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SOLAR ENERGY
FOR
AGRICULTURAL AND INDUSTRIAL PROCESS HEAT

A PRESENTATION FOR MEMBERS OF CONGRESS
AND THEIR STAFF

JUNE 22, 1979

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NEAR-TERM PROSPECTS FOR SOLAR INDUSTRIAL PROCESS HEAT

Kenneth C. Brown
Solar Energy Research Institute
Golden, Colorado

ABSTRACT

Although still relatively unfamiliar to the general public, solar industrial process heat technology has been increasingly emphasized in the federal solar energy program. Because the demand for energy by industry is larger than any other single consuming sector (37% of total U.S. demand in 1977), it is logical that the potential of solar systems to replace or supplement industrial fuels should be explored. Twenty pilot projects which demonstrate the application of solar thermal systems to a variety of industrial process heating needs have been proposed or constructed. These projects illustrate the technical feasibility of solar energy to supply hot water, hot air, and steam. High-temperature solar technology developed in solar thermal power programs may also be applied to industrial process heating. Cost-competitive systems can be identified in certain applications. But most commercial solar installations in the near-term will probably be motivated by other important industrial concerns. The near-term impact of solar process heat will be affected by the resolution of certain key problem areas, including the removal of economic uncertainties and inequitable subsidies, market identification, cost reduction, performance improvement, improved communication, and accumulation of operating experience.

INTRODUCTION

One would probably be surprised to meet an average homeowner today who was not aware of the potential of solar energy to provide heat or hot water to the home. The traditional association of solar energy with residential applications, reinforced by several years of research and demonstration, has heightened public awareness of solar energy usefulness in the home.

On the other hand, it is unlikely that one would find that a majority of plant engineers or industrial managers were familiar with the potential of solar energy for process heating. This is hardly surprising, for the feasibility of solar industrial process heat was only recently recognized within the research and development community itself. Nearly five years after the first specific program enabling legislation was written, (Solar Heating and Cooling Act of 1974, Section 9) solar process heat appears to have come of age. Within the past year support has been clearly voiced by the Department of Energy [1] and more extensive and prominent articles have appeared in public media [2, 3]. The Solar Energy Research Institute is increasingly approached for information on the subject of solar industrial process heat by plant engineers and managers who are concerned about energy supply, energy cost or competitive posture with regard to new developments in industrial energy technology. Solar manufacturers appear to be more and more conscious of an emerging industrial market and are

redesigning old products and developing new products in order to compete for industrial dollars.

In all, the solar energy community anticipates a potentially massive industrial market. Industrialists are increasingly interested in, though justifiably cautious about, the applicability of solar energy to their own plants. And the Federal Government, through the programs it supports, is encouraging the commercialization of solar process heat via development and demonstration. With this increasing level of activity it is proper to evaluate the prospects for early application and impact of solar industrial process heat. This paper will address that issue, seeking first to review the state of solar technology and programs to date and then to present the issues which most prominently affect the near-term prospects for solar energy in industry. Given these issues, and the likely response to them, some indication of the future direction of solar process heat will be apparent.

PROGRAM DEVELOPMENT

Concern over U.S. energy posture which was generated after the 1973 oil embargo probably had some influence over the emergence of solar industrial process heat. Solar energy policy since 1974 has been concerned with the displacement of nonrenewable energy supplies, particularly those which are imported. Industry accounts for approximately 37% of the end-use demand for energy in the United States (1977)--a share which is in excess of total residential and commercial energy use and 1.4 times the total demand for transportation, (see Figure 1).

FIGURE 1. Distribution of Energy Demand Among Major Consuming Sectors

If the energy displacement impact of solar energy is an important issue, then the large demand of the industrial sector supports an emphasis on solar industrial applications. However, certain critical questions must be answered before it is clear that solar energy is applicable to industry on a significant scale. For instance, while total industrial energy demand is large, what is the extent of the thermal energy demand? Furthermore, how much of the industrial process heat (IPH) market is at low and intermediate temperatures as opposed to high temperatures? Finally, questions are rightly voiced about the location of industry. Solar energy is abundant in the southwest, but much less so in the industrial northeast. How much of the IPH market is locationally suitable to solar? The Department of Energy sought answers to these questions in two studies commissioned in 1976 [4, 5].

Their results were fairly encouraging. First, the relative demand for thermal energy by industry is large. Though somewhat inconclusive, it is estimated that at least 40% and possibly as much as 68% of total industrial energy demand is for process heat. Secondly, the use of heat in industry covers a broad temperature spectrum from very low to extremely high temperatures, (see Figure 2).

Reference: Inter-Technology Corporation, Analysis of the Economic Potential of Solar Thermal Energy to Provide Industrial Process Heat, February 7, 1977, Volume 1, p. 53.

FIGURE 2. Distribution of IPH Energy Demand by Required Temperature

Fortunately significant requirements (27% of the needs are below 550°F) exist at temperatures accessible to available solar technology. Finally, energy displacement potential in good solar climates appears to be significant. That potential may even be enhanced if tendencies continue toward southward industrial migration.

The potential for energy displacement surfaces as the key motivating factor in the increasing attention given solar IPH since 1974. In FY75, the combined ERDA and USDA budget for agricultural and industrial process heat was \$1.5 million (most of that for agriculture). In FY79 the budget is \$14.5 million, the majority of that funding going to the industrial applications program. This program growth results from the apparent success of federal programs, the growing concern over solar energy generally, and from a belief in the potential displacement impact of solar IPH within the foreseeable future. The most optimistic impact assessment comes from the InterTechnology Corporation [4] which places the displacement potential of solar IPH at 0.6 quads (10^{15} Btu) in 1985 and 7.3 quads in 2000. This assessment was based only on the 20-year life-cycle cost competitiveness of applications below 550°F. Adding considerations for market penetration rates, incremental demand and other competitive alternatives, MITRE Corporation [6] used its SPURR Model (System for Projecting the Use of Renewable Resources) to project displacement of 0.13-0.20 quads by 1985 and 0.90-1.60 quads by 2000. The CONAES Study (Solar Resource Group Report, Committee on Nuclear and Alternative Energy Systems, 1977) and the ERDA-49 assessment (National Solar Energy Research, Development, and Demonstration Program: Definition Report, 1975) give higher penetration estimates in 1985 (0.0-0.3 quads and 0.05 quads respectively) and 2000 (0.0-2.67 quads and 1.0 quad). Energy and Environmental Analysis, Inc. (Market

Oriented Program Planning Study [MOPPS], 1978) gives less optimistic projections, 0.005 quads in 1985 and 0.02 quads in 2000 [7]. Considering these studies and the implicit and varying assumptions made in each, the RD&D Panel of the Solar Domestic Policy Review Committee has estimated that between 1.0 and 2.0 quads might realistically be contributed by solar IPH in the year 2000 [8]. In the final analysis, then, the eventual impact of solar IPH appears to be significant. There seems to be sufficient justification for a growing program of research, development, demonstration, and commercial encouragement.

THE STATE-OF-THE-ART

Industrial process heat is normally defined as the thermal energy used in the preparation and treatment of goods produced by manufacturing processes. The number of industrial processes is immense, so immense in fact that it is impractical to list all of the ways in which solar systems might be applied to industry within this paper. For convenience, solar IPH systems may be classified in four ways: (1) those that supply hot water, (2) those that supply heated, dry air, (3) those that supply steam, and (4) those that supply direct solar heat. With the exception of direct heat (4), solar IPH systems have been designed for each category, and certain systems have been built. The designs incorporate a number of solar collector technologies. The approximate range of operating temperatures for these technologies is shown in Figure 3.

