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THE POTENTIAL FOR RENEWABLE ENERGY TECHNOLOGIES IN THE RURAL POSTHARVEST FOOD SYSTEM IN DEVELOPING COUNTRIES

by

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INTRODUCTION

Until recently, little international attention has been given to the conservation of non-renewable energy or the enhanced use of renewable energy sources in developing countries. However, increases in oil prices have prompted much greater interest and activity in this area. This paper describes a selection of postharvest technologies, examining typical and potential renewable energy power source alternatives, and (makes recommendations to) promotes the use of renewable power sources in the postharvest food system. The primary focus of this paper is on postharvest power sources adapted to on-farm and rural needs and resources in developing countries; however, there is overlap with other sectors inasmuch as some potential postharvest technology power sources can be adapted to a number of other mechanical processes.

The subject matter covered in this paper is broad. On one hand, it attempts to briefly span a plethora of postharvest technologies used in different cultures, and climates, and for different food products. It also briefly assesses a diverse variety of renewable energy technologies which have widely divergent applications and limitations, resource and skill requirements, and for which documentation on actual performance in developing countries is, with few exceptions, far from idea for a thorough analysis.

For the purpose of this analysis, the diversion of postharvest techniques contains seven categories: (1) harvest; (2) drying; (3) threshing and winnowing, (4) shelling, hulling and grinding, (5) storage and refrigeration, (6) canning and related processing, and (7) cooking. The heaviest

emphasis in this paper is on technologies related to grain, both because grain is the principal food staple in developing countries, and as such, it has historically received the most development support, with consequently limited experience and data available on pulses and common perishables. Common technologies in each category are examined in terms of their function, constraints, and actual and alternative power sources.

Renewable energy power sources are examined in terms of their function, relative costs, potential constraints in their adaption to the rural economic and cultural environment, and their potential postharvest applications. In some cases, recommendations are made where further research or field experience is needed to bridge existing information gaps or to modify the technology for improved adaptation to the rural socio-economic environment of developing countries.

BACKGROUND

In most developing countries, the traditional sources of energy used in rural areas have been animal and human effort and various forms of vegetable matter. Firewood, charcoal, agricultural residues and dung are the fuels used by the majority of rural dwellers for their principal energy needs--cooking and heating. In some places, wind and water power have also been used in agricultural activities.

During the last twenty years however, a growing acceptance of petroleum-based power sources has occurred in urban and rural sectors of developing countries. Kerosene is becoming a major fuel for the lighting, cooking, and heating needs of urban populations. Electricity, usually

supplied by fuel oil or diesel powered generators, has become a common urban feature. Diesel powered mills and pumps have been introduced in rural areas by prosperous farmers, merchants and government agencies.

Traditional development strategies and foreign assistance supporting them have often emphasized adoption of technological practices similar to those of advanced industrial societies. This mind-set has led to an emphasis on capital and energy intensive heavy industry and high yielding crops which require heavy fertilization and energy intensive irrigation and processing techniques. Earlier energy development assistance emphasized capital intensive electricity production facilities--large hydro-electric installations, coal, nuclear and oil-fired electric generation stations and grid systems. Such technologies assume the availability of cheap energy sources, a situation that characterized the economic history of most industrialized countries, but which is no longer the case.

Impoverished economies of the Third World presently consume a small percentage of the world's oil. Nonetheles, they will run up a fuel bill this year of more than $50 billion, much of which must be paid for with borrowed funds. Practical alternatives to oil in poor countries are not readily apparent. Moreover, there presently appear to be few easy ways to reduce oil consumption without also reducing economic output.

For most developing nations the result of oil price increases has been a devastating explosion of national indebtedness. Net oil import costs to the World Bank's developing member nations rose ten-fold in real terms in the past decade and will more than double again by 1990 (World Bank, 1979).

In Kenya the energy ministry claims that nearly 30 percent of that country's foreign exchange earnings are now spent on oil imports, compared with about 8 percent in 1973. In 1973, it took seven-tenths of a bushel of wheat to buy one barrel of oil. In 1980 more than seven bushels were needed. Other agricultural commodities and raw materials have experienced the same weakening price relationship to oil.

In spite of their relatively low commercial energy consumption, it is critical to note that the growth rate of commercial energy consumption in developing countries is even greater than in industrialized countries. From 1960 to 1974, the average annual commercial energy consumption growth rate in low income countries was 5.7 percent; for middle income countries; 7.6 percent; and for industrialized countries, 4.9 percent. From 1974 to 1976, the consumption growth rate for low income countries was 4.6 percent; for middle income countries, 5.2 percent; and for industrialized countries, only 1.3 percent (World Bank, 1979).

By the year 2000, world population is expected to reach 6 to 6.5 billion compared to a present level of 4.3 billion. This means that by the turn of the century, barring major population-reducing catastrophes, the world will have to produce greater than 50 percent more food than it now does to maintain the present level of inadequate nutrition. Much greater increases will be required if famine and massive malnutrition are to be averted. The low-energy production and processing techniques presently used in developing countries will not produce the increases required to feed the rapidly growing population.

Thus, two things are clear regarding future energy demands and resources in developing countries: energy demands will increase markedly, and new sources for supplying this energy must be found.

Traditional sectors of most developing countries make extensive use of noncommercial, nonconventional energy sources. Firewood, charcoal, plant and animal residues, human and animal power, and direct and indirect solar energy are used in the household and for a variety of agricultural and rural industrial tasks. It is estimated that although these forms of energy supply only about 5 percent of world energy consumption, they represent between 60 and 80 percent of the total energy production of developing countries (World Bank, 1979). While renewable energy sources alone probably cannot provide enough energy to foster development in most countries, they must increasingly substitute for imported fuels if developing countries are to avoid crippling fuel import debts. Because no single alternative energy source or technology offers a complete solution to the energy requirements of national development, the broadest possible range of available energy sources must be used and international efforts must be devoted to identifying, developing and exploiting these resources.

Finite supply and escalating price of the world's oil dictate that new and enhanced use of renewable energy technologies must occur on a broad scale even though the present cost of many of these technologies is beyond the reach of most rural populations. Capital costs of renewable energy technologies are often prohibitive even though the amortized cost of energy is or may soon be competitive with fossil fuel prices. In such cases,

renewable energy technology subsidization and credit programs may be justified and required.

The often high start-up costs of new energy technologies limit their applications in developing countries as do the sometimes unfamiliar, culturally conflicting, or impractical behavior patterns associated with new technologies. Overcoming these social constraints in the design and introduction of new technologies often proves to be a greater problem than in the design of technologies which are technically and economically viable. Moreover, the introduction of labor saving technologies can have major impacts on rural employment and income redistribution, causing unforseen hardships, often among the poorest sectors of society.

COST FACTORS

In the final analysis, if new technologies are to be adopted on a broad scale, energy users must see a change of technology to be in their own best interests, both economic and social. Economic costs of new technologies must be offset by increased output or efficienty, reduced crop losses, lower energy costs or greater convenience. These benefits must be very clear if people who are struggling for their daily subsistence are going to take the time to test a new technology. Unlike the large investor, the perspective of the poor is not often one which accepts the advantages of economies of scale. Experience has repeatedly shown them that innovations involving relatively large, long-term individual investments are simply too risky when any losses in financial investments directly jeopardize their health and very existence.

From the perspective of the policymaker or project planner, it would be invaluable to have access to data which accurately detail the breakdown of capital and operating costs of alternative technologies. In principle, as the available data become more extensive and accurate, planning will be greatly facilitated. Unfortunately, the extremely limited cost and output data currently available for most technologies has typically been reported by field technicians whose appreciation of policymakers' information needs is understandably limited.

Costs are often summarized as a simple figure, without breakdown for the value of imported and local materials or the amount and value of labor. As such, it is misleading to refer to seemingly straightforward statements of cost and output which exist for some technologies, without an appreciation of the large number of variables that need to be accounted for when comparing cost and output of even relatively similar technologies from different regions. To compare the feasibility and economics of wind and diesel powered grain mills for example, accurate documentation should include: potential and actual mill output for both power sources; minimum power requirements of the grinder; the real and actual milling charges; the expected depreciation time of the windmill and diesel engine; the local and imported parts costs of both power sources; the amount and value of skilled and unskilled labor for construction, operation and maintenance; the average daily windspeed; and the real and actual cost of diesel fuel. For accurate comparison, all costs should be stated in constant dollars and adjusted to account for taxes or subsidization.

In the following sections, cost figures are cited for the various postharvest processes and power sources discussed, as the data is available. However, this can only give a general idea of relative costs and should only be referred to in light of the above-mentioned variables.

Even in the limited cases where local technology costs are detailed accurately, their applicability to other regions and countries will always depend on a host of economic and cultural variables which can only be known after actual site-specific experience. When dealing with subsistence farming incomes, even small cost variations can be crucial to acceptance of a new technology. These include variation in depreciation time, cost and availability of local transportation, imported and local materials and skilled labor, among others.

Initially, it is possible to make general comparisons of technology costs from other countries or regions in order to determine the general feasibility of applying those technologies in a given situation. However, field trials will always be necessary for accurate local documentation of costs and cost competitiveness, in addition to the equally important assessment of cultural acceptance. This local testing must necessarily preceed any commitment to promote new postharvest or renewable energy technologies.

Before examining specific postharvest technologies and their potential power sources, it is useful to examine postharvest food system energy consumption in terms of overall energy use in both industrialized, energy intensive food systems and in marginally mechanized systems of developing countries.

ENERGY CONSUMPTION IN THE U.S. FOOD SECTOR

According to various estimates, total energy consumption in the production and postharvest food system is between 12 and 20 percent of all commercial energy consumed in the U.S. The higher estimates include indirect energy consumption in the food system, such as the energy used in construction of related buildings, machines, materials, transport from food store to home, disposal of home food wastes, etc.

U.S. production agriculture uses 3 to 3.5 percent of the nation's total commercial energy consumption. By contrast, at least three times as much energy is used to process, transport, market and prepare food than is used to produce it. Preparation of food appears to require as much as 50 percent more energy than food production. Food processing uses about the same amount of energy as food production, and marketing only slightly less (Stout, 1979). Moreover, virtually all energy consumed in the U.S. postharvest food system is derived from fossil fuels, with the only significant exception being hydro-electricity.

Unlike developing countries where most food processing occurs in the home as part of the food preparation process, many U.S. foods enter the home ready to eat or require minimum preparation efforts. Increasingly popular convenience foods consume much more energy for processing than do simple staples which entail more time and effort to prepare once in the home.

Though popular due to enhanced flavor and color, the energy consumed in freezing of fruits and vegetables is significantly greater than for canning, averaging 1815 kcal per kg of frozen food compared to 575 kcal

per kg for canned food (Pimentel, 1979). The higher energy consumption of frozen foods is because canning requires only heating while freezing involves energy for brief heating, cooling and then freezing. Canned foods can be stored at room temperature, but frozen food must be kept cold, consuming about 265 kcal per kg per month.

Manufacturing food packaging containers often requires more energy than was used in processing the food contained within. A half-gallon plastic milk container consumes 2160 kcal for manufacture while processing the milk requires only about 700 kcal. A 355 ml steel can for soft drinks requires about 570 kcal of energy to manufacture; the same size aluminium can requires 1643 kcal. Processing the soft drink consumes only about 450 kcal (Pimentel, 1979).

The highly centralized, mechanized and energy intensive U.S. food system clearly cannot be expected to be duplicated on a broad scale in developing countries, however it can be expected that in developing countries the food system will become more mechanized and that increased energy demands will result.

ENERGY CONSUMPTION IN DEVELOPING COUNTRIES' POSTHARVEST FOOD SYSTEM

The postharvest food system in developing countries is characterized by a number of activities involving each food product, varying among cultures, countries and regions. For example, grain may be eaten fresh before maturity, grilled or boiled, fermented and/or dried. Grain flour may be baked, fried, made into gruel or dumplings. Cassava, yams and potatoes may be dried, ground, pounded and/or fermented and consumed in a wide

variety of preparations. Fresh fruits and vegetables, due to lack of adequate practical preservation techniques are generally consumed as quickly as possible after harvest. The extent and type of postharvest processes depend on a number of environmental and cultural factors but the type of food or commodity and the intent to market or consume it in the home are usually the most important determining factors.

Revelle (1976) cautions that international statistics on energy use are generally based only on consumption of "commercial" energy and hence seriously underestimate total energy consumption in poor countries. In rural India, he estimates real per capita energy consumption at 490 kg coal equivalent, contrasted with official figures of 150 to 190 kg. This is so, he asserts, inasmuch as in rural areas of poor countries fuel gathered by the people themselves is 5 to 10 times that obtained from commercial sources.

In the rural areas of developing countries, energy accounting can be misleading if not broken down into various categories of activities. As well, non-commercial energy such as human and animal labor, crop residues, dung and firewood are very important in these settings, though their consumption is not easily monitored or accurately measured. Energy consumption is particularly difficult to analyze in rural settings where it is part of complex and highly interdependent agricultural, labor and marketing systems. Further, data on the postharvest food system is limited due to the historically low prioritity and status postharvest activities have until recently been accorded in development policy.

A thorough policy-oriented analysis of developing country energy consumption would ideally require reliable data on the amount and type of each energy form, the tasks performed by each, and the efficiency with which that task is performed. Available data on rural energy consumption, especially in the postharvest food system, falls well short of this ideal in all three respects. What little evidence exists documenting energy use in rural sectors of developing countries, and the even more scanty data concerning postharvest food systems, is often in the form of roughly estimated percentages of total energy use. Rarely does such documentation include the specific type, amount or value of energy consumed. Energy consumption is sometimes estimated for an aggregate of activities. For example, "transportation and processing" may be assessed as a single category making it virtually impossible to separate how much is consumed by each activity.

Notwithstanding the above, existing estimates of rural energy use provide useful indications of the relative amounts and types of energy consumed. Pimentel (draft 1977) estimated developing country food production as requiring 31 percent and food preparation about 62 percent of total rural energy consumption. Revelle (1976) estimated that more than 50 percent of all hours worked in rural India are spent directly in agriculture, while food preparation and other domestic activities take up another 39 percent of all hours worked. He estimated that 82 percent of total rural energy use is for the food sector. Of this energy, approximately 10 percent is provided by fossil fuels, the remaining 90 percent furnished by human, animal or biomass energy including wood, crop residue and dung.

Walton (1978) estimated that in a typical village in Senegal, nearly 80 percent of the total rural energy demand is for cooking. All reports appear to agree that throughout developing countries, in-home food preparation and cooking require the largest portion of energy used in the postharvest food system and at least 60 percent of the energy in the entire food system.

Makhijani (1971) estimates that the annual use of wood or any of the other photosynthetic fuels for cooking in India is about 5 to 7 million BTU per day per person or about the equivalent of 2 pounds of dry wood per capita per day, which is considerably larger than the 3 million BTU per capita used in more efficient U.S. gas stoves and ovens (not accounting for fuel burned by the pilot light).

Myles and Singh (1979) estimate that Indian farmers burn in cooking fires 300 to 400 million tons of wet cattle dung yearly which they calculate is equivalent to about 35 percent of total fertilizer used in that country. They estimate that fifty million additional tons of grain could be produced if this manure were returned to the soil. If converted to methane and fertilizer, this dung fuel could meet the daily fuel needs of 375 million people.

