SOLAR ENERGY FOR AGRICULTURE

Review of Research

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This report reviews research underway on solar energy use in various agricultural applications: grain drying, heating and cooling of greenhouses and rural residences, heating livestock shelters, drying crops other than grain, food processing, and irrigation. Solar energy systems for agriculture are in an early stage of development; this study makes an exploratory economic assessment of current and prospective solar energy technologies.

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SUMMARY

Farm production depends greatly on petroleum-based fuels. Dwindling supplies of such fuels and their rising prices have focused attention on alternative energy sources, including solar energy.

This report reviews research underway on solar energy in various agricultural applications: crop drying, heating and cooling greenhouses and rural residences, heating livestock shelters, food processing, and irrigation.

Solar energy technology for agriculture has advanced rapidly and has several promising applications, especially in crop drying and the heating of animal shelters. But, the introduction of solar energy to an agricultural system built around fossil fuels and a cheap energy policy will not be easy. For example, the high initial costs of solar energy systems will discourage adoption. And, grain drying, usually done quickly at high temperatures to keep up with tight harvesting schedules, would be difficult to adapt to a low-temperature, slower drying system based on solar energy. Plant breeding to develop grains which will stand longer in the field after maturity may be necessary to permit slower harvesting schedules.

Fixed costs associated with each unit of energy produced from a solar collector will decline as use of the collector is extended over more months of the year and to other enterprises. Multiple use of the collector, by lowering costs per Btu of energy produced, makes good economic sense and must be emphasized.

The overall impact of solar energy in agriculture will be limited until dramatic technical breakthroughs to lower costs are achieved. But, for certain segments of the agricultural industry threatened by fuel shortages, such as greenhouse production, the sun represents an economically viable energy alternative for the future.

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INTRODUCTION

The growing energy shortage could threaten the longrun productivity of U.S. agriculture. Solar energy, the subject of this report, could help ease that threat.

The U.S. food and fiber production system is highly energy intensive and very vulnerable to fuel shortages and rising energy prices. The system uses over one-fifth the total energy consumed by the American economy (1). 1/ Energy consumed in farm production amounts to about 1 million barrels of crude oil per day and could grow to as much as 1.5 million barrels per day by 1990.

The two major farm production uses of energy are field machinery and transportation; they use about 55 percent of total energy used in farm production (12). Gasoline, diesel fuel, natural gas, and LP gas account for over 88 percent of total energy used in farm production (11). A shift to solar energy technology would require a great deal of adjustment in the U.S. food and fiber system.

This report reviews research underway on solar energy use in various agricultural applications. Solar energy systems for agriculture are in an early stage of development, which limits this study to only a preliminary economic assessment of current and prospective solar energy technologies.

Solar energy strikes the earth at a rate of about 2,000 Btu's per ft^2 each day. All of the energy required in U.S. agricultural production each year would fall on an area 10 miles square. The equivalent of all the U.S. energy requirements projected for 1985 will fall as sunshine on an area 80 miles square during that year.

Solar energy has a number of disadvantages when compared with conventional energy sources. Reece gives this comparison:

> "Petroleum-based fuel, being fluid in nature is easy to handle, transport, and store. Equipment for releasing and applying heat from fuel is simple, low in cost and easy to control. Petroleum fuels are highly concentrated forms of energy. Large amounts of heat can be released with a comparatively small burner; large quantities of energy can be stored indefinitely in comparatively small containers. Economically, the major cost in use of petroleum is for the fuel itself; equipment to apply the fuel is usually a minor cost. Solar energy is altogether different. It is extremely diffuse; large pieces of equipment are required to capture it, and the amounts captured may be surprisingly small. Solar energy usually is converted directly into heat as it is collected. Therefore, to store it for future use generally requires a large mass of some material such as water or rock for storing significant amounts of energy. Economically, most of

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1/ Underscored numerals in parentheses refer to items in Reference section.

the cost of solar energy is for the equipment to capture and store it; the "fuel" itself is free of charge." (23).

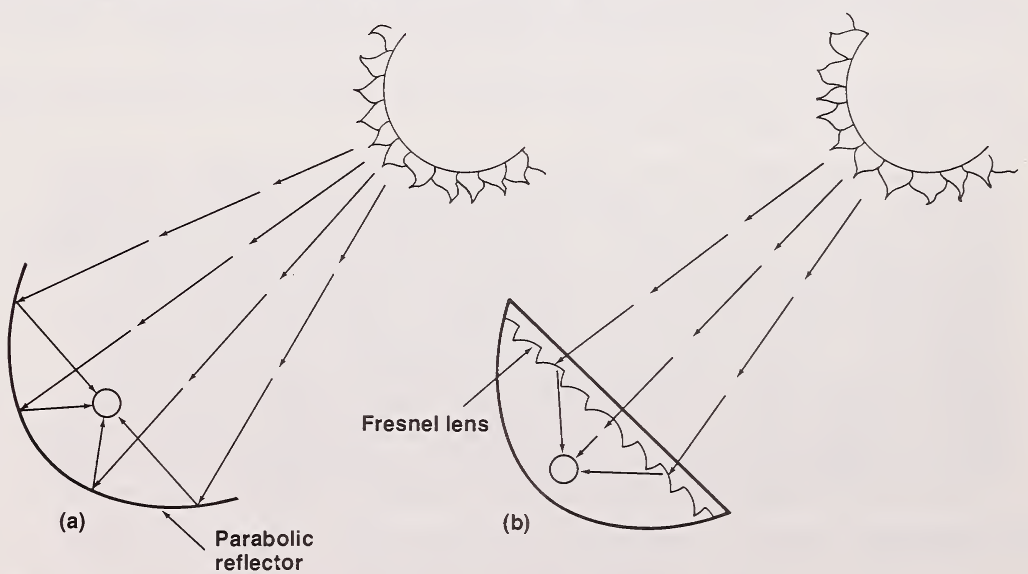
There are two ways to directly trap and use solar energy. One is to let sunrays fall on some type of absorber plate which converts the sun's radiant energy to thermal energy. This energy can be used to heat either water or air which, in turn, can be used to heat or possibly cool a building, dry grain, and cure tobacco, or, with concentrated heat, drive a turbine. The other method is to allow sunrays to fall on an array of cells which directly convert radiant energy to electricity. Such photovoltaic cells convert the absorbed photons of sunlight into electrons. Photovoltaic cells formed the solar panels which provided electricity to the Skylab space mission. Most of the work on agricultural applications of solar energy centers on solar thermal energy--the direct use of solar heat without conversion to electrical or mechanical energy.

The basic component of a solar energy system is the collector. There are two general classes: concentrating or focusing collectors and nonconcentrating or flat-plate collectors. The concentrating collector uses mirrors and/or lenses to concentrate sunrays on an absorber. The absorber is usually a tube upon which the sunlight is focused. The tube contains a fluid which is pumped from a storage tank, through the tube absorbing the heat, then back into the tank. Depending on the size of the reflector array and the concentration ratio, very high temperatures can be achieved.

Two types of concentrating collectors are shown in figure 1: a parabolic mirror that reflects and concentrates the direct sunlight into a narrow band on the absorber tube (fig. 1a) and a fresnel lens that can be used to concentrate radiant energy onto an absorber (fig. 1b). Concentrating collectors must be motorized for tracking the sun as the earth rotates; the band of focused light must be kept on the absorber tube for the collector to operate most efficiently.

