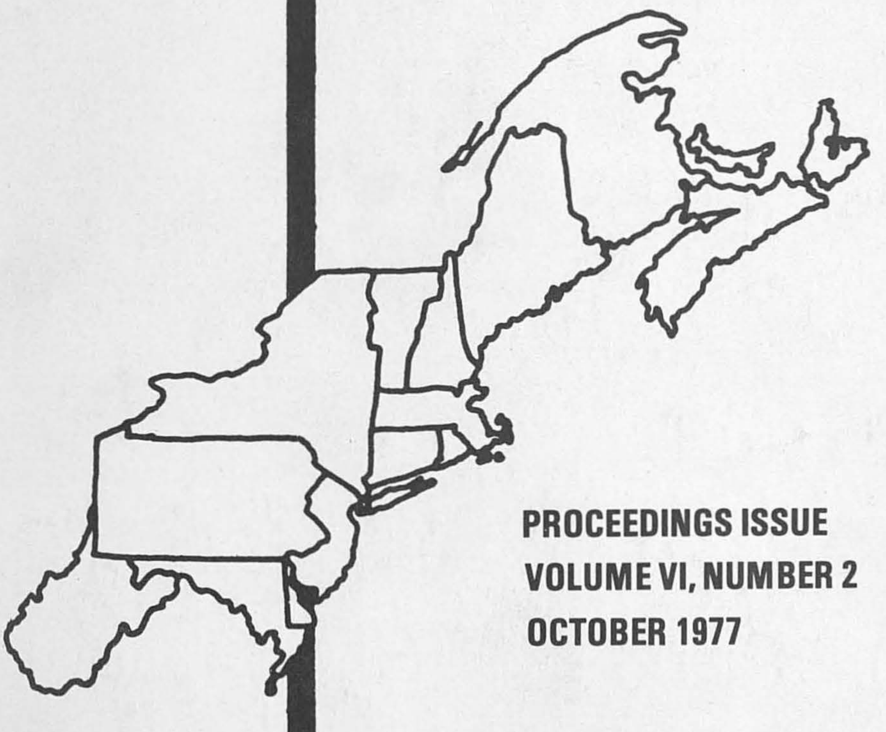
JOURNAL OF THE

Northeastern Agricultural Economics Council



PROCEEDINGS ISSUE
VOLUME VI, NUMBER 2
OCTOBER 1977

SOLAR ENERGY APPLICATION FOR SPACE AND HOT WATER HEATING PURPOSES IN AGRICULTURAL PRODUCTION

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The cost and availability of conventional energy sources currently used as inputs for agricultural production continue to be a very important concern in planning and decision making. Interest in solar energy for use in space and water heating, grain drying, and other areas, has been stimulated because it is technically feasible, abundant, renewable, and nonpolluting. Although it is reasonably reliable and can provide a large portion of the total heat need for many situations, it does require an auxiliary source of energy.

In this paper three topics are discussed: 1) results of a simulation-economic cost effectiveness study of solar energy heating application for a broiler house in Maryland; 2) cost changes necessary to enhance the economic feasibility of solar energy; and 3) model modifications necessary for application to other agricultural enterprises.