The actual use of fossil fuels in developing countries' rural postharvest food systems has been largely undocumented, in part due to their apparently limited use. Very few postharvest processes are mechanized or powered by fossil fuels, and heat, as mentioned is generally provided by burning firewood, crop refuse and dung. However, the proliferation of small diesel

and gasoline engine powered hulling and grinding mills represents a major use of fossil fuels in the postharvest food system. If alternative renewable energy power sources are not developed and made available, slowly increasing mechanization in developing countries will also increase demand for oil based fuels.

The Brookhaven National Laboratories, under contract with USAID, has produced one of the most exhaustive efforts to document food system energy consumption in a developing country, the Dominican Republic. Exhaustive as it is, this effort does not answer significant questions concerning the actual amounts and types of energy consumed by various processes in the food system although it does have important implications for future energy-related policies in the Dominican Republic.

Even in the somewhat mechanized farming economy of the Dominican Republic, food production is not keeping up with population growth and food demands. Dependence on imported staple grains increased 14 percent to a total of 48 percent during 1968-78. The Brookhaven report concludes that, "the environment for bringing about energy improvements will also be influenced by government policies on fuel prices, regulation, subsidies, etc. So long as electricity and oil are subsidized and the current gasoline price... is still subsidized, enterprises will be discouraged from providing solar heaters, gasohol, or other substitutes for the traditional sources of energy." However, the study suggests that such a pricing policy change is expected to have political impact in the Dominican Republic, such as the taxi driver strike, when the price of gasoline went up there recently.

Of the eight most economically important food crops produced in the Dominican Republic—sugar, rice, cocoa, plantain, yucca, beans, corn and sweet potatoes—the majority are produced on farms with little or no mechanization or fertilizer, in spite of the fact that more than 45 percent of farming land is in units of 100 hectares or larger. Processing of major food staples produced in the Dominican Republic consumes about 20 percent of the total energy required to produce, process, market and distribute these food products to the consumer. Export crops, however, consume more than half their total energy in processing.

Though the study recognizes that data is weak, it appears that marketing, transportation and storage consume approximately 47 percent of the total fossil energy in the food system. Primary transport consumes 4.5 percent of the marketing, transportation and storage energy for major staples and about 9 percent for minor crops.

Observations of general relationships between rural energy consumption and productivity may be useful in spite of the limited nature of energy consumption data, in initially justifying and planning rural (postharvest food system) energy development policies and programs. For example, (Revelle, 1976) the people of rural India are tied to poverty and misery because they use too little energy and use it inefficiently, and nearly all they use is secured by their own physical efforts. Increasing the quantity and improving the technology of energy would bring about a transformation of rural Indian society. New sources of energy must be developed to bring about this transformation as developing economies and individuals in these economies find petroleum products too expensive and traditional fuels no longer suffice for their burgeoning populations.

POSTHARVEST ACTIVITIES IN DEVELOPING COUNTRIES

From one region to another, the is a wide variety of postharvest activities and processes for each of the various grain and perishable crops moving from harvest to final preparation and cooking. For the purpose of this analysis, the postharvest food system is divided into seven categories:

1. harvest
2. drying
3. threshing and winnowing
4. shelling, hulling and grinding
5. storage and refrigeration
6. canning and related processing
7. cooking

Even if there were reasonably complete and reliable data on the broad spectrum of these food processes, it would be well beyond the scope of this paper to address more than a selection of the most common postharvest technologies. The processes dealt with here are discussed in terms of traditional and improved technologies in use, energy sources and renewable energy technologies which might be adapted as alternatives.

Harvest

In most developing countries, harvesting is done almost exclusively by hand labor, using small knives, machetes or scythes. In Java, Cain (Evans, 1979) reports that the use of such simple improvements as scythes instead of knives for harvesting reduces labor from 200 or more person days per hectare to 75 person days per hectare, a labor savings of 65 percent.

On those large private or public land holdings where mechanized harvesting is introduced, harvesters are typicaly powered by diesel or gasoline tractors. Fuel consumption of tractors can be reduced significantly through proper maintenance. Alcohol or gasohol fuels might be used as well to replace or reduce gasoline consumption. Animal draft could be used to power small mechanical harvesting equipment, although no detailed reports of this application of animal draft were found in the available literature.

Drying

The drying of grain is a critical process in its safe preservation during storage. Unless reduced to sufficiently low moisture content, generally about 12 percent, storage losses due to mold and insects are difficult to avoid. Reducing grain moisture content is particularly important for storage in sealed, non-aerated bins where the heat and moisture resulting from moist grain respiration can not dissipate and consequently foster mold and insect infestations. Some perishables such as casava, yams, peppers and some legumes may be dried for storage, depending on the climate and the availablity of other foods throughout the year.

Where possible, the simplest and most economical grain drying technique is to harvest during the dry season, after full maturity and on-stalk field drying have occurred. Losses caused by insects, birds and other animal pests feeding in the fields can necessitate harvest before adequate drying has occurred, as can the threat of oncoming rains or winds and the need to clear the fields for the next planting. The introduction of new grain varieties with shorter growing seasons which make possible double cropping, may also place harvest dates during the rainy season creating the need for

new grain drying techniques. In such cases, unless practical drying technology alternatives are available to local farmers, the new grain varieties are not likely to be widely accepted.

For perishables, and where pre-harvest grain drying is inadequate, the most commonly practiced technique is simple open air sun drying after harvest. This involves the use of much tedious hand labor to spread; turn; gather; and containerize the produce; guard it from thieves, wandering birds or other animals; and bring it under shelter to protect it from inclement weather. For lack of more suitable drying surfaces, farmers may spread drying grain or other produce on the hard-packed roadside where passing vehicles can crush or blow it away, causing significant, through undocumented losses.

Improved drying techniques involve the use of additional heat sources such as burning firewood, crop residues, or petroleum products and/or increased air flow through the drying chamber achieved by dryer designs to augment natural convection, or by the addition of motor-driven fans. In developing countries throughout the world, farmers dry and store grain in the rafters or in special shelters built above the home cooking fire to take advantage of this regular heat source. The smoke and heat passing through the grain stored above the cooking fire has the added benefit of retarding insect infestation. However, the insecticidal function of this technique has not been sufficiently researched to determine actual performance and advantages.

Various forms of fire heated batch dryers have been developed for use in developing countries. In Benin and Nigeria, a firewood-burning, adobe

walled dryer with three used oil barrels for the fire chamber has been popularized through extension programs beginning in 1967. This model can be used for drying up to 500 kgs per day of copra or grains, except rice which requires more sophisticated heat control to avoid heat-caused cracking. Heated air passes through the drying produce by natural convection, as the dryer is not equipped with a fan. Non-local material costs are about $50 plus labor to build the dryer and the protective shelter over it.

The International Rice Research Institute (IRRI) has developed a forced air batch grain dryer heated by a combination kerosene/rice hull burner and powered by a three hp gasoline engine or two hp electric motor to drive the fan which forces heated air through the drying paddy rice. Fuel consumption is reported by IRRI to be 0.75 liters gasoline per hour, two liters kerosene per hour and three to four kgs rice hulls per hour. Drying capacity is one tonne in four to six hours. The IRRI model dryer costs about $1000 (1980) though documentation on the number of dryers in use is not available.

The relatively high capital and operating cost of fuel burning dryers have prompted widespread experimentation with solar crop dryers, adaptable to grains and perishables. The solar collector is made of transparent material (glass or plastic) which increases the temperature inside the drying chamber by the greenhouse effect. A 25 to 50 kg crop dryer developed by the UNICEF-sponsored Appropriate Technology Center in Nairobi costs about $3.00 plus local materials and labor but its limited capacity makes it rather impractical for drying very large quantities of grain. Among others, the Brace Research Institute in Canada has done some of the most extensive

documentation and research in this area, however there appear to be no countries or areas in which solar crop dryers are as yet extensively used.

The demand for new drying technologies will increase, especially with the further popularization of shorter growing season grain varieties and as more farmers adopt closed-system grain storage technologies which, for reasons explained above, require lower grain moisture content than traditional unsealed or aerated storage bins. To permit widespread use by average small landholders, dryer designs will require low capital and operating costs and ease of maintenance and operation.

Threshing and Winnowing

Threshing and winnowing processes are usually performed by tedious hand labor. The most simple method of threshing--the process of removing grain from the plant stalk--is accomplished by spreading the heads or plant stalks on a hard packed surface and either beating them with sticks or having draft animals repeatedly trample them. Draft animals may pull heavy rollers or logs behind them to speed the process.

The most basic method of winnowing grains to remove pieces of stalk, leaves and other inedible material typically involves the use of baskets or forked sticks to throw the unseparated, threshed grain into the air where even a light breeze separates the grain from the lighter straw. This method is not successful in removing small stones and other heavy foreign particles, which must be picked out by hand.

Pedal powered, portable rice threshers have been developed in Taiwan and Japan which average 600 to 800 kgs output per day. A team of four to

five individuals is required to operate the thresher for an output 50 to 100 percent greater than non-mechanized threshing. The team of workers takes turns pedaling because the physical exertion demanded by the pedaling can only be sustained by one individual for 20 minutes or less. An additional advantage in the use of this device is that threshing can take place in or near the field minimizing shattering losses during transport from the field, estimated to be between 5 and 10 percent of the harvest (Wu and Esmay, 1975).

IRRI reports June 1980 prices of approximately $2,500 for a 16 hp gasoline engine driven rice thresher, an eight hp model for $1,080, and a five hp model for $700, although output and fuel consumption are not available. Hand powered winnowers rated at 600 to 1000 kgs per hour are available from manufacturers in India, Japan, the United Kingdom and the United States, with prices ranging from $250 to $1,000. They can be adapted to be driven by small engines or pedal power. The cost of importing such manufactured devices would probably be prohibitive except for when used as demonstration models for local research and performance trials. Where these devices prove to be practical and well-received, local manufacture generally would be required to reduce costs within reach of average farmers or farm cooperatives.

Shelling, Hulling and Grinding

The shelling process, typically identified with maize, is usually done after storage, though the restricted volume and higher cost of closed-bin storage and the use of insecticide in storage makes it more practical and economical to shell before storage to reduce the bulk. Shelling may be

done by hand, one cob at a time, or as in parts of West Africa, harvested corn cobs are placed in burlap bags and beaten with sticks to shell the grain. Kernels remaining on the cobs after the beating process are then removed by hand.

An FAO-sponsored storage research and extension project at the International Institute of Tropical Agriculture (IITA) in Nigeria has assessed a variety of hand and motorized shelling devices to compare output and labor costs. Boshoff (1976) reports the following:

Method	Output/kg	
	per hour	per day
simple hand shelling (one person)	7-12	50
beating cobs in sack (two persons)	30-40	200-500
handheld hardwood sheller (TPI) (one person)	15-20	not documented
rotating disk sheller hand cranked (two persons)	180-190	1000
pedal operated (two persons)	190-203	1000
engine driven (two persons)	270-300	2500

The FAO project report calculates that the pedal or hand powered rotating disk sheller (with twin intake for two cobs at once) becomes cost competitive with hand held shellers when 10-11 tonnes are shelled per year. The engine powered sheller becomes more economical than the hand or pedal operated version if at least 20 tonnes are shelled per year. Capital costs

are not evaluated, though labor costs are reported to be in the order of $13.00 per tonne for the handheld shellers, and $5.00 per tonne for the engine driven sheller at a minimum of 30 tonnes per year (costs from 1976).

The handheld hardwood sheller, developed by the Tropical Products Institute in the United Kingdom is suited for local manufacture, though the extent of its use by local farmers is not documented. It is a small two to three cm thick, paddle-like tool with a ribbed hole in the center the size of a corn cob. The ribs strip off the kernels of corn as the cob is pushed and twisted through the hole in the paddle.

Hulling of rice, wheat, millet and sorghum is most simply, though tediously, accomplished by hand pounding in a wooden pestle and mortar. Mechanical rice hullers, however, powered by small engines, have become popular in Asia. Evans and Adler (1979) report Indonesian hand pounded rice hulling output of 40 kg per laborer per day with labor costs $1.45 per 100 kgs. By contrast, they report a mechanized $3,100 rice hulling center rated at 580 kgs per hour which performs the same task for a fee of $.54 per 100 kgs. Rice hulling machines could be adapted to be powered by pedal power, hand cranking, wind or water power.

Most on-farm grinding is performed by women using wooden mortar and pestle, laboring to supply the cooking needs for each day or two at a time. The type of grain and the flour quality desired determine the rate of output. Wealthier families often hire out this tedioius task to poorer, widowed or landless women.

Small hand cranked or motor powered grain mills are manufactured with capacities ranging from two to five kgs per hour. United States manufactured models range from $50 to $250. Small diesel or gasoline engine powered grinding mills with capacities ranging from 200-600 kgs per hour are becoming increasingly common in rural areas of Africa, though documentation is not available on the extent of their use. Minimum capital costs in the range of $1,000 to $1,500 plus diesel or gasoline engine, restrict ownership to established merchants, wealthy farmer-entrepreneurs or cooperatives.

A prototype photovoltaic powered grain mill (and water pump) has been installed by a USAID-financed project in Upper Volta. The mill has a capacity of 136 kgs per hour and uses a 1 hp d.c. motor powered by the array of photovoltaic cells. Its peak power production is reported to be 2.4 hp (Rosenblum, 1980). The capital costs of the installation were about $57,000, though as a prototype it is more costly than if a number of units were to be installed in the same area. Weiss (1976) calculates that start up costs for solar cells and storage batteries generally are three to six times that of diesel or gasoline powered units, with costs varying by location, available solar insolation and power storage requirements.

Wendroff (undated) evaluated a water wheel powered maize grinding mill in Mlowe, Malawi, which was constructed in 1974. The project received a great deal of technical assistance from VITA, among other organizations and was very costly due to a number of factors including poor initial planning and the crisis circumstances during which it was conceived and constructed. Due also in part to its prototype nature, capital costs escalated from an initial $17,500 projected cost to $30,000 final cost.

The Universitiy of Dar es Salaam in Tanzania is presently working to develop hand, animal and tractor powered grinders as well as a wind powered model but details on these endeavors are not available. VITA reports mini-hydro and water wheels are adapted to power grain grinders in Nepal, and locally made wooden water wheel powered grain grinders in Afghanistan, though costs and output are not documented.

Storage and Refrigeration

In developing countries, the storage of grain and dried pulses is a much more practical and far less demanding technological undertaking than the storage of perishables, due principally to the resources required for the cooling, drying or canning of perishables. On-farm storage of grain and dried pulses in developing countries is a low energy user. Filling and emptying storage bins is typically done by hand, using small baskets or sacks. Grain storage bins are commonly made of adobe, thatch or woven branches, though small, locally constructed 1000-1500 kg capacity steel bins are becoming more popular in some countries such as El Salvador and Costa Rica. Cement and ferrocement bins have been tested in a number of African and Asian countries, though farmer acceptance is not widespread. This is in large part due to the high cost and low availability of cement in rural areas.

As chemical insecticides are used more extensively for on-farm grain storage, the indirect energy use for insecticide manufacture and transportation will become more significant on country-wide bases. The U.S. manufacture, packaging, transportation and application of insecticide consumes about 40,000 kcal per pound or the equivalent of about 1.3 gallons of gasoline. Just the production of the simplest and cheapest pesticides such

as DDT requires 11,000 kcal per pound. For more complex pesticides, energy inputs for production range as high as 12,500 kcal per pound or the equivalent of about 0.4 gallons of gasoline (Pimentel, 1976).