FIGURE 3. Typical Operating Temperature Ranges of Solar Collectors

Twenty solar IPH projects in various stages of development are spread across the United States today, (see Figure 4).

FIGURE 4. Location of Major IPH Projects (Private & Federally Sponsored)

Nine of these projects are currently operating; four are in construction. Two of the projects identified are private ventures, although there may be several more than are listed here. The majority of projects shown in Table 1 have been funded as a part of the Department of Energy's experimental program to design, construct, operate, and collect data from typical industrial pilot projects. The next step in the DOE program is to initiate large-scale cost-shared demonstrations for both low-temperature ($<212^{\circ}\text{F}$) and high-temperature (212°F - 550°F) applications [9].

Experience with the DOE experimental program has resulted in valuable insight into several key areas:

- System cost reductions can be achieved through experience. The energy capacity cost of comparable systems has been decreasing, though solar collector costs have not, in general, decreased. Instead, the costs of field installation, piping, controls, and design have seen reduction because of both experience and economies of scale.
- System performance, under ideal circumstances, has lived up to predictions based on simulation models. However, the effective delivery of usable heat has been hampered by problems with system downtime and with changing plant operation schedules. The construction of solar systems which contribute directly to central energy supply, rather than to a single process line, may be warranted.
- The deleterious effects of air pollutants in the plant environment on solar system performance cannot be overlooked.
- Operating experience is invaluable in refining and improving solar system design. For example, it may be possible to suggest standard collector field piping layouts based on past experience. Many of the problems in solar system operation come not in solar collector performance, but in improper

TABLE 1. Information on Major IPH Projects

Location	Process	Collectors	Owner	Status
Hot Water (140°-212° F)				
Sacramento CA	can washing	flat-plate & parabolic trough	Campbell Soup Co.	operational (June 1978)
Harrisburg, PA	concrete block curing	multiple reflector	York Building Products	operational (Sept. 1978)
La France, SC	textile dyeing	evacuated tube	Reigel Textile Corp.	operational (June 1978)
Hot Air				
Fresno, CA	fruit drying	flat-plate	Lamanuzzi & Pantaleo Foods	operational
Canton, MS	kiln drying of lumber	flat-plate	LaCour Kiln Services, Inc.	operational
Decatur, AL	soybean drying	flat-plate	Gold Kist, Inc.	operational
Gilroy, CA	onion drying	evacuated tube	Gilroy Foods Inc.	construction
Low Temperature Steam (212°-350° F)				
Fairfax, AL	fabric drying	parabolic trough	WestPoint Pepperell	operational (Sept. 1978)
Sherman, TX	gauze bleaching	parabolic trough	Johnson & Johnson	construction
Pasadena, CA	laundry	parabolic trough	Home Cleaning & Laundry	construction
Bradenton, FL	orange juice pasteurization	evacuated tube	Tropicana Products, Inc.	construction
Intermediate Temperature Steam (300°-550° F)				
Mobile, AL	oil heating	parabolic trough	Ergon, Inc.	design
Dalton, GA	latex production	multiple reflector	Dow Chemical	design
Newberry Springs, CA	hectorite processing	parabolic trough	Nat'l Lead Industries	design
Hobbs, NM	oil refinery	parabolic trough	Southern Union Co.	design
San Antonio, TX	brewery	parabolic trough	Lone Star Brewing Co.	design
Henderson, NV	chlorine manufacturing	parabolic trough	Stauffer Chemical Co.	design
Ontario, OR	potato processing	parabolic trough	Ore-Ida Co.	design
Privately Funded				
Youngstown, OH	aluminum anodizing	fixed half- parabolic	General Extrusions, Inc.	operational (Sept. 1977)
Jacksonville, FL	beer pasteurization	evacuated tube	Anheuser-Busch, Inc.	operational (Feb. 1978)

design interface with standard components like pumps, valves, and heat exchangers.

KEY ISSUES

Department of Energy Secretary James R. Schlesinger has stated that "Solar energy can be increasingly useful for industrial process heat and . . . has probably been neglected in that area . . . We should put a great deal of emphasis behind an industrial process heat program [1]." The statement is indicative of the sense of confidence within the solar community regarding the near-term prospects for solar IPH. As has been illustrated, the market for industrial process heat is substantial. Solar equipment has been constructed or designed which is capable of supplying energy to that market. What, then, are the key issues which must be addressed before significant impact of solar industrial applications can be realized?

At the 1978 Solar Industrial Process Heat Conference in Denver, Colorado, interested researchers, solar manufacturers, engineers, industrialists, and government representatives met to discuss the above question. Their discussions converged on five key issues which were critical to the near-term development of solar IPH. Those five issues are summarized below [10]:

- Economic uncertainty and inequitable subsidy of conventional energy sources are the major barriers to solar IPH in the United States
 - * In particular, current tax policies allowing the deduction of fuel purchase costs as an operating expense, an advantage not extended to solar energy, reduce the value of fuel savings to large companies by an amount equivalent to the corporate income tax rate, about 50%. In addition, the severity of requirements for return on investment in the very competitive industrial marketplace will continue to be a hindrance to capital intensive solar energy. Investment incentives, such as the 20% tax credit or low-interest purchase loans, may not be sufficient to mitigate these requirements and make solar an obvious competitive alternative. In the near term it is much more likely that acceptance of solar IPH will come as the result of desires to ensure energy supplies or to become familiar with potentially valuable future technology.
- The IPH market must be better identified.
 - * Manufacturers and researchers are interested in pinpointing the most likely applications and regions for solar IPH development. Identification of industrial growth areas to allow initial incorporation of solar IPH systems would be greatly helpful. The identification of applications would allow the design of more standard and cost-effective equipment for the most promising markets.
- Technology transfer and communication must be a key element of the federal program.
- Cost-reduction efforts for current technology will not suffice to improve solar IPH competitiveness; technology improvements and/or breakthroughs must be pursued.
 - * Bare collector equipment costs account for only about 30% of the total cost of solar IPH systems. Even with very significant reductions in collector costs, a large portion of system costs will remain. Emphasis must be placed on collector performance breakthroughs and on significant improvements in system engineering. Furthermore, very large improvements in solar market potential might be achieved by addressing the problem of

manufacturing process design with solar in mind; i.e., process modifications which take advantage of solar energy.

- Invaluable experience is gained from a vigorous government program. The program will enhance the near-term viability of solar IPH by providing risk-reduced hands-on experience for potential users.

These issues are only a summary of the many concerns and suggestions of those involved with solar IPH today. But the issues addressed form a valuable benchmark whereby the probable future, or at least the desired future, of solar IPH may be assessed.

PROSPECTS

According to the Domestic Policy Review, low-temperature systems for solar IPH, particularly for the supply of hot water, could see near-term commercial competitiveness in certain markets.

Solar IPH development programs for industrial hot water systems have shown the technical feasibility of such systems, and continued improvements in low or moderately concentrating solar equipment and systems will probably result in potential commercial applications such as food processing, metal plating, and textile finishing. Low and intermediate temperature steam systems could supply a significantly larger market than hot water systems and appear to be technically feasible though more expensive. Hot air solar IPH systems could benefit from several design improvements. Engineering and R&D activity in this area is needed. Once that is obtained, similar feasibility might be expected.

