AGRICULTURAL APPLICATIONS OF SOLAR ENERGY

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ABSTRACT

This paper examines energy utilisation in Developing Countries, problems with present utilisation methods, and suggests possible solutions to these problems through use of solar energy.

KEYWORDS

Solar; energy; cooking; drying; water; heating; fuel-wood; charcoal.

INTRODUCTION

Energy and Societies

Involved in every ecosystem is energy. In one of the most primitive societies evident today, such as that of the Canadian Eskimo, survival has two primary requirements: adequate caloric intake and maintenance of a suitable microclimate in terms of shelter and clothing. Such needs initially called for an input of human energy in the pursuit of game; the meat provided adequate food and the fur of the animal provided material for making clothing. Hunting was done by use of spears and bows and arrows made from animal bones, etc. It has been determined that primitive man used only 8368 kJ per day. However even today this is changing. Animal pelts are sold to buy other foods, guns, and in some cases snowmobiles, which are in turn used to increase hunting and trapping efficiency.

In the more advanced technological societies of North America we find the other extreme. Modern technological man in the U.S. consumes 962,320 kJ daily of which 41,840 is used for food, 276,144 for home and commerce, 380,744 for industry, and 263,592 for transportation (Cook, 1971).

Forms and Costs of Energy

Energy is used in many forms. It may be used in the form of light, of heat, of motion, or in various combinations. Often options exist since one form may be converted to another, even though the efficiency of such a conversion may not be 100 per cent. For example, in Upper Volta, an energy source for cooking the family meal could come from fuelwood($0.09/kWh), kerosene ($0.06/kWh), butane gas ($0.10/kWh), or electricity ($0.19/kWh),(Arnold, 1978). The choice is very much consumer-dependent. Obviously, electric ranges provide some prestige but they can only be used where electricity is available. Kerosene and butane would, from a social point of view, be a second choice but are more cumbersome to handle, although better suited to utilisation in the countryside, since the power source is self-contained. All three require a high intial outlay of cash (often not available). The simple fire made with fuelwood then becomes the suitable alternative if the consumer is willing to accept it.

TABLE 1 Costs for Selected Source of Energy (Urban Conditions in Upper Volta) (Arnold, 1978)

A. Cost of the basic requirements for the various sources of energy

	Equipment required	Cost FCFA*
Fuelwood	some stones	zero
Charcoal	stove	200 - 1,000
Kerosene	stove	2,500 - 3,500
Butane gas	stove - bottle	approx. 13,000
Electricity	stove - deposit	approx. 30,000

B. Comparative kwh costs for the various sources of energy

	Calorific value kcal/kg	Energy value kWh/kg	Thermal efficiency per cent	Price per unit FCFA*	Price per kw FCFA*
Fuelwood	4,500	5.23	8	7.69	18.0
Charcoal	7,800	9.06	28	24.50	9.6
Kerosene	12,000	13.95	50	75.00	11.0
Butane gas	12,500	14.50	60	171.50	19.7
Electricity	860 cal.	1 kWh	70	26.0	37.1

*FCFA-Cfa franc - $1 U.S. = 200 FCFA

There is a danger in looking at only cost, availability and acceptability without considering the whole ecosystem. For example Floor (1978) has evaluated several of the energy sources used in cooking. If one were to accept an evergy source based on one criteria it may not be the same as an energy source chosen within the context of the total ecosystem in which the consumer finds oneself. (see Table 2, on the following page)

Efficiency in Energy Utilisation

The fewer conversions from one energy form to another, the more efficient the system becomes. For example, it takes approximately 3-8 kg of plant matter to produce 1 kg of meat. Thus, the society eating foods of plant origin would utilise

TABLE 2 Classification and Evaluation of Various Energy Forms (Floor, 1978)