In some countries, especially in areas which have had little contact with industrial technology, there is still common use of indigenous organic insect control methods (e.g., roots, bark, leaves, etc.). However, extremely little sophisticated research has been undertaken to study the performance and effect of the various products used. The Tropical Products Institute in the U.K. has recently begun a world-wide survey of indigenous organic insecticidal agents used in developing countries, although much additional research is needed to determine the viability of such products.

As noted above, the storage of perishables (roots, tubers, fruits and vegetables) presents very different technological and resource problems than cereal grain and grain legumes. Because perishables have a high moisture content—from 50 percent upwards—they are expensive and difficult to dry and store as dry product. Moreover, the dried product has a very different taste and texture than the fresh product and it often is less preferred in the local diet.

Perishables bruise easily in handling and transport which makes them much more vulnerable to degradation and loss during storage, even over a few days. Although very few reliable figures are available for losses of perishables, and those that do exist are limited to a specific commodity in one location for a specific set of conditions, the National Academy of Sciences (1978) cites the following figures as being typical of normal ranges of loss experienced under usual conditions:

White potatoes in Chile, Peru and Venezuela	25-30 percent
Cassava in Venezuela, Colombia, Ecuador, Dominican Republic and Central America	15-25 percent
Tomatoes for fresh market in most developing countries	50 percent
Yams in Nigeria and Ghana	10-20 percent

In most developing countries, there has been little interest in trying to reduce these significant perishable losses because of abundant, cheap supplies of the fresh produce. Refrigeration can prolong the storage life of most perishable produce but has serious limitations for reducing food losses in developing country settings. However, particularly at the farm-level, capital, power, and maintenance costs of refrigerated storage are too high for low unit cost fresh produce.

Even if relatively low-cost refrigeration technologies can be developed, assuring a reliable power source will be a key problem area. Methane, solar plates and solar cells are potential renewable energy sources as well as electricity produced by wind and hydro-powered generators. The Asian Institute of Technology has developed a small prototype solar powered refrigerator capable of cooling 3.5 kg of fruit below 15° C in ambient temperature of 37° C. Although the refrigerator uses no other power source, it requires a great deal of watchful attention and labor to orient the solar collector and to adjust insulation of the refrigerator during daily temperature variations. The prototype cost was $730 for materials alone, including such non-local materials as amonia, steel pipe, sheet metal, valves and welding supplies and facilities (Exell, 1978). Even at reduced costs, the refrigerator would be

most economically viable for production and sale of ice in areas where supply is limited, or for the storage of medicine in remote areas.

Carr (1978) describes a low cost, eight cubic foot evaporation refrigerator which has been demonstrated in a number of appropriate technology centers in Africa. It requires two cubic feet of charcoal, renewed every three months, and other local materials, and can be constructed by one person in two days. Water drips slowly through a tray on top of the refrigerator and moistens a three inch layer of charcoal pieces which surrounds the cooling chamber. As the water evaporates, it removes heat from its surroundings, reducing the temperature inside the cooling chamber. No reports are available on its cooling performance or acceptance at the village-level.

In the absence of economically viable refrigeration technologies, farmers are obliged to store produce such as onions, potatoes and yams, which can be kept for up to several months, in shaded structures or covered piles. Losses can be reduced by assuring good insulation and shading from the sun's heat, aeration and regular culling to remove bruised, diseased or rotting produce.

Canning and Related Processing

Efforts to develop rural cottage canning industries in developing countries have met with little success, due to a variety of technical and economic problems, even though this is often suggested as a suitable method for preserving seasonal surpluses of fruits and vegetables that occur in rural areas. In brief, canning is a sophisticated, energy intensive, high cost operation and local markets are difficult to assure for the consequently higher cost canned products.

Canning requires a supply of suitable containers which can be effectively sterilized and sealed with a simple apparatus. Canning jars are breakable and costly, and metal cans, though less costly per unit, require rather sophisticated seaming equipment to seal the cans. Without scrupulous attention to cleanliness throughout the stages of preparation and processing, there is danger of food poisoning or food spoilage.

Worgan (1977), from the University of Reading, in the U.K., stresses the need for close supervision by qualified personnel in rural canning efforts to avoid food contamination and food poisoning. Low acid foods, including meat, fish, vegetables and some fruits are particularly susceptible to contamination by botulism, whose consequences, unlike other types of food poisoning, are often fatal.

Heat processing to avoid such contamination requires at least six hours at 100° C. Above sea level, the boiling point of water is less than 100° C, meaning that at higher altitudes, well over six hours heating in boiling water is required to ensure that the bottled food is safe from contamination. Heating time can be reduced with the use of pressure cookers, but consequently adds to the cost and limits feasibility for village-level application.

Foods of high acidity, such as citrus fruits and tomatoes, prevent the growth of botulism and are safer for canning, though inadequate heat processing or unsuccessful sealing can cause spoilage, and only high quality produce can be used.

The Serowe Food Laboratory in Botswana concluded that canning at the rural level is not recommended for either low or high acid foods due to high capital costs, technical supervision required for quality control, high energy consumption and high packaging costs (Evans, 1980). If canning is to be promoted, it should be preceded by very thorough research and accurate projections established for processing and product costs, market and technical feasibility.

Apparently, no major efforts have been made to encourage other processes such as pickling and fermentation in areas where they have not developed indigenously. However, in Thailand, China and Korea a variety of vegetables are pickled on a small scale. Cucumbers and carrots are pickled in limited quantities, principally for use as condiments, and cabbage is preserved for use during winter months as sauerkraut or kimchi. In India, many fruits and vegetables are preserved as chutney. The National Academy of Sciences 1978 report on postharvest losses notes that expanded application of pickling and fermentation methods for preservation of tropical vegetables is potentially important as an area for research.

Cooking

In developing countries worldwide, the most important cooking fuel is firewood although in areas where it is in limited supply, animal dung and crop residues are relied upon as fuel sources. Charcoal is used for cooking principally in urban areas where transport costs to bring fuel in from the countryside make charcoal more economical than firewood. As trees are cut down near villages, firewood gathering becomes a major demand on labor, and in extreme cases requires one full-time fuel gatherer for each family. Wide-

spread deforestation in developing countries results from such practices and has dire consequences both in ecological and economic terms. Resultant erosion and loss of crop land, changes in rainfall patterns and desertification are problems which will become even more severe if present firewood consumption levels are further increased by the combination of continued population growth and primary reliance on fuelwood for cooking. Firewood is already a scarce and expensive fuel source throughout much of the developing world, especially in sub-Saharan Africa. In Niamey, for example, families already spend 10 percent of their income on fuel for cooking (Walton, 1978).

The cooking fuel problem is being addressed from several directions including the reforestation of fuel-scarce regions, the development and promotion of cookstoves with improved fuel burning efficiency, and the use of alternate cooking fuel sources such as methane. Reforestation and methane production will be discussed later in the section on renewable energy technologies.

Improvements in cookstove fuel burning efficiency depend on three basic variables: the design of the stove, the type and quality of fuel used, and the skill with which the stove fire is tended. Basically, stove design should direct the maximum amount of heat to the cooking pot(s) with the smallest fire possible to get the cooking done. Improving heating efficiency is achieved by: (1) insulating the fire box thus reducing heat dissipation through the stove walls and reflecting it back to the fire and cooking pots; (2) placing the pot so that maximum pot surface is exposed to the fire's heat, but not so close as to reduce the heat of the fire which reduces combustion efficiency; (3) controlling the flow of cold air to the fire through

dampers, baffles and chimneys; (4) burning small pieces of dry wood; (5) removing and extinguishing the fire after cooking is finished and; (6) covering the cooking pot(s).

If the stove is used several times throughout the day, the ideal stove is one that has thick walls which will retain heat and take less time to reach cooking temperatures. If food is typically cooked for a short time or if cooking is done just once or twice a day, stove walls should be thin or of a material that does not absorb much heat.

In the last several years, there has been a proliferation of articles and pilot research efforts attempting to document the fuel burning efficiency of various improved cook stove designs. However, the efficiency ratings vary widely due to a number of factors. Foremost is that testing the stove use under controlled laboratory conditions typically produces very different ratings than stoves tested during actual home use. In addition, varying methodologies are used in stove testing. Unfortunately, it is much more difficult if not impossible to apply accurate, scientific monitoring techniques to in-home cooking without creating a mini-laboratory in the user's kitchen area, which will unpredictably skew the attitudes and behaviors of the user, as well as the efficiency test results. For this reason, in-home stove efficiency ratings are less precise or simply rough estimates.

The Technical University of Eindhoven in the Netherlands has collected a number of reports on stove burning efficiency in an attempt to verify reported data and to determine guidelines and standards for cook stove designs (Prasad, 1980). Exemplary of varying efficiency ratings, the CILSS Report (1978) made field observations of 5 to 8 percent efficiency

for the three-stone open fire. Van Daelen (1978) reports open cooking fires yielding efficiencies ranging from 2.5 to 17 percent. Singer (1959) reports a traditional two-hole wood stove used in Indonesia to have an efficiency of 6.1 to 7.3 percent and a three-hole model, 6.4 to 7.3 percent. Salariya (1978) reported a traditional Indian stove to have 12.3 percent efficiency. The University of Eindhoven study found that efficiencies measured under laboratory conditions were consistently higher than those quoted above, apparently due to the care with which the wood was prepared and sized before burning, and the control which was exercised in stoking the fires.

The attraction and acceptability of any particular cook stove model to be used in the home is influenced by practical and cultural factors, in addition to fuel-burning efficiency—factors which have often been overlooked in the design and promotion of improved cook stoves. Common practical considerations include: the preferred height of the stove, depending on whether cooking is done in a standing, squatting or sitting position; the size, shape and number of pots heated at one time and the variety used throughout the day; firebox adaptabilitiy for various types and sizes of fuel (if wood must be chopped into small pieces, the additional labor required may be impractical for the cook); the preference for heat and smoke venting inside the cooking building to dry grain stored in the rafters or to keep thatched roofs dry and insect-free; the use of the cooking fire for space heating or lighting; and the cost of the stove.

The simplest and cheapest cooking technology is the open fire with three or more rocks placed around it to hold the cooking pot. The advantages of

this technology include its portability, cost, adaptability to pot size and shape and to varying sizes and types of firewood or refuse. Its disadvantages are that the pot loses large amounts of heat by convection, especially if there is a breeze, which additionally dissipates the fire's heat before it reaches the pot, and the danger of accidental burning.

There is a broad range of cookstove designs, though all are essentially variations of the basic Chula stove and Kamodo cooker. The Chula cookstove was developed by the Hyderbad Engineering Research Laboratory in India, where some of the earliest development work on improved cookstoves began. Adapted from traditional Indian fireplaces, the Chula is made from a block of clay with a tunnel running horizontally through it. Holes to fit the cooking vessels are cut through the top of the block through to the tunnel. A chimney of clay or sheet metal is installed at one end and the cooking fire is built at the other end of the tunnel beneath the first cooking pot. Hot gases and flames from the fire flow through the tunnel, under the pots and out the chimney. The Chula is equipped with a damper which provides draft control to regulate the fire. The number of pot holes and the size and height of the stove can be built to the user's preference. If the Chula is used skillfully, it can reduce wood consumption by as much as 40 percent over open fires (VITA, 1980).

The Lorena stove, developed in Guatemala, is essentially a more sophisticated model of the Chula, incorporating a longer baffled fire tunnel which winds through a more massive stove. In principle, these modifications provide for higher temperatures, more complete fuel combustion and retention of heat for cooking and baking after the fire has died out. VITA (1980) claims it can

reduce wood consumption by 25 to 50 percent over open fire cooking if used properly. The Lorena stove is made almost entirely of local materials, principally clay, although assuring the correct clay mixture is critical to avoid heat cracking and to increase durability. Scrap sheet metal is used to make the dampers. The entire construction takes from six hours to several days depending on the size of the stove, drying time and the skill of the builder.

A basic modification to increase the durability of cookstoves is the use of sun dried or fired bricks for construction. The use of fired brick is more expensive but the stove will last much longer than the molded clay models which last about a year. In Asia, portable and stationary stove variations have also been developed to burn sawdust, straw and rice hulls.

The traditional portable Japanese Kamodo earthenware cocker is made with an air space separating the fire box from the outer shell of the stove, reducing heat loss the same way as a thermos bottle. It is made of a rounded, insulating ceramic shell that holds a removable ceramic firebox. A metal grate, the only non-ceramic part, holds the pot above the fire. A hinged ceramic lid allows the stove to be used open or closed for baking, boiling, frying or broiling. Variations on the Kamodo cooker have been demonstrated using a five gallon bucket or sheet metal cylinder as the outer shell, although the extent to which this variation has been adopted in home use is not documented.

More varieties of cookstoves could be detailed here to indicate the range of possibilities currently being proposed as fuel efficient altena-

tives to the open cooking fire. However, that might obscur the more important point that fuel efficient stoves which are developed must pass one overriding evaluation—user acceptance. It is only through in-home trials that new stove models will receive the ultimate test to determine whether users believe there are actual fuel savings and whether the stove design is practical, affordable, or worth getting used to if it requires new skills or procedures to operate effectively.

An effective cookstove promotion program requires careful design adaptation to produce a stove which can be easily constructed from locally available materials and which conforms to the users' requirements including cooking habits and cooking fuels. Well-organized extension efforts are required to train users or local artisans in stove building techniques and to demonstrate to the general population the actual fuel savings benefits in the adoption of an improved stove.

RENEWABLE ENERGY SOURCES ADAPTABLE TO THE POSTHARVEST FOOD SYSTEM

Renewable energy, whatever the form, may be transformed into useable power in a variety of ways. The ultimate design of a renewable energy technology depends on many factors, including:

- the use and amount of power needed;
- whether the machine to be powered is portable;
- the environmental, economic, material and human resources required;
- the availability of suitable maintenance facilities.

In this section, renewable energy technologies potentially adaptable to power postharvest food system processes are assessed with a brief description of the function and possible applications of each energy technology. Discussion includes potential social and economic limitations and constraints for application in developing country situations. Cost and power output data are included as available.

Obvious and generally applicable constraints of any renewable energy technology include the adequate local availability of biomas, sun, wind or water power potential, and the capital and operation costs which are required to convert these energy sources into useable power. Where surveys of renewable energy sources have not been conducted, this must be a first priority. At the same time that the survey is conducted, it is essential to assess the potential uses for available power, and to at least roughly estimate the costs and practicality of developing specific technologies. Unfortunately, many renewable energy technologies have had limited application in developing countries (or little well-documented application) from which to extrapolate potential viability in other situations.

This lack of documented applications makes it difficult to arrive at policy decisions to weigh technology promotion efforts in favor of one technology or group of technologies. More critically, in-field development workers are obliged to rely heavily on expensive trial and error procedures without benefit of referring to a range of specific guidelines or experiences from applications in other areas. Consequently, the data base grows very slowly.

