systems are broadly divided into flat-plate systems, generally used for heating water or air, and concentrating systems, used for producing higher temperature fluids or steam for industrial processing applications. In 1986, U.S. firms shipped more than 1.1 million square feet (118,000 square meters) of active solar thermal collectors. Figure 15 is a diagram of active solar systems, both flat-plate and concentrator, and several common applications. Many small systems are used in individual homes, as in Barbados where 30-40% of homes have solar hot water heating. Besides individual heaters for single family homes, active solar systems are often used with larger arrays and a central storage tank to provide hot water for multi-family residential or commercial buildings, schools and hospitals, and other public buildings.

The term passive solar systems is commonly used to describe climate-sensitive architectural designs, in which the building itself is used to buffer the interior space from outside climatic swings. In cold climates, the building is specially designed to collect incoming solar energy during the day, store it in massive heat-absorbing structural components, and release it slowly during the night. In this case, the building itself serves as the solar collector. In hot, arid locations, the building can be designed to minimize interior temperatures and maximize natural convective cooling.

Passive solar design has been developed and perfected by a generation of U.S.-based architects and solar engineers. Hundreds of different designs and building materials have been tested and evaluated, and the results have been incorporated into standard building practices. It is a sign of the maturity of U.S. passive solar design that in fast-growing sections of the U.S., such as New Mexico and Colorado, 20% of all new homes are constructed using passive solar heating and cooling design principles. These buildings are designed to be comfortably warm in the winter using little auxiliary heat, yet they remain cool in the summer. These principles are now being successfully applied by U.S. engineers and architects in countries as diverse as Botswana and Nepal for space heating, and a number of North African countries for natural passive cooling of buildings. Passive solar design expertise and products are being supplied to or licensed to local partners throughout the world.

U.S. firms are eager to collaborate with local partners to modify their designs to local climates, preferences, building practices, and materials. Available options for active systems range from importing complete U.S.-built systems to turnkey design and construction of a plant which the local partner owns and operates. For passive systems, U.S. architectural and engineering firms provide services ranging from conceptual design to complete design and construction supervision.

SOLAR HOT WATER FOR FOOD PROCESSING
A large array of solar thermal flat-plate and concentrator collectors, installed in 1978 at a Campbell Soup manufacturing plant in Sacramento, California produces water at 180°F for their can washing process

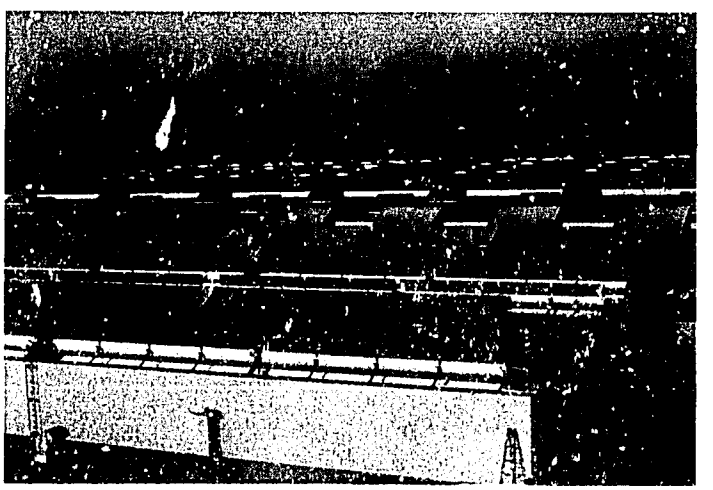
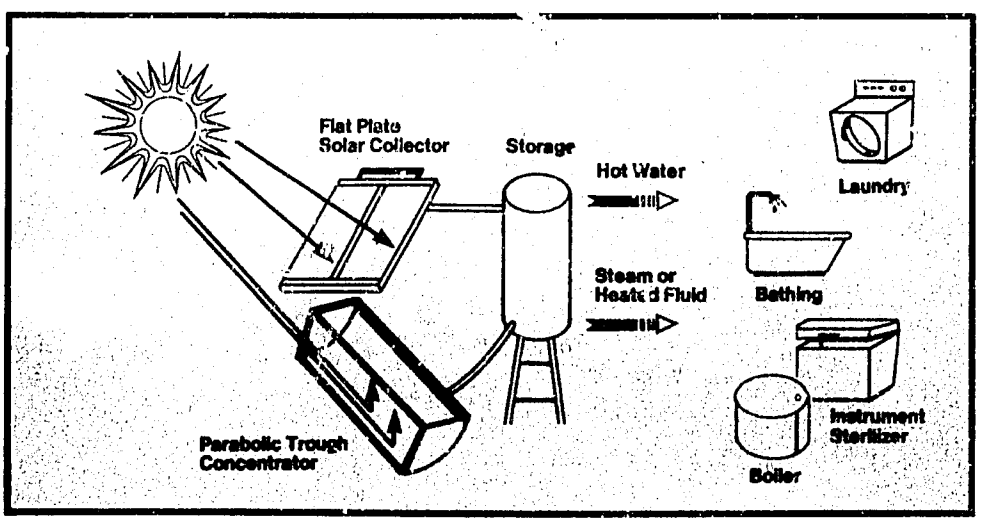