Some of the above systems will actually be cost competitive in certain applications in the very near future. The majority will not be strictly cost-competitive. Commercial applications will most likely be motivated by other important considerations, such as:

- participation in government experimental or demonstration programs;
- mitigation of environmental regulations, such as air pollution controls on fossil fuel burning;
- insurance against operation shut-downs due to loss of conventional fuels;
- desire to explore potential competitive advantages of new technology; and
- public relations benefits.

These considerations are no less motivating in the near-term than cost competitiveness. Continued application of solar IPH in the low to intermediate temperature market, though gradual, will certainly be found.

High-temperature process heat systems have a less well developed application-specific technology base, though the potential market impacts of high-temperature IPH are enormous. Exploratory efforts in high-temperature system application to direct process heat production will probably result in prototype hardware systems which may be suitable for pilot-scale testing in the near-term. Research and development in solar thermal power system technology can be heavily relied upon. The issues identified at the 1978 Solar Industrial Process Heat Conference will apply as strongly to high-temperature solar IPH as to the more developed low and intermediate temperature technologies. Identification of markets will be particularly important here. High-temperature systems should take explicit advantage of certain applications. For example, unlike low-temperature systems the benefits of

cascading and heat recuperation will be available to high-temperature solar IPH systems, as will the benefits of potential cogeneration (total energy).

The solar industrial process heat program has seen meaningful progress in five years. The prospects for putting the sun to work in industry are clearer, and perhaps more optimistic. Solar IPH is technically feasible, and demonstrably so in many cases. Only in certain application markets, however, will the near future see aggressively cost-competitive systems. Market penetration will probably proceed at a measured pace, supported by major concerns which skirt simple economics: energy shortage, corporate research needs, and regulatory constraints on fossil fuel use. The most significant measures of the success of solar IPH in the near-term will relate to the improvements, experience and acceptance which can be developed.

Useful contributions to the nation's energy supply will build upon this development.

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10. AGRICULTURAL AND INDUSTRIAL PROCESS HEAT APPLICATIONS

AGRICULTURAL APPLICATIONS

Basic Technical Description

Historically, agricultural applications of the sun's heat were widespread. The use of natural sources of energy was universal in the agricultural economy of pre-industrial society. The age of industrialization and industrial fuels not only reduced the scope and area of agricultural employment, but also changed the nature of farming processes and their requirements for energy. Industrial fossil fuels, because they were both convenient and abundant, were soon substituted for "natural" forms of power such as animal work, wind and solar heat. The energy intensity of agriculture became greater as new processes were employed directly on the farm and even more dramatic increases in energy use followed the development of chemical fertilizers and pesticides. The sun still supplies large amounts of energy for photosynthesis and for the natural circulation of air and water. But the direct use of solar thermal energy has diminished in relative importance to United States agriculture because of the substitution of fossil fuels.

Energy used in American agriculture amounts to nearly 3% of the total energy consumed in the United States annually, though only about 2% is energy used directly on farms (1.3 Quads in 1974). The remaining 1% is energy invested as feedstock and production energy of agricultural chemicals such as fertilizers, feeds and pesticides. It is also estimated that another 13% of United States energy consumption is used in the processing, distribution and preparation of food.¹ Although certain food processing projects are included in the agricultural applications solar program, emphasis of the program has been on the direct use of energy on farms. Food processing in plants which are removed from the farmsite is termed an industrial use.

Applications of solar thermal energy in agriculture can be divided into two major areas: irrigation and heating.

IRRIGATION

Approximately 20% of the direct energy used in the agricultural sector is consumed in irrigation pumping for crop production (260 trillion Btu's annually). The distribution of pumping energy re-

quirements is heavily weighted toward seven southwestern and midwestern states which together account for over 77% of the total irrigation power consumption in the United States today (See Figure 10-1.)² The use of solar energy to fulfill these requirements is promising for a number of reasons. First, the concentration of uses is in a climatological area with abundant insolation. Second, irrigation power requirements are predominately confined to the range of 20 to 300 kW per station; this can be supplied by moderate-sized fields of currently available concentrating collectors and organic vapor-cycle engines. Third, in most cases, the seasonal peak in demand for irrigation will correspond to seasonal peaks in insolation. Although daily thermal storage may be chosen, irrigation schedules could be adjusted to preferable daytime pumping schedules, or pumped water storage could be used effectively to reduce system costs associated with storage.

The seasonal nature of irrigation pumping requirements may also be taken advantage of by designing multiple-use systems which use heat collected from the collector field to provide heat for drying or auxiliary electric power, or shelter/greenhouse heating during nonirrigating seasons.

The use of solar energy for water pumping has a distinguished history; some of the most elaborate solar systems built in early years of solar energy development were designed for the application. The very earliest designs were for integral collection and displacement pumping devices like those of Deliancourt in Algeria and of Mouchot in France in 1860. However, it soon became apparent that solar heat could drive a separate heat engine (such as a steam engine) to power a pump. Mouchot designed such a device in 1878 and exhibited it at the Grand Exhibition in Paris that year. Very large systems of this sort became more appealing as large areas of the arid southwestern U.S. became settled, requiring large amounts of agricultural water pumping. A.G. Eneas and the Solar Motor Company of Boston distributed a concentrator-steam engine system capable of delivering 1400 gallons per minute in 1901. The experiments of Shuman led to installation of a 40 kW system in Meadi, Egypt in 1912, which strongly resembles some of the latest systems installed in the 1970s under ERDA and DOE. Between 1920 and 1973, little was done in solar irrigation applications in this country. A few experiments with ethyl chloride engines to drive irrigation pumps were conducted in Italy in the 1920s and a large, multi-use

Figure 10-1. TOTAL IRRIGATION ENERGY CONSUMPTION* (10¹² Btu/yr)

*Seven states account for 77% of the consumed energy.

Source: FEA/D-76/459, September 1976.

irrigation solar system was built in the 1950s in Uzbekistan, U.S.S.R.³

Current irrigation systems employ a two-loop system to drive Rankine-cycle turbines for pumping power. Water under pressure or organic fluid is circulated in a collector field of concentrating collectors and heated to 300°F or more. The hot fluid flows through a heat exchanger to vaporize a working fluid, such as Freon, ammonia, or ethyl chloride, which then expands through a specially designed turbine to provide shaft power. The fluid is normally passed through a regenerator and a condenser after exiting the turbine, and then is returned to the heat exchanger. Storage may be added in the primary (collector field) loop if desired.

- Proposals recently have been made for a one-loop system which heats the working turbine fluid directly in the collector, eliminating the need for an exchanger. Such systems, however, may present problems in the handling of low-vapor pressure fluids in collector receivers.⁴

AGRICULTURAL HEATING

Solar energy may be collected in on-site systems and delivered as direct heat to various agricultural production processes or as space heat for agricultural shelters. Approximately 10% of agriculture's total energy demand can be attributed to on-site demand for heat. The demand areas selected for development by the DOE/USDA program in agricultural process heat account for about 7.5% of the

total agricultural energy demand. The areas selected for solar system development, and the 1974 energy demand and primary fuel for each, are listed in Table 10-1.

Table 10-1. 1974 ENERGY DEMAND AND PRIMARY FUELS FOR SELECTED AREAS OF AGRICULTURAL HEATING

Operation	1974 Energy Use (10 ¹² Btu)	Primary Fuel Used
Grain and Crop Drying	105.3	LPG
Livestock Shelter Heating & Brooding	30.1	LPG
Greenhouse Heating	35.0	Natural gas
On-Site Food Processing	Unknown	Unknown

Source: FEA/D-76/459, September 1976.