Figure 1

Two designs of concentrating solar collectors

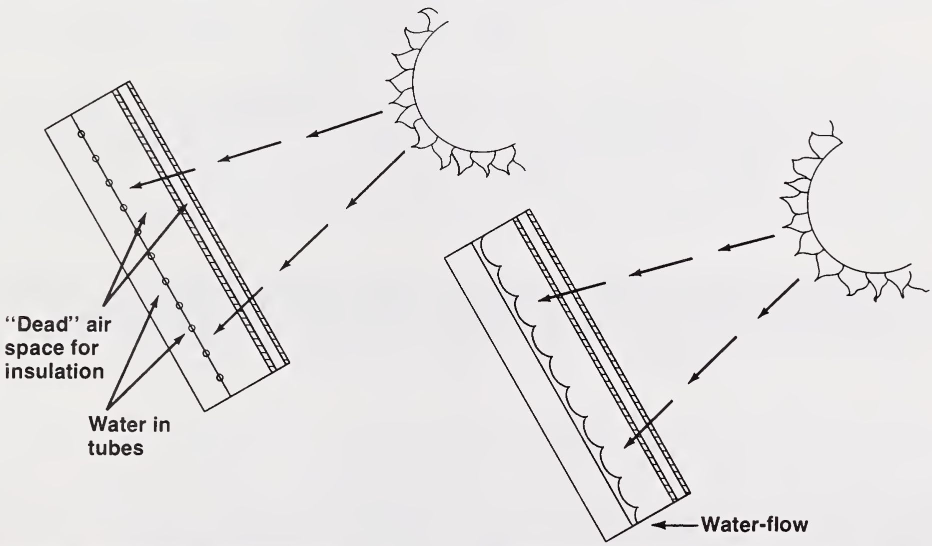


The more common type of collector for most agricultural applications is the non-concentrating or flat-plate collector. The principal component is the absorber plate, usually made of either copper or aluminum and painted flat black to improve thermal absorbency. Clear plastic or glass is normally used on the face of the collector. The back is insulated with a rigid foam or fiberglass to reduce heat loss. This type collector uses either water or air as the heat transfer medium.

Attached or inlaid water tubes usually form an integral part of the absorber plate in a hot water system. The water passes through these tubes, picks up heat, and carries it out of the collector. Variations of this design may have water flowing across the surface of the absorber plate or use black plastic or rubber, instead of metal, for the absorber plate. Fluids other than water may also be used as the heat transfer medium. Examples of hot water flat-plate solar collectors are shown in figure 2.

Figure 2

Flat-plate solar collectors with water as heat transferring medium

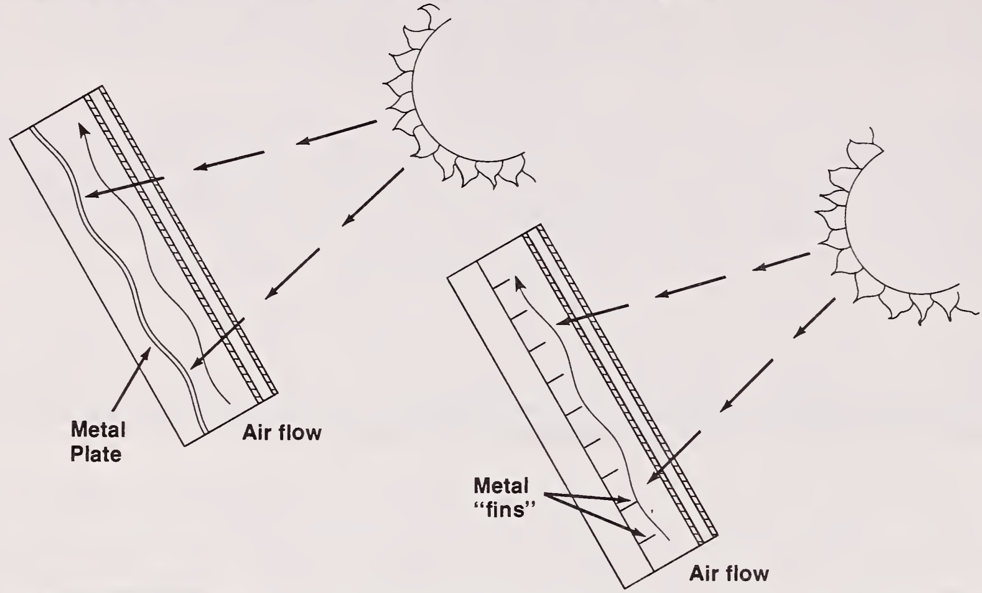


Air is heated as it passes over or through the metal or plastic surfaces of the absorber plate in a hot air system. The rate of heat transfer depends upon the amount of the surface area of the absorber plate. A good hot air collector requires a large surface area for the absorber plate. Fins or corrugations are frequently used to increase this surface area. Examples of hot air collectors are shown in figure 3.

Some method of heat storage is usually required in combination with the collector. Insulated water tanks are used with hot water systems. An enclosed bed of rocks is normally used for heat storage in hot air systems. Water and rocks can retain heat from 3 to 5 days depending on the amount of insulation and ambient conditions.

Figure 3

Flate-plate solar collectors with air as heat transferring medium



Although basic designs of solar collectors, heat exchangers, storage techniques, and other components of solar energy systems are fairly well established, practical systems for use in specific agricultural applications are still being developed. Much complex engineering is needed.

SOLAR RESEARCH IN AGRICULTURE

Research on solar energy technology and use in agriculture is being carried out under several federally funded programs; there is also independent research by various State agricultural experiment stations, universities, and private firms. A large part of the effort is centered in a program administered by the U.S. Department of Agriculture (USDA) cooperating with the U.S. Department of Energy (DOE) and a number of State agricultural experiment stations. Emphasis is on applications where solar heat can be substituted directly for heat generated from the combustion of fossil fuels without intermediate conversion of the heat to electrical or mechanical power. There are five major application areas: (1) grain drying, (2) heating of livestock shelters, (3) heating and cooling greenhouses and rural residences, (4) drying of crops other than grains, and (5) food processing applications such as dehydration and water heating. Development of solar energy systems for pumping irrigation water is also underway. This application involves the conversion of solar energy to electrical or mechanical power in contrast to the applications above which make direct use of solar heat.

Grain Drying

Grain drying has increased sharply in recent years with the advance in grain harvesting technology. An estimated 65 to 70 percent of the corn crop is now mechanically dried. All rice production and 10 to 20 percent of soybean and grain sorghum production may receive some mechanical drying at the farm or commercial elevator level. Grain drying is an energy intensive farm operation that will be increasingly affected by diminishing supplies and increasing prices of fossil fuels.

The equivalent of around 650 million gallons of LP gas is used annually in grain drying, with over 90 percent of this used for corn alone. LP gas is the principal fuel used, although some natural gas and electricity also are used.

A range of different solar collector designs for grain drying have been evaluated, from the rather simple, relatively inexpensive, air-inflated plastic tube collectors to more sophisticated concentrating collectors. The practicality of collectors that form part of the wall or roof of the storage structure also is being examined.

Conventional grain drying systems may be divided into two basic types: (1) high-temperature, high-speed systems, and (2) low-temperature, in-storage drying systems. Most grain is now dried with high-temperature, high-speed systems. These may be either batch or continuous-flow systems designed for easy, fast movement of the grain into and out of the drying chamber into storage.

Low-temperature grain drying systems use low levels of heat over extended periods to remove moisture while the grain is held in the storage bin (13). Such systems can operate on intermittent or variable levels of heat input and are designed to maximize the use of heat in natural air. Solar energy appears more feasible for use with this type of system than with high-temperature systems. Solar collectors for a low-temperature system are more efficient and can be constructed at substantially less cost.

Parker and others concluded that use of solar energy for high-temperature grain drying cannot economically compete with LP gas at current gas prices (22). The projected gas savings were not enough to justify the capital investment required for a high-temperature system, especially at high rates of interest.

Heid examined the economic feasibility of eight solar grain drying systems (17). The systems were selected as a sampling of the experimental models then under study in the North Central States. Systems included in the study ranged from simple, homemade designs with rather short life expectancies to more durable commercial designs. Fixed costs of the eight systems ranged from 6.6 to 26.6 cents per bushel of grain dried (table 1). A homemade collector can be constructed for between $1 and $2 per square foot of collector surface at this stage of technology. While this is cheaper than current commercial models, homemade collectors are not necessarily the most economical in the long run because of the difference in life expectancy. Variable costs ranged from 1.5 to 8.4 cents a bushel among the various models studied. Estimates of total costs for the lowest cost solar systems show them to be as low as or lower than costs for some conventional dryers.

Haas and others compared costs of solar and alternative systems for drying wheat (14). Total projected costs of drying wheat from about 25-percent moisture content to 13.5 percent were less using solar-heated air than with air heated by LP gas or a combination of air heated by LP gas and unheated air.