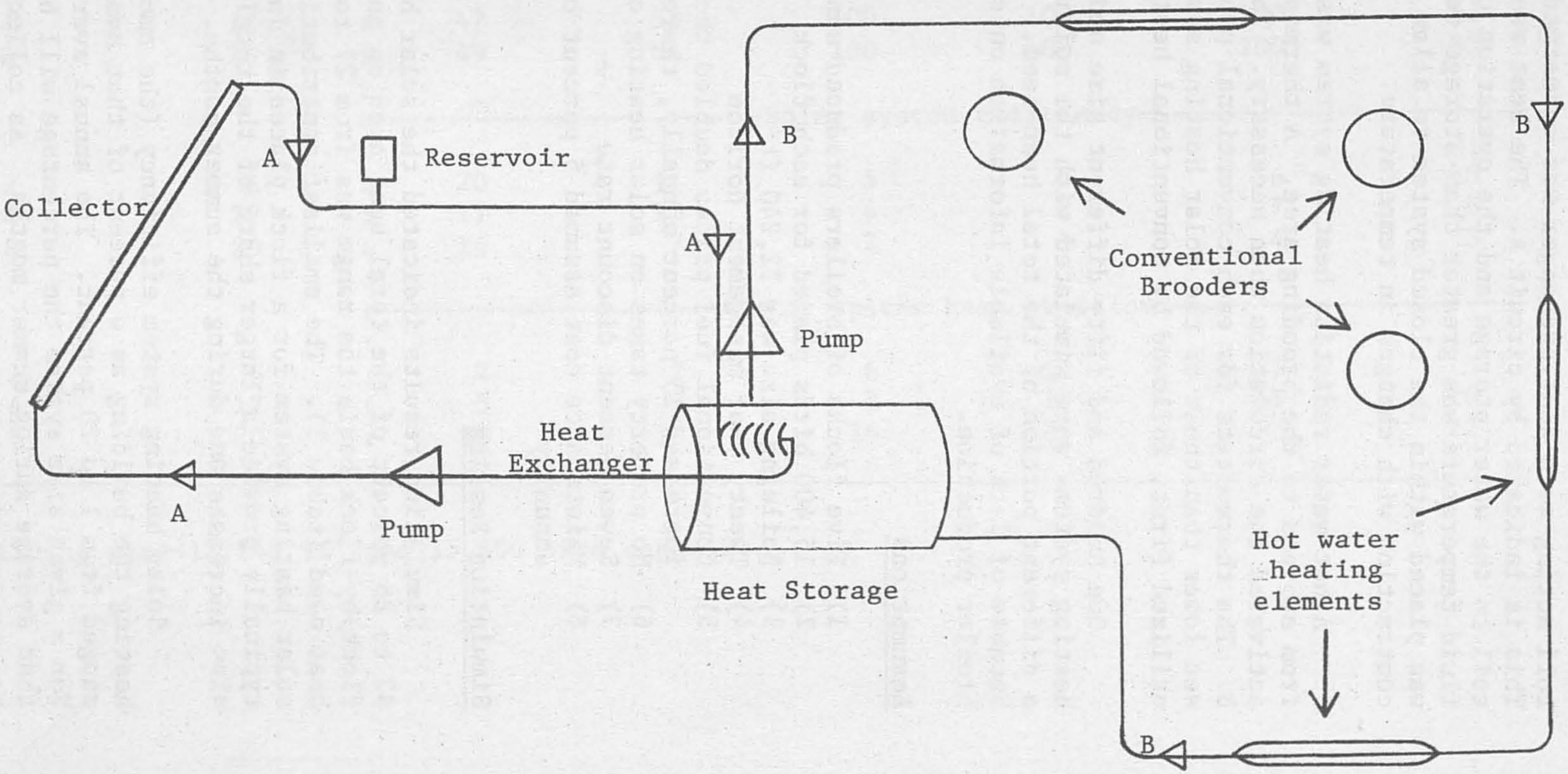
Methodology

Methodology used in examining the economic feasibility of using solar energy in heating Maryland broiler houses included a simulation analysis and present value cost effectiveness routine. The simulation analysis included: 1) a Monte Carlo weather simulation routine to generate hourly weather for a year; 2) broiler growth on a daily basis and 3) the building heat balance on a daily basis. Historical weather data from the study area (Maryland's eastern shore) were used as input for the weather simulation routine. Estimates of sensible heat produced daily by the broilers were obtained from bird growth equations. Five flocks of birds were assumed produced annually and a standard mortality rate was assumed. The daily building heat balance considered heat loss by infiltration, conduction, and ventilation (including evaporation of excess moisture) plus sensible heat gain from the birds.

A water-to-water solar heating system with auxiliary propane brooders was assumed for purposes of the study (figure 1). Heat collection and transfer to storage occurred within a closed system, which was activated by a thermostat when the collector temperature became greater than storage temperature. The water-anti-freeze solution was circulated by a water pump over the collector for heat collection and moved to storage where a copper

Figure 1

Flowchart of the water-to-water solar heat collection and storage system plus the hot water heating system.



coil acting as a heat exchanger was submerged in the water storage tank. This is indicated by circuit A. The heat was transferred from within the coil to the water storage and the operation continued as long as circulating fluid temperature was greater than storage temperature. A small reservoir was placed within the closed system to allow for water expansion and contraction with changes in temperature.