The national distribution of these energy requirements is shown in Figures 10-2 and 10-3.

Figure 10-2. TOTAL ENERGY REQUIREMENTS FOR GRAIN AND CROP DRYING (Btu 10^{12} /year)

Source: FEA/D-76/459, September 1976.

Figure 10-3. TOTAL ENERGY REQUIREMENTS FOR LIVESTOCK SHELTER, HEATING AND BROODING (Btu 10^{12} /year)

Seven states account for over 55% of these energy requirements.
Source: FEA/D-76/459, September 1976.

Drying of agricultural products falls into two broad categories. In the midwestern areas of the United States, harvested grains must be dried soon after harvest to allow long-term storage. Grains typically dried on-site include corn, wheat, rice, oats, barley, sorghum, millet, rye, and hops. Although the energy requirements on a national scale are small, dried grain represents the single largest value United States export item. Most research has concentrated on the use of solar collectors (including various forms of flat-plate air collectors, low-cost plastic film collectors, integral building wall collectors and solar ponds) to provide low-temperature air, typically 3-6°F above ambient, to conventional drying bins. Natural air has been extensively used for drying by circulation in upright storage bins or in storage rooms where grain is spread. The emphasis in solar augmentation has been on reducing the drying time required by introducing low-level heat; large air flows are still required. Research is also proceeding into low-temperature collectors to assist heat pumps and high-temperature concentrating collectors/dryers for significantly reduced drying time. Desiccants such as silica-gel or overdried grain may be used to reduce the humidity of air entering the drying bin.

Very large energy requirements for the curing of products like tobacco, peanuts, and forage, are found in the southeastern and mid-Atlantic regions. As in grain drying, flat-plate or plastic film collectors may be used to provide low-temperature air to drying rooms. In addition, crops such as tobacco may be dried in "greenhouse-type" rooms to make use of passive techniques such as optimal field drying. Research in these areas simply serves to quantify principles which have been used by farmers for years. Stem drying of tobacco and the drying of alfalfa require higher temperatures—the use of concentrating collectors or heat pumps may be necessary.

Livestock shelter heating and brooding facility heating requirements are concentrated in two major areas of the country. Poultry and swine farms have large heating demands in the Southeast, while dairy farm requirements for heating and hot water are significant in the upper Midwest. The technology associated with residential heating and hot water, including the use of the flat-plate air or water collectors, may be applied directly to livestock uses. In many cases, the range of environmental temperatures tolerated by livestock may be greater than for humans, leading to systems of smaller required size, of less cost, or requiring less back-up. Dairy operations require considerable amounts of hot water in addition to space heat. Flat-plate collectors using water or a working fluid might supply both needs. In addition to conventional collector systems, designs have been proposed which use building walls (as in swine farrowing houses) to heat or preheat ventilating air by circulating air in the wall cavity.

Greenhouse heating always has been a solar function. In certain climates, greenhouses may require supplemental heating and/or cooling beyond the intrinsic collecting capacity of the structure. Enhanced solar energy use in greenhouses may be accomplished by:

- improved design of greenhouse buildings, including the integration collectors in the structure, integral storage systems (such as slab floors), and less expensive construction (such as the use of plastic films);

- supplemental air or water heating, using various forms of detached flat-plate or shallow solar pond collector;
- supplemental cooling, using solar energized absorption refrigeration of deep-mine air ventilation.

Certain advantages may also accrue from the combined heating of greenhouses and nearby homes. Heated air may be drawn directly from an adjacent greenhouse into the home during periods of greenhouse overheating when the home requires heat. Alternatively, it may be more cost-effective to heat both home and greenhouse with the same detached solar collecting system rather than separately heating either structure.

Most food processing requirements beyond grain, crop and fruit drying are confined to the industrial sector in the United States. Solar technologies in this area would be similar to those for industrial process heat.

WATER DISTILLATION

An additional area of solar thermal applications to agriculture deserves mention, though this application sees little use in the United States. The use of solar heat to distill and purify water (particularly to disalinate) was first used on a large scale in Las Salinas, Chile, by Wilson in 1872. His system consisted of 64 shallow troughs with sloping clear glazings. Vapor from sea water heated in the troughs would condense on the glazing and flow to a collection tank in which nearly 6,000 gallons of fresh water were collected daily. The principles employed in solar distillation are the same today, and solar distillation "plants" are used on a small scale in isolated areas of Australia, and in small villages in the Mediterranean basin and the Caribbean.⁵

Water distillation systems may be classified in two ways. "Single-effect" systems require an energy input exactly equal to that required to vaporize water; they provide no recovery of the heat released by condensation. "Multiple-effect" systems recover some portion of the heat of condensation. The simple single-effect still, having a clear sloping window over a shallow saline trough, may have an efficiency of 40% and a water yield of 1/10 gallon per square foot per day. A multiple-effect system designed by Hodges (University of Arizona) for Sonora, Mexico, delivered 5000 gallons a day with the use of 10,400 square feet of simple collector.⁶

Federal Program Goals

Agricultural applications of solar thermal energy have been developed in two major programs—irrigation and process heat—and reflect the goals instituted in these programs. Goals of applications to irrigation are to:

- demonstrate the feasibility of distributed concentrating collector systems, using state-of-the-art components, to provide power to pumps rated up to 300 kW at competitive energy costs;
- encourage via demonstration the commercial manufacture and installation of such systems;

- define system and component development requirements for continued commercial adoption of solar thermal irrigation;
- define incentives and barriers to widespread adoption, and formulate plans to enhance the market penetration of solar systems.

For applications to agricultural heating the goals are to:

- encourage the adoption of near-term solar technology which can provide substantial heat input to grain drying, crop curing, on-site food processing, and heating and/or cooling of livestock shelters and greenhouses, by demonstrating the technical and economic advantages of available equipment and systems;
- stimulate further research and development of promising components and system designs, and identify performance and climatological data necessary to system design, and demonstration program;
- insure the ability of industry to provide and maintain acceptable levels of cost, reliability, and availability of agricultural heating systems;
- promote the adoption of incentives which will stimulate the conversion from fossil fuels to solar heat;
- identify existing or potential applications for agricultural heating, including multiple uses of solar energy on farms.

Description of Federal Programs

The program developed by DOE has been concentrating on a demonstration of the feasibility of solar thermal energy in agricultural applications. Management of the DOE program in direct heating applications has been delegated to the Agricultural Research Service (ARS) of the Department of Agriculture, which cooperates with state agricultural experiment stations, ARS laboratories, universities, and industry. DOE (through the Agricultural and Industrial Process Heat Branch) maintains a monitoring role in the program. The early emphasis in the process heat program has been on state-of-the-art components for applications.

The Federal program in irrigation applications has been the responsibility of the Solar Thermal Power Systems Division in its applications support program. One project has been completed and one has been proposed to demonstrate the feasibility of distributed collector system to power small and large irrigation pumps in the southwestern United States. Research and development in concentrating collectors and organic Rankine-cycle engines is included in this program.

Expenditures in these two programs in FY77 (by application) are listed in Table 10-2.

Table 10-2. FY77 EXPENDITURES FOR SELECTED AGRICULTURAL APPLICATIONS

(in thousands of dollars)

Crop Drying	57
Greenhouses	596
Irrigation Projects	235
Grain Drying	530
Livestock Production	456
Food Processing	254
	<u>2,428</u>

Source: ERDA 77-72, June 1977.