Figure 15

Solar Thermal Power



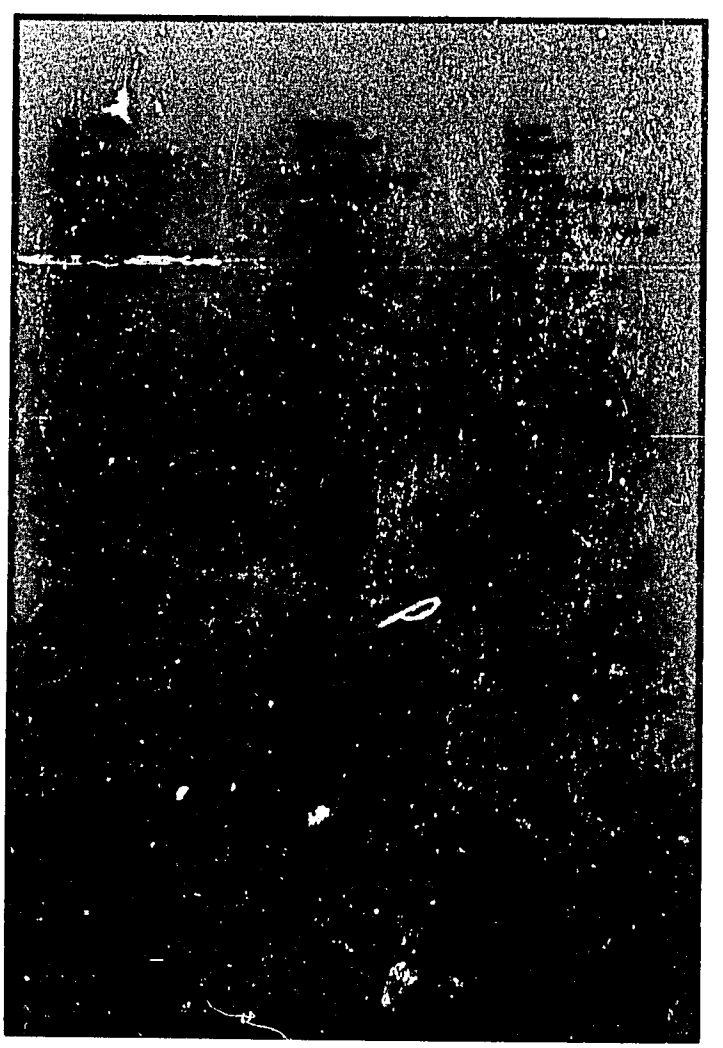
The U.S. Renewable Energy Industry

Renewable energy in the U.S. is a large and well developed business with proven products in use worldwide. The U.S. government and renewable energy industry have invested over $3.5 billion in both technology research and product commercialization. To date, thousands of practical and economic applications have been installed in the U.S. and around the world, either directly by U.S. companies or through their many joint ventures or licensing agreements.