Use of solar energy is most promising with low-temperature, in-storage drying systems, particularly in the warmer, more humid parts of the Corn Belt (30). Added heat is needed in this area to lower humidity so drying can proceed to a moisture level safe

Table 1--Estimated costs of owning and operating eight selected solar grain drying systems, 1976

Item	Rock-heat storage (Kansas)	Flat plate (Kansas)	Inflated tube (Kansas)	Suspended plate (Iowa)	Wraparound (S. Dak.)	Intensifier (S. Dak.)	Air supported (Ohio)	Multi-use (Colorado)
	Cents per bushel							
Fixed costs	19.7	11.4	9.1	6.6	7.8	26.6	9.1	17.0
Variable costs	3.5	6.5	3.4	8.4	2.5	6.9	3.7	1.5
Total costs	23.2	17.9	12.5	15.0	10.3	33.5	12.8	18.5
	Bushels							
Amount dried	1,502	5,029	1,548	3,440	5,200	1,300	6,720	260
	Percentage points							
Points moisture removed	11.2	11.4	11.5	5.4	5.5	16.4	5.7	10.5
	Cents							
Total variable cost per bushel per each percent of moisture removed	.3	.6	.3	1.6	.4	.4	.6	.1

Source: (17).

for storage within a reasonable time. Solar energy can be used to provide this added heat. Drying can be completed without added heat most of the time in less humid areas, such as Kansas. Solar energy may not furnish enough extra heat to assure adequate drying in more northern locations.

A comparison of solar and conventional grain drying is between a sure, dependable drying method and one susceptible to the weather. When solar energy is needed most, it is least available. Total reliance on solar energy will likely be limited to a solar grain drying belt, and even then a backup system using conventional fuels will likely be warranted. Solar energy use for grain drying in other areas may be considered a supplement to conventional fuels or aeration.

Research is needed on several questions relating to solar grain drying, including: (1) What geographic areas are most favorable to solar energy use? (2) What are the optimal combinations of solar energy, aeration, and fossil fuels? (3) What are the potential savings in solar collector investment costs as technology improves and mass production occurs? (4) What are the economies of size as solar drying is used on larger farms? Most experiments have focused on relatively small 40- to 50-acre enterprises. (5) To what extent can the large fixed investment in solar energy technology be spread over several uses?

Greenhouse/Rural Residence

There are about 9,000 acres in U.S. commercial greenhouse production of florist, nursery, and vegetable crops. The equivalent of nearly 600 million gallons of LP gas is used annually for heating in this fossil fuel dependent industry. Lack of fuel for a few hours at a crucial time can completely destroy a season's production. The uncertainty of fuel supplies coupled with rapidly rising fuel costs may lead greenhouse operators to consider solar energy as a supplemental heat source.

Among the solar research projects relating to greenhouses are projects in South Carolina and Arizona focusing on greenhouses as part of residences. Structures in these projects are designed to conserve energy (by mutual exchange and use of heat between the two structures), optimize use of solar energy for supplemental heat, and produce more food on less land. One greenhouse/residence has been constructed and two more are planned by the U.S. Department of Agriculture rural housing research unit at Clemson, South Carolina. The completed structure combines the solar heating of the greenhouse itself with additional solar collectors. A control greenhouse, conventionally heated, is also growing a crop to monitor horticultural performance of the solar greenhouse. A second greenhouse/residence, now under construction, will use only the excess heat from the greenhouse (no separate solar collectors).

The other greenhouse/residence research project, at the University of Arizona, has developed the "clear view" solar collector to incorporate into the greenhouse structure. This collector works like a venetian blind. Louvers, housed between two panes of glass forming the south wall, absorb heat because of their flat-black surface. Air is either forced or drawn by convection between the glass panes, passed over the heated louvers, and heated and ducted through the building. The prototype under test is a small greenhouse attached to several offices. A modification of this collector, made of heat-absorbing glass, is also being tested.

Cornell University's solar research focuses on three areas: mathematical modeling, energy conservation, and heat storage. Most of the emphasis is on heat storage: for greenhouses with raised benches, stones under the benches hold the heat. Another system uses water instead of stones as the heat-holding medium. Components of a third system are a matrix of corrugated pipes within a long block of soil beneath the greenhouse.

The Cornell greenhouse itself is the solar collector. Excess solar energy is collected in the air in the top of the house. The energy is then pumped through the pipe network and absorbed by the soil. Cool night air from within the house will extract energy from the soil to heat the house. The large block of soil will also receive long-term warming during the summer and give off heat in the late fall and early winter. Unusual cloud cover over Ithaca since 1977 has interrupted the flow of results from this project.

Colorado State University also employs soil heating in its greenhouse solar heat research. Space heating is the primary function and is provided by solar energy whenever the collector temperature is sufficient. When the collectors operate at a lower temperature or when the rock heat storage unit is fully charged, the system shifts to soil heating. If the collector operation temperature is too low for soil heating or if the soil heat is fully charged, the system shifts to irrigation water heating, the lowest temperature load. The complete system began operating in January 1978.

Heat exchangers for solar hot water systems are being studied by Rutgers University scientists. Vertical curtain heat exchangers, now under study, hang from under a short bench in the center of the house. Solar-heated water flowing down these sheets warms the air. Different materials for the curtains and various surface embossing patterns (to disperse the flowing water) are being studied. New Jersey weather for the 1977-1978 winter limited data collection and low-light levels have affected the crop.

Ohio State University engineers are applying the technology of solar ponds to space heating. Natural solar ponds, discovered in Hungary in the early 1900's, are fed, theoretically, from underground saltwater springs with rainwater periodically flushing the surface. This gives a pond with gradients: solar-heated brine at the bottom and fresh surface water. The density of the salt water prevents its circulation to the top. Temperatures of up to 80° C (176° F) have been recorded in Hungary's ponds.

The Ohio research has developed a way to artifically establish and maintain the salt to fresh water gradients in a solar pond. The Ohio pond is 560 m^3 (747 yd^3) with insulated walls and black polyethylene liner. Heat energy can be collected and stored in all seasons in this system. The bottom half of the pond can reach boiling temperatures after a full summer. The full system began operating in the winter of 1977.

A breakthrough is needed in lowering collector costs. Typical costs are from $5 to $10 per ft^2 which seems to rule out prefabricated collectors under present conditions. The lowest cost system so far seems to be the Rutgers design. Total investment, including labor, is between $3 to $4 per ft^2 of greenhouse. This is less than $0.50 per ft^2 per year.

Animal Shelters

Research on solar heating of animal shelters centers around three applications: poultry brooding, swine farrowing, and dairy milking. Heating of animal shelters appears to be one of the more promising uses of solar energy because of the longer period over which the facility can be used.

Poultry

The poultry and egg industry, 80 percent of which is concentrated in the South Atlantic and South Central States, has excellent potential for solar heating. LP gas supplies over 50 percent of the industry's Btu requirement for poultry production. Over 70 percent of the energy used in poultry production is used for brooding (24). For the first 2 or 3 weeks of a baby chick's life, supplemental heat is especially critical; the industry is especially vulnerable to energy shortages and rising costs at this production stage. Some supplemental heat is needed for brooding throughout the year; the peak requirement occurs in the winter.

Most of the fuel used for brooding is LP gas although some fuel oil, natural gas, electricity, and coal are used. Brooding broiler chicks alone requires about 60 percent of the total LP gas used in poultry production (24).

Current design and evaluation of solar energy systems for poultry production center on roof mounted flat-plate collectors. These use either heated water or heated air.

Broilers: USDA engineers at Mississippi State University have designed a solar energy collection and storage system for use in conjunction with advanced energy conservation techniques in broiler production (23). During an 8-week midwinter test, the system reduced fuel requirements by 73 percent, from 30.5 gallons of LP gas per 1,000 broilers to 8.2 gallons. Previous research had already demonstrated that limited area brooding, adequate insulation, and controlled ventilation could reduce midwinter fuel requirements by two-thirds, from around 90 gallons of LP gas per 1,000 broilers to around 30 gallons. Through a combination of solar energy and special energy conservation techniques, fuel requirements for raising broilers were thus reduced by 90 percent. Solar heat in two subsequent 8-week tests furnished 95.5 percent and 75.0 percent of the energy required for heating.

Two types of solar collectors were used in the design of the system. One type provided daytime heat by warming the daytime ventilation air directly. Another type heated water which was then used to heat nighttime ventilation air.