Value of contracts awarded for research, development, and demonstration in agricultural heating was distributed in the following way: 74% to universities, 16% to USDA labs or to ARS, 9% to private laboratories or organizations, and 1% to state agricultural experiment stations.

Principal Developments in FY77

- An irrigation demonstration project at a site near Willard, N. Mex. became operational, supplying 630 gallons per minute from a deep well with a 25 hp solar-powered pump.
- A contract was let for a second irrigation demonstration project at a site near Coolidge, Ariz. which will have a 150 kW pump.
- Fifteen solar grain drying projects were funded.
- Eight crop drying projects were funded.
- Twelve projects in the use of solar energy in livestock production were funded.
- Thirteen projects were funded in the construction, design and optimization of greenhouses and greenhouse/residential combinations.
- Six projects to assess the feasibility and to propose designs and demonstrations for solar heating of food processes were funded.
- Reports on five solar greenhouse demonstrations were presented at a DOE-sponsored workshop on agricultural and industrial process heat. Low-cost systems exhibiting potential cost-effectiveness were emphasized.

Advantages of Solar Agricultural Systems

- The temperature requirements for agricultural heating frequently are modest. Therefore, applications can rely on cur-

rent technology and are not dependent on high-cost and technically completed systems. There are significant possibilities for individually designed, very low-cost systems which can be constructed by farmers with technical assistance from the extension service.

- Land area is readily available for collector installation.
- In most cases, solar systems will be competing with LPG or electricity. Both of these energy sources are now relatively expensive (compared to other fossil fuels) and likely to increase in cost.
- Agricultural applications are often seasonal. Multiple-use solar systems tied to total farmstead energy management are likely to be cost-effective.
- Farmers' experience with solar energy in natural solar driers and greenhouse systems, as well as with commercial "active" units, is likely to encourage use of new solar systems on the farm. Farmers may be less resistant to the concept of diffuse or intermittent sources of energy than industrial or residential users.
- There exists significant potential for the use of solar thermal energy in agricultural applications abroad. For example, an assessment of priorities for solar energy in West and Central Africa places irrigation and pumping systems (0.5-10 hp) first, and solar distillation third.⁷ Agricultural energy requirements are large in LDCs. There is widespread familiarity with solar crop and grain drying. The export of low-cost technology for solar agricultural applications could be beneficial to international relations and to export trade.

Problems, Uncertainties, Dissenting Views

Agricultural applications of solar thermal energy, at least in terms of direct use of solar heat, have been closely associated with the use of solar energy for industrial process heat. Most market penetration studies and critiques of Federal programs have dealt with the agricultural and industrial sectors as a single entity, though it is increasingly clear that the nature of applications, technology, and problems may be strikingly dissimilar in the two sectors. The rate of penetration of solar technology is likely to be greater in the agricultural than in the industrial sector though agriculture's share of total energy consumption is much smaller. The following problems and uncertainties have been cited:

- The potential impact of solar agricultural applications on total United States energy requirements will be small (maximum of about 0.5%).
- Most favorable areas of insolation do not correspond to areas of highest demand for direct heating; however, the correspondence is (in general) better than for the industrial market and there is a nearly perfect correspondence for irrigation systems.
- There is a lack of experienced and nationally recognized design, installation, and maintenance organizations to rapidly extend the use of solar agricultural equipment. In addition,

farmers, ranchers, and agricultural advisors need to be educated about the use of solar thermal energy in specific climates and applications. A Federal demonstration and assistance program, with greater visibility, will help increase acceptance of solar systems. However, poor performance in publicly or privately funded applications will have a negative impact on acceptance.

- There are two constraints on the rapid commercialization of agricultural systems. First, the supply of durable, low-temperature collectors for agricultural use may be restricted. Second, low crop prices may put severe constraints on capital available for investment in new systems; government loan, grant or guarantee programs specifically directed at agriculture may be required.
- Although low-temperature nonstorage systems are currently the best alternative in drying systems, a conventionally-fueled backup or boosting burner will be required to complete drying of certain grains. As a result, returns of the solar system are sometimes only credited to fuel savings, and cost-effectiveness may appear marginal.
- Two solar thermal irrigation projects indicate that equipment costs are still too high to justify widespread private investment in solar irrigation. Two major components will require significant cost reduction (and/or efficiency improvements). Specially designed organic Rankine-cycle turbines and gear boxes are expensive items of equipment. In addition, engine efficiency was only 15% at design output when the collector field was operating at 450°F in the Willard, N. Mex. demonstration project. Concentrating collectors (designed for 600°F operation) must also be reduced in cost by a substantial degree. The Gila Bend irrigation project will cost nearly \$2.5 million (private).⁸ Some analysts believe solar irrigation systems will be economical only in areas where no alternative fuels are available (i.e., remote sites).
- If solar system use is strictly seasonal, and no provision for multiple-use is made, payback may be hindered by returns (in terms of fuel savings) accumulated over only a part of the year.

There seems to be less disagreement among researchers in agricultural applications than among those in industrial applications of solar energy. Overall, the market potential of agricultural applications has not received the attention it deserves. Although MITRE/METREK analysis indicates a greater market potential for high-temperature industrial process heat than for low-temperature agricultural applications, DOE suggests that 50% of the agricultural heating market could be served by solar energy by 2000—a significant opportunity for solar commercialization. While no real opposition exists to agricultural solar energy, positive support is needed to accelerate commercialization of this technology.

INDUSTRIAL PROCESS HEAT APPLICATIONS

Basic Technical Description

Industrial process heat is defined as thermal energy used directly in

Figure 10-4. PROCESS HEAT REQUIREMENTS IN MAJOR INDUSTRIAL GROUPS*

the preparation and/or treatment of materials and goods produced by mining and manufacturing processes. Though process heat is required in nearly every type of industry, over 80% of the demand is concentrated in only six major industrial categories. (See Figure 10-4.) Process heat energy can be supplied through a transfer fluid or by direct heating. In practice, heating fluids include hot water, low-pressure steam, or hot, dry air. Surveys of the relative quantity of heat energy required at various temperatures in the industrial sector have shown that a significant fraction of industrial process heat is used at temperatures within the operating range of currently distributed solar collector technology. For example, 40% of the total industrial process heat demand for direct applications and preheating occurs below 600°F (Figure 10-5).

As a result, the possibility of using solar collectors to heat a fluid (such as water) and subsequently transfer heat from this fluid, either directly or via heat exchangers, to materials in process appears quite feasible. Conventional flat-plate collectors may be satisfactory in many low-temperature applications, but the use of various forms of solar concentrators will be necessary in the majority of industrial applications where higher temperatures are required. The development of cost-effective concentrating collectors therefore deserves attention.

In addition, new concepts of large-area, shallow solar ponds to provide low-temperature hot water and of evacuated-tube banks for higher-temperature fluids are likely to find application. Hybrid systems may provide better performance in areas of variable cloudiness or for processes with a broad range of temperature tolerance. Such systems, consisting of collector fields of flat plates and parabolic troughs, have already been designed and installed for industrial applications.

Industrial applications will normally require much larger areas of collectors in order to provide substantial quantities of heat. The principles of system operation will be similar to those for residential heating and hot water, but because of strict reliability requirements,

a smaller fraction of the annual heat required will probably be supplied. Consequently, long-term storage will not be required. Most near-term industrial solar systems will probably provide only one to two days of storage in order to collect solar energy on idle weekends or provide no storage and act merely as fuel-savers which are supplemental to full-capacity, conventional process heat systems.