The United States renewable energy industry is the worldwide leader in renewable energy technology and products. Industry firms are active in all phases of the market, from basic raw materials and components to subsystems and fully operational turnkey systems. U.S. service companies also support basic needs from energy resource development and monitoring to system design, product testing, and even system operation and maintenance. The U.S. industry has sold, installed, and serviced renewable energy products in over 150 countries and the list of active areas increases daily as new systems are delivered. The list of installation sites is shown in Figure 16. Figure 17 lists representative renewable energy products and services available from U.S. firms.

Figure 16

Worldwide Renewable Energy Locations Using U.S. Equipment

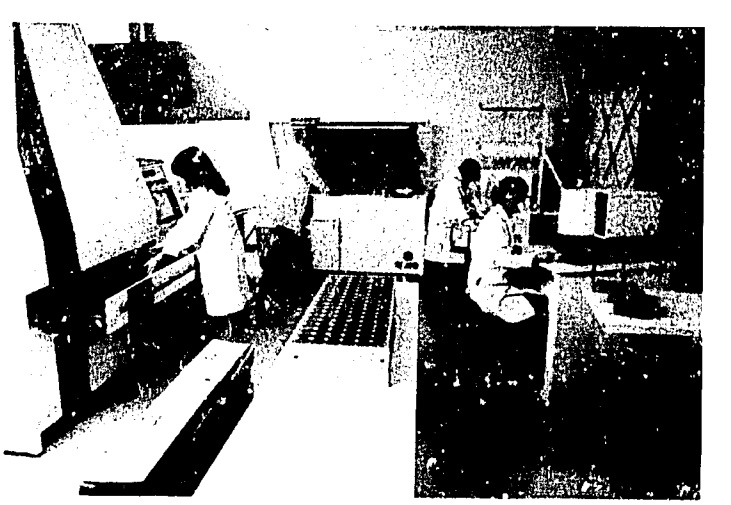


History of the U.S. Renewable Energy Industry

Renewable energy has played a meaningful role in the energy economy of the United States for over 50 years. Many renewable energy systems were actually first used in the U.S. in the 1920s. During the early years, residential and commercial solar thermal heating and hot water systems were installed throughout the U.S. Wind systems were used for electricity and water pumping in the farming industry and small-scale hydro systems supplied both mechanical and electrical energy for homes and commerce.

When the major "oil shock" in the early 1970s led to increased costs and raised serious security concerns relating to supplies of traditional fuel sources, both the United States government and the U.S. industry implemented substantial renewable energy advancement programs directed at using existing renewable energy technologies as well as developing and demonstrating new renewable technologies. The government, through the Department of Energy (DOE), has supported extensive efforts in wind, solar thermal, photovoltaic, biomass, small-scale hydro, and other renewable energy technologies and products. Since 1975, the DOE has supported annual renewable energy budgets of $100 million or more each year. The U.S. renewable energy industry has invested even higher levels of annual funding.

PV SYSTEM MANUFACTURING FACILITY
Making PV cells involves highly developed and integrated manufacturing technologies and processes. These proven manufacturing systems are in-use in domestic U.S. plants and in a large number of joint venture operations around the world.