Other work at Mississippi State has involved converting the roof of a conventional poultry house into a solar energy collector and applying the collected heat to the heating of a caged-layer house and the drying of manure from caged layers. Another project there uses a prefabricated metal building with an integral solar air heater in the south wall to heat ventilation air for growing out broiler chickens. A rock bed is used as the heat storage medium.

Engineers at Georgia Tech, using a south-facing hillside just below a 25,000-bird commercial broiler house, constructed a 16 x 208 feet solar collector on a 30-degree slope (16). Air moves by convection from the collector through pipes into the broiler house. Sixty percent of the heat requirement of the broiler house was supplied by the solar collector during a test brooding period in late fall. Work continues at Georgia Tech on the design of other low-cost solar energy systems suitable for existing commercial broiler houses.

USDA engineers at Athens, Georgia, have constructed two identical controlled-environment broiler houses for solar heating studies (9). The brooding heat for one house comes from a solar energy system with LP gas as backup, while heat for the other house comes entirely from LP gas. Studies are being made to determine (1) fuel saved in different seasons using a solar-supplemented brooding system, (2) efficacy of different systems for delivering heat to brooding space, (3) optimization of collector area and heat storage, and (4) economies of solar heating broiler houses.

University of Maryland researchers use a 1,000-bird environmental research chamber to carry out solar energy brooding studies (6, 16). The solar energy system provided three-fourths of the energy required for heating a limited area brooding chamber in initial tests. The supplemental heat required for the chamber was only one-fifth that required in a conventionally heated, full-area brooding chamber. Solar collectors are used in these studies to heat air which is passed through a heat exchanger to heat water. The hot water is used to store heat for overnight use and to introduce heat into the brooding chamber through aluminum-fin convectors.

University of Maryland researchers have examined the economics of solar energy for broiler houses. Simulation techniques were used to generate data on weather, available solar energy, and building heat requirements. Performance of 150 different combinations of size and quality of solar collection and storage systems were analyzed (4). The most economically feasible system, assuming a 20-year life cycle, provided about 42 percent of the required heat and became less expensive than propane after 13 years. A highly speculative assumption used in the analysis was that propane prices would double the second year and increase 15 percent annually thereafter. The most economically feasible system for a 15,400-bird broiler house consisted of a 2,000 ft^2 collector and a 6,000-gallon heat storage component. The initial purchase and installation cost of the system was estimated to be $14,667 or about $7.30 per ft^2 of collector area (1975 costs).

Auburn University workers are determining the most economically feasible method of transferring stored solar heat to the broiler brooding area (3). Fin tube convectors, concrete slab brooders, and heated ventilation air show promise. Flat-plate collectors mounted on top of the broiler house are used (fig. 4). Heat is stored in water and electric water heaters are used as backup when solar heat is inadequate.

Figure 4--Solar energy research and demonstration facility for broilers at Auburn University showing roof-mounted flat-plate collectors.

An economic study, made as part of the Auburn effort, found solar energy would not be competitive with LP gas until the price of LP gas reached 85 cents a gallon (versus the then current 36 cents) (35). Simulation techniques, not actual experience, generated the data in this analysis; they should be considered preliminary. The study compares five production systems, three using LP gas and two using solar energy with LP gas hot water heating as backup (table 2).

Table 2--Investment, fuel savings, and grower costs of five broiler brooding systems

System	Investment per 1,000-bird annual capacity	Fuel savings compared to system 1	Grower costs per 1,000 birds
	Dollars	Percent	Dollars
(1) LP gas heat, whole house brooding	355	-	79.75
(2) LP gas heat, partial house brooding	352	55	71.24
(3) LP gas heat, multistage brooding	291	55	55.86
(4) Solar heat, partial house brooding	469	75	77.55
(5) Solar heat, multistage brooding	376	80	65.37

Source: (35).

System 1 (see table 2) represents the conventional method under which most broilers are now produced. System 2--partial house brooding--illustrates what can be done to conserve energy using conventional fuel. Partial house brooding consists of partitioning off and using only part of the house during early growth stages when most heat energy is required. In multi-stage brooding (systems 3 and 5 in table 2), the chicks are moved out of the brooding chamber every 3 or 4 weeks and a new batch started. This permits more efficient use of capital and energy required in the brooding chamber. However, disease problems and possibly increased transportation and handling costs for the processor/integrator may offset advantages of this management system.

University of Delaware engineers use computer simulation to optimize collector and storage design for a solar energy system for a broiler house. A prototype system will be constructed to verify the computer simulation. Costs and supplemental heating loads will be evaluated.

Layers: Increasing feed costs in recent years has stimulated interest in maintaining a warmer in-house environment during winter months as a means to increase feed use efficiency. A low-cost solar energy system to provide a more optimum in-house environment for maximum feed efficiency is being developed at Michigan State University. The system can be used to dry manure from the laying house during the summer.

Turkeys: An equivalent of about 380 gallons of LP gas is required to produce 1,000 turkeys. University of Minnesota engineers are seeking ways to use solar energy to heat turkey housing during the winter. A hydronic solar heating system has been installed on a commercial turkey farm at Willmar, Minnesota. Data from this installation will be used to verify a simulation model, which is being used to coordinate system design, weather variables, and production schedules to optimize solar energy use.

Swine

Solar energy could provide heat for all stages of swine production, especially farrowing and nursery. Supplemental heat is essential during the early stages of a baby pig's life. LP gas heaters or electric heat lamps are normally used to supply the required heat.

Harris and others provide a rough basis for estimating the amount of heat required for this purpose (15). There are approximately 9 million litters of pigs produced in the United States each year; about 80 percent require supplemental heat. Each litter requires about 1,500 Btu's per hour for approximately 35 days. This amounts to a total of 9.07×10^{12} Btu's or the equivalent of 98.6 million gallons of LP gas. Because of rising feed costs, more growers are becoming interested in providing supplemental heat for growing and finishing areas to improve feed conversion efficiency.

Besides research on conventional flat-plate collectors, several alternative collector designs are being studied. The demand for heat is greatest in winter when the sun is lowest on the horizon; vertical, south-facing walls may thus be effective collectors. Kansas State University researchers have constructed a 16-inch thick wall on the south side of a swine farrowing barn to serve both as a solar heat collector and as a heat storage medium. The 380 square feet of wall surface are painted black and covered with a double layer of plastic film. The wall is constructed of solid concrete block with gaps in the vertical joints to provide openings for air to move through the wall. Ventilation air passes through the collector and then through the wall before entering the farrowing chamber. The concrete block storage also can be used for summer cooling by flushing heat out of storage with cool night air and then cooling ventilating air during the day.

The Kansas system could save 570 gallons of LP gas each year, according to a one-season test. Average annual cost for the system was estimated at $298 including repairs and maintenance, taxes, interest, and a 10-year amortization of investment. On this basis, the system would be economically feasible when the price of LP gas reaches 52 cents per gallon (compared to the Manhattan, Kansas, price at the time of less than 30 cents per gallon). Several hog producers in Kansas have already adopted the system in their commercial operations. Purdue University is testing the system under Indiana conditions.

University of Nebraska engineers are testing the feasibility of using solar heat to provide a better environment and improve feed efficiency in a swine growing/finishing building (8). Flat-plate collectors mounted on the roof of a conventional modified open-front growing/finishing barn are used in the studies. The system uses an active floor storage system which eliminates need for fans to transport heat into the building at night. The Nebraska researchers also are investigating methods of using solar energy collectors to reclaim latent heat of vaporization from the swine building.

University of Missouri researchers are developing a heat transfer system to efficiently move heat from solar collectors to the farrowing chamber. Conventional flat-plate collectors are being used to provide heat to one unit of a two-unit swine farrowing house. The other wing is equipped with conventional electric heaters for comparison. The system is designed to use solar heated liquid to transmit heat to specially designed brooding pads and hovers in the creep area. Two 1,000-gallon and two 500-gallon underground insulated steel tanks are used to store heat.

Work at the Virginia Polytechnic Institute and State University centers on the use of waste treatment lagoons as solar energy storage reservoirs. The suitability of various types of solar collectors for heating lagoons and methods of recovery of the stored heat from waste lagoons through use of heat pumps are being studied.

South Dakota State University research on solar heating of swine shelters is being integrated with work on solar drying of shelled corn. A two-sided, diurnally tracking collector, with a curved reflector to intensify the solar energy collected, is being used in these studies. Native stone will be used to store energy. The economic feasibility of the system, both for individual applications and for multiple use, will be evaluated.