One can identify four generic categories of industrial process heat applications:

HOT WATER

Large amounts of heated water at temperatures between 120°F and 212°F are required in almost every industry for cooking, washing, bleaching, anodizing, refining, and related uses. Hot water requirements are approximately 2% of the direct total industrial process heat demand, amounting to 0.2 Quads of energy at a temperature level which can be easily supplied by current solar technology. Preheating water to provide boiler feed for higher temperature industrial processes probably accounts for 3.0 Quads of energy. Hot water solar systems may be applicable to industrial preheating, although indications of prospects for boiler preheating (in electric utility generation, for example,) are discouraging.

Hot water may be supplied by directly heating water in the absorber tubes of flat-plate, evacuated tube, or concentrating collectors and piping this water to the process terminals. If processing standards require uncontaminated water, a separate fluid may be piped through the collector field and then used to heat potable water via a heat exchanger. Large, shallow solar ponds may also be used to heat substantial volumes of water for batch usage. Heated water is often drained into insulated storage tanks at the end of a day, although it may be economical to provide night insulation on the ponds for integral storage.

STEAM

Except for direct process heat above 350°F, the demand for process

Figure 10-5. CUMULATIVE DISTRIBUTION OF PROCESS HEAT REQUIREMENTS (2)

Notes: Data Points Refer to:

- (1) Hall, E., *Survey of the Applications of Solar Thermal Energy Systems to Industrial Process Heat*, Report: ERDA TID-27348-1, Columbus: Battelle Columbus Laboratories, 1977.
- (2) Fraser, M. D., *Analysis of the Economic Potential of Solar Thermal Energy to Provide Industrial Process Heat*, Report: ERDA/COO/2891-1, Warrenton: InterTechnology Corp., February 1977.

steam is the largest single process heat requirement of the industrial sector. Somewhat more than 6 Quads are required for steam production and over 80% of this requirement is for low-pressure saturated steam below 350°F. In fact, standard industrial requirements are often for saturated steam at 100 psig, corresponding to a saturation temperature of about 340°F. Steam at this temperature can be produced in a solar system principally in two ways. Pressurized water may be circulated in the collector field and then flashed into steam in a low-pressure chamber. Alternatively, a heat transfer fluid capable of higher temperature operation may be circulated in the collector field, and then fed to a steam generator, where the fluid serves as a heat source to produce the steam.

Because of the higher temperatures required, industrial steam applications will normally require concentrating collectors, such as a parabolic trough, or certain nonimaging, high-temperature collectors such as the evacuated tube.

DRYING/DEHYDRATION

Nearly 1.4 Quads of energy are required for the production of hot, dry air in industrial processes below about 350°F. This air is required in a large variety of drying and dehydration operations: many applying to food processing or crop drying. Air may be heated to this temperature directly in collector systems designed to handle air as a circulating fluid. Alternatively, a liquid circulating fluid may be used and pumped through an air heat exchanger to heat ambient air.

DIRECT PROCESS HEAT

High-temperature, direct process heat accounts for an overwhelming fraction of industrial process heat. Sixty percent of all industrial heat is required at high temperatures (defined here as an application temperature of 650°F and above); and the major portion of this requirement is supplied as direct refractory heat in industries such as primary metals, glass, Portland cement, etc. Except for very small-scale solar furnace applications, it is unlikely that solar energy will be used for process heating at the temperatures in the near future. However, recent research into high-temperature, distributed-focus solar concentrators lends some hope for direct solar heating in certain processes. For instance, the receiver tube of a powerful tracking concentrator might be used as a reactor for synthetic fuel production from biomass at temperatures on the order of 1000°F.

In addition, preheating of combustion air, as is done in at least one industrial demonstration today, might provide significant fuel savings without requiring inefficient high-temperature collector operation.

Sample applications of industrial process heat are shown in Table 10-3.

Federal Program Goals

- Develop designs, test and demonstrate solar industrial process heat systems exhibiting outstanding potential for providing process heat, and to identify problems and barriers to development for those systems.
- Encourage development of collectors and storage systems capable of advancing solar process heat system performance and temperature range.
- Show to potential users of solar energy systems, via a demonstration and testing program the economic and technical advantages of applying solar process heat systems to their industrial requirements.
- Encourage the adoption of various investment incentives by the Federal government.
- Encourage commercial production and development of solar components via a demonstration and testing program.
- Assess the potential for application of solar energy to industrial process heat and identify those processes and locations where solar energy can supply a significant amount of process energy needs.

Table 10-3. INDUSTRIAL APPLICATIONS

Location	Contractor/Sponsor	Solar Collector/Process/Company	Status
Athens, AL*	Teledyne-Brown/DOE	SSP/Hot process water/Sweet Sue Kitchens	Design Only
Decatur, AL	Teledyne-Brown/DOE	FPA/Soybean drying/Gold Kist	Mid-1978
Fairfax, AL	Honeywell, Inc./DOE	CS/Cylindrical can dryers/West Point-Pepperell	Mid-1978
El Centro, CA	Jacobs Engineering/DOE	CW/Industrial laundry/American Linen Supply	Design Only
Fresno, CA	Cal Poly State Univ./DOE	FPA/Fruit drying/L&P Foods	Early 1978
Gilroy, CA	Trident Engineering/DOE	FPA/Onion drying/Gilroy Foods	Design Only
Sacramento, CA	Aerotherm-Acurex/DOE	CW/Canwashing/Campbell Soup	Operational
Lawrence, KS	MRI/DOE	CA/Alfalfa drying/Western Alfalfa Corp.	Design Only
Canton, MS	Lockheed-Huntsville/DOE	FPW/Lumber Kiln/LaCour Kiln Service	Operational
Grants, NM	LLL/DOE	SSP/Uranium ore processing/Sohio	Operational
York, PA	AAI Corp./DOE	LA/Block curing/York Bldg. Products	Mid-1978
LaFrance, SC	General Electric /DOE	ET/Dye beck/Riegel Textile Corp.	Mid-1978

*Key to acronyms:

CA	Parabolic trough concentrator using air
CS	Parabolic trough concentrator using steam
CW	Parabolic trough concentrator using water
ET	Evacuated tube collector
FPA	Flat-plate air system
FPW	Flat-plate water system
LA	Linear array, fixed receiver
SSP	Shallow solar pond

Description of the Federal Program

The DOE program has been concentrating on an aggressive demonstration plan, calculated to encourage system and component development, while demonstrating to private industrial investors the near-term capabilities of solar industrial process heat (Figure 10-6). The Federal role in funding demonstrations has been to reduce the risk associated with R&D and installation of such systems, and thus to accelerate industrial acceptance. Funding has been geared to encourage state-of-the-art component applications; long-term component R&D has been primarily funded through other programs in solar heating and cooling, and solar thermal power systems. The 1977 budget for industrial applications was less than 2% of the total budget of the ERDA Division of Solar Energy. Of a total expenditure of some \$5.34 million, \$3.86 million (72%) was spent on demonstrations, and \$645,000 (12%) was spent in supporting major studies of the process heat sector. Approximately \$800,000 (15%) was spent by Agricultural and Industrial Process Heat Program in support of research programs in other areas or in the development of systems and/or components applicable to needs in these areas. The remaining sum was directed to the annual workshop.⁹

Principal Developments in FY77

- Designs were completed for ten industrial process heat system demonstrations.
- Conceptual design was completed for the installation of a shallow solar pond at a food processing plant in Athens, Alabama.