To improve this situation as quickly as possible, further renewable energy technology projects and project evaluation efforts should be encouraged to document project activities thoroughly, including as a minimum of information, the following categories:

-- basic description of the technology and its application,
-- materials required,
-- cost of purchased materials,
-- labor and various specialized skills required,
-- types and costs of special equipment needed to construct and maintain,
-- power output of technology and manner of power utilization,
-- cost and output of powered implements,
-- ownership and management,
-- cultural or social constraints encountered,
-- mechanical and technical problems yet to be resolved.

Fuelwood

It is estimated that 1.5 billion people now depend on firewood and charcoal to meet their daily cooking and heating needs. In the absence of practical and affordable alternatives, this dependence on fuelwood in addition

to industrial uses such as brick firing, is likely to continue for some time to come. However, at current fuelwood consumption rates, it is estimated that tropical forests in developing countries, which cover half of their aggregate land areas, will disappear in 60 years (World Bank, 1979).

The World Bank (1980) estimates that the forests of developing countries are being consumed at an annual rate of 1.3 percent of the total forest area, or about 10 to 15 million hectares per year and that in order to meet the projected fuelwood demands for domestic cooking and heating, about 50 million hectares of fuelwood need to be planted in developing countries by the year 2000. This represents a five-fold increase over average planting rates worldwide and much greater in some areas. For Africa, this represents a 15-fold increase.

To put fuelwood demands in a village-level perspective, a village of 1,000 people would need about 200 tons of fuelwood each year, even assuming current cooking fuel use were cut in half by efficient stoves and cooking methods. To supply this amount of fuelwood, a village woodlot of about 10 hectares would be required, if cut at a sustainable yield of about four tons per hectare per year (Makhijani, 1976). Complete cutting of an existing forest, yielding about 40 tons per hectare. would require 2.5 hectares per year (Goldemberg and Brown, undated). Under favorable conditions, a sustained fuelwood plantation would cost about $200 per hectare and begin yielding 10 tons of fuelwood per hectare per year after 5 to 10 years (World Bank, 1979).

Many early reforestation programs in which the government forest service planted, managed and controlled firewood plantations in fuelwood scarce areas

have had limited success. The most common problem is that firewood is typically considered a free, public good which makes uncontrolled and premature cutting hard to avoid. In fuelwood scarce areas, government or commercial firewood plantations do little to improve the situation for poor families who cannot afford to buy firewood from the plantation, and must still travel long distances to find wood which is freely available, or pilfer from the government plantation.

Even a fast growing tree variety requires 5 to 10 years to reach the size at which it should be harvested. Knowing that someone else will cut a small tree if s/he doesn't, the individual is not inclined to plant and care for his or her own trees or to refrain from chopping down a small tree before it reaches its ideal harvest size. As such, local attitudes and customs concerning the ownership and cutting of firewood must be adapted to (or changed) in each local context to develop reforestation and woodlot management strategies which will not be threatened by uncontrolled, premature cutting and inadequate care and management of tree seedlings.

Recently, community fuelwood programs have been attempted, based on the conclusion that it is essential to involve concerted, cooperative involvement on the part of the local communities. The objective is to develop and sustain a collectively agreed and enforced commitment to plant, protect, and cooperatively manage village-owned woodlots. A key issue in attracting communal participation is in developing agreed upon plans for the distribution of fuelwood harvested from community plots both as an inducement to participate in the labor required, and as a guarantee that each individual's efforts will be equitably rewarded. Participation by

local community members includes active involvement in project planning, land clearing, tree planting, weeding, watering, group regulation of animal grazing, as well as tree harvesting and fuelwood distribution.

One of the most reportedly successful village woodlot schemes began in Korea in 1973, aimed at establishing self-sustaining, village-managed and owned fuelwood plantations throughout the country. State and national forestry institutions provided technical assistance, seedlings, fertilizers and equipment while locally-elected committees, as part of a larger integrated development program, set local priorities and villagers collectively supplied labor. By 1975, the annual planting rate was 40,000 hectares (Cecelski, et al, 1979).

To develop solid community involvement requires active and on-going participation (and local acceptance and trust) of forestry extension agents or community organizers who preferably live and work in the villages. To hire and train the number of agents required to organize widespread woodlot programs demands resources that few developing country governments are able to provide. A 1980 AID-financed study, The Social-Economic Context of Fuelwood Use in Small Rural Communities, observes that "Unfortunately, most national forestry departments are incapable of attracting and coordinating local community participation in fuelwood programs on an extensive scale. Shortages of qualified personnel and an absence of forester training in community-level extension work make it difficult for these departments to identify and address the socio-economic priorities of rural villages."

Such research efforts as the study quoted above have proposed broad, general guidelines for the process of planning and developing community fuelwood programs, at the same time stressing that the actual nature and structure of a program must be worked out in the context of each particular community because of the highly location-specific, socio-economic aspects of fuelwood use in individual rural communities. As a result no set of guidelines or list of issues to be addressed can be universally applicable. The only "formula" for community fuelwood program success appears to be in genuinely and attentively involving local community members and leaders in the identification of and agreement on programs goals; in the determination of the type and extent of community participation and labor; and in devising, complying with and enforcing agreements and regulations designed to protect and sustain the woodlots.

Charcoal

Charcoal is produced primarily for sale in urban areas, and although charcoal production tends to take place at greater distances from rural villages than does firewood gathering, it depletes future fuelwood sources for use in rural areas. Charcoal is produced by carbonizing, or partially burning, wood or other fibrous products such as coconut shells, using very intense heat in an enclosed environment with restricted air flow.

Traditionally, charcoal is made in hand dug pits which are stacked with wood, ignited and covered with earth to retard air flow. This method has very low capital costs, requiring only labor to dig the pit, fill it with wood, and to cover and empty it after the carbonization process is completed several days or weeks later, depending on the quantity of wood in the pit.

An additional advantage of this method is that the pit can be dug to whatever size is needed, and located adjacent to the wood supply. However, this method is inefficient compared to improved methods, producing 8 to 12 percent charcoal from the weight of the wood burned compared to 20 to 25 percent in improved kilns (Wood, et al, 1980).

The amount of charcoal produced per ton of wood depends primarily upon the degree to which the combustion process in the kiln is controlled and the type and moisture content of the wood used. Improved types of more efficient charcoal kilns have been developed which have improved control of air flow and heating during the carbonization process. Most models are stationary, considerably more expensive, and suitable primarily for large-scale charcoal production. The Tropical Products Institute in the U.K. has developed a portable 10 m^3 capacity, steel kiln which has a production output of 20 to 22 percent charcoal by weight. The estimated cost of the portable kiln is $1,000 to $2,500 depending on the quality and importation costs of the steel used (Wood, et al, 1980).

Stationary masonry kilns cost about $1,000 to $2,000, depending on the kiln size and type, and the cost of local materials. The Katugo kiln, for example, is made of masonry with a metal roof, costs about $1,000 and handles about 25 m^3 of wood, yielding about 20 percent charcoal by weight (Wood, et al, 1980).

The advantage of portable kilns, either hand dug pits or the pre-fabricated metal kiln, is that they can be moved to the source of wood as cutting depletes the local wood supply. Stationary kilns require additional costs

to transport wood to the kiln as local sources are increasingly depleted, making them impractical for the small entrepreneur. Given the wood savings achieved by improved kiln technology, government-sponsored credit programs or price subsidization of improved portable kilns may be desirable, especially where small entrepreneurs produce the majority of charcoal and are unable to afford improved kilns.

Solar Cookers and Ovens

One of the most thorough research projects to survey and assess various types of solar cookers was financed by the Al Dir'Iyyah Institute in Geneva, Switzerland. Undertaken by the Georgia Institute of Technology Engineering Experiment Station in Atlanta, Georgia, their findings are included in the project's final technical report entitled A State of the Art Survey of Solar Powered Irrigation Pumps, Solar Cookers, and Wood Burning Stoves For Use in Sub-Sahara Africa, (Walton, et al, 1978). The report summarizes the principal requirements for successfully using solar-powered cooking units in developing countries as follows:

- the unit must cook effectively, providing energy at a sufficient rate and temperature to properly prepare desired quantities and types of food;
- it must be sturdy enough to withstand rough handling, wind and other hazards;
- it must be sociologically acceptable and fit in with local cooking and eating habits;
- it must be made of readily available material by local labor;
- it must be possible for the user to obtain a cooking unit at a sufficiently low cost to realize financial savings by its use.

In principle, solar powered cookers are a very attractive energy technology alternative, particularly in fuelwood scarce areas. One of the simplest solar cookers uses a parabolic or spherical dish-type of concentrator with the cooking pot placed at the focal point of the concentrator. Although a number of laboratories and appropriate technology demonstration centers around the world have experimented with variations of this type of solar cooker, it has apparently never found widespread acceptance at the village level. The most common problems cited for lack of user receptivity are the cost of the solar cooker and that cooking can be done only when the sun is shining and while standing in the hot, midday sun; an uncomfortable requirement, which is additionally impractical if field work is normally done at that time and cooking done early in the morning or in the evening.

One other simple solar cooker design variation is the solar oven or food warmer. The oven or warming chamber is an insulated box with a glass cover which traps heat in the oven by the greenhouse effect. The temperature of the oven can be increased by attaching flat, metalic reflectors which concentrate additional rays on the glass concentrator. The advantages of the solar oven compared to the parabolic concentrator cooker include:

- capability for baking or roasting;
- fewer required adjustments to repeatedly focus and orient the collector;
- cooking vessels are protected from the wind;
- several pots or pans can be used at the same time;
- heat can be stored, permitting the preparation of food in partly cloudy weather;

-- food can be kept warm after sunset.

No documentation is available on the extent to which solar ovens have been adopted for home use.

To overcome the limitations of the relatively simple solar cookers which require midday cooking, solar cookers have been proposed which have heat storage systems. All proposed heat storage systems however, involve considerable expense and complexity. One of the most practical heat storage systems proposed requires about 140 liters of vegetable oil as the heat transfer medium, circulating in pipes from the stove and through an insulated tank filled with rocks--the heat storage medium. No prototype or demonstration models have reportedly been built, although the system cost (including the 140 liters of oil, the insulated tank and metal pipes to connect the cooker with the heat storage tank) would certainly be out of reach of the average family.

For most parabolic cookers, maximum cooking capacity is two to four kgs. Depending on the design of the solar cooker, the required heating time to bring one liter of water from room temperature to the boiling point varies from 15 minutes in rigid paraboloid cookers to 30 minutes in a solar oven. By contrast, the normal heating time on a simple wood fire is about five to ten minutes (Walton, et al, 1978).

Manufacturing costs vary from $16 to $30 for parabolic cookers and about $35 for a focusing-oven cooker (Walton, et al, 1978). By contrast, an AID-financed report, Renewable Energy in Egypt, Analysis of Options (1980), estimates that locally manufactured solar cookers (of unspecified design)

would cost from $84 to $196 per unit, including imported materials. Solar cookers with heat storage capacity are still in prototype stage, and although prices are not known, they will almost certainly be too expensive and complex for village use.

No solar cooker design appears to be ideally suited for local manufacture. All types require at least some components or materials either imported from industrialized countries or manufactured internally. The focusing types involve metallized plastic films, molded plastic reflector shells and shaped metal components. Ovens require glass or plastic films, polished aluminum and desirably, sheet metal for the oven box. However, solar cooking units could be assembled in small industrial establishments, using some imported parts, local labor and various local materials.

Solar Crop Dryers

Simple open air drying is the oldest and most common form of crop drying in the world. Thin layers of harvested crop are spread on the ground, exposed to the sun and breeze. When drying produce is placed in racks or trays, affording better controlled exposure to solar radiation and wind, the result is reduced handling and increased product quality.

In recent years, "solar drying" has also come to refer to a process in which the crop is placed in solar-heated, enclosed containers. The collector is a clear sheet of glass or plastic, although the drying chamber can be made of a variety of local materials such as wood or adobe.

Thin polyethelene sheeting is most often used as the collector in solar crop dryers for use in developing countries. Glass could be used but it is

more expensive and breakage problems make it even more impractical. However, polyethelene also has disadvantages. Thin polyethelene is easily punctured or torn and even heavy gauge polyethelene becomes brittle and more susceptable to puncturing and tearing after several months' exposure to the sun's heat and ultra-violet rays. A UNICEF-financed appropriate technology demonstration center in Nairobi found that 250 gauge polyethelene lasted about six months before brittleness occurred (personal communications). The cost of sheeting for small solar dryers will vary according to location and availability, although it should fall in the range of $2 to $5. Where solar dryers are promoted, the supply of polyethelene sheeting would likely have to be assured by the project, as few rural areas have regular supplies available.

The effectiveness of solar dryers depends primarily on prevailing weather conditions and the quantity and moisture content of the crop to be dried. The UNICEF model dryer can handle about 25 to 50 kgs per batch depending on the moisture of the produce. In Nairobi, six to eight hours of strong sunshine is reportedly sufficient to dry most products to 12 percent moisture, although high moisture products are dried in smaller batches (personal communications).

Because of seasonal, short-term use, crop dryers are best designed so that a variety of crops, maturing at different times, can be dried in sequence over a long period of time. Even so, the limited annual use of a solar dryer will require it to be low in cost so that the investment can be recuperated in a relatively short time.

Future work in developing and promoting solar dryers should emphasize the use of local construction materials and include detailed documentation of dryer costs and performance in actual on-farm use. Dryer performance should be contrasted with that of simple open air drying (or the prevailing technology) with particular attention given to user reactions to the convenience (or lack of) in using the new dryers.

Photovoltaics

Major advances in ultra-modern technology may in the next five to ten years make photovoltaic (PV) cells, which convert solar energy into electricity, economically feasible for powering some mechanical processes in rural areas of developing countries. PV cell cost has declined considerably since the first major use in space exploration technology due to improvements in design, manufacturing technology and mass production. Early Mariner spacecraft PV arrays cost several million dollars per kilowatt (NAS, 1976) compared to today's cost of about $2,000 per kilowatt (World Bank, 1980).

PV power system costs are commonly divided into costs associated with the actual photovoltaic module and what is termed BOS (balance-of-system). BOS costs include the module frame and support structure, electrical wiring and control circuits, storage batteries, system design and inspection. Department of Energy module cost projections in 1978 dollars are as follows: $9.00 per Wp in 1979, $5.00 per Wp in 1980, $2.45 per Wp in 1981, and $.61 per Wp in 1986. (Wp or peak watt is the maximim power produced during full solar exposure). Optimistic projections for cost reductions in PV cells must be tempered with the fact that BOS costs, which are not expected to drop

significantly, are a large part of setting up a PV system. Rosenblum, et al (1979) assess BOS costs in a variety of developing country applications to be in the range of 46 to 47 percent of total installed system costs.

Even though the long range costs of PV systems may be competitive with diesel or gasoline power sources due to low PV maintenance costs and zero fuel costs, the initial start up costs for small scale applicators are estimated to be three to six times greater than for gasoline generators. (Weiss and Pak, 1976). An AID-financed prototype PV power project in the village of Tangaye, Upper Volta required some $57,000 in capital cost for a 1.8 kWp PV system to power a small grain grinder and water pump. The Project Paper initially estimated that a diesel powered mill would have cost less than $5,000.