A new swine production research unit at Auburn University includes facilities for carrying out solar energy heating studies. Feasibility of a solar energy system in comparison with conventional energy sources for heating swine farrowing and nursery buildings are being determined. Solar energy is used to heat water which is circulated through the floors of the creep and nursery areas.

Dairy

Whereas thermal energy requirements for poultry and swine production vary with the age of the animal and with the season, large and more predictable amounts are required on a year-round basis in a dairy operation. Much of the energy use in a dairy is centered in the milking parlor. Nationwide, the energy equivalent of some 250 million gallons of LP gas is used in milking activities (28). Of this total, water heating uses 35 percent; milk cooling, 26 percent; milking, 22 percent; space heating and ventilation, 9 percent; and lighting, 7 percent.

Work is underway at USDA's research center at Beltsville, Maryland, and at the University of Arizona to develop a solar heating system to supply part of the energy requirement of dairy operations. Both projects seek to integrate solar energy with appropriate energy conservation and waste heat recovery systems. Recovery of waste heat from the milk cooling operation is stressed. Solar energy in both projects is being used for water heating and space heating in the milking parlor.

A milking parlor of a 200-cow dairy operation was retrofitted with a solar energy system in the Beltsville project. It employs 1,000 ft^2 of solar collectors mounted on the roof of the parlor (fig. 5). Four different types of collectors are being evaluated. Hot water from the collectors can be piped to a 10,000-gallon underground storage silo or used directly for heating or cleaning.

The average dairy farm could be converted to solar heat for as little as $4,500 or less if the farmer does much of the installation himself, the Beltsville researchers estimate. The cost of the system can be made up in fuel savings in 5 to 10 years.

A major advantage of applying solar energy to a dairy operation is that energy requirements are fairly evenly distributed throughout the year and the facility can be utilized year-round. Use of a solar heating facility is highly seasonal in most other agricultural applications, thus greatly increasing the investment cost per unit of solar energy used.

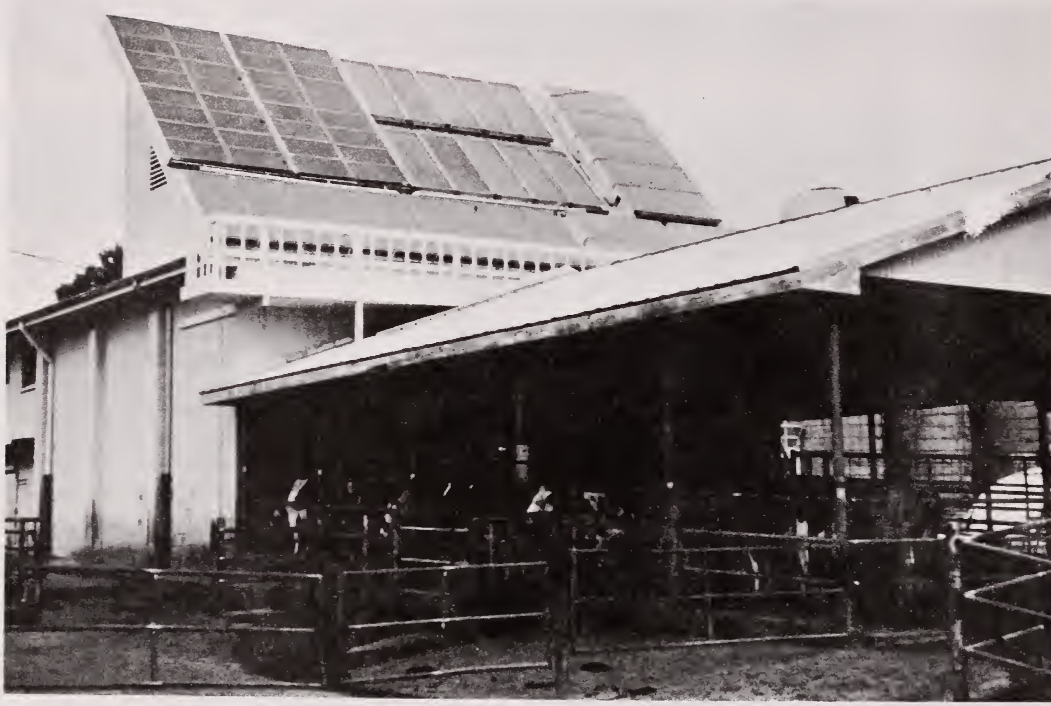
Crop Curing and Drying

This section considers the development of solar energy systems for tobacco curing, peanut curing, and forage drying. Combined energy use in these applications amounts to 49 trillion Btu's annually, the equivalent of 530 million gallons of LP gas.

Tobacco Curing

Tobacco is second only to corn in the quantity of fuel used to dry various crops. The two principal types of tobacco are flue-cured and burley which together account for over 90 percent of tobacco acreage. Burley tobacco is cured with natural air, normally

Figure 5--Solar collectors added to milking parlor at Beltsville, Maryland



without added heat. The flue-curing process involves gradual drying of fresh leaves over a period of 5 to 7 days under controlled conditions of temperature, moisture, and air supply. Temperatures as high as 77° C or 170° F are reached during the latter stages.

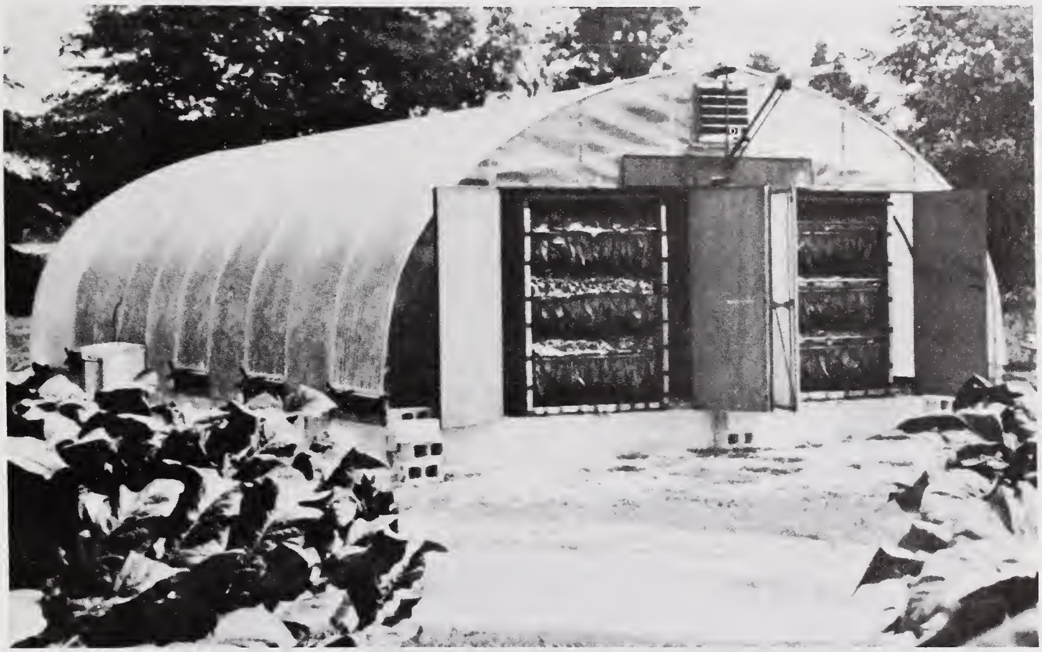
Flue curing of tobacco requires 32 trillion Btu's of energy each year, according to estimates by the Council for Agricultural Science and Technology (7). This is equivalent to 348 million gallons of LP gas. LP gas is the predominant fuel used although substantial quantities of fuel oil also are used.

Engineers at the Georgia Institute of Technology are working on the design of solar collectors suitable for tobacco curing. Work is underway at the University of Kentucky on field curing of tobacco under direct solar radiation, followed by curing with energy from solar collectors. USDA engineers at Tifton, Georgia, have constructed a multiple use solar energy system designed for several crops in sequence including tobacco, peanuts, and grains. Such a system also could be used to heat nearby worksheds or animal shelters during winter months.