Figure 10-6. INDUSTRIAL PROCESS HEAT FEDERAL PROGRAM MILESTONES

Experiments & Prototype Systems

	1976	77	78	79	80	1981
Industrial Cycle:	1	2		3	4	5
Hot Water	▲	▲		▲	▲	▲
Hot Air	1			2	3	4
	▲			▲	▲	▲
Steam		1	2	3	4	5
		▲	▲	▲	▲	▲
Commercial Agriculture	1	2	3	4	5	
	▲	▲	▲	▲	▲	▲

Source: ERDA 77-72, "Solar Energy for Agriculture and Industrial Process Heat, Program Summary," June 1977.

- Eight selected solar process heat application demonstrations were under construction during the year.
- Two privately funded solar industrial process heat systems were operating or planned in FY77.
- The Second Annual Solar Industrial Process Heat Symposium

was held in College Park, Maryland, in September, 1977. Reports on DOE-funded demonstrations were given to assembled researchers, industrialists, builders and collector manufacturers.

- Two studies concerning the application of solar energy to industrial processes and assessing the technical and economic potential of solar industrial process heat were completed. The studies provided substantial industrial process heat data and a clear interpretation of the temperature range of industrial requirements.¹⁰

Problems, Uncertainties, Dissenting Views

The technical feasibility of solar systems to provide industrial process heat at temperatures below approximately 350°F is easily demonstrable. Providing process heat at higher temperatures can be demonstrated in certain cases; but in others, application must await technical advances in high-temperature coatings, insulation, and equipment design. Current technology to provide preheating energy may serve some high-temperature process heat demands; however, economic feasibility for solar industrial process heat is more difficult to demonstrate, and considerable uncertainty exists regarding the future economic viability of solar industrial process heat.

Differing views of industrial process heat's potential are indicated by two major ERDA-sponsored studies in Figure 10-5. Among the general studies specifically directed toward a market analysis for solar energy (EEA and METREK)¹¹, differences can be attributed to analytical discrepancies in:

- market segmentation;
- solar technology suitability;
- solar equipment projected costs;
- conventional fuel cost projections;
- conservation techniques as opposed to solar energy;
- methodologies for projecting market capture.

InterTechnology estimates of the market share for solar industrial process heat are made only on the basis of technical performance and strict marginal economic analysis and, therefore, might be viewed as an upper limit (without substantial incentives) to the application of solar energy in this sector. The market penetration analyses of EEA and METREK, however, both depend on the analysis by InterTechnology of process demands at various temperatures. METREK assumes a possible market for solar energy in providing preheat to high-temperature processes. EEA disregards this potential market, assuming that waste heat will be used in all cases. This difference in market potential estimates is significant and is reflected in the optimistic/pessimistic views expressed.

Limitations in the application of solar industrial process heat can be attributed to the following factors:

- Application of solar energy must, in general, compete with cheaper alternatives, including coal, oil, gas, and conservation measures.
- Industry requires a very short payback period (i.e., high return on investment) on capital projects.
- Collector costs have not reached a level characteristic of a mature industry and, more importantly, system construction experience is not sufficient to reflect eventual competitive levels of system costs.
- Federal fuel-use tax credits are a disincentive to solar investment.
- Unless extremely large areas of collectors are considered, the impact of solar process heat is likely to be a small fraction of the total required energy for a given industrial plant. There is a temptation to neglect systems with such a small impact among large industrial energy users.
- The limitations on operating temperature for current solar systems exclude a large portion of the process heat market where direct applications are considered and make recuperative use of initial high-temperature heat a more economic alternative for low-temperature needs in many industries. However, a substantial portion of high-temperature demand can be attributed to preheating over a lower temperature range.
- The costs of idle manufacturing capital and labor are such as to require high system reliability. If long-term storage (which is costly) is not considered, then full capacity backup must be provided, making the only return on solar system investment equal to the annual savings on the fuel bill for conventional systems. The inclination of any industry to seek these savings may be a function of the energy intensiveness of product manufacture.

In addition, the wide application of solar industrial process heat will face a number of nontechnical problems, such as:

- reluctance of industry to accept "new venture" technology until widely demonstrated and shown reliable;
- tendency of industry to remain with present heating systems or to consider energy conservation methods as an alternative to solar energy (particularly true when expansion of plant capacity is not anticipated);
- environmental and economic problems in devoting large areas of land to collector fields or, in retrofit applications, finding suitable land or roof area.

Solar industrial process heat also has certain advantages which may make its future more promising than what some recent studies indicate:

- Industrial loads are usually constant over the year; hence, solar process heat systems do not show the seasonal disadvantage of

low solar input and high demand which is characteristic of solar space heating systems.

- The potential impact of solar process heat is much larger, in total energy demand terms, than the potential impact of residential solar heating.
- Greater amounts of capital are available in the industrial sector for system investment.
- Life-cycle costing is more acceptable in the industrial sector than in the residential sector. One would expect industrial managers to be more receptive to the concept of calculated future returns.
- Large-area collectors are applicable and may show cost advantages.
- Large-area solar systems may show cost advantages of scale in construction methods.
- Reductions in atmospheric and thermal pollution and enhancement of energy resource conservation may confer public relations benefits on companies adopting solar systems.
- Probable reductions in system costs and an escalation in alternative energy costs (in real terms) may offer investment advantages in the future.
- Solar systems are less susceptible to potential supply interruptions than are conventional fossil fuels.

- Greater reliance on the life-cycle costing in industrial investment analysis may favor solar systems.
- There are significant prospects for "hybridization" of processing systems in order to make use of more efficient solar preheating for high-temperature processes.

Notes

¹Federal Energy Administration and USDA, *Energy and U.S. Agriculture: 1974 Data Base*, FEA/D-76/459, Washington: September 1976.

²Ibid.

³A.B. and M.P. Meinel, *Applied Solar Energy* (Reading: Addison-Wesley, 1977), pp. 554-556.

⁴W. Roberts, "Islander Seeks Patent for Solar Irrigation Unit," *Grand Island Daily Independent*, November 14, 1977.

⁵National Academy of Science, *Solar Energy in Developing Countries*, PR-208550, Washington: March 1972.

⁶Meinel and Meinel, *Applied Solar Energy* (1977), pp. 554-556.

⁷National Academy of Science, *Solar Energy in Developing Countries* (March 1972).

⁸L. Listiak, "Sun Shines on Gila Bend Farm," *Yuma Daily Sun*, Yuma, Arizona, November 6, 1977, p. A-14.

⁹*Solar Energy for Agriculture and Industrial Process Heat: Program Summary*, ERDA 77-72, Washington: June 1977.

¹⁰*Survey of the Applications of Solar Thermal Energy Systems to Industrial Process Heat*, Final Report (3 volumes), Battelle, TID-27348/1, Columbus, OH: Jan. 1977.

¹¹*Analysis of the Economic Potential of Solar Thermal Energy to Provide Industrial Process Heat*, InterTechnology Corp., COQ/2829-76/1 Warrenton, VA: Feb. 1977.