A hot-water radiation heating system was assumed to circulate heat from storage to the brooding area. A thermostat within the building activated the circulation when necessary. This is indicated by circuit B. The thermostats for each conventional propane brooder were assumed set lower than those of the solar heating system. Thus, solar heat was utilized first, followed by conventional heat when necessary.

One hundred and fifty different size and quality solar-auxiliary heating systems were simulated with the solar component of each providing a different portion of the total heat need. The large number were studied because of lack of available information on solar heating application to broiler production.

Assumptions

1) Five flocks of broilers produced annually
2) 15,400 birds placed for each flock
3) Building size was 12,240 ft^2
4) Twenty year management horizon
5) Conventional fuel prices doubled the second year and increased 15 percent annually, thereafter
6) No property taxes on solar heating equipment
7) Seven percent discount rate
8) Maintenance cost assumed 5 percent of initial purchase price annually

Simulation Results

Simulation results indicated the solar heating systems provided from 42 to 85 percent of the total heat need on an annual basis [17]. On a flock-by-flock basis the range was from 27 to 100 percent of the total heat need (table 1). The smallest contribution resulted from a small solar heating system for a flock placed in January. Solar heating systems typically provide a larger share of the total heat need as the system size increases and during the summer months.

Solar heating system efficiency (the amount of solar energy used in heating the building as a percent of that available to the collector) ranged from 1 to 20 percent. The annual average was from 5 to 10 percent. For a given size system the percentage will be higher in winter and lower than average during summer months. As collector size increased, relative to storage size, the solar heating system efficiency decreased substantially.

Table 1
Solar heat as a percent of total building heat used, system efficiency, and system overflow for different size solar heating systems, Salisbury, Maryland, 1975. 1/

Collector Size (1,000 ft^2)	Storage Size (1,000 gal.)	Flock 1 (1/6 - 3/2)	Flock 2 (3/17-5/12)	Flock 3 (5/27-7/22)	Flock 4 (8/6-10/1)	Flock 5 (10/16-12/11)	Annual Summary
		(Percent)					
		Solar heat as a percent of total heat					
2	6	27	34	67	100	82	42
4	12	47	58	100	100	100	63
8	20	49	84	100	100	100	85
		Solar system efficiency					
2	6	20	11	5	5	6	10
4	12	17	10	4	2	7	8
8	20	14	7	2	1	4	5
		Solar system heat overflow					
2	6	2	2	6	11	5	5
4	12	5	3	8	17	13	10
8	20	13	13	16	32	32	22

1/ Building size-12,240 ft^2 and 15,400 bird capacity.

Heat overflow from the solar heating systems ranged from about 5 to 22 percent on an annual basis and from 2 to 32 percent on a flock-by-flock basis. The percentage was higher in the summer and lower in the winter months than the annual average. Overflow as a percent of total radiation available increased during the summer months and as collector size increased, relative to storage size.

Economic Results

A present value, cost effectiveness approach was utilized to determine when the most economically feasible solar heating system would break even and become less expensive than the commonly used propane heating system in the study area. Also estimated were the costs of heating with natural gas, fuel oil, and electricity. Total costs were calculated for purchase, installation, fuel and energy for operation, repairs, and insurance for each heating system and then discounted to present value. Cost per 100 broilers produced was calculated by dividing total present value costs over time by the number of birds produced during the same time period. The least costly conventional heating system in the study area, based on 1975 fuel prices, was natural gas (table 2). Very little is used in broiler production because few units are located adjacent to supply lines. Fuel oil was the second least expensive, followed by propane and electricity. The average present value cost for propane after the first year was \$3.79 per 100 birds. The average cost at the end of 5, 10, 15, and 20 years was \$3.64, \$4.30, \$5.21, and \$6.43, respectively.

Table 2
Average present value cost of brooding and heating with different types of systems per 100 broilers produced, Salisbury, Maryland, 1975.