	Firewood	Charcoal	Kerosene	Butane gas	Electricity (thermal)	Coal
Locally available	yes but deforestation	yes	no	no	no	no
Initial investment	negligible	low	inter-mediate	high	very high	low
Simplicity of use	low, constant surveil-lance, smoke	good	good	good	good	good
Efficiency	bad	low	inter-mediate	good	low	low
Possibility of cooking large quantities	yes	no	no	no	no	yes
Adapted to traditional cooking	yes	yes	no	no	no	yes
Fuel cost	low	inter-mediate	very high	high	very high	low
Possibility of purchase of small quantities (penny capitalism)	yes	yes	yes	no	no	yes
Major qualities	simple to use, safety	simple to use and store, no smoke	fast cooking	practical	cleanli-ness, safety	
Major draw-backs	defores-tation	not adapted for large family cooking. Inefficient cardonisa-tion	too expensive limited capacity of cooking utensils	expensive safety measures needed	invest-ment & consump-tion too expensive	trans-portation problems

far less energy than a society eating foods of mainly animal origin. The following table, although it includes energy related to the other aspects of food production can be used to illustrate this point (Borgstrom 1976). For example, in Indonesia, a large percentage of total food intake made up of plant products uses considerably less energy/caput than a country such as the U.S. where a large percentage of food is of animal origin.

TABLE 3 Energy Balance per Caput, 1971-72
(Adapted from Borgstrom, 1976)

Selected country	Food per day in kJ	Primary food as percentage of energy account	Total energy per day in kJ
Indonesia	8,774	90.8	9,663
India	11,021	75.6	14,578
Portugal	26,384	41.8	63,120
China	13,209	30.0	44,030
Taiwan	20,250	29.5	68,644
Spain	29,907	23.6	126,725
Yugoslavia	28,447	22.5	126,431
Ireland	49,036	19.0	258,048
South Korea	12,719	18.8	67,654
Mexico	18,292	18.3	99,956
Jamaica	17,644	16.8	105,024
Switzerland	44,133	15.7	281,102
Italy	32,338	15.4	209,987
Israel	32,652	15.3	213,412
Hungary	35,635	13.8	258,225
Romania	27,380	11.7	234,017
West Germany	46,794	11.4	410,473
Denmark	46,673	11.2	416,723
The Netherlands	43,911	11.0	399,191
United Kingdom	44,447	10.3	431,524
Australia	43,342	10.3	420,796
Poland	33,976	9.9	343,172
Norway	40,112	9.9	405,172
Belgium	44,342	9.2	481,978
Sweden	40,857	8.6	475,081
Trinidad	21,025	6.8	309,191
Japan	16,502	6.4	257,844
Czechoslovakia	32,648	6.3	518,222
USA	48,070	5.5	889,823

The more striking loss in efficiency in energy conversion is that of biogas production directly from plant material since both the photosynthetic and the gas production stages are of a low efficiency. (Manasseh, 1980)

The whole question of biogas production should therefore be kept in its proper perspective. For example, certain countries are strongly pushing the idea of biogas production from aquatic weeds. The energy expended in harvesting the plant material is enormous and is considerably more than the returns.

The above situation is different than that of the third-world family who uses animal dung for biogas production. In such a case the family already has the raw material on hand so the efficiency associated with its collection is very high. The family has several options on the use of animal-dung:
a) direct use for fuel (no fertilizer)
b) direct use for fertilizer (no fuel)
c) generation of biogas--using the gas for fuel and the sludge for fertilizer (but no construction value)
d) use in construction (no fertilizer or fuel value).

On a broader scale the form of available energy and related efficiency influences the type of food production system in use. The "Green Revolution" came about in response to the need for more food production. Although the "Green Revolution" agricultural technology greatly increased food production it did so at relatively high costs because of high energy inputs required such as fertilizer, pesticides and hybrid seeds.

However, it has been observed by various scientists that manual application of animal dung is considerably cheaper than mechanical application of chemical fertilisers. Similarly, often it is cheaper and more energy-efficient to pull out weeds manually rather than to apply herbicides over a whole field.