Smith (1979) calculated a breakeven cost of $1.49 per Wp (the 1983 price projection) for installed PV arrays including BOS costs, compared to the installation, fuel ($.50 per liter) and maintenance costs of a five hp diesel engine suitable to run a typical village rice huller or grain grinder. In his calculations, the PV system is projected to have a life of 10 to 12 years and the diesel engine 8 years. However, the actual power output and breakeven costs of PV and diesel systems is variable, depending on the cost of the diesel fuel, maintenance requirements and on the number of hours either system is used each year. As well, the cost of electricity from PV systems is complicated to estimate in advance for any specific location due to regional and seasonal variations in solar insolation, differences in storage requirements and uncertainties in the actual lifetime of PV cells and of storage batteries.

PV power sources, which have been used to power a variety of devices, such as educational television units and telecommunications relays, could be adapted to power virtually any postharvest device which can be driven by an electric motor. However, given the high capital costs, their application will be restricted to heavily donor-supported projects. When these are undertaken, site specific cost analyses over the life of the PV system will be very useful to establish cost data in different settings and to more clearly determine cost comparisons with other sources such as diesel, gasoline, wind or hydro-powered generators.

Animal Draft

The use of animal draft has to date received limited support in development programs worldwide. Typically, the use of small tractors has been encouraged instead, often with little success, due largely to the high capital costs and problems of inadequate spare parts supply and inadequate maintenance.

The use of draft animals is generally restricted to areas where there is a year round supply of forage for the animals and where animal disease is not a major problem. Where year round supply of forage is a problem, the use of ensilage pit storage may be effective. However, alleviating tick and tse-tse-borne diseases has been particularly problematic in tropical and subtropical Africa. A major AID-supported research effort is underway at the International Laboratory in Animal Diseases (ILRAD) in Kenya.

Where animal draft has been successfully introduced, in Benin, Togo and Senegal for example, a major initial application has been in local transport,

both for the owner's field-to-home and home-to-market transport as well as rental to neighboring farmers for the same purpose. There is no detailed reporting of projects to adapt or promote animal draft to power postharvest processes such as threshers or grinders (as was commonly done in pre-industrial U.S.) although VITA reports that the University of Dar el Salaam in Tanzania is beginning a research program to develop animal powered grain mills and threshers. The Peace Corps is presently preparing a manual on the introduction and use of animal draft which will address issues of cultivation and transport implement design and construction, in addition to animal health, feeding and training. Where animal traction promotion programs are undertaken, project plans should include feasibility studies for the design and adaptation of such animal draft powered implements as threshers, grinders and hullers.

Pedal Power

Pedal power is widely used as a power source for small transport throughout the world. However, little research has been done to harness its potential as a direct source of energy to power stationary mechanical devices such as grinders or hullers which require more power over a longer duration than is practical for hand-cranking.

McCullough (1977) estimates a 300 percent increase in the output of a small pedal powered grinder compared to the same hand-cranked model, finding that a pedal powered grinder could process five pounds of wheat in 20 minutes while hand grinding the same amount took one hour. Weir (1979) found that a man can produce four times more power by pedaling than by hand-cranking, however the duration is limited due to the strenuousness of the exertion

required. For example, a man can pedal for ten minutes producing 1/4 hp where only 1/8 hp can be maintained pedaling for an hour.

Weir has developed designs (available through VITA) for a portable, one or two person pedal power unit which is suitable for local manufacture using a bicycle sprocket wheel, chain and seat mounted on a wooden frame. He estimates a cost of about $40 for local manufacture. Although no documentation is available on the extent of its use at the village level, it is purported to be adaptable to a variety of small mechanical devices such as winnowers, cassava graters, coffee pulpers, grain threshers and hullers. Wu and Esmay (1975) report that locally made Taiwanese pedal powered threshers process 600 to 800 kg per day, which is 50 to 100 percent more than the hand threshing output of the four or five people required to operate the pedal thresher. The Taiwanese model costs about $24 (1972) and in 1966 there were nearly 200,000 in use.

Pedal power units which can be adapted to a variety of mechanical devices have the advantage of being able to recuperate capital costs more quickly than units which are built as part of a single device such as a thresher, which is used only seasonally. However, each kind of equipment may have different r.p.m. ratings which necessitates a variable transmission system for an adaptable power unit, adding to the expertise needed to design, build and operate the unit. Research on a local basis to determine the feasibility of pedal power adaptation to (potentially) available mechanical implements could include design modifications to make the power unit adaptable to the most common and economically viable power needs in order to retain but limit unit adaptability and reduce construction cost.

Wind Power

The wind has been recognized for thousands of years as a very useful energy source. In early Persia, windmills were used to grind grain, while the Chinese employed vertical axis mills to pump brine. The Crusaders returning to Europe in the 13th century, brought with them knowledge of Middle Eastern windmills which had been used extensively there for more than 200 years (Lumsdaine, 1980). More recently, windmills were used to generate electricity in rural areas of the U.S., prior to the grid-based Rural Electrification Program. Some 500,000 wind-electric systems are known to have been built, but most fell into disuse as fossil fuel derived electricity became cheaper (Battelle, 1977). During the years between 1950 and 1970, industrialized countries largely abandoned wind power as an economically competitive form of energy.

Today, with increased petroleum prices, windmills are becoming more economically attractive. Windmills for mechanical applications are, though still scarce, becoming more widespread in developing countries, while industrialized countries have begun to return to windmills for generating electricity--a more adaptable and transportable energy state, although more complex and expensive to produce.

Wyatt (1981) has summarized the developments in windpower in African countries noting a number of on-going projects, primarily wind-mechanical pumping systems. Among these countries, Cape Verde, Kenya, Tanzania, and South Africa manufacture windmills--with South African production the highest. A variety of designs are being experimented with, such as the Cretan sailmill, the Dempster-like multi-blade fan mill, and the VITA Arusha.

Asia has long used low-head water pumpers utilizing a lifting chain connected to canvas covered blades (or impellers) by a variety of possible drives and usually oriented on a vertical axis. In Asia at present, China, India and Thailand appear to be the greatest users of technologically simple windmills.

In Latin America, documented windmill use is sketchy. Costa Rica has conducted a number of activities such as holding a 'Sun Day' and solar workshops where wind power was given some attention. A good survey by Lumsdaine (1980) of existing windmill systems, and future windmill and component developments was presented at a workshop sponsored by the Costa Rican National Council for Research and Technology and the U.S. Academy of Sciences. Wyatt also is reported to have begun a survey of wind power developments in Latin America.

The amount of energy which can be transformed from wind into useable energy depends essentially on the efficiency and size of the windmill and on wind speed. The amount of energy that can be theoretically captured or extracted from the wind by the most efficient windmill imaginable is 59.3 percent (Lumsdaine, 1980). This, in effect, means that no additional energy can be extracted without causing the air to lose its motion, whereupon the windmill blades would stop turning. However this is the theoretical maximum energy extractable in a frictionless environment. The actual amount a mill can extract is considerably less. The windmill designs which come closest to this maximum are modern, high speed propellors with minimal drag, and even these only capture 46 percent of the total energy. More commonly expected

amounts are between 10 and 40 percent (Hackleman, 1974 and Lumsdaine, (1980). Windmill efficiencies may also be expressed as a percentage of the theoretical maximum energy available. That is to say, a mill capturing 30 percent of the total wind energy blowing across its blades is approximately 52 percent efficient with respect to the amount of energy that is theoretically possible to extract.

The size (or area swept by the rotor or blades) of a windmill is another factor determining the potential energy which can be extracted from the wind. An increase in the length of a rotor is expressed as an area of units squared ($A=\pi r^2$). This means that if for example, the radius of a propellor is doubled, its swept area quadruples. Logically though, stresses imposed by the greater mass of the lengthened rotor and the costs of strengthening support structures limit the maximum feasible size of the propellor for most small wind power applications.

The velocity of the wind is the single most important factor to determine how much power can be produced by a windmill. It is particularly important to note that the power produced by a windmill, expressed in watts or horsepower, is proportional to the cube of the velocity of the wind (Lumsdaine, 1980). This means that a 20mph wind can produce eight times more energy than a 10mph wind.

High energy winds (12-25mph), while less frequent than prevalent winds (5-12mph) can provide 75 percent of the available wind energy even though blowing only 25 percent of the time (Hackleman, 1974). This is so because wind energy is arrived at by taking the cubes of all the various wind speeds

which have occurred during the day: $(A^3+B^3+C^3) = V^3$. It is not correctly expressed as the cube of the average daily velocity: $V^3 \neq (A+B+C)^3$. This seemingly minor point can result in a difference of 150 percent more available wind energy if the measurements intervals are shortened to, for example, hours rather than given as a daily average (Hackleman, 1974). This underscores the need for rather sophisticated measurement of the daily distribution of wind speeds, especially high energy winds, in determining the feasibility of windmills at any given site. However, data on average daily wind speeds, which may be more readily available, can be useful in initially identifying potential wind power sites which have the minimum power requirements for a specific application.

Average wind speed data may be roughly determined with inexpensive equipment such as the hand held Dwyer wind meter ($7 to $30). However, frequency distribution requires more elaborate equipment, and if automatically recorded data is needed, a complete metering station can cost $750 or more (VITA staff). Existing meteorological summaries such as the N-summary and the World Wide Airfield Survey, compiled by the National Oceanic and Atmospheric Administration (NOAA) could be used to provide baseline data for the initial identification of countries with the greatest wind power potential.

The relationship beteen these three important factors--mill efficiency, wind velocity and swept area--to the power output can be summarized in the following equation as:

$$P_{output} = 1/2 \quad \rho . E . A . V.^3$$

where

ρ = air density of 1.21 kg/m^3 — assumed to be constant for simplicity.

E = the calculated percentage of the theoretical maximum.

A = the swept area in m^2.

V = the wind velocity in m/sec or mph.

P = power in watts or horsepower, at the blades (Soderholm, 1974 and Hackleman, 1974).

This 'P' is the gross power produced by a windmill athough the net available to run motors or mechanical devices may be substantially less due to conversion and transmission losses.

Windmills may be divided into two broad classes based on the orientation of the axis, either vertical or horizontal, about which the rotor spins. These two classes are generally subdivided, in turn, by the application to which they are put, i.e., the generation of mechanical or electrical power.

Vertical axis windmills are generally lower in cost and relatively simple to construct when compared to horizontally oriented mills. The disadvantages of the vertical axis types (such as the Savonius mill, made from a split oil drum) are low efficiencies and lack of effective speed governors for protection in high winds. The low efficiencies of the Savonius are due to the fact that its blades revolve relatively slowly in relation to the speed of the wind and the heavy blades of this vertical axis mill produce large amounts of drag when facing edge-on or rearward in relation to wind direction.

The Savonius or a similar design may be suitable where light to moderate winds are prevalent and the power applications are, for example, low head pumping. Areas of directionally variable winds could benefit from a vertical design as it can be powered by wind from any direction and need not turn to face the wind as is the case for horizontal axis mills.

Horizontal axis mills generally produce greater amounts of power than equivalent sized vertical machines because the horizontal mill points the entire frontal area of the rotor into the wind, in contrast to the vertical mill which always has part of the rotor producing drag rather than power (Park, 1975). The varieties of this type of mill being experimented with are numerous but the main characteristics can be summarized in three examples: the Cretan sail, the multi-blade fan and the modern two-and three- bladed propellor.

The Cretan sail is a rather simple, low cost mill, which can be locally constructed of wood or bamboo and sail cloth. It produces the high torque at low speeds suitable for mechanical applications. Although no cost information is available, one such application is being tested for grinding grain by the Faculty of the Agricultural College of Morogoro, Tanzania (Wyatt, 1981). A disadvantage of the Cretan sail is that due to its large mass, it is not well suited to respond quickly to changing wind directions and so should be considered for areas where winds blow generally from the same direction. Controls are relatively simple but not automatic--hand reefing of the canvas sails is called for in gale winds.

The widely used multi-blade fan design was developed in the USA in 1854 and has been mass produced, exported, and copied around the world. Although it may not be as efficient as the propellor driven mill, the multi-blade fan is rugged and well designed for water pumping. Any such mills used in developing countries should incorporate an automatic governing system that causes the blades to face edge-on into gale winds and prevent overspeeding.

The common fan mill employs a crank or eccentric wheel to transfer power from the horizontal axis towards the ground. Unless this crank or eccentric wheel is replaced with a more 'even' power transfer, it is not recommended that mechanical devices be powered other than the water pumps for which it was designed. Such devices as grinders can apply stresses on the shaft, rotor and crank causing mill failure (VITA recommendation).

Except for water pumping, little recent work has been done to adapt mills to the wide variety of tasks encountered in the postharvest food system which require simple mechanical power. A technologically simple, multi-purpose mill needs to be developed that would effectively combine water pumping with grain grinding and threshing or any activity not necessarily requiring constant speed regulation.

Wind-electric systems with aerodynamic high-speed propellors have received attention mostly in industrialized countries. Developing countries have had little reported experience with this technology, in large part because wind electric systems are considerably more costly and complex than mechanical mills. In the future however, many rural tasks could be powered

by wind generated electricity. Where feasible and economically viable, wind-electric systems could provide necessary power to remote hospitals, drive electric motors attached to refrigeration units or grain grinders, or provide light to villages.

Storage of sufficient amounts of electrical energy for periods of little or no winds can add significantly to the cost of wind-electric systems. Lead-acid batteries are still the most commonly used storage medium, however research is progressing on a number of alternative systems, such as hydrogen fuel cells, fly wheels, and pumped water storage. At the present time, no reasonable alternative exists to the lead acid battery for the small wind-electric system. The most practical batteries are 6 volt, 3 celled truck or electric industrial vehicle batteries which are better than regular automobile batteries as they are less likely to be damaged if completely drained during low wind or calm periods.

Accurate local data on wind speed distribution, including the frequency of calm periods which determines the needed power storage capacity, is particularly important to match windmill to generator and storage capacity. The expected load (in kilowatt hours) is caculated from the number of appliances or motors that are intended to be employed. Then by matching the manufacturers' suggested operational wind speed and power output to actual wind speed, the appropriate size windmill, generator and storage capacity can be determined.

It is difficult to make general statements about the economic feasibility of either mechanical or electrical wind power sytems. Wind

data, installed equipment cost, maintenance requirements and power requirements as well as the cost of purchase, operation and maintenance of alternative equipment (such as a diesel powered grain grinder) must be considered, and vary according to location. Such existing cost data on wind power systems are limited to comparisons of diesel and windmill systems for water pumping and electrical generation, with no known reports documenting windmill-mechanical and alternatively powered grain grinders, for example.

The World Bank (1980) cites capital costs of commercial wind-electric generators at $5,000 to $15,000 per kilowatt installed, including storage batteries, compared to $800 per kilowatt for small diesel powered generators. The higher capital costs of wind systems may be offset in the long run, however, because fuel costs are zero.

Pak (1974) presents an interesting comparison of various wind-electric and diesel generator systems. Although somewhat dated, the study indicates that where there is adequate wind speed, wind-electric generators begin to be competitive with diesel generators at investment interest rates of 8 percent or less and delivered diesel fuel costs of more than $.60 per gallon. With delivered fuel prices of well over $2.00 per gallon increasingly common in remote inland locations, wind generators may be competitive with diesel generators, even at interest rates as high as 15 percent.

It is important to note that Pak's cost projections are based on an assumed 15 year life of the windmill and 10 years for the storage batteries. However, in several African countries, for example, the useful life of imported windmills has been very poor due largely to problems in the supply

of spare parts and inadequate maintenance skills. If imported commercial wind-electric generators are to be encouraged, every effort should be made to assure adequate maintenance training and spare parts supply.