Years	Type of heating system				
	Propane	Natural gas	Fuel oil	Electricity	Solar
	Fuel cost per 100 broilers produced (dollars)				
1	3.79	2.71	3.60	4.66	21.01
5	3.64	1.93	3.34	4.89	6.59
10	4.30	2.14	3.91	5.84	5.06
15	5.21	2.54	4.73	7.13	4.90
20	6.43	3.09	5.83	8.81	5.23

The most economically feasible solar heating system over a 20 year management horizon provided about 42 percent of the total building heat need and became less expensive than propane after 13 years. It consisted of a 2,000 ft^2 collector and 6,000 gallon heat storage component. The initial purchase and installation cost for the solar-auxiliary system was \$14,667 or about \$7.30 per ft^2 of collector area in 1975. The average present value cost per 100 broilers produced at the end of 1, 5, 10, 15, and 20 years was \$21.01, \$6.59, \$5.06, \$4.90, and \$5.23.

Other solar heating systems providing about 63 and 85 percent of the total building heat need became less expensive than propane at about 16 and 18 years, respectively. These data assume relatively inexpensive solar heating systems and substantial (15 percent) annual increases in the price of propane. These are the two most important variables in the economic feasibility of using solar energy for space heating purposes.

With the solar heating system providing about 42 percent of the total heat need, cost increases to \$10.50 and \$13.50 per ft^2 of collector area resulted in the break even years, with respect to propane, becoming 17 and 20, respectively (figure 2). A system with the initial price of about \$16.50 was more expensive than conventional propane throughout the entire 20 year period. Economic feasibility for other size solar heating systems was similar as increases occurred in initial system purchase and installation costs.

Size of fuel price increases was the other important variable affecting the economic feasibility of solar heating for broiler houses in the Eastern Shore area of Maryland. Anything less than doubling of propane prices the second year with 15 percent annual increases thereafter resulted in solar heating being more expensive than propane throughout the entire 20 year management horizon (figure 3).

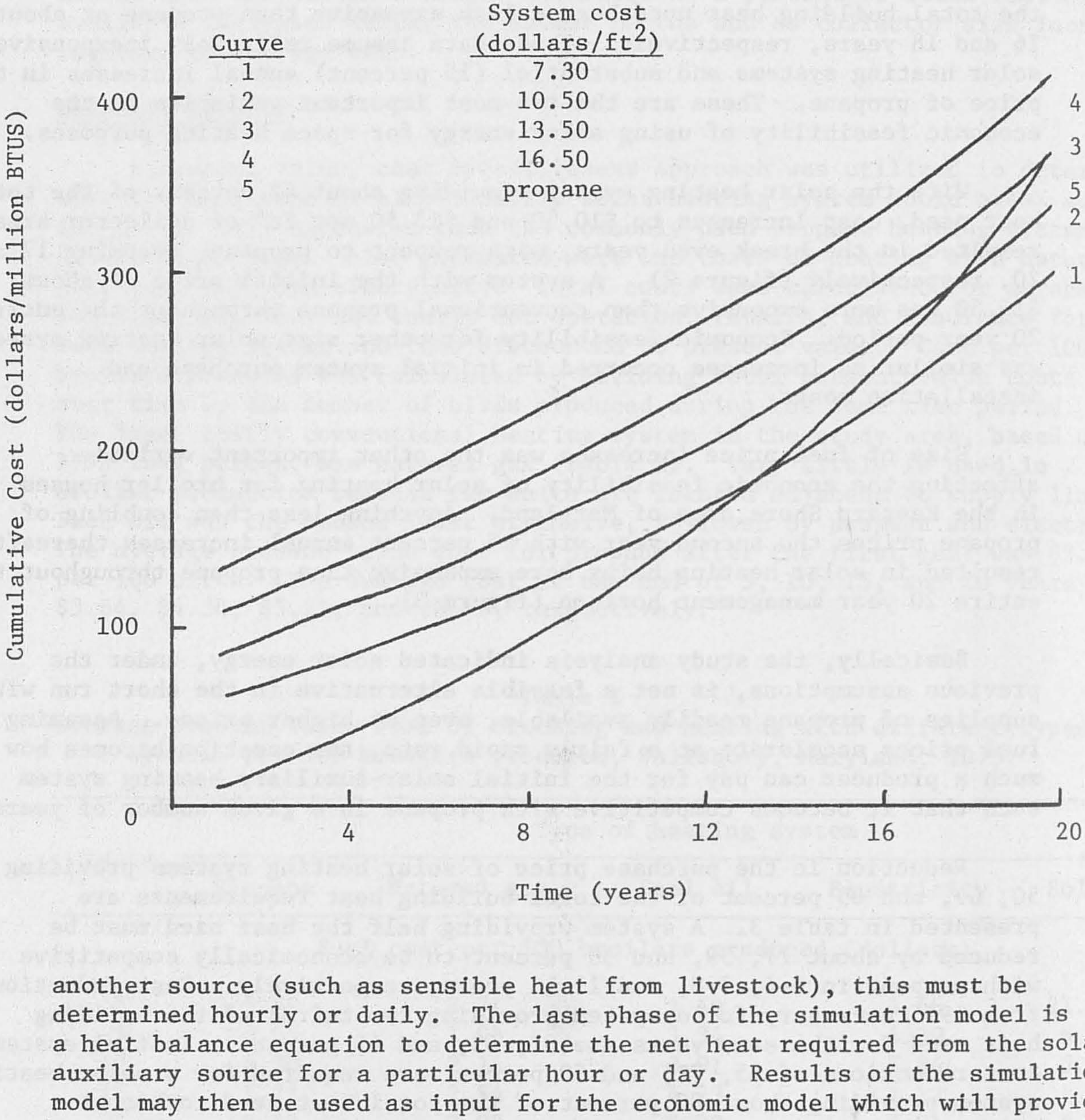
Basically, the study analysis indicated solar energy, under the previous assumptions, is not a feasible alternative in the short run with supplies of propane readily available, even at higher prices. Assuming fuel prices accelerate at a fairly rapid rate, the question becomes how much a producer can pay for the initial solar-auxiliary heating system such that it becomes competitive with propane in a given number of years.