U.S. Industry Status Today

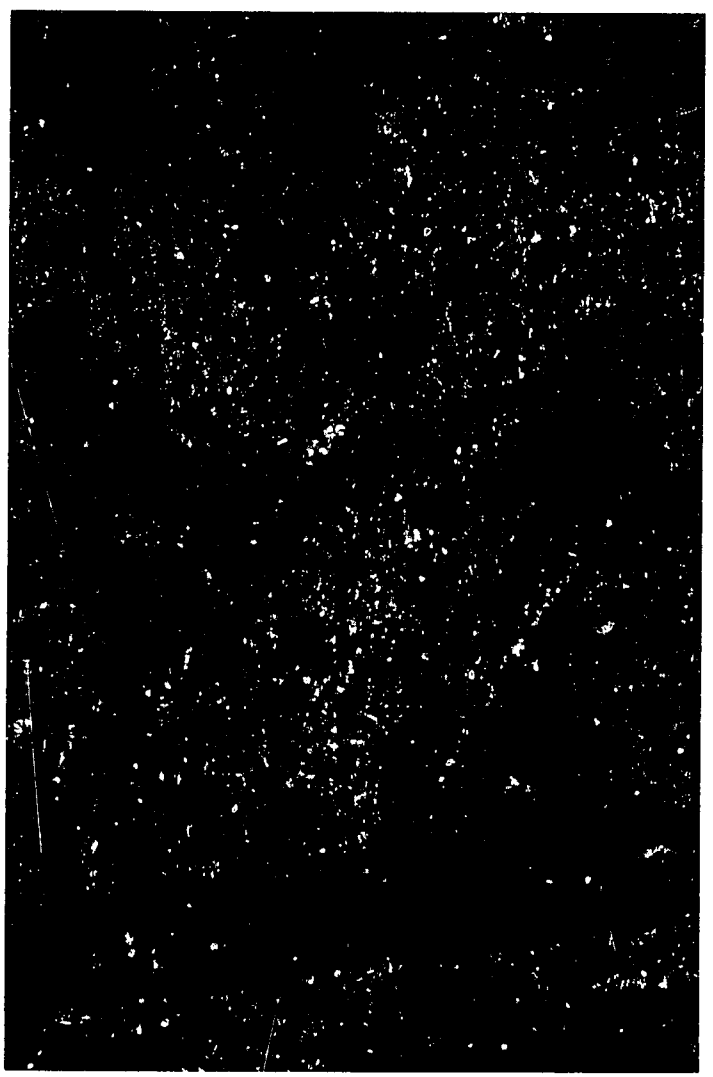
As a result of these investments, the U.S. industry is fully prepared to support renewable energy needs for any application in any location worldwide. Commercial products are available which are customized for the specific needs of each application and location and which have been proven in operation for over 10 years. The U.S. renewable energy industry supporting these products is a diverse and comprehensive group of companies including at least 900 biomass firms, 300 PV firms, 100 hydropower firms, 150 wind companies, and 80 solar thermal companies. Geothermal, energy conservation, and cogeneration technologies are similarly well represented by other U.S. companies. In total, the U.S. renewable energy industry includes several thousand companies, employs over 15,000 individuals and last year accounted for sales in excess of U.S. $10 billion.

Renewable energy resources promise new forms of energy for all countries around the world. To utilize these resources, they must first be identified, qualified, and measured. Renewable energy products and systems may then be purchased or manufactured, installed, and serviced to take advantage of these local sources of power. The U.S. renewable energy industry can assist in all steps of this process – from identifying resources to supplying the products and services to use them. In addition, the U.S. industry is committed to working with the private sector to establish local ventures to facilitate development and jobs wherever possible.

The advantages of renewable energy are clear – environmentally sound and sustainable domestic energy supplies for any country coupled with reduced dependence on international energy sources and reduced foreign exchange requirements. Working with the U.S. renewable energy industry, the worldwide leader, provides direct access to the most advanced renewable energy technologies and products available today. This association can also bring the advantage of increased local participation in energy development, another significant step on the road to sustained industrial and national development.

Figure 17

Representative Products and Services*



For Additional Information

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Information on experience with renewable energy in developing country applications, and availability of U.S. foreign assistance programs and services in renewable energy.

Mr. Robert H. Annan, Staff Director

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Information on federal programs providing foreign buyer assistance.

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Information on U.S. renewable energy industry products, services, and points of contact.

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Technical assistance service for project feasibility, design and procurement; training; competitive assessments; general technical information transfer; and application identification.

AID representatives and commercial attaches at U.S. embassies can provide additional general information and foreign buyer assistance.

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