Existing Solar I. P. H. Installations

Industrial Process Heat Projects

<u>location</u>	<u>process, collector type, & temperature</u>	<u>owner & contact</u>	<u>contractor & contact</u>	<u>phase & funding</u>	<u>status & startup date</u>	<u>data aquisition system</u>
DOE Industrial Process Heat program - Bill Nettleton: SAN, Oakland, CA 8 - 536 - 7975						
Cycle I - Hot Water, 140°-212°F.						
Sacramento* CA	can washing flat plate and parabolic trough 185°F.	Campbell Soup Co.	Acurex, Mtn. View, CA Jorgen Vindum (415) 964-3200 x3342	Phase I \$204,000 Phase II \$561,000 Phase III \$186,000	operational June, 1978	mag tap, data reduction at Acurex, also IBM/Huntsville
Harrisburg* PA	concrete block curing linear segmented mirror array 180°F	York Building Products	AAI Corp., Baltimore, MD Hal Wilkening 8-920-311 x222 (301) 666-1400	Phase I \$114,000 Phase II \$450,000 Phase III \$100,000	operational Sept., 1978	
LaFrance* SC	textile dyeing evacuated tube 190°F	Riegel Textile Corp.	General Electric, Phila., PA J. B. Trice (215) 962-2000	Phase I \$258,000 Phase II \$580,000 Phase III \$148,000	operational June, 1978	

*denotes projects monitored by SERI

Industrial Process Heat Projects (cont)

<u>location</u>	<u>process, collector type, & temperature</u>	<u>owner & contact</u>	<u>contractor & contact</u>	<u>phase & funding</u>	<u>status & startup date</u>	<u>data aquisition system</u>
Cycle II - Low Temperature Steam, 212°-350°F.						
Sherman TX	gauze bleaching parabolic trough 350°F.	Johnson & Johnson	Acurex, Mtn. View, CA Stan Youngblood (415) 964-3200 x3530	Phase I \$214,000 Phase II \$800,000	under construction	
Pasadena CA	laundry parabolic trough 335°F	Home Cleaning and laundry	Jacobs-Del Solar Systems, Inc., Pasadena, CA M. M. Delgado 8-213-264-5900	Phase I \$194,000 Phase II \$489,000	receiving construction bids	
Bradenton FL	orange juice pasteurizing evacuated tube 350°F.	Tropicana Products, Inc.	General Electric, Phil., PA J. B. Trice (215) 962-2000	Phase I \$235,000 Phase II \$790,000	construction early in 1979	
Fairfax AL	fabric drying parabolic trough 317°F.	West Point-Pepperell	Honeywell, Inc., Minn., MN P. D. Mitchell (612) 378-5431	Phase I \$146,000 Phase II \$645,000 Phase III \$150,000	operational Aug., 1978	

Industrial Process Heat Projects (cont)

<u>location</u>	<u>process, collector type, & temperature</u>	<u>owner & contact</u>	<u>contractor & contact</u>	<u>phase & funding</u>	<u>status & startup date</u>	<u>data aquisition system</u>
Cycle III - Medium Temperature Steam, 350°-500°F.						
Mobile AL	oil heating parabolic trough 365°F.	Ergon, Inc.	Acurex, Mtn. View, CA Jorgen Vindum (415) 964-3200 x3342	Phase I	in design*	
Dalton GA	latex production linear segmented mirror array 366°F.	Dow Chemical, Inc.	Foster-Wheeler Devlp. Corp., Livingston, NJ Dr. G. D. Gupta 8-341-3000. Gupta	Phase I	in design*	
Newberry Springs CA	hectorite processing parabolic trough 366°F.	National Lead Industries	Jacobs-Del Solar Systems, Inc., Pasadena, CA Bernard G. Eldridge 8-213-449-2171 x6829	Phase I	in design*	
Hobbs NM	oil refinery parabolic trough 380°F.	Southern Union Co.	Monument Solar Corp. Dallas, TX L. Dale Clark 8-749-1011	Phase I	in design*	
San Antonio TX	brewery parabolic trough 353°F.	Lone Star Brewing Co.	Southwest Research In. San Antonio, TX Danny M. Deffenbaugh 8-730-5511	Phase I	in design*	
Henderson NV	chlorine manufacturing parabolic trough 368°F.	Stauffer Chemical Co.	Chilton Engr., Sparks, NV Sheldon Gordon 8-470-5911	Phase I	in design*	
Ontario OR	potato processing parabolic trough 417°F.	Ore-Ida Co.	TRW, Redondo Beach, CA J. M. Cherne 8-213-536-1955	Phase I	in design*	

*designs are due June, 1979.

Industrial Process Heat Projects (cont)

<u>location</u>	<u>process, collector type, & temperature</u>	<u>owner & contact</u>	<u>contractor & contact</u>	<u>phase & funding</u>	<u>status & startup date</u>	<u>data aquisition system</u>
Hot Air Projects			(Jerry Blevins), Oak Ridge National Lab Oak Ridge, TN			
Fresno* CA	fruit drying flat plate 150°F.	Lamanuzzi & Pantaleo Foods	Calif. Polytechnic State Univ. San Luis Obispo, CA E. J. Carnegie (805) 546-2814	Phase I \$269,000 Phase II \$545,000 Phase III \$168,000	operational	
Canton* MS	kiln drying of lumber flat plate (water with heat exchanger) 180°F.	J. A. LaCour Kiln Services, Inc.	Lockheed, Huntsville, AL S. J. Robertson (205) 837-1800	Phase I \$ 71,000 Phase II \$286,000 Phase III \$119,000	operational	
Decatur* AL	soybean drying flat plate 160°F.	Gold Kist, Inc.	Teledyne-Brown Engr. Huntsville, AL Perry Fisher (205) 532-1402	Phase I \$287,000 Phase II \$748,000 Phase III \$126,000	operational May, 1978	
Gilroy CA	onion drying evacuated tubes (water with heat exchanger) 210°F.	Gilroy Foods, Inc.	Trident Engr. Associates, Inc., Annapolis, MD R. Wagner (301) 267-8128	Phase I \$226,000 Phase II \$525,000	construction in 1979	
Total Energy Project						
Shenandoah GA	knitwear plant parabolic dish 750°F	Wilhelm Bleyde Co.	General Electric	Phase III \$1,500,000	preliminary design, operational in Feb., 1982	

*denotes project monitored by SERI

Industrial Process Heat Projects (cont)

<u>location</u>	<u>process, collector type, & temperature</u>	<u>owner & contact</u>	<u>contractor & contact</u>	<u>phase & funding</u>	<u>status & startup date</u>	<u>data aquisition system</u>
DOE Solar Heating and Cooling Demonstration Program - Tom Webster, Lawrence Livermore Lab (Fen Salter) Livermore, CA						
Fresno CA	industrial laundry flat plate (water) 180°F.	Red Star Industrial Laundry, ARATEX Services Inc. (owner & designer) Eric S. Burnett	Ying Manufacturing Co. Gardenia, CA Ying-Nien Yu 213-327-8399 (collector manufacturer)	\$165,000 (plus \$17,000 from State of Calif.)	operational Sept., 1977	IBM/Huntsville
Privately Funded Projects						
Youngstown OH	hot dip aluminum anodizing parabolic relector, fixed absorber, limited tracking (water) 180°F.	General Extrusions, Inc. Duane R. Rost	General Solar Systems Youngstown, OH (216) 783-0270	(does not apply)	operational Sept., 1977	has only limited instrumentation
Jacksonville FL	beer pasteurizing evacuated tube (water) 150°F.	Anheuser-Busch, Inc. Walter Allen	Barry-Wehmiller Tom Coats	(does not apply)	operational Feb., 1978	
Richmond VA	film processing flat plate (water) 115°F	Easco Photo	Torrence, Dreelin, Farthing, & Buford, Inc. Richmond, VA Richard Hankins (804) 358-9111	(does not apply)	operational July, 1978	