Reduction in the purchase price of solar heating systems providing 50, 67, and 85 percent of the total building heat requirements are presented in table 3. A system providing half the heat need must be reduced by about 77, 59, and 36 percent to be economically competitive with propane in 3-4, 7-8, and 11-12 years, respectively. Cost reductions from 1975 necessary for a system providing two-thirds of the building heat need for the same years are 82, 63, and 45 percent. Initial system cost reductions of 85, 71, and 50 percent are required for a solar heating system providing about 85 percent of the total heat need to become competitive with propane for the same time periods.

Application to Other Enterprises

The simulation model used in developing the technical data for this study can be adapted to other enterprises for which a relatively low temperature heat is required. The weather generation and solar heat collection routine may be used for any geographic location in the world by merely changing the weather input data. If heat is contributed from

Figure 2
Cumulative present value cost of heating a broiler house assuming a constant size solar heating system, with different system costs, Salisbury, Maryland, 1975.

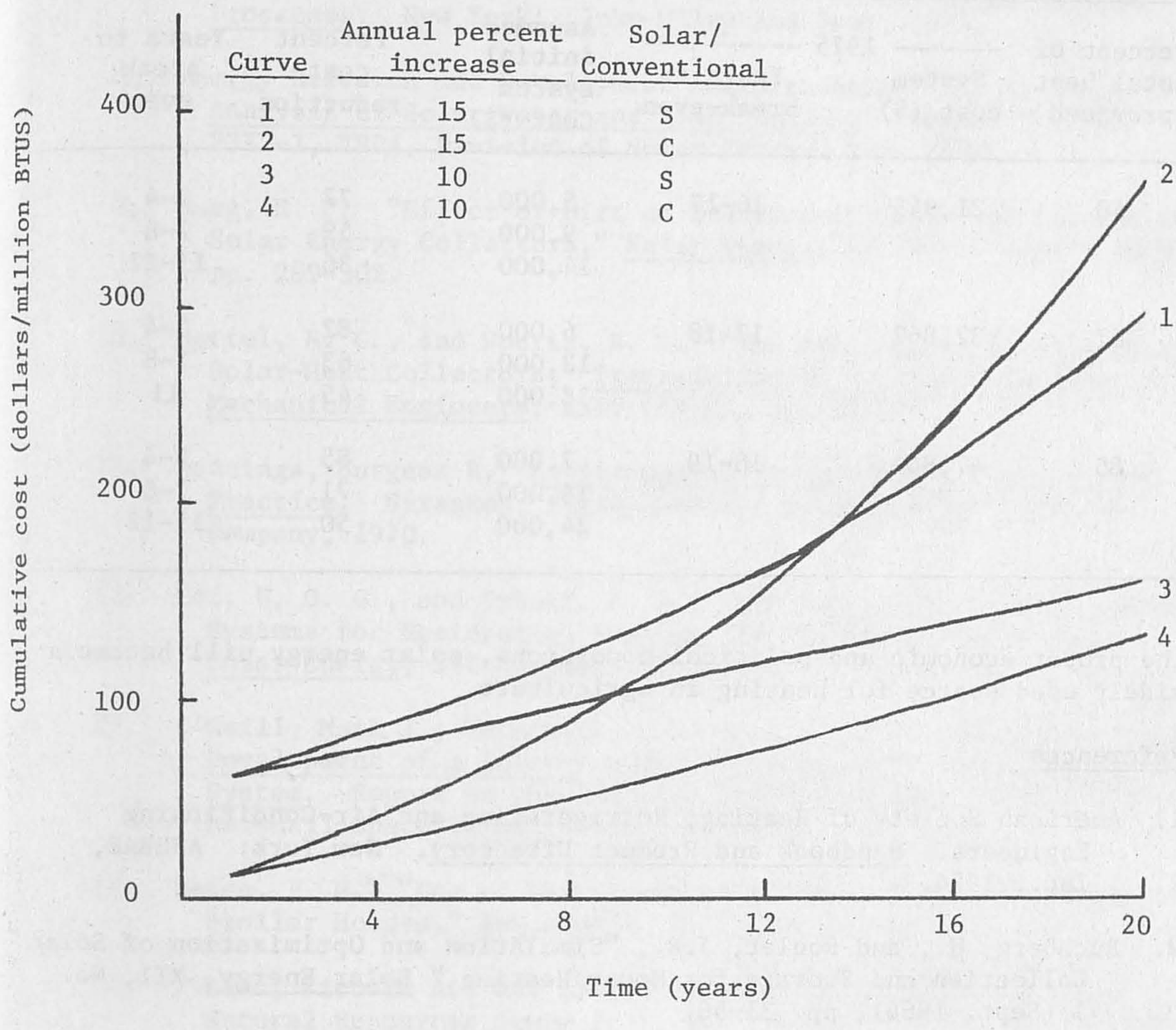


another source (such as sensible heat from livestock), this must be determined hourly or daily. The last phase of the simulation model is a heat balance equation to determine the net heat required from the solar-auxiliary source for a particular hour or day. Results of the simulation model may then be used as input for the economic model which will provide estimates of the most cost effective heating system for different lengths of time with given economic assumptions.

Implications for Solar Energy