North Carolina State University work has progressed on two distinct solar energy systems for tobacco curing. One of these involves development of a solar collector as an integral part of the roof on a typical bulk-curing barn. Air passing through the collector is preheated by solar heat before being passed on to the furnace for further heating and distribution through the bulk-packed tobacco. This type of bulk barn is in commercial production. Compared to a conventional bulk barn, fuel savings of around one-third are reported by the manufacturer of the solar barn.

The other experimental system represents a much more substantial departure from current tobacco curing practices. It is an ordinary greenhouse structure adapted for curing tobacco (fig. 6) (19). A metal framework is placed inside the greenhouse to hold the bulk-curing racks. The framework is then enclosed with black, heat-absorbing panels. The solar heat generated by the "greenhouse effect" supplies 30 to 40 percent of the heat required in the curing process. The cost of the complete prototype structure and auxiliary equipment is about the same, on an equivalent capacity basis, as a conventional bulk curing barn, according to the developers. Thus, the 30- to 40-percent saving in fuel would represent a net saving in curing costs. A commercial version of this greenhouse curing barn is available.

Figure 6--Greenhouse bulk curing barn filled with tobacco



An attractive feature of this system is that the greenhouse would have post-curing season uses after disassembly and removal of the bulk-curing racks. Researchers at North Carolina State University have devised systems to raise tobacco plants and dry peanuts in the greenhouse. Winter vegetables or other greenhouse crops might also be grown in the off-season.

Peanut Curing

Freshly dug peanuts contain too much moisture for safe storage. They are left in windrows to partially sun-dry for several days before being combined and loaded into field wagons. The wagons can be attached to a mechanical dryer to complete the drying without unloading the peanuts. Drying requires careful control to maintain quality. Too rapid drying at high temperature can cause splits and loss of flavor. Drying too slowly may allow mold growth and contamination by aflatoxin, a toxic byproduct of the mold. Peanuts found to contain aflatoxin must be used for oil stock and the meal is relegated to fertilizer use. Because of the aflatoxin problem, there has been some trend recently toward eliminating the relatively slow windrow drying and relying completely on mechanically assisted drying.

Virtually all peanuts receive some artificial drying. LP gas is the principal heat source; the amount used may vary from 4 to 10 gallons per ton depending on the amount of moisture to be removed and ambient conditions. Assuming an average of 6 gallons per ton, the 1977 peanut crop of 1.8 million tons would have required 10.8 million gallons of LP gas.

USDA engineers at Tifton, Georgia, compared two solar energy systems for drying peanuts with a conventional LP gas system. In one system, water was heated by solar collectors and stored in tanks, then used to heat the air for drying. Supplemental heat was provided by an LP gas burner when solar heat was inadequate. In the second system, air was heated by a solar collector and used directly for drying with no energy storage. Several types of solar collectors were constructed and their relative effectiveness evaluated in both systems. The solar-heated water system with heat storage supplied about 60 percent of the energy requirements for drying peanuts while the solar-heated air system with no storage supplied about 50 percent. Results of these experimental studies were used to construct a prototype commercial system (fig. 7). The prototype is being evaluated for multiple purpose use, including tobacco curing and grain, forage, and peanut drying.

Figure 7--Multiple-use solar curing and drying facility at Tifton, Georgia

Georgia Institute of Technology engineers have constructed and tested three types of low-cost solar collectors to determine suitability for peanut drying. They are a black film hot air collector, an integral rock storage and collection system, and a shallow solar pond collector. The first two designs are the most promising. The designer aimed for inexpensive materials and easy onsite construction by a farmer.

Oklahoma State University researchers are developing practical systems for storing solar energy for use in drying and curing peanuts. A 72,000-ft^3 solar energy storage pond will be heated to approximately 43° C (100° F) by direct insolation, with supplemental heat from a low-cost, flat-plate collector. The heat equivalent of approximately 650 gallons of LP gas--enough to dry 100 tons of peanuts--can be stored in the pond to be ready for use at the beginning of the peanut drying season.

Oklahoma State researchers are also using porous matrices as absorbers for solar collectors. The high ratio of heat transfer area to volume of such materials should result in higher heat transfer rates than conventional flat-plate collectors, less heat loss, and, consequently improved collector efficiency.

Research at Texas A&M University centers on the use of a solar-powered modified heat pump to dry and cure peanuts. This system would result in a closed-air cycle with minimum energy losses to ambient air. Air leaving the drying peanuts would pass over the evaporative coils to remove moisture, then to the condenser unit to be reheated before being passed back through the peanuts. Since this should result in minimum energy losses to ambient air, the system offers highly efficient drying.

Forage Drying

Energy required for drying forages in the United States each year has been estimated at around 16 trillion Btu's, the equivalent of about 170 million gallons of LP gas (29). Practically all of this energy is used by the alfalfa dehydration industry to produce dehydrated alfalfa pellets and meal. Alfalfa dehydration is a very energy-intensive process requiring 10.5×10^6 Btu's per ton, the equivalent of 114 gallons of LP gas.

The Midwest Research Institute, Kansas City, Missouri, has designed a solar energy system for drying alfalfa in rotary dryers (10). The system design calls for 5,700 ft^2 of flat-plate collectors and 5,800 ft^2 of tracking concentration collectors. The proposed system is designed to provide preheated air at 149° to 204° C (300° to 400° F) to a rotary flame furnace. The preheated air would then be raised to the required temperature of 982° C (1,800° F) by a natural gas flame. Solar energy could provide about 13 percent of the heat required. The institute estimates that energy consumption by rotary drying equipment of this type used in processing a wide range of industrial and agricultural products exceeds 1.5×10^{15} Btu's per year.

The feasibility of drying forage with solar energy to produce several high quality feed additives is being explored at the University of Colorado. Three types of forage products (whole alfalfa, alfalfa tops, and grass clippings) will be processed in three ways (field curing, conventional high-temperature dehydration, and solar dehydration) to produce nine endproducts. These endproducts will then be evaluated, in the laboratory and by feeding trials, to determine the effect of the treatments on the product's composition and nutritional value.

University of Tennessee researchers are exploring the use of solar energy to dry conventional and large hay bales and stacks of hay (2, 18). Hay quality hinges on suitable weather conditions under conventional field curing. If solar energy could be used economically to dry high-moisture bales, the timeliness of harvest operations and the quality of hay could be improved. Two types of solar collectors are being used in the Tennessee studies. One is designed into the roof of an existing barn using the corrugated metal roofing painted flat black as a bare-plate collector with air ducts constructed underneath. The other collector is a free-standing, suspended plate collector with black polyethylene as the absorber surface. The large hay packages are placed on metal frames over solar heated air discharge ports in the floor.

Food Processing

The food processing sector consumes around 5 percent of total U.S. energy requirements. Such applications as process water heating, wash water heating, drying, dehydrating, concentration, cooking, and low-temperature steam account for a major share of this energy use. Solar thermal systems could supply a part of this requirement.

Direct use of thermal sun energy to dry and preserve food was one of the earliest methods of food processing. It is still widely used today in many parts of the world to dry raisins and other fruit, coffee, cocoa, fish, and other food materials. Improved use of solar radiation and other climatological factors could produce a higher quality, more evenly dried product in less time.

Six projects were funded under a 1977 USDA-DOE solar energy program in food processing. Two of these were concerned with solar energy systems to supply part of the hot water requirements of meat, milk, fruit, and vegetable processing plants. Hot water requirements of selected plants were determined and the compatibility of solar energy systems with food processing systems were investigated. Economic feasibility of solar energy in food processing was included in the study.

Another project in this program investigates the use of solar stills to dry beef packing plant paunch (undigested food in slaughtered ruminants) as an example of a food processing byproduct. Development of environmental guidelines is forcing the meat industry to consider alternatives in plant waste disposal. The basic solar still design consists of a transparent sheet forming an air-tight seal over a quiescent chamber filled with an aqueous mixture. Solar radiation passes through the transparent cover and heats the contents, causing evaporation. The moisture condenses on the cool cover and drips into a storage container.

The other three projects focus on drying fruits, vegetables, and potatoes. University of Hawaii scientists are investigating the use of solar energy in air drying, freeze drying, and osmovac-dehydration of foods. Scientists at USDA's Citrus and Subtropical Products Laboratory are developing a practical process for drying southeastern fruits and vegetables, using solar energy augmented with fossil fuel energy. Colorado State University scientists plan to develop a solar process for drying potato products.