Windmill costs will vary considerably if they are imported models or constructed locally, and costs of locally made windmills will depend on the design and the availability of local materials. VITA, for example, offers plans for a wind-electric mill which is made from scrap automobile parts, including a rear axle, voltage regulator and generator or alternator. Depending on modifications and windspeed, the unit will produce from 500 watts to 3kW.

Although the cost of most wind-mechanical and wind-electric systems are likely to be beyond the means of individual farmers or small farmer-cooperatives, there may be a variety of promising postharvest applications for windmills, particularly in supplying the power needs of such activities as grain grinding and refrigeration. Given high capital costs, appropriate credit programs will need to be developed to encourage windmill use.

In many cases the collection of reliable wind speed data, on a national level, may be a critical first step in initiating wind power programs. In some cases, this will require the installation of new meteorological equipment and the training of personnel in data collection and assessment. Where feasible wind power sites are identified, windmill trial and demonstration units adapted to local power demands should be installed to assess economic and practical viability, with particular emphasis placed on designs suited to local manufacture.

Hydro Power

Hydro power in the Third World has been largely under utilized, both for the generation of mechanical power and electricity. In fact, developing countries have more than 70 percent of the world's major hydro-electric potential although they have only 24 percent of the installed generating capacity (Howe, 1980). Long recognized in industrialized countries as an economical and reliable power source, hydro power application has lagged in developing countries, due in part to the enormous capital costs demanded for large dams and civil works for major hydro-electric installations and to limited donor organization support for small scale applications such as water wheels and mini-hydro (turbines).

Power generation by the use of moving water is by no means a new technology. Extracting power from a certain quantity of water (flow), falling a certain vertical distance (head), by striking and moving a wheel is a technique that has been known for centuries. The vertical water wheel dates back to 1st century B.C. Rome, with variations which slowly evolved over the centuries into three commonly known water wheel designs: the undershot, breast and overshot wheels.

The overshot wheel is probably the most commonly used water wheel design due to its typically higher efficiency and power output. Falling water, with a head usually of 6 to 8 feet or more is supplied to the wheel via a shute or flume. As the water wheel's buckets are filled with water, they are pushed downward, turning the wheel and producing power through the wheel's axle.

Sturdy and reliable, water wheels were one of the means of grinding grain and running some of the first machinery of the Industrial Revolution. The water wheel with its slow rotational speed (5 to 30 rpm) was suitable for powering simple machines and mills which did not require strict speed regulation. Although the power which can be derived from a water wheel depends on site-specific factors such as flow, head and wheel size and efficiency, for illustrative purposes, an average size overshot wheel with a 16 ft. (4.8m) diameter, with an average efficiency of 60 percent should produce at least 10 hp under moderate flow and head conditions (VITA, 1980 and Ovens, 1975).

Modern use of the water wheel in developing countries has been limited and poorly documented, with no known, major development efforts to encourage its use. One documented water wheel development project in Mlowe, Malawi met with mixed results. Initiated in 1974 by a missionary doctor, the water wheel project was a response to villagers' needs for grain grinding when maize was newly introduced into the area as a replacement for the disease devastated cassava crop. Although originally projected to cost $17,500, due to the crisis circumstances and initial poor planning,the wheel project finally totalled $30,000 (Wendroff, undated). Generous technical assistance was provided by the Canadian University Service Overseas (CUSO), Oxfam of England, and by VITA. Under more favorable circumstances, water wheel costs should be considerably lower. There are reports of locally made, wooden water wheels employed for grain grinding in Nepal and Afghanistan, although costs are not documented (VITA staff). An advantage of water wheels is that they can be constructed locally using wood as the primary construction

material. Depending on the site, necessary water diversion structures may be relatively simple and low cost, particularly if constructed with self-help labor and local materials such as earth, stone, or wood. Ovens (1975) offers a basic guide to water wheel design and construction.

Water wheels, while relatively simple to contruct and operate, are limited to the production of mechanical power which is transmitted over very short distances. The powering of machinery can be accomplished relatively easily by employing used automobile drive shafts and the attached universal joints for power transmission. Various postharvest devices such as hullers, shellers, or grain grinders may be powered by a water wheel (Ovens, 1975).

As a practical measure, electrical generators, owing to the high speed requirements (1500 rpm) cannot be powered by water wheels since the step-up gearing that would be necessary is costly and cumbersome. It was this slow speed limitation and the demand for electricity which, in industrializing countries, prompted the design evolution of the water turbine from the water wheel.

The cross-flow turbine, commonly known as the Michell/Banki turbine, is one of the most promising turbine designs for use in developing countries. The cross-flow turbine's moving part is a spinning cylindrical drum of 'Venetian blind' blades moved once by the water rushing in, and then again by the water's exit The Michell/Banki turbine, by design, accepts a wide variation in flow and is simple to manufacture (McPhee, 1981 and Haimerl, 1960). Because of its simplicity, the cross-flow turbine is most applicable to manufacture in developing countries. Simple variations in the width of

the cylindrical drum and the nozzel through which water enters, determine the output of the turbine. No other turbine design can be manufactured so readily for a variety of possible water flows. Since little else needs to be changed for differing water discharge rates, considerable costs can be saved by stocking identical parts for different sized turbines (Breslin, 1979 and Meier, 1978).

Recently, mini-hydro has been the subject of renewed interest in industrialized countries where this renewable energy source has again become competitive with fossil fuel derived electricity. In the United States, this has come about due to the combination of fuel price increases, and the recently passed National Energy Act of 1978 which mandated that utilities must accept power from private dams and pay fair prices. These developments led to a veritable rush to renew and repair old sites that had fallen into neglect, particularly in the Northeast (McPhee, 1981).

Increased interest in mini-hydro in industrialized countries has helped spur interest in its application in developing countries. To date, however, with the exception of China, the actual construction and installation of large numbers of units has not yet taken place. China is reported to have built 60,000 mini-hydro units of 50kW or less since 1958 (ITDG, 1979).

A small program has gotten underway in Nepal with assistance from development groups such as the Swiss Association for Technical Assistance (SATA) and the Intermediate Technology Group (ITDG). More than 30 turbines generating 10 to 15 kW each are mechanically powering milling operations there, and three small Nepalese companies have begun producing a version of the

Michell/Banki cross flow turbine for low power tasks. Six village electrification plants, having capacities of 20 to 50kW, are presently in various stages of construction and are also believed to employ cross flow turbines (ITDG, 1979).

Tanzania is reported to have 14 small scale plants, either in operation or under construction, with generating capacities of 5 to 180kW. These plants, built primarily to service the needs of various church missions, have estimated life expectancies of 30 to 40 years (Kadete and Reichel, 1978). If these mini-hydro plants can actually be maintained for that long, there should be strong economic competitiveness of small scale hydro in comparison to electricity produced by burning fossil fuels.

From the variety of commercially available turbine designs for small power applications, axial flow propellor turbines are generally best suited to low heads (1-3m). Francis and Michell/Banki turbines are suggested for medium heads (3-20m), and the Pelton impulse types are better adapted to high heads (20m and above). The Michell/Banki appears to be best suited for its adaptability to large fluctuation in flow; the Pelton to low flow and high pressure; and the propelor turbine to low heads and low to moderate flows (VITA, 1980; Breslin, 1979; and McPhee, 1981).

Properly evaluating and selecting a plant site is extremely important to the success of any hydro power project. This involves assessment of a number of factors. The potential power that can be derived from the stream or river, dependent upon the minimum and maximum flow throughout the year and the available head, will determine the proper size of the waterwheel or

turbine and generator. The flow and the geology and topography of the stream banks define the required civil works, including the necessity and size of the dam and the penstock length. Soil and water conditions are important factors in potential maintenance problems (e.g., a high silt content in the water can wear turbine blades.)

Performing site selection does not necessarily require highly trained specialists. ITDG (1979) points out that teams of local technicians could be trained in evaluation and siting, thus avoiding the dependence on foreign experts. This London-based, technical assistance development group has had extensive involvement in mini-hydro technology for developing countries and offers training and technical assistance capabilities for site surveys, plant design and installation, with the principal objective being to establish local manufacturing and installation capacity.

The projected costs of mini-hydro plants are difficult to express, except within a fairly wide range, due to a variety of factors encountered. Some of this is due to the paucity of data provided concerning the various assumptions used by different authors in determining and reporting costs. Other uncertainties are present simply because an average system is very difficult to portray with factors such as individual site topography, necessary civil works, local labor costs, and flow history of a stream or river all highly variable.

World Bank (1980) estimates installed costs of low head, mini-hydro to be $3,500 per installed kilowatt at a power cost of 12.7¢ per kilowatt-hour, compared to small inland diesel generator installed costs of $800 per

kilowatt at a power cost of 13.2¢ per kilowatt-hour. Reports of ITDG (1979) and Meier (1978) indicate that installation costs may be somewhat lower, based on mini-hydro plants operating and under construction in Nepal.

Meier (1978) cites the total cost of 10 to 15kW mini-hydro plants supplying direct mechanical power for three grain milling machines (including head works, power house and milling machinery) at $400 to $1,000 per kilowatt. Also cited are costs for 20 to 50 kW electrical generation plants at $1,000 to $2,000 per kilowatt including the cost of all equipment and construction works, although excluding transmission costs. ITDG (1979) estimates a cost of $66,000 for a 40kW electrical generation plant, or $1,650 per kilowatt including transmission costs, based on reported costs at six existing or planned Nepalese mini-hydro sites Cost breakdowns are as follows:

Civil works	24.0%
Generating Equipment	27.4
Transmission	36.5
Other	8.2
Transport	3.9
	100.0%

ITDG (1979) estimates that at a load factor of 30 percent, Nepalese mini-hydro kilowatt-hour production costs are equal to the fuel costs of equivalent sized diesel generators, even excluding diesel generator maintenance cost. The ITDG study concludes that even though the data cited is specific to Nepal, it is reasonable to expect that similar results will be

found at sites in other countries where the choice of technology for rural electrification is to be made between mini-hydro and diesel-electric systems.

To encourage hydro power exploitation on a national level, most countries need first to conduct surveys to identify potential hydro power sites, both to locate sites where there is feasible hydro power potential and where there is present or future potential demand for mechanical or electrical power. The ownership of land in potential hydropower sites and any projected displacement of cultivated land or habitations due to constructiontion or damming are very important local issues which must be thoroughly investigated to assure local support for any hydro-power iniatives.

Due to high capital costs of mini-hydro, the provision of credit will be necessary and the terms of financing schemes will be crucial to the success of any hydro power project. Emphasis should be placed on training local technicians in identification and evaluation of potential hydro power sites, plant design, construction and maintenance. Wherever possible, local manufacture of turbines should be encouraged, although imported turbines and equipment may be necesary at the outset of national programs.

Biogas

The production of methane (commonly referred to a biogas) by the anaerobic fermentation of animal dung, crop residues and human waste is a renewable energy technology which has been used extensively in China, India, Taiwan and Korea, with limited experiences in many other developing countries. Methane can be used as a fuel source for cooking, lighting, or heating. It can also be used as a fuel for stationary internal combustion engines to

power grain grinders, hullers, electrical generators, etc. The use of methane to fuel transportation vehicles requires gas pressurizing equipment which is generally too costly and complex an undertaking for small biogas plants in rural areas of developing countries.

In addition to the production of methane fuel, the anaerobic fermentation process produces a residue that retains its near-original nitrogen content which can be used as an excellent fertilizer. Further, the heat produced during anaerobic fermentation of animal and human wastes destroys or greatly reduces pathogens in the digested material, effectively minimizing public health hazards associated with handling and disposal of animal and human wastes. Although anaerobic fermentation is not uniformly effective in destroying pathogens in waste, it is one of the most practical methods known to reduce fecal-borne disease in developing countries (NAS, 1977).

There is considerable variation in the estimated quantity of different fermentable feedstocks needed to produce a given volume of methane. Variations depend on the digester system efficiency, environmental conditions and on the type and quality of manure or plant material used as fermentation feedstock. For example, the number of cows or pigs needed to supply sufficient dung for a given digester to produce a specific methane output varies with the diet and health of the animals, as this influences the quality and quantity of dung produced. Generally however, the manure supplied daily from four to six cows will produce sufficient methane for the cooking needs of a four or five member family, or about 0.34 to 0.42m^3 of gas daily per person (NAS, 1977).

There are two basic types of small scale digesters practical for use in rural areas of developing countries. One, the continuous feeding type

digester, requires the addition of feedstock and the removal of an equal amount of residue on a daily basis. The second type is the batch digester which is filled with feedstock and sealed until the methane production has leveled off, at which time it must be completely emptied of residue and refilled to begin the process again. The batch type digester is adapted to areas where fermentation feedstock supplies are periodic, such as where the principal materials available are seasonal crop residues. However, because it requires a high, periodic demand for arduous labor to empty and fill the digester each time the fermentation process is completed, it is generally not as practical as the continuous feeding digester.

Simple continuous feeding digesters typically have three parts: the slurry mixing chamber, which feeds into the enclosed digester, and the slurry evacuation chamber. Digester design can be adapted to locally available construction materials. However, because the combination of oxygen and methane is an explosive mixture if ignited, extreme care is required to assure that the fermentation tank is airtight. The construction of digesters using corrosion resistant materials such as stone, brick, ferrocement or concrete which are much cheaper and more available than metal in rural areas, reduces construction costs and extends the useful life of the digester.

There are essentially three designs for gas collection from digesters used in developing countries. The Indian design has floating metal dome covering the digester. The methane collects under the dome which rises and falls with the production and use of methane, keeping the gas at a constant pressure. The Chinese model has a stationary dome cover which collects the biogas as it is produced. Care must be exercised to assure that internal

pressure in the digester does not become so great that the digester walls or dome are damaged. A simple U-barometer can be attached to the gas pipeline from the digester to monitor gas pressure by the level of water displacement in the U-barometer. Alternatively, an inflatable butyl or rubber balloon may be connected to the digester by a pipeline, serving as the gas collection and low-pressure storage mechanism.

Achieving the optimal mixture of fermentation feedstocks requires a certain amount of skill and experience since each digester responds slightly differently. The best feedstocks are wet biomass such as fresh animal manure, human waste, aquatic plants or wet food processing wastes. Crop residues such as straw, plant stubble or vines which are used as feedstock need to be chopped or shredded into small pieces to increase gas production and to facilitate their flow through the digester. It should be noted that materials for fermentation must be mixed with an equal volume of water, which may tax available water supplies in some areas. Additionally, biogas production may be difficult to introduce in areas where there are strong cultural taboos against the handling of human or animal waste.

The anaerobic fermentation process operates within a pH tolerance level of 6.6 to 7.6 (NAS, 1977). Even though rural digester operators rarely have the means to accurately monitor pH levels, when methane production drops and there are no other suspected reasons such as temperature changes or a change in the mixture of the feedstock, lime may be added to bring the pH back to the desired level. Anaerobic fermentation requires relatively constant internal digester temperatures in the range of 95° and 140°F. Insulating the digester tank by covering it with earth or compost helps to reduce temperature

fluctuation in temperate areas. Heating of the digester to maintain optimal temperatures during cold periods is generally impractical for small scale digesters.