Solar can be an economically competitive source of energy for space and water heating in agriculture. It will be most economically feasible in areas characterized by constant and abundant radiation, cool or cold

Figure 3
Cumulative present value cost of heating a broiler house with a selected size solar system assuming ten and fifteen percent annual fuel price increases, Salisbury, Maryland, 1975.



temperatures, constant demand for a relatively low temperature source of heat, and high conventional fuel prices. Less expensive solar heating systems could result from: 1) mass production; 2) buying a complete system rather than components; and 3) improved technology. Each of these possibilities could decrease cost which would enhance solar, relative to conventional, heating. Rapid and sizeable price increases plus an irregular supply of conventional fuels will also significantly decrease the time before solar energy is economically competitive. Other factors which will make solar energy more competitive with conventional energy sources include: 1) altering management practices; 2) using solar heating equipment more intensely; and 3) government subsidy or tax enhancements.

Solar energy is abundant, renewable, technically feasible, and non-polluting. These are desirable qualities in a heating source and, given

Table 3
Cost conditions necessary to make selected solar heating systems competitive with propane in shorter time periods

Percent of total heat provided	1975 System cost ($)	1975 Years to break-even	Assumed initial system Cost ($)	Percent cost reduction	Years to break even
50	21,945	16-17	5,000	77	3-4
			9,000	59	7-8
			14,000	36	11-12
67	32,862	17-18	6,000	82	3-4
			12,000	63	7-8
			18,000	45	11
85	47,849	18-19	7,000	85	3-4
			14,000	71	7-8
			24,000	50	11-12

the proper economic and political conditions, solar energy will become a widely used source for heating in agriculture.

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