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INTERNAL POSITION PAPER

High-Temperature Industrial Process Heat

Technology Assessment and Introduction Rationale

Prepared for

DEPARTMENT OF ENERGY

Washington, D. C.

3 March 1978

Prepared by

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THERMAL POWER SYSTEMS
DIVISION OF SOLAR ENERGY

DEPARTMENT OF ENERGY
Washington, D. C. 20545

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I. INTRODUCTION

I. INTRODUCTION

A technical, economical, and programmatic basis is presented to expand the current Department of Energy (DOE) Solar Industrial Process Heat Program to include high-temperature, high-grade thermal energy generated via solar thermal electric system technology. The activity represented by this report was conducted by The Aerospace Corporation under the sponsorship of DOE's Advance Technology Branch, Division of Solar Energy. The time period involved was 1977 and early 1978. The activity was originated under the Energy Research and Development Administration (ERDA) and subsequently transferred to DOE. Many of the results presented were derived in coordination with industrial firms dedicated to maintaining and advancing their technology and business posture in the process heat market.

A. PURPOSE AND SCOPE OF THE REPORT

The purpose of this report is to address three specific topics of interest to DOE:

1. To establish the significance and identify the role of high-temperature process heat in the nation's energy economy
2. To identify the role of solar thermal power in these high-temperature industrial applications in terms of possible markets and economic potential
3. To recommend programmatic approaches for these solar thermal high-temperature process heat activities, including proposed content for initial Request for Proposals (RFPs) to accomplish such activities.

The scope of the work required to accomplish these three purposes included the following: review of U. S. industrial energy requirements, survey of current DOE low-temperature Agricultural and Industrial Process Heat Program, examination of high-temperature solar thermal electric systems already developed or under development by DOE and industry, and coordination with the high-energy user segments of industry (i.e., cement, chemical and petroleum) to find additional markets for some or all of the systems or components being developed in the DOE solar thermal electric program.

B. PROGRAM BACKGROUND AND TECHNOLOGY STATUS

The basis that prompted the activity reported here was DOE's charter to develop solar heat energy applications and to utilize their on-going hardware programs. Both the scope of DOE's development efforts and the status of their hardware technology are pertinent to an appreciation of the results of this report.

1. Background of DOE Process Heat Activity

DOE's Agricultural and Industrial Process Heat Branch is working with DOE laboratories and industry in the development of solar heat energy applications to industrial processes in three areas (Reference 1):

- Low-temperature applications (below 212°F)
- Intermediate temperatures (212°F to 350°F)
- High-temperature applications (above 350°F)

The emphasis in this report is on the latter, but all three areas are addressed where appropriate.

The low-temperature industrial process heat experiments and prototype systems pertain to applications in which temperatures under the boiling point of water are required. Low- temperature technology is basically similar to that for the heating and cooling of buildings and agricultural applications.

Intermediate-temperature process heat applications include production of low-pressure steam for industrial uses, and various drying operations. The technology for this portion of the program comes in part from the research and development conducted for the heating and cooling of buildings, and in part from the solar thermal electric programs directed toward the generation of electric power.

Planning for high-temperature process heat experiments and prototype systems includes production of high-pressure steam, heat for chemical processes, and other industrial uses of solar energy. The technology for these prototype systems will come primarily from research and development conducted for solar thermal electric generation systems which are discussed in this report.

It is important that solar systems designed to supply industrial process heat must show economic viability, maintainability, reliability, and be capable of integration into existing industrial processes. To accomplish this, the industrial portion of the DOE program has been planned to:

- Assess those processes in the various industries where solar energy can supply a significant amount of the process energy needs;
- Design solar energy systems that can provide significant amounts of process heat;
- Experiment with various system designs to determine the best method of deriving industrial process heat;
- Demonstrate, by the installation of prototype systems, the capacity of solar energy to provide significant amounts of the process heat requirements of various industries.

2. Technology Status

Hardware has already been developed by DOE for non-process heat applications that may be used directly, or with minor modification for industrial process heat. Shallow solar pond technology has been developed and is available for meeting part of the lower-temperature preheat requirements up to 140°F (Reference 2). Other technologies exist or are being developed to satisfy higher-temperature requirements expected to ultimately reach 2700°F applications.

The present DOE Industrial Process Heat Program and also their Total Energy Program are intensive efforts to stimulate and give impetus to industry to use solar energy for low-temperature industrial processes. The programs are based on the application of state-of-the-art technology and are being implemented in a series of progressive steps that began in 1977.

In May 1977, DOE (then ERDA) issued an RFP for solar production of industrial process steam (Reference 3). The objective of that procurement was the the determination of the technical and economic feasibility of producing low-pressure steam (212°F - 350°F, 14.7 - 135 psi) for industrial process heat by solar energy. RFP's had previously been issued and projects are still under contract to DOE for (a) solar heating of industrial process hot water, temperatures ranging up to 180°F, (b) drying/dehydration with temperatures over 200°F, and (c) industrial total energy systems (co-generation) (Reference 4). In the latter project, heat from the turbine generator is to be used to provide space heating and cooling, hot water, and process heat.

Each of these DOE funded projects involves a specific industrial process application in a specific industrial plant. The current programs are based on relatively simple collectors, incorporating low concentration to heat water, steam or air to temperatures in the range of 100°F - 350°F. The primary value of the initial systems is expected to be as a fuel saver, displacing the need for critical fossil fuel. Low-temperature storage concepts are being utilized where required.

C. REPORT FORMAT AND SECTION INTENT

The remainder of this report contains three sections corresponding to the three purposes of the report. Appendices are also provided to present additonal detail and technical substantiation to the material in the sections. These sections and their intent are:

o	Section II:	Role of Process Heat in the Nation's Energy Economy - present statistical data identifying energy allocations to process heat and define DOE's involvement
o	Section III:	Role of Solar Thermal Energy in Process Heat - provide three current fossil fuel process heat system examples and identify the corresponding solar potential
o	Section IV:	Recommended Programmatic Approach to Further Solar Thermal Process Heat Activities - identification of an overall approach, initial steps, and RFP content for a High-Temperature Industrial Process Heat System

II. ROLE OF PROCESS HEAT IN THE NATION'S ENERGY ECONOMY

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The role of process heat in the energy economy can be described in terms of existing energy uses and the functional energy relationship to temperature. In particular DOE has defined four key descriptors of the role, pertaining to the following:

- Fraction of energy consumed by process heat
- Process heat percentages versus temperature
- Significant high-temperature heat applications
- Definition of high-temperature heat

This section discusses each of these role descriptors, and concludes with an additional discussion of the responsibility of the DOE Agriculture and Process Heat Branch regarding these descriptors.

A. U. S. ENERGY FRACTION TO PROCESS HEAT/PREDOMINANT FUELS

A significant fraction of U. S. energy is devoted to process heat and to specific process heat applications. These fractions are developed in this section in steps. First, a correlation is established between the overall energy consumption and the nation's economy. Next, the portion of U. S. energy consumed by industry is developed, and this portion is further distributed in terms of process steam, heat, and thermal energy versus power. Industrial energy consumption is then interpreted in terms of the predominant fuels used in various regions and in terms of fuel conversion and priorities, to provide a basis for potential solar thermal applications.

1. Energy Consumption and the Economy

To identify the relationship between energy consumption and the economy, Figure 2-1 presents a plot of real gross national product and industrial energy consumption versus the time interval from 1950-1976. During this period the gross national product has shown a 3.7% straight line annual growth trend while industry