The impetus to begin biogas projects may be as much prompted by the desire for fertilizer from the digester residue as by the desire for methane fuel. In India, concern over the loss of fertilizer caused by the widespread burning of cow dung as a cooking fuel prompted research to develop a simple and low cost biogas plant. Since research began in 1939, some 50,000 to 100,000 plants have been built in India, most of them in rural areas providing cooking fuel for one or several families. Supporting infrastructure has been established including the industrial manufacture of methane-adapted stove burners and lamps, and the provision of credit and technical supervision for the construction of the digesters (Warpeha and Goldman, 1980).

French (1980) cites installation costs for small single-family sized plants in India at about $375 plus the daily labor to collect and feed in 175 pounds of cow dung and an equal volume of water and to remove some 315 pounds of slurry from the tank, as well as maintenance costs. The single family Indian digester requires three to four cattle to supply the manure feedstock, which limits its use to about five percent of Indian farmers who own that many cattle.

In spite of the large number of digesters which have been built in India, several problems have limited the program's success. Proportionately few of India's farmers can afford the capital costs of the digester and poor people, whose cooking fuel is supplied by scavenging cow dung, lose their source of

fuel when it is retained for methane production. Also, the design of the digester is problematic inasmuch as the metal gas collection dome is in constant contact with the liquified manure and methane which contain corrosive hydrogen sulfide. To avoid corrosion and eventual gas leakage, the metal dome must be coated with a corrosion-resistant paint about once a year, although this maintenance is often neglected (Warpeha and Goldman, 1980).

The Chinese biogas program has been widely promoted since 1970 when a few hundred digesters were built in two counties in the Szechwan province. By 1974, there were 30,000 small scale digesters in that province alone (NAS, 1977) and Ru-Chen (1978) reports that seven million digesters have been constructed throughout China. Chinese digesters are primarily one-family devices. Although a variety of designs have been tried, all models are relatively simple and made of local materials such as stone or brick. The capital cost of a Chinese, single-family digester is between $15 and $20, depending on the construction materials used (Hayes, 1977). If non-local materials are used, costs go up markedly. For example, in Ecuador a community digester for eleven families was built of ferrocement, following the Chinese design, costing $1,200 (Warpeha and Goldman, 1980).

Makhijani (1976) estimates that biogas from a community sized Indian model digester (400m3 biogas per day) would cost about $4.50 per million BTU which is comparable to electricity at about $.06 per kilowatt-hour. However, large community digesters require significantly larger supplies of feedstock and water, and an effective management and labor system to collect and transport feedstocks to the digester and to transport the residue to the

fields. Communal penning of animals near the digester and the installation of communal latrines which feed directly into the digester's mixing chamber could simplify this organizational and labor requirement although the feasibility of such arrangements would be subject to local customs and social organization. Additionally, the design of an effective, equitable and affordable means of gas and fertilizer distribution for community digesters requires careful planning and organization of all participating community members.

Programs to promote biogas plants in areas where there is no previous experience with this technology will need to experiment with different digester designs, emphasizing the use of locally available construction materials in order to develop low cost digester models. If the capital cost of the digester requires multi-family units, particular attention should be given to user receptivity to such considerations as cooperative penning of animals for ease in feedstock collection, and communal cooking areas to reduce gas distribution costs.

Alcohol Fuels

Ethanol production from biomass feedstocks represents a major liquid fuel alternative to petroleum based fuels. Ethanol can be used as an automobile fuel either as gasohol by mixing up to 10 percent anhydrous (99.8%) ethanol with gasoline, or as a substitute for gasoline, in which case hydrated ethanol (94% purity) is used. No engine modifications are necessary for use of gasohol although the use of straight lower proof ethanol (which is more practical for production in small scale plants) does require engine modifications. Straight ethanol is not suitable for use in diesel

engines, although with diesel engine modifications it can be mixed with diesel fuel.

Ethanol can be produced from three main types of biomass raw materials: (1) sugar bearing materials such as sugar cane, molasses and sweet sorghum, which contain carbohydrates in sugar form; (2) starches such as cassava, grains and potatoes, which contain carbohydrates in starch form; and (3) celluloses such as wood and agricultural residues for which the carbohydrate molecular form is more complex. Ethanol production from cellulosic materials involves a more costly and complex production process than the sugar or starch bearing materials and there are no demonstrated processes yet available for commercial scale plants in developing countries (World Bank, 1980).

The basic process for ethanol production through fermentation consists of four basic steps: (1) first the feedstock is treated to produce a sugar solution; (2) the sugar is then converted to ethanol and carbon dioxide by yeast or bacteria fermentation; (3) the ethanol is removed from the fermented solution by distillation which yields a solution of ethanol and water (which cannot exceed 95.6 percent ethanol at normal pressures, due to the physical properties of the ethanol-water mixture) and; (4) for the production of pure ethanol, the water is removed by distilling again in the presence of chemicals (OTA, 1980).

The four crops which are most economically viable for developing country ethanol production are sugar cane (and molasses), sweet sorghum, corn and cassava (World Bank, 1980). However, sweet sorghum is a new crop

for most developing countries, and considerable agricultural research and extension is required before this crop can be considered as a major source for ethanol production.

In addition to the cost of feedstock used for fermentation, the cost of alcohol production is significantly influenced by the source of energy consumed in distillation. When sugar juice is extracted from sugar cane and sweet sorghum, the bagasse (plant residue) can be burned as a fuel to provide steam and electricity required for ethanol production. Although corn and cassava stalks and leaves could be burned as a distillation fuel source, the collection, transport and drying costs are prohibitive at present (World Bank, 1980). The use of conventional fuel sources such as coal or fuel oil instead of bagasse to provide heat energy for the production of ethanol increases the cost of the ethanol produced and also increases the demand for non-renewable resources. Furthermore, the use of food staples such as corn or cassava for alcohol production in food shortage areas would be undesirable.

Most existing alcohol plants are in the range of 60,000 to 120,000 liters produced per day. Capital costs for plant construction vary significantly, depending on location, plant design and size. There is little certainty in the cost of plants based on raw materials other than sugar cane because there is practically no industrial scale experience with such plants. As a rough indicator of plant costs based on Brazilian experience, the World Bank (1980) estimates that sugar cane based alcohol plants producing 20,000 liters per day have 1979 capital costs of about $2,000,000. Plants producing 120,000 liters per day are estimated to cost $7,600,000 and

plants producing 240,000 liters per day, about $12,500,000. There are no reliable cost data for plants producing less than 20,000 liters per day.

Molasses based alcohol plants constructed adjacent to sugar mills to take advantage of existing steam and power generation facilities, and which do not require additional capital costs to crush the cane to separate the sugar juices, are estimated to cost at least 20 percent less than sugar cane based alcohol plants. Cassava and other starch based plants require additional equipment to convert the starches into sugar, increasing plant costs about 10 to 20 percent more than similar sugar cane based plants (World Bank, 1980).

It is important to note that the overall economic viabiliy of alcohol production indicates that plant capital costs are relatively less critical than raw material cost, plant fuel consumption, and operating days per year (World Bank, 1980). As well, the economic viability of alcohol fuels production will depend on the future price of petroleum-based fuels.

With present distillation technology and the scale of production required to offset high capital and operating costs of alcohol plants, alcohol fuel production is not viable in developing countries for on-farm small scale production. Where sufficient quantities of feedstocks are potentially available for commercial scale alcohol production, the economics of alcohol production will depend on country-specific circumstances in the agricultural, industry, energy and transportation sectors. To determine economic viability, detailed review of each candidate country will be required.

RECOMMENDATIONS AND CONCLUSIONS

The development and promotion of renewable energy technologies adapted to the needs and resources of developing countries is clearly a priority development issue. It is dictated both by the finite supply and escalating price of the world's oil and by the continued weakening of national economies in non-oil producing developing countries due to their increasing expenditure of foreign exchange earnings for oil imports. Although the consumption of fossil fuels in the rural postharvest food sector of developing countries is presently limited, in large part because farming populations are already priced out of the petroleum fuels market, the continued reliance on traditional energy sources such as biomass fuels and human and animal power proves to be increasingly inadequate under the pressure of population growth and augmented demands for food supplies.

As a major example, serious repercussions are already evident in areas where firewood shortages force populations to burn dung and crop residues for cooking fuel, seriously affecting soil fertility and decreasing agricultural productivity. Fuelwood gathering is a primary cause of deforestation, whose ecological effects result in increased flooding, soil erosion, desertification, loss of arable land and the reduction of agricultural productivity.

Many of the renewable energy technologies considered in this report are beyond the financial means of most farming families in developing countries. As such, the extent of technology adoption will depend on the success of local research efforts to develop viable low cost models made of a maximum of locally available materials, and on promotion efforts which include credit provisions and/or subsidies to make the technologies avail-

able to the broadest possible population. Before undertaking any large scale technology promotion effort, implementation trials need to be undertaken to determine economic viability at the user level and to gauge user receptivity--in particular to assess the practicality of the technology in terms of local cultural beliefs, attitudes and behaviors.

Postharvest technology development and promotion personnel need to be keenly aware of the fact that in most cases women traditionally have the major, if not exclusive responsibility for postharvest activities. Historically male staffed and male-oriented research and extension programs will need to be especially aware and culturally sensitive to develop and introduce innovations which do not unfavorably disrupt womens' social role and function in the postharvest food sector, especially as "improvements" may involve the erosion of womens' incomes and their ability to provide for their familial financial responsibilities.

No one program of action can be recommended that will be uniformly appropriate for all developing countries inasmuch as each program must be adapted to specific local needs, priorities and resources. As such, local surveys need to be undertaken to document local energy use priorities and attitudes, as well as unexploited and inefficiently exploited energy resources, as an initial step in establishing national renewable energy development policy and programs.

The establishment and provision of sustained, technically competent expertise required for the development of renewable energy technology promotion efforts may best be assured through the formation of national level renewable energy research and development centers. The function of

a national center might include responsibility for the design and implementation of energy surveys, research to develop and field test locally-adapted technologies, training of extension personnel and artisans in construction and maintenance skills, the preparation of extension materials such as local language manuals for construction and maintenance, and the provision of technical assistance in the design and implementation of technology promotion efforts.

This report has examined energy demands in the postharvest food sector and potential renewable energy technologies which could meet these demands. However, some of the renewable energy technologies considered here have a variety of potential applications in other sectors. Given the present state-of-the-art of most renewable energy technologies adaptable to the economic and cultural environment of developing countries and the general lack of experience and documentation in their actual use, there is a primary need at this point to encourage further use of these technologies in practical, well-documented applications. Practical applications in the postharvest sector as well as in other sectors are to be encouraged, with positive cross-sectoral ripple effects to be expected in areas such as increased local familiarity with the technologies, the establishment of local capabilities for manufacture and maintenance, and the increased availability of construction materials and spare parts supplies.

With the understanding that renewable energy technology promotion efforts must be adapted to local needs, resources and priorities, the following areas appear to have the broadest potential application in the immediate or near-term:

— increasing fuelwood production

— promotion of efficient cookstoves

— exploitation of small scale hydro resources

— exploitation of wind resources

Fuelwood production is a development priority which cannot be overemphasized. Increased population pressures create a demand for firewood which calls for massive tree-planting efforts well beyond present levels in order to avoid even more severe fuelwood shortages, widespread deforestation and consequent ecological effects. Although large-scale plantations will play an important role in meeting national fuelwood demands, long-range demands favor the establishment of community-based efforts to plant and manage woodlots which will serve as continually renewed sources of fuel and other products such as local construction materials. Training of foresters and extension personnel in community organization and extension techniques should be emphasized to develop the large cadre needed to provide organizational and technical support of widespread community woodlot programs.

Programs to increase the efficiency of cookstoves can produce significant, low cost reductions in demand for fuelwood, dung and crop residues for use as cooking fuels. Cookstove promotion programs require careful design adaptation to develop stove designs which can be easily constructed from locally available materials and which are practical and conform to the users' requirements. If stove designs are to be developed which will be accepted on a wide scale, from the outset of local design efforts, it is critical to involve local stove users in the design process in order to develop a thorough understanding and sensitivity to their cooking practices

and priorities. Well-organized extension efforts are required to train users or local artisans in stove-building techniques and to demonstrate through actual in-home use the fuel savings which are possible with an improved stove.

Exploitation of small scale hydro resources. Waterwheels designed and constructed by local artisans are presently used in several developing countries. Waterwheels appear to be an energy technology within the reach of some relatively low-income communities where hydro resources exist and where there is need for such tasks as grain grinding which can be performed by a low r.p.m. power source. More sophisticated mini-hydro power systems are commercially available and some designs are suitable for manufacture in developing countries. Where hydro resources exist, and if the system is well-maintained, mini-hydro electricity production costs can be competitive with small diesel-electric systems. In countries where preliminary energy resource surveys indicate that significant unexploited hydro power resources exist, local technicians should be trained to survey and evaluate potential hydro sites and to supervise plant design, construction and maintenance. Where appropriate, local manufacture of turbines should be encouraged, with emphasis on the Michell/Banki design. Due to high cap tal costs, financing arrangements are essential for the promotion of mini-hydro.

Exploitation of wind resources. Windmill designs exist which are suitable for local construction or manufacturing in developing countries, as well as very sophisticated designs available from commercial manufacturers in industrialized nations. Most applications in developing countries have been limited to windmills used for water pumping although other wind-mechanical

and wind-electric applications are possible. Historic windmill designs for mechanical power applications such as grain grinding or threshing should receive research emphasis, developing designs relying on the use of local construction materials as much as possible. Electricity production costs from modern wind-generating systems may be competitive with diesel-electric systems, subject to interest rates, the adequate maintenance of the wind system, and high diesel fuel costs in remote areas.

The coastal areas in many developing countries appear to have enough wind energy to permit windmill installations, although feasible wind power sites are not limited to coastal areas. A very useful information resource to target wind energy exploitation programs could be developed through the compilation and assessment of all relevant existing wind speed data from sources such as the World Meteorological Organization and the U.S. National Oceanic and Atmospheric Administration (NOAA). In countries where wind power potential appears to be promising, in-depth, on-going multi-site surveys of wind energy should be encouraged through the provision of necessary meteorological equipment and the training of local technicians in collection and assessment of wind speed data. Local research and development efforts should be pursued with a strong emphasis on field testing and demonstration of practical applications of wind-mechanical and wind-electric systems, and the training of local artisans in maintenance skills. National efforts should be supported to encourage local production of appropriate windmill designs, perhaps in the form of providing windmill buyers with financing at favorable interest rates.

The above list of suggested energy technology promotion programs should not limit other technology development efforts. National and international renewable energy research and development programs should continue to pursue research and well-documented field trials to develop and promote other promising renewable energy technologies, such as solar crop dryers, animal power and pedal power units and low-cost biogas digesters. As well, international efforts should be strongly encouraged to research and document the efficacy of traditional organic insect control methods used for centuries in rural areas of developing countries. Urgency is necessary to document those organic methods still in use before the modernization of rural agricultural systems and the death of village elders eliminates even the memory of their use.

In summary, the combined short-term effect of a massive international promotion effort including all of the renewable energy technologies reviewed in this report, would probably not be very significant in terms of rapidly increasing rural energy supplies. The acceptance of new technologies will take time, particularly as farmers are skeptical of innovations, and for good reason when they live so close to the margin that any unexpected losses can put them at great risk. However, renewable energy technologies can make significant long-term impact on increasing rural energy supplies, increasing rural productivity and income and improving the quality of life. What is required is a serious long-term commitment on the part of individuals in national and international development policy making branches, development assistance organizations, research institutions and extension networks.