Preliminary findings of the first year's work on these six projects indicate fruits and vegetables dried by direct application of solar energy compare favorably in physical properties and flavor with conventionally dried products (31). Reflectors were useful in intensifying solar radiation and helping to increase drying rates.

The temperature capabilities of flat-plate solar collectors are compatible with potato drying requirements, but the temperature achieved was too low to operate a spray dryer at full capacity. A better method is to use solar energy to preheat drying air, then use conventional fuels to boost temperature to the full capacity level.

Fruit and vegetable plants had the least potential among food processing plants for use of solar water heating because of their seasonal energy demands. An off-season energy use would need to be found to help spread fixed costs. Dairy and meat processing plants were more promising because they had year-round hot water demands compatible with a solar hot water heating system.

Current economics of solar water heating in food processing require a payback period of around 20 years. Potential energy savings on hot water is limited to 20 to 50 percent, depending on type of plant, annual demand schedule, water temperature required, costs of conventional energy, and payback period required.

Irrigation

Irrigation accounts for about 20 percent of all direct energy uses in agriculture (12). About 68 percent of the U.S. irrigated acreage requires on-farm pumping of irrigation water. Electricity and natural gas together presently provide the power source for 75 percent of the pumping, with diesel, LP gas, and gasoline making up the remaining 25 percent. Much of the irrigated land is in the Western States.

Recent increases in utility rates coupled with high interest rates, the need to borrow large amounts of operating capital, and low farm commodity prices have placed a severe cash flow strain on many irrigation operations. These economic conditions have sparked a demand for more economic means of irrigating. Center-pivot type equipment is becoming increasingly popular as a means of decreasing labor requirements and investment costs. Center-pivot systems are compatible with existing solar technology.

Solar power to drive irrigation pumps is not a new idea. Solar Motor Company of Boston built a conical collector of over 30 feet in diameter composed of more than 1,000 small mirrors. That was in 1904. Two units of this type (5 hp) were used in an experiment to pump water for irrigation in Arizona. Shuman and Boys used a large number of parabolic trough collectors to provide heat to drive a steam engine (50 hp) to pump water in Egypt in 1912.

Interest in solar-powered pumping was renewed in the mid-sixties in the desert regions of Africa. A French company installed several solar-driven irrigation pumps in both Africa and Latin America. These units use flat-plate collectors and organic Rankine cycle engines. One, a 30-kWh system, began operation near San Luis de la Paz, Mexico, in 1975 (34).

Several experiments are being conducted in the United States. Northwestern Mutual Life Insurance Company opened a large, solar-powered irrigation system at Gila Bend, Arizona, in 1977 (5). This system includes a 50-hp pump capable of delivering up to 10,000 gallons a minute. Solar energy is collected by parabolic collectors covering 5,500 square feet which follow the sun during the day, concentrating the sun's heat on tubes filled with circulating water. The heated water vaporizes Freon which, in turn, spins a turbine to run the irrigation pumps (27).

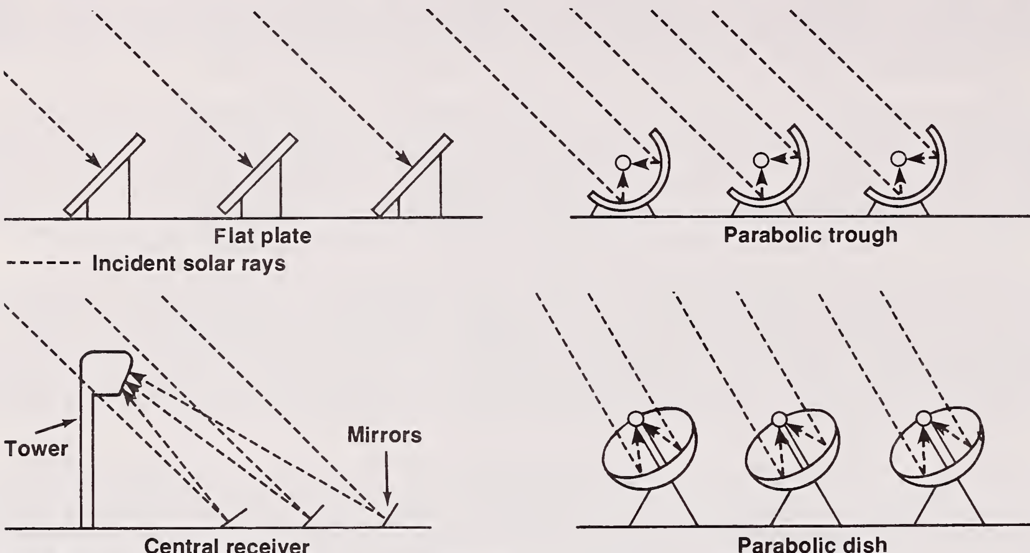
A DOE-sponsored project near Coolidge, Arizona, has been selected to evaluate a 150-kW solar thermal power plant, a size intermediate between the Gila Bend, Arizona, experiment and proposed solar thermal-electric plants (20). This experiment was designed to evaluate the operation and management of a localized solar power plant by a farmer, as opposed to a utility.

Strickland reported in 1976 on a solar thermal system developed by Texas Tech University (26). Energy is collected in a single phase fluid by a central receiver collector (fig. 8). Then, a Rankine steam turbine system converts the thermal to mechanical energy. The turbine may be designed to power an electrical generator or to drive an irrigation pump directly. The system also features a storage reservoir which permits continuous scheduled irrigation by buffering variations in the pumping rate.

A solar experiment in Nebraska, being conducted by the Lincoln Laboratory of the Massachusetts Institute of Technology and funded by DOE, is concentrating on photovoltaic cells (25). These appear to be an attractive means of providing pumping power since electric pumps are most common. Photovoltaic (solar) cells convert light energy directly to electrical energy in contrast with solar heat and the thermal power plants which require turbines and other mechanical equipment. The photovoltaic cell experiment, started at Meade, Nebraska, in 1977, is designed to irrigate 80 acres of corn and aerate the stored production from those 80 acres in two 6,000-bushel bins. The experiment, using 1,000 cells, is designed to produce 200 volts of direct current which will

Figure 8

Types of solar collectors most commonly used in irrigation-related experiments



Source: (32).

be transformed to alternating current for running the irrigation pumps and the 3-phase aeration motors.

The technology for solar-powered irrigation pumps is rapidly advancing. Costs are not yet low enough to compete with conventional energy sources. However, DOE has reported its aim to bring the price of solar cells down to $0.50 per peak watt by the middle eighties (32). In an economic analysis using DOE's solar cell cost goal as an assumption, Matlin and Katzman (21) conclude that solar energy for irrigation will become economically viable in the early to middle eighties.

The use of solar energy to provide power for irrigation will be most economical in those regions where: (1) the greatest amount of solar energy is available because of latitude and weather, (2) power demand is relatively most uniform or power needs most nearly correspond to solar energy availability throughout the year, and (3) power can be used as it is generated rather than having to be stored.

The Multiple-Use Concept

Fixed costs associated with each unit of energy produced from a solar collector will decline as use of the collector is extended over more months of the year and to other enterprises. Multiple use of the collector, by lowering costs per Btu of energy produced, makes good economic sense. However, there may be engineering problems.

A collector designed for low-temperature uses may not fit applications requiring high temperatures without considerable modification or adaptation. Alternative uses for a collector built into the roof of a building may be limited because of lack of portability. In the longrun, however, farmstead layout may be altered, bringing alternative uses closer together.

Manufacturers of solar collectors, by building the multiple-use concept into their designs, could help bring about more economical solar energy systems. And, farm managers could find innovative ways to adapt existing solar equipment to other functions.

Several systems have already demonstrated adaptability to the multiple-use concept. USDA-University of Georgia research at Tifton, Georgia, furnishes an example. The same roof collector can cure tobacco in July, cure peanuts from mid-August until mid-September, dry corn in October, and dry grain sorghum for 2 weeks in November. This combined use of the system covers 5 months; any one of the other uses would have employed the system for only 4 to 6 weeks. Use of the collector to dry small grains will facilitate double cropping by allowing for earlier harvest. There also is multiple-use work underway at the State universities of South Dakota, North Carolina, Colorado, and Kansas, as well as at other locations.