As well, provided that energy is available, societies using manpower are often more efficient in terms of energy utilisation in food production than those using mechanized power. (Pimental and Pimental, 1979)

From the following table one sees, for example, that maize production in Mexico is more energy efficient when manpower is used rather than oxen. It should be noted that efficient use of energy is often negatively correlated with unit food production. The ideal production system is one with high unit productivity and high energy efficiency but I do not know of such an example. (see Table 4 on following page)

Introduction of a New Technology

As can be seen efficiency, cost availability, and acceptability all play a role in acceptance of a technology. This can be further expanded and a more complete list of criteria for a developing country would include: (Middleton Associates, 1979)

1. The equipment should be simple
2. The technology should have a variability of scale so it can be modified to user needs
3. The equipment should require little maintenance
4. The technology should be applicable to rural areas
5. The technology should not be site specific if possible
6. The technology should be such that it can be applied to several countries
7. Local resources should be used to develop any equipment
8. The system or its components should be manufactured locally
9. The technology should be oriented to the consumer's needs
10. The technology should be socially acceptable to the target population
11. The technology should be low level so any maintenance can be done locally
12. The technology should strive to improve local environmental conditions.

TABLE 4 Energy Efficiency (Pimental, 1979)

Crop	Country	Main Energy Source	J Output/ J input
maize	Mexico	manpower	10.74
maize	Guatemala	manpower	4.84
maize	Nigeria	manpower	6.41
maize	Mexico	oxen	4.34
maize	Guatemala	oxen	3.11
maize	Philippines		5.06
maize	U.S.A.		2.93
maize	U.K.		2.34
wheat	India		0.96
wheat	U.S.A.		2.41
wheat	U.K.		3.51
oats	U.S.A.		3.11
rice	Borneo		7.08
rice	Philippines		3.29
rice	California		1.55
rice	Japan		2.45
sorghum	Sudan	manpower	14.43
sorghum	U.S.A.		1.96
soybeans	U.S.A.		4.15
cowpeas	Nigeria		6.46
groundnuts	Thailand		2.60
groundnuts	Georgia (U.S.A.)		1.4
cassava	Tanzania		22.93

13. The technology could aim at substituting for costly imports
14. The technology must be cost effective
15. The technology must fit into the total system of which it is a part.

I like to sum up the above with three all-encompassing statements--"technically feasible";"economically viable"; and "socially acceptable".

PROBLEMS IN ENERGY UTILISATION

Energy and Developing Countries

I would like to examine the energy systems of some third world countries and suggest how solar energy may provide some of the alternatives. My choice appears logical for two main reasons:

1. The developing countries are the hardest hit by increasing petroleum prices. The International Agricultural Development Service uses this criterion as an agricultural development indicator. In 1974, the United Nations Emergency Operation was set up to help countries affected by the sudden rise in petroleum prices. Countries with per caput income of less than $400 in 1971 and having a balance of payments deficit in 1974 equivalent to 5 per cent of more of imports were classified as Most Seriously Affected (MSA) countries (IADS, 1978). The Sahelian African countries (Mauritania, Mali, Niger, Senegal, Gambia, and Upper Volta) are all included in this group.
2. The forty-five MSA countries are all located at latitudes where solar insolation is high and continuous throughout the year. For all practical purposes this energy form is unlimited and free and does not depend on world economics, politics or social status.

Since my experiences are largely limited to the Sahel the paper will centre around problems and solutions with reference to that area.

Energy Use in the Sahel

In the Sahel countries energy is required for three types of activities:

1. Domestic activities
   a) cooking and heating (using primarily firewood, charcoal, agricultural waste, dung, human energy)
   b) transport (using human energy, animal power, gasoline)
   c) lighting (using firewood, kerosene, vegetable oils, batteries, electricity)
2. Farming activities
   a) soil preparation (using human energy, animal power, gasoline)
   b) planting (using human energy, animal power, gasoline)
   c) irrigation (using human energy, animal power, gasoline)
   d) weeding (using human energy, animal power, gasoline)
   e) harvesting (using human energy, animal power, gasoline)
   f) marketing (using human energy, animal power, gasoline)
   g) post-production (using sun, human energy, gasoline, electricity)
3. Industrial activities (using firewood, human energy, gasoline, electricity)

The following table shows one estimate of energy use by sector. It is evident that domestic activities use the greater portion of energy in developing countries. (see table on following page)

Energy Problems in Present Utilisation Patterns

Let us know look at the different activities singly in a specific area such as the Sahel in which many MSA countries are situated, to examine the problems in present utilisation methods.

Cooking and heating in the home. Cooking of foods implies heating the food and cooking water to temperatures ranging between 100 to 130°C for a lengthy time, depending on the end product. Heating water involves raising the temperature of the water approximately 60°C. In developing market economies the enrgy source is commonly wood as is shown in Table 6 (Arnold, 1978). In certain countries such as those in the Sahel over 80 per cent of the wood is used primarily for cooking and heating.

Existing cooking methods have several drawbacks (Evans, 1978):

TABLE 5 Comparison of Energy Use in Developing World Rural Villages (Middleton Associates, 1979)
(kilograms of coal equivalent per caput)

A village in:*	Domestic	Per cent of total	Non-Domestic	Per cent of total	Total
India	430	(77)	125	(23)	555
China	1,035	(90)	120	(10)	1,155
Tanzania	895	(97)	25	(3)	920
Nigeria	638	(95)	32	(5)	670
Mexico	2,120	(94)	140	(6)	2,260
Bolivia	1,465	(86)	245	(14)	1,710

*It must be noted that these figures are based on studies in individual villages with widely varying living patterns and stages of development and populations and therefore the figures are useful only as indicators.

1. Open fires can only burn firewood
2. Considerable heat is wasted in getting the fire hot enough to cook
3. A lot of smoke is generated
4. The stove is normally at floor level making the work backbreaking
5. The heat from the fire makes for uncomfortable working conditions
6. There is little protection from the fire--children and animals often suffer from burns and scalds.

Energy requirements for cooking on open fires have been estimated to be five times as high as for cooking with a kerosene stove. In a study in Indonesia it was found that 94 per cent of the heat value of wood was wasted and by simple improvements in wood preparation, in stove design and in cooking pot design, consumption of firewood can be reduced by 70 per cent (Arnold and Jongma, 1979).

In a recent survey in Senegal (Yaciuk, 1977) it was observed that in March 1976, 95 per cent of a sample of 800 rural families used wood as an energy source while 16 per cent reported that charcoal, butane gas, or millet stalks were either the primary or secondary energy source. Of these 800 families 90 per cent cooked three meals a day, 7 per cent cooked only one or two meals and the remaining 3 per cent used fuels either four or five times daily for cooking purposes. Costs ranged from zero to over 50 cents per day if the cost of gathering the fuel was not included. Often the women had to walk long distances to obtain adequate fuel.

The effect of this heavy and inefficient use of wood has lead to extensive deforestation and often conversion of the once-productive land to desert. For example, the entire area around the town of Niamey has been completely denuded and wood is now obtained from distances at least 30 km away (CTFT, 1972). Forestry officials estimate that the annual firewood consumption for the town of Niamey requires 160,000 hectares with traditional forestry systems. If other energy sources could be substituted a good part of this land could be used for food production.

Apart from deforestation, excessive pressures on forests result in the burning of tree species that would be of greater benefit if used for other purposes. For example, in Upper Volta in a rural study (Ernst, 1978) over one-third of the fuelwood gathered was <u>Guiera senegalensis</u>, while <u>Butyrospermum parkii</u> was quite common. Traditionally, branches of <u>Guiera</u> are cut off for the building of the woven grain stores

TABLE 6 Fuelwood and Roundwood Consumption and Fuelwood Energy, 1974 (Arnold, 1978)

Region	Fuelwood	Total roundwood	Fuelwood as per cent of roundwood	Energy from fuelwood[1]	Commercial energy	Fuelwood as per cent of fuelwood and commercial energy
	$\times 10^6$ metres^3	$\times 10^6$ metres^3	Per cent	$\times 10^{15}$ joules	$\times 10^{15}$ joules	Per cent
Developed Market Economies	54.9	790.6	6.9	531	140,449	0.4
North America	17.6	474.7	3.7	170	77,763	0.2
Western Europe	32.3	240.8	13.4	312	45,161	0.7
Oceania	2.5	21.5	11.6	25	2,654	0.9
Eastern Europe and the USSR	99.7	462.1	21.6	964	54,267	1.8
Total developed countries	154.6	1,252.7	12.3	1,495	194 716	0.8
Developing Market Economies	1,145.3	1,336.1	85.7	11,074	22,038	33.4
Africa	268.3	299.6	89.5	2,594	1,848	58.4
Latin America	243.9	298.0	81.8	2,358	9,383	20.1
Far East	577.0	667.9	86.4	5,579	7,577	42.4
Near East	56.1	70.6	79.4	543	3,230	14.4
Asian centrally planned economies	153.5	205.7	74.6	1,485	16,790	8.1
Total developing countries	1,298.8	1,541.8	84.2	12,559	38,828	24.4
World	1,453.4	2,794.5	52.0	14,054	233,544	5.7

[1]Assuming 1 m^3 of fuelwood contains 9.67×10^9 joules of energy.

throughout the Sahel, leaving the tree alive. In Senegal, the utilisation of this species for firewood has lead to its being increasingly difficult to find a suitable size shrub for bin building. Where farmers reported being able to find the species within one kilometre before the 1968 drought, in high-density areas such as those in the groundnut basin of Senegal, farmers now have to go as far as 5-10 kilometres. In other areas, the wood has become completely unavailable, resulting in a breakdown of the traditional post-harvest system. This is very unfortunate, because this traditional system of storage often ~~affords~~ better protection against losses due to insects than do new, improved systems. gives

The other species mentioned as being used for firewood is Butyrospermum parkii, the shea butter nut tree, a veritable wonder tree with a multitude of uses. The branches of the tree make good charcoal, the wood is used in construction since it is termite proof, and the wood ash is used in indigo dyeing. The bark and leaves are used by certain ethnic tribes to make medicines. Most important, butter is derived from the nut. This butter is the major source of cooking oil within the region. In addition, the high allantoin content in the butter renders it useful as a base for many pharmaceutical and cosmetic preparations to treat rashes on children, as a skin conditioner for nursing mothers, for massaging, and as a cure for inflammation. The butter is also used to make soap. The butter use even extends to the construction industry when poorer quality butter is smeared on the mud walls of a house during the rainy season to prevent the wall from being washed away. There is also an export potential in developed countries where the butter is used to formulate a cocoa butter substitute and due to its crystallization properties is used in making margarine. Use of this tree for fuel only leads to increased amounts of imported oil for cooking purposes.

Already some conventional options exist in increasing efficiency of energy utilisation or in changing the energy source. These include:

1. More efficient use of fuelwood by improvements in wood preparation, in stove design, or in cooking-pot design. Considerable work has been done on better stove design--one being the development of the Lorena stove. This stove has many advantages (Evans, 1978):
   a) burns most organic materials
   b) wasted heat is minimized
   c) good heat-holding capacity
   d) smokeless
   e) can be built with unskilled labour
   f) hygienic and safe
   g) inexpensive
   h) long-lasting
   i) can be built in many shapes, depending on consumer needs
   j) can also be used for house heating or as a table
   k) cannot be mass-produced
   l) is not region specific--it can be used wherever there is mud and sand.

2. The second option is to replace some or all of the trees that have been removed. This can be done by the use of village woodlots. Natural forests in semi-arid areas have survived their enemies-- fire and browsing animals--at the price of productivity. Provided that the forest can be protected from these enemies, new species can provide the much-needed fuelwood.

   A single hectare of Eucalyptus in a plantation irrigated from a river can supply the fuel needs of fifty people, while drought-resistant species, such as Acacia and Prosopis supply the needs of twenty-five people, in rainfed conditions, where there is less than 500 mm of rainfall per year (Sanger, 1977). In the traditional Sahel forests, approximately two hectare are required per caput.

3. Alternatively, charcoal manufacturing techniques can be improved. Wood is very

bulky per unit of heat and therefore transport over long distances in not practical. For this reason, charcoal-making came about. The traditional system involves the use of kilns, which means that the heat from the volatile gases is lost. More expensive retorts could be used to permit gas and distillable by-products to be captured.

4. Even with the use of kilns, the making of charcoal from forestry harvesting residues should be encouraged. In Uganda, use of this technique increased charcoal production thirty-fold over a ten-year period (Arnold and Jongma, 1978)

5. Use of biogas from agricultural waste products should be encouraged, while use of agricultural residue for fuel should be discouraged. In burning of agricultural residue, such as stalks, leaves, dung, etc., the soil is rapidly depleted. By methane production, the biogas is used for fuel, but the sludge can be placed back on the farmer's land.

<u>Other domestic and farming activities</u>. Human energy, animal power, gasoline and electricity are the prime energy sources for transport, farming activities such as soil preparation, planting, weeding, harvesting, and marketing activities.

In the Sahel there is a continuing trend to move toward the use of draft animals for farm-related activities. With the low food crop productivity per unit area, I do not see this changing for some time.

<u>Post-production activities on the farm</u>. The hot, dry wind of the Sahel does serve a useful purpose. Traditional agriculture was centred around loose-panicled varieties which matured outside the rainy season. The grain thus loaded into traditional stores was very dry and since there were few damaged kernels, insects did not find it too interesting.

Fruits, vegetables, fish and meat have been sun-dried from time immemorable. Using traditional methods, the product which took a fairly long time to dry was often insect and dirt-infested and filled with contaminants of all sorts. The quality of the product was quite low. It is in this area where the use of solar energy shows the greatest promise. This will be explored more fully in the next section.

<u>Energy use in industry</u>. Although my discussion is related to the Sahel consumer, a look at industry in the Sahel can provide many examples of inefficient energy utilisation.

The largest one of these is electric power. At present all electric power is generated from thermal sources. Granted that there are times when electricity as an energy source is the only option,more often than not this is not the case. Too often one sees grinders, mills, etc. in villages being driven by electric motors. At the same time both gasoline and diesel fuel are sold in the same village. Even more severe is the use of electric heating elements both in terms of stoves and water heaters. For example, I do not know of a single hotel in the region that is using solar energy for heating water at the moment. Generally thermally generated electricity is used for this purpose although in some cases gas is used directly.

POSSIBLE SOLUTION--AGRICULTURAL APPLICATIONS OF SOLAR ENERGY

<u>Definitions</u>

Before looking at possible solutions, it may be useful to look at what is included in the term "solar energy". As can be seen from the solar energy applicability matrix below, the scope can be quite broad. I would like to restrict my definition to those technologies which are direct products of heat from the sun. My definition would, therefore, include solar cells, solar collectors, and solar engines.

In 1975, it was calculated that large conventional steam-driven power plants can be built for less than $150/kW, but small solar engines will probably cost $1,000/kW (Daniels, 1975).

Similarly, thermoelectric devices to convert solar energy directly into electrical energy are not feasible in agricultural applications since the thermocouple must have a high electrical conductivity and a low thermal conductivity. ~~and~~ This is not easily obtained.

Semiconductors, however, with their higher thermoelectric forces (up to 1,000 microvolts per degree, as opposed to 20-60 for thermocouples) have some possibility when the price comes down somewhat. One hope in developing solar cells may come about from recent discoveries in photo-chemistry at the University of Western Ontario. I shall therefore concentrate on the other technologies.
(Table 7, the following page)

Based on the above, options exist to reduce conventional energy requirements through the use of solar energy for lighting, water desalination, cooking, water heating, heating of homes, and drying.

Solar Cookers

Efforts have been made to introduce solar cookers by several countries. Two types have been tested; one is based on concentrating the solar energy by a reflector onto a cooking vessel through the use of a paraboloid mirror; the second, is an oven-type closed system with glass cover and extra mirror surface radiating into the oven. The acceptance of these two types of cookers has not been great. Consumers prefer to cook indoors and prefer to do so after sundown. For example, the ONERSOL at Niamey has developed a solar cooker of the first type, which is technically sound, but, according to Dr. Moumouni, the Director, is not accepted by the rural population. Dr. Bassey of Fourah Bay College is presently working on a cooker of the second type. One way to resolve the problem of acceptability of a solar cooker is to develop one with a built-in heat storage unit. This would solve the two major problems of non-acceptability. This will make the cooker very expensive and, at the moment, I do not really see a suitable solution. However, I do feel continued research and development funds should be made available for this activity.

Solar Water Heaters

Water heating can be done by solar energy. A considerable amount of energy from wood and electricity is presently consumed in the heating of water. For example, at 10 per cent efficiency it takes 33 kg of fuelwood to heat 300 litres of water from source temperature of $20^{\circ}C$ to $70^{\circ}C$. This energy can be saved through the use of solar energy.

A typical solar water heater consists of a flat plate collector and an insulated storage tank. Water circulates through the heater by thermosiphon circulation. The technology is well established and has been shown to be socially acceptable, and economically viable.

As examples, ONERSOL in Niamey is now mass-producing solar water heaters within its own production plant. These come in four sizes, 200, 400, 600, and 1,000 litres. A new hotel to be constructed at Niamey by UTH, will have all its water heated by

TABLE 7 Solar Energy Applicability Matrix
(Middleton Associates, 1979)

Solar Technology	Energy Use													
								Heating						
	Water pumping	Lighting	Cooling	Communications	Water desalting	Spinning	Sawing	Cooking	Space	Domestic water	Grinding	Drying	Transport	Fertilizing
Solar cells	*	*	*	**	-	*	-	-	-	-	*	-	-	-
Flat plate collectors[1]	*	-	*	-	**	-	-	*	**	**	-	**	-	-
Concentrating thermal collectors	*	*	*	*	*	-	-	*	-	-	-	-	-	-
Solar, Stirling (small scale)	*	*	*	*	-	*	*	-	-	-	*	-	-	-
Solar, rankine	*	*	*	-	-	*	*	-	-	-	*	-	-	-
Wind (mechanical)	**	-	-	-	-	*	*	-	-	-	**	-	-	-
Wind generator	**	**	**	**	-	*	*	-	-	-	**	-	-	-
Water (mechanical)	**	-	-	-	-	**	**	-	-	-	**	-	-	-
Hydroelectric	**	**	**	*	-	**	**	-	-	-	**	-	-	-
Bioconversion wood/charcoal	-	*	-	-	-	-	-	**	**	**	-	**	-	-
Biogas	*	**	*	-	-	-	-	**	-	*	-	*	*	**
Draft animals	**	-	-	-	-	-	-	*	-	*	**	-	**	**

Symbols: ** = applicable; * = potentially applicable; - = not applicable.

[1]Includes solar stills.

the ONERSOL-designed heaters. Similarly, the LES (Solar Energy Laboratory) at Bamako has been instrumental in designing water heaters which are now sold throughout Mali and are being used in homes, hospitals, and schools.

Solar Distillation

Solar distillation units can be used to remove salts from water. The basic design consists of a shallow covered trough. The water evaporates from the brine and condenses on a plate over the collecting trough. For a high-efficiency solar still one should have high solar radiation, high air temperature, low wind velocity, and a small condenser surface (Daniels, 1975).

The first known application of solar distillation was at Las Salinas in Chile in 1872. This unit functioned for thirty years without any problems (Middleton Associates, 1979).

Research is till needed to study use of locally available materials to bring down the cost.

Solar Evaporators

Solar evaporation can be used to obtain salt. The basic concept is to have a very shallow pond containing seawater exposed to the sun. In areas where evaporation exceeds rainfall, the water is evaporated and eventually, the salt is crystallized. The rural people in countries such as Senegal obtain most of their salt from this process. The process is very labour intensive and research at present is involved in better methods of collecting the salt.

Solar Drying

Sun-drying of food crops has been practiced from times dating back to primitive man The product was usually spread on the ground to expose it to direct solar radiation and wind. The method was not too acceptable since:

1. there is no control over the drying process
2. the food product is often contaminated by dust and sand floating in the air
3. since drying took several days, the drying during the day and rewetting at night tends to deteriorate the product
4. insects, birds, rodents, and animals attack the product with resultant losses of considerable magnitude.

Drying requirements. The purpose of drying should be to dry a food product to a moisture content at which it will store for a given time period but at a quality acceptable to the consumer. The moisture content of the food product establishes a relative humidity in the air surrounding the product, which may support the growth of moulds. Generally, the minimum r.h. below which moulds cannot survive is 65-70 per cent and corresponds to the following moisture contents: Grain 13-15 per cent; Dried fruit 14-26 per cent; Dried fish 25-40 per cent.

The only alternative available to many of the Third World countries other than drying is to store the product fresh. Table 8 gives the storage requirements and properties of perishable products and serves to show why in many cases, drying of food is necessary.

Types of dryers.

1. Drying floor--The simple improvement over drying on a dirt surface is a concrete

TABLE 8 Storage Requirements and Properties of Perishable Products (Ashrae, 1967) ASHRAE

Commodity	Storage Temp.	r.h.	Storage life	m.c.
apricots	0	85-90	1-2 weeks	85.4
avocados	7-13	85-90	4 weeks	65.4
coconuts	0-2	80-85	1-2 months	46.9
coffee (green)	1-3	80-85	2-4 months	10-15
eggplant	7-10	85-90	10 days	92.7
endives	0	90-95	2-3 weeks	93.3
figs	0	85-90	5-7 days	78.0
fish	1-3	90-95	5-15 days	62-85
beef	0-1	88-92	1-6 weeks	62-77
mangoes	10	85-90	2-3 weeks	81.4
okra	10	85-90	7-10 days	89.8
oranges	0-1	85-90	8-12 weeks	87.2
papayas	7	85-90	2-3 weeks	90.8
sweet potatoes	13-16	90-95	4-6 months	68.5

platform. Drying is carried out by direct solar radiation and wind. The product to be dried is still of a very poor quality, but at least one has less sand and dirt in the final product than by drying on a dirt surface. The cost of the drying floor is minimal but due to the poor quality of the product it may not be cost effective.

2. Drying racks--Drying racks (platforms on poles) have been used for drying of meat, fish, fruit, vegetables, and unthreshed cereals throughout developing countries. This method is an improvement over a drying floor, since the product is not in contact with the ground. This results in fewer losses due to rodents, insects, animals, etc. Convection heat flow is better and therefore the drying time can be reduced. Depending on wind speeds, control of product temperature and subsequent product quality are quite good.

3. Drying cribs--Drying cribs are in effect closed racks. They have been tested and are being used in West Africa for drying of millet and sorghum. Attack from farm animals is negligible. Shields can be placed on the upright supports to keep away rats. Insect attack is primarily contained within the outer periphery of the crib. The cribs can be of any length and height, but cannot be more than 60-80 cm in width in the tropics. If more than this, drying takes too long and often moulds attack the grain. Drying is done by the wind.

The cribs have been made from bamboo or wire mesh. In Senegal, cribs for sorghum drying were made from Andropogon grass, and also from sorghum stalks. This type of crib ~~was~~ is good for at least two harvests and is very inexpensive. The maize crib using bamboo and/or wire mesh are rather expensive and have not really gone into extension, in spite of the fact that they have a long life.

4. Direct dryers--In the three above-noted methods of drying the product is exposed to flying insects, rodents, etc. By placing the product in a chamber, these can be kept out. In direct dryers, drying is accomplished by direct solar radiation and wind. The efficiency of the dryer depends on dryer design but it is a great improvement over previously discussed methods. The only concern I have with this type of dryer is that the drying process is hard to control so product quality is not always acceptable. Direct dryers are best not used for drying of food products.

5. Indirect dryers--In the use of indriect dryers, drying is accomplished by air heated in a plenum, passing through a drying bed. This type of drying process is easier to control than in direct drying and product quality is considerably better. This is the type of dryer that is most commonly used. A separate paper will discuss the design, operation, and maintenance.

CONCLUSION

This paper is meant to be an overview of agricultural applications in solar energy. It is the author's hope that the participants find this useful before the more detailed topics are discussed.

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