This commitment must be to continue the effort to work with and for the individuals who make up rural farming populations in order to develop and promote technologies which are adapted to their needs, resources and priorities.

A SELECTED BIBLIOGRAPHY

Appropriate Technology Development Association. Appropriate Technology Directory of Machines, Tools, Plants, Equipment, Processes and Industries. India, 1977.

Arnold, J. E. "Wood Energy and Rural Communities." paper presented at the 8th World Forestry Congress, Jakarta, Indonesia, October 17, 1978.

Battelle Memorial Institute, PNL. Survey of Historical and Current Site Selection techniques for the Placement of Small Wind Conversion Systems. 1977.

Bosnoff, W. "1976 Annual Report, FAO/DANIDA African Rural Storage Center." International Institute of Tropical Agriculture. Ibadan, Nigeria, 1976.

Bossel, H. Low Cost Windmills For Developing Nations. Mt. Rainier: VITA Publications, 1970.

Bowman, et al. Solar Cookers For Haiti: A Feasibility Study. Florida Institute of Technology, 1977.

Boyd, J. Tools For Agriculture, A Buyer's Guide To Low Cost Agricultural Implements. London: Intermediate Technology Publications, 1973.

Brace Research Institute. Survey of Solar Agricultural Dryers. McGill University. Canada, 1975.

Breslin, W. R. Small Michell (Banki) Turbine: A Construction Manual. Mt. Rainier: VITA Publications, 1979.

Brookhaven National Laboratory. Energy needs, Uses and Resources in Developing Countries. Upton, New York, 1978.

Carr, M. Appropriate Technology For African Women, an annotated bibliography. United Nations. Rome, 1978.

Cecelski, et al. Household Energy And The Poor In The Third World. Resources For the Future, Inc. Washington, D.C., 1979.

Centre d'Etudes et de Recherches sur les Energies Renouvelables. Les Cuisinieres "Ban Ak Suuf". University de Dakar. Senegal, 1980.

Checci & Company in collaboration with Brookhaven National Laboratory. Senegal Food and Energy Study. Washington, D.C., 1980.

CILSS. Energy In The Development of The Sahel. Club du Sahel. Upper Volta, 1978.

Cloud, K. Sex Roles in Food Production and Food Distribution Systems in The Sahel. USAID. Washington, D.C., 1977.

Collier, W. et al. A Comment. Agricultural Development Council. 1974.

Darrow, K. et al. Appropriate Technology Sourcebook. Volunteers in Asia, Inc. 1977.

Department of Energy & U.S. Army Corps of Engineers. "Water Power '79." Abstracts From International Conference on Small Scale Hydro Power. October, 1979.

DOE Rocky Flats Wind Systems Program. Selected References in Small Wind Energy Conversion System. DOE, 1979.

Douglas, J. S. and Hart, R. A. Towards a Solution to Problems of World Hunger and Conservation. Robinson & Watkins Books, Ltd. 1976.

Dulansey, M. "Can Technology Help Women Feed Their Families?" Prepared for AAAS Workshop on Women and Development. May, 1979.

Dutt, G. S. Reducing Cooking Energy Use In Rural India. VITA. Mt. Rainier, Maryland, 1978.

Eckholm, E. The Other Energy Crisis: Firewood. Worldwatch Institute. Washington, D.C. 1975.

Evans, D. and Adler, L. eds. Appropriate Technology For Development: A Discussion and Case Histories. Westview Press. Boulder, Colorado, 1979.

Evans, H. "Food Processing In Rural Botswana." Serowe Food Laboratory, Botswana, 1980.

Exell, R. "Using The Sun To Power A Refrigerator." Appropriate Technology. Vol. 5, No. 3, 1978.

FAO. Equipment Related To The Domestic Function Of Food Preparation, Handling and Storage. United Nations. Rome, 1974.

. Processing And Storage of Food Grains. FAO Agricultural Services Bulletin. Rome, 1979.

Forrest, R. S. et al. The Post Harvest Food Grain Industry in Semi-Arid Africa. IDRC. Ottowa, Canada, 1975.

Fraenkel, P., Food From Windmills. Intermediate Technology Publication, 1975.

. The Power Guide: A Catalogue of Small Scale Power Equipment. Intermediate Technology Publication, 1979.

French, D. Appropriate Technology in Social Context: An Annotated Biblography. VITA, Mt. Rainier, Maryland, 1977.

French, D. and Larson, P. eds. Energy For Africa, Selected Readings. USAID. Washington, D.C., 1980.

Geller, H. S. "Cooking in the Ungra Area: Fuel Efficiency, Energy Losses, and Opportunities for Reducing Firewood Consumption." Centre For The Application of Science and Technology To Rural Areas (ASTRA), India, 1981.

Goldemberg, J. and Brown, R. "Cooking Stoves: The State-of-the-Art." Institute of Physics, University of Sao Paulo, Brazil. undated.

Hackleman, M. and House, D. Wind and Windspinners: A Nuts & Bolts Approach. California: Peace Press, 1974.

Haimerl, L. A. "The Cross-Flow Turbine." Water Power, London, January, 1960.

Hamm, H. Correspondence with VITA Technical Coordinator, George Codrea. March 28, 1975.

. Low Cost Development of Small Water Power Sites. Mt. Rainier: VITA Publications, 1967.

Hayden, A. C. S. "Efficiency of Wood-Fired Appliances." Canadian Combustion Research Lab, 1978.

Hayes, D. Energy For Development: Third World Options. Worldwatch Paper 15. Worldwatch Institute, Washington, D.C., 1977.

Herdley, O. St.C., and Springer, B.G.F. "A Natural Convection Solar Crop Drier." University of the West Indies. St. Augustine, Trinidad, 1976.

Howe, J. W. U.S. Energy Policy in the Non-OPEC Third World. The Overseas Development Council. Washington, D.C., 1979.

Iceman, L. "Appropriate Technology For Renewable Resource Utilization Project." VITA-CDT Cookstove Panel, 1979.

Islam, M. Food Preservation in Bangladesh. UNICEF. Dacca, 1977.

ITDG. New Technologies For the Development of Micro-hydro. London: ITDG Publications, 1979.

Kadete, H. and Reichel, R. "Experiences With Small Hydro-Electric Power Stations in Tanzania." Presented at Seminar on Technology in Rural Development, University of Dar es Salaam, Tanzania. September, 1978.

Kozlowski, J. Savonius Rotor Construction, Vertical Axis Wind Machines From Oil Drums. Mt. Rainier: VITA Publications, 1977.

Krendel, E. S., "Man and Animal-Generated Power." Standard Handbook For Mechanical Engineers, Revised 7th Edition. New York: McGraw-Hill, 1979.

Lindblad, C. and Druben, L. Small Farm Grain Storage. Peace Corps/VITA Publication, 1976.

Lipper, R. and Davis, D. "Solar Energy For Crop Conditioning: A Progress Report." VITA, 1976.

Lozana, J. C. et al. "New Developments in Cassava Storage." Fitopacolcolomb, Vol. 7, No. 1, 2-14, 1978.

Lumsdaine, E. The Potential of Wind Energy. Presented at the Costa Rican Workshop on Energy and Development, San Jose, Costa Rica, 1980.

Makhijani, A. "Solar Energy and Rural Development For the Third World." Bulletin of the Atomic Scientists, Vol. 32, No. 6, 14-24, 1976.

McCullogh, J. C. Pedal Power in Work, Leisure and Transportation. Rodale Press, 1977.

McPhee, J. "A Reporter At Large: Mini-hydro." The New Yorker, February 23, 1981.

Meier, U. et al. "Development of Equipment for Harnessing Hydro Power on a Small Scale." Presented at Seminar on Mini/Micro Hydro-Electric Plants. Kathmandu, Nepal, November, 1978.

Melaneasian Council of Churches. Liklik Buk, a Rural Development Handbook. Liklik Buk Information Center, 1977.

Myles, R. and Singh, J. "Promotion of Biogas Plants For Small and Marginal Farmers on an Individual and Community Basis." Presented at Seminar on Action For Food Production, Bangalore, India, 1979.

National Academy of Sciences. Proceedings International Workshop on Energy Survey Methodologies for Developing Countries. Washington, D.C.: National Academy Press, 1980.

- Postharvest Food Losses in Developing Countries. Washington, D.C.: National Academy Press, 1978.

- Methane Generation From Human, Animal, and Agricultural Wastes. Washington, D.C.: National Academy Press, 1977.

- Energy For Rural Development. Renewable Resources and Alternative Technologies For Developing Countries. Washington, D.C.: National Academy Press, 1976.

National Aeronautical Laboratory. Wind Power and Wind Mills, an annotated bibliography. Bangalore, India, 1975.

Office of Technology Assessment. Energy From Biological Processes, Vol. II Technical and Environmental Analyses. Washington, D.C., 1980.

O'Kelly, E. Simple Technologies For Rural Women in Bangladesh. UNICEF, Dacca, Bangladesh, 1977.

Ovens, W.G. A Design Manual For Water Wheels. Mt. Rainier: VITA Publications, 1975.

Paddon, A. R. and Harken, A. P. The Production of Charcoal in a Portable Metal Kiln. Tropical Products Institute, London, 1979.

Pak, S. "Cost Comparison of Village Level Power Sources, Draft." International Bank For Reconstruction and Development, 1974.

Park, J. Simplified Wind Power Systems For Experimenters. Brownsville: Helion Press, Inc., 1975.

Philippine Center For Appropriate Training and Technology (PCATT). Water Power. Manila, Philippines, 1980.

Pimentel, D. "Energy Needs, Uses and Resources in the Food Systems of Developing Countries." Draft 1977.

. "World Food Crisis: Energy and Pests." Bulletin of the Entomology Society of America. 22 (1): 20-26, 1976.

Pimentel, D. and Marcia. Food, Energy and Society. New York: Wiley & Sons, 1979.

Pinson, G. S. A Pedal Operated Grain Mill. Tropical Products Institute, London, 1979.

Platt, D. et al. A Solar Grain Dryer For Developing Countries. College of Engineering, University of Maryland, 1978.

Practical Concepts Incorporated and Brookhaven National laboratory. Energy In The Food System: Dominican Republic. PCI, Washington, D.C., 1980.

Prasad, K. Some Performance Tests on Open Fires and the Family Cooker. Technical University of Eindhoven, The Netherlands, 1980.

Ritchie, J. "Impact of Changing Food Production, Processing and Marketing Systems on the Role of Women." Presented at World Food Conference, 1977.

Reveile, R. "Energy Use in Rural India." Science, 192. June 1976.

Rosenblum, L. et al. "Photovoltaic Power Systems For Rural Areas of Developing Countries." NASA, Cleveland, Ohio, 1979.

Ru-Chen, C. et al. A Biogas Power Station in Foshan, Energy From Night Soil. Guangzhou Institute of Energy Conversion, Chinese Academy of Sciences, 1973.

Salariya, K. S. "Fuel Conservation in Domestic Combustion." Department of Mechanical Engineering, College of Agricultural Engineering, Punjab Agricultural University, Ludhiana, India, 1978.

Schoenau, G. Solar Grain Drying. University of Saskatchenwam, Canada, 1980.

Simmons, E. The Small Scale Rural Food Processing Industry in Northern Nigeria. Food Research Institute, Stanford University, 1975.

Singer, H. Improvement of Fuelwood Cooking Stoves and Economy in Fuelwood Consumption. Report to the Government of Indonesia. FAO, Rome, 1961.

Smith, D. V. "Photovoltaics in the Third World." Working Paper No. MIT-EL 79-045WP. Energy Laboratory, M.I.T., Boston, 1979.

Soderholm, L. H. and Andrew, J. F. Wind Electric Power. American Society of Agricultural Engineers, 1974.

Stanley, R. The Arusha Windmill: A Construction Manual. Volunteers in Asia/VITA Publication, 1977.

Stout, B. A. et al. Energy For World Agriculture. FAO, Rome, 1979.

Sumicad, R. O. "Biogas Technology." Small Industry Journal, Vol. 9, 1976.

Swiss Association For Technical Assistance (SATA). Development of Equipment For Harnessing Hydro Power on a Small Scale. 1978.

Tabor, H. Criteria for the Application of Solar Energy to Developing Countries. National Physical Laboratory of Israel, 1977.

Tazania National Scientific Research Council. Workshop on Solar Energy For The Villages of Tanzania. Dar es Salaam, 1978.

Tinker, I. New Technologies For Food Chain Activities: The Imperative of Equity For Women. CIDAT Occasional paper C-1. Center for International Development and Technology, Washington, D.C., 1980.

Torrey, V. Wind-Catchers: American Windmills of Yesterday and Tomorrow. Brattleboro: The Stephen Green Press, 1976.

Van de Vern, N. Construction Manual For a Cretan Windmill. Amerstoort, The Netherlands: S.W.D. Publications, 1977.

VITA. Abstracts of Hydro-Electric Systems. December, 1980.

. Electricity From the Wind For Developing Countries: An Introduction. Mt. Rainier: VITA Publications, 1977.

VITA/ITDG. Wood Conserving Cook Stoves: A Design Handbook. Mt. Rainier: VITA Publications, 1980.

Volunteers in Asia, Inc. Appropriate Technology Sourcebook. 1977.

Walton, J. D., Jr. et al. A State of the Art Survey of Solar Powered Irrigation Pumps, Solar Cookers and Wood Burning Stoves For Use In Sub-Sahara Africa. Georgia Institute of Technology. 1978.

Warpeha, P. R. and Goldman, L. C. "Some Considerations Concerning the Application of Biogas Technology: A Socio-cultural View." Presented at The Second Annual Symposium of the International Association for the Advancement of Appropriate Technology for Developing Countries: "Agriculture, Rural Energy, and Development." Denver, October, 1980.

Weir, A The Dynapod: A Pedal Power Unit. Mt. Rainier: VITA Publications, 1980.

Weiss, C. and Pak, S. "Developing Country Applications of Photovoltaic Cells." Paper presented to ERDA, January, 1976.

Wendroff, A. P. "The Mlowe Mill: A Study in the Application of Alternative Technology." Unpublished VITA report, undated.

Werner, E. Biogas: A Decentralized and Economically Feasible Alternate Energy Source. University of Puerto Rico. December, 1978.

Windworks. Wind Energy Bibliography. Mukwonago, Michigan, 1973.

Wyatt, A. "Wind Energy Activities in Africa." VITA Report, 1981.

Wood, D. H. et al. The Socio-Economic Context of Fuelwood Use in Small Rural Communities. USAID, Washington, D.C., 1980.

Worgan, J. T. "Canning and Bottling as Methods of Food Preservation in Developing Countries." Appropriate Technology. Vol. 4, No. 3, November, 1977.

World Bank. Alcohol Production From Biomass in the Developing Countries. World Bank, Washington, D.C., 1980.

. Energy in Developing Countries. World Bank, Washington, D.C., 1980.

. World Development Report, 1979. New York: Oxford University Press, 1979.

Wu, M. and Esmay, M. L. "Adoption of the Drum Thresher For New Rice Varieties in Asia." Agricultural Mechanization in Asia, 1975.