Multiple use may be facilitated with portable collectors. To maintain portability, the maximum collector size would be about 12'x60'. This size would accommodate farm gate size and general maneuverability.

Small portable collectors may be hooked in tandem for peak capacity needs and then separated and relocated for other uses. Such flexibility would enhance multiple use. There are methods to reduce peak requirements and increase use of solar collectors. In crop curing or drying, for example, these may include: (1) selecting varieties with different maturity dates, (2) staggered planting, or (3) crop diversification.

Some farms, because of their specialization, will have few opportunities for complementary uses of collectors. However, by including the heating and cooling needs of the farm home, most farms will have several uses for a solar collector. New England's independent oil heat companies recently concluded that solar and oil could be complementary and profitable (33). Figure 9 shows the concept of multiple use. One use with a high peak requirement will generally determine the maximum collector surface needed. Other uses would be scheduled to maximize use of the system throughout the year.

Most solar collector research has been directed toward a single use, with little attention given to alternative uses. This is largely due to the nature and complexity of subject matter of the investigations. Yet, the finding of multiple uses may mean the difference of whether or not solar energy is economically feasible for use in commercial agriculture and how soon it is adopted.

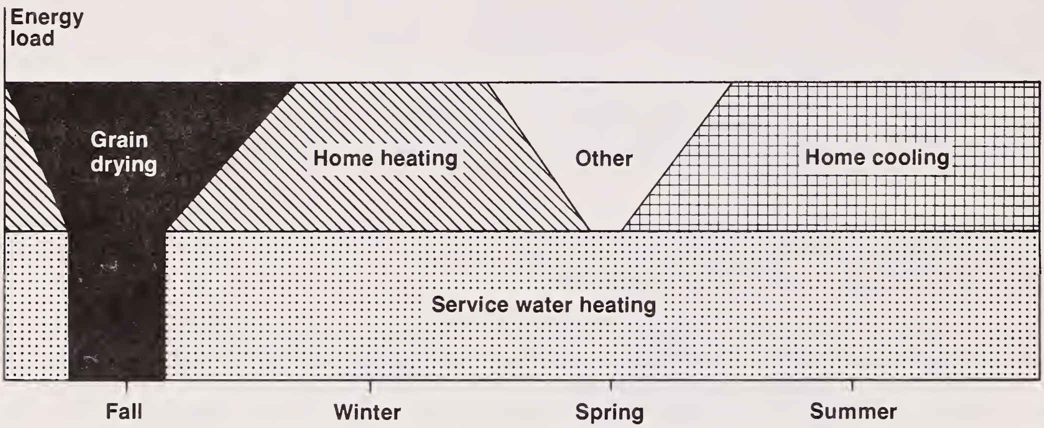
ECONOMIC AND RELATED ISSUES

The current body of economic knowledge of solar energy use in agriculture is scant. Current data are largely limited to systems costs included in various engineering design reports. Economists must now build a firmer data base upon which economic evaluations of solar systems can be made. Solar energy technology has reached a stage where several alternative systems are available for various agricultural applications. Economists can now generate investment and operating costs based on the engineering specifications of these systems. They can then arrive at the most cost effective systems.

Forecasting the future development and adoption of solar energy use will require both current data and estimates of future costs. Alternative fuel supplies and prices are vital elements of this needed data base. The rate at which conventional fuel prices advance will have a major influence on the rate of solar technology adoption. Shortages and/or allocations, even if prices are regulated at low levels, could also play a major role in its rate of adoption. For example, natural gas is one of the

Figure 9

Seasonal farm demand for solar-powered energy: A multiple-use concept



least expensive fuels, but new service hook-ups are not available in many areas. This forces the manager to choose from available alternative supplies, often at higher cost.

Including solar energy in future energy choices could have a number of indirect effects on agriculture. Price instability of agricultural commodities could be one of those effects. An increase in broiler production fixed costs relative to variable costs, which would result from an investment in solar facilities, would likely make the broiler supply more inelastic. Such an inelastic supply would magnify the cyclical movement of market prices.

Production arrangements in the broiler industry could also be altered significantly. The initial cost of a solar energy system could add 30 to 40 percent to broiler producers' initial investment in production facilities. Therefore, special incentives, low-interest loans, or special tax treatment for example, may be needed to encourage installation of solar facilities. The broiler producer is usually a limited-resource farmer, frequently farming part time. Terms of production contracts may need to be changed--perhaps extended over longer periods--with some sharing of the investment burden by the integrator. Without such adjustments to ease the initial investment burden, there may be more concentration in broiler production, elimination of smaller growers, and less opportunity in rural areas.

Agriculture has been shaped and institutionalized by cheap energy. The Nation's traditional cheap energy policy has resulted in the substitution of capital for labor and, in turn, a highly mechanized, large-scale farming system. Fitting solar energy technology to such a farming system will be a difficult task.

Early experiments with solar power suggest that this new technology might better fit small farms. In grain drying, for example, the largest experiments to date have been concerned with 5,000 to 6,000 bushels of grain, or the equivalent of about 50 to

100 acres. Most experiments have focused on enterprises of less than 50 acres. With larger dryers utilizing low-temperature solar drying, problems of quality control exist. High-moisture grain may spoil before it gets dry.

A diversified farming system--opposite to the current trend to specialization--may be better suited to the solar multiple-use concept. Diversification does two things: (1) the acreage or volume of each crop is reduced and (2) multiple uses for solar power may be found. A solar collector could be used year around for a combination of crop drying, heating a livestock or poultry enclosure, heating water, and air conditioning a home (fig. 9).

Crop drying presents a very basic question: should crops be artificially dried? Grain drying became common as farm size increased and mechanical harvesting gained prominence. Along with mechanical harvesting came the development of new varieties of crops better suited to mechanical harvesting. Such changes in plant breeding, at least in the short run, have perhaps locked the farmer into a rapid harvest situation. As low-temperature systems are employed to dry crops, smaller harvesting machines could be employed to prevent bottlenecks in the drying process. If it were desirable to synchronize harvest to a low-temperature drying system, how much grain would be lost by a slower harvesting schedule? What would be the time required to breed crops with better traits for maintaining quality while standing in the field after maturity?

An alternative to crop drying is the feeding of high-moisture grain and forage. Facilities for storage of high-moisture grain and forage should become more feasible as the cost of drying increases.

Existing farmstead layouts may not permit most effective use of solar energy, especially with respect to multiple use. In addition to the question of proper collector orientation and the esthetics of collector design and location, there is the problem of heat ducts crossing driveways and their location relative to livestock. Ducts can be placed underground in some cases. Even well-insulated ducts lose heat. Some of these problems can be alleviated by conversion to hot water. Solar energy converted to electricity, of course, would be more appropriate for traditional farm layout and energy use patterns. Also, surplus electricity might be sold back to the power company, thus avoiding the multiple-use problem. New farm buildings and their layout can be designed with solar heating or drying in mind. Retrofitted systems on existing farm buildings and layout may not make most effective use of the available solar energy.

Environmental regulations in areas other than pesticides and chemicals can also affect farmers. The use of high sulfur oil and coal is closely watched. The food processing industry depends on fuel oil and coal and if cleaner and higher priced fuel is required, solar assisted heating may become more economically feasible.

Legal issues need increased attention. Various levels of government have granted or are considering granting special tax incentives to help offset the high initial cost of solar equipment. Also, several States have passed legislation authorizing the exemption from property tax of any increase in property value resulting from the addition of a solar energy system. While most legislative activity at the State level has focused on tax incentives, the question of consumer protection has received little attention. The lack of legislation dealing with the right to sunlight could seriously hinder adoption of solar energy in some areas. Since most sunrays approach the earth at an angle, they may need to cross adjoining property before striking a solar users' collector. Existing or potential obstructions on adjacent property could be a serious impediment to solar use in congested urban areas. This would be less of a problem in farm areas. Very few State legislatures have dealt with performance standards for solar equipment.

The overall impact of solar energy use in agriculture will likely be rather limited until dramatic technical breakthroughs to lower costs are achieved. The amount of fuel used in applications where solar energy can assist is rather small compared with quantities needed for vehicular and other uses. The amount substituted likely would be less than 1 percent of total U.S. energy consumption. But, for certain segments of the agricultural industry, such as greenhouse production, the sun represents a very promising energy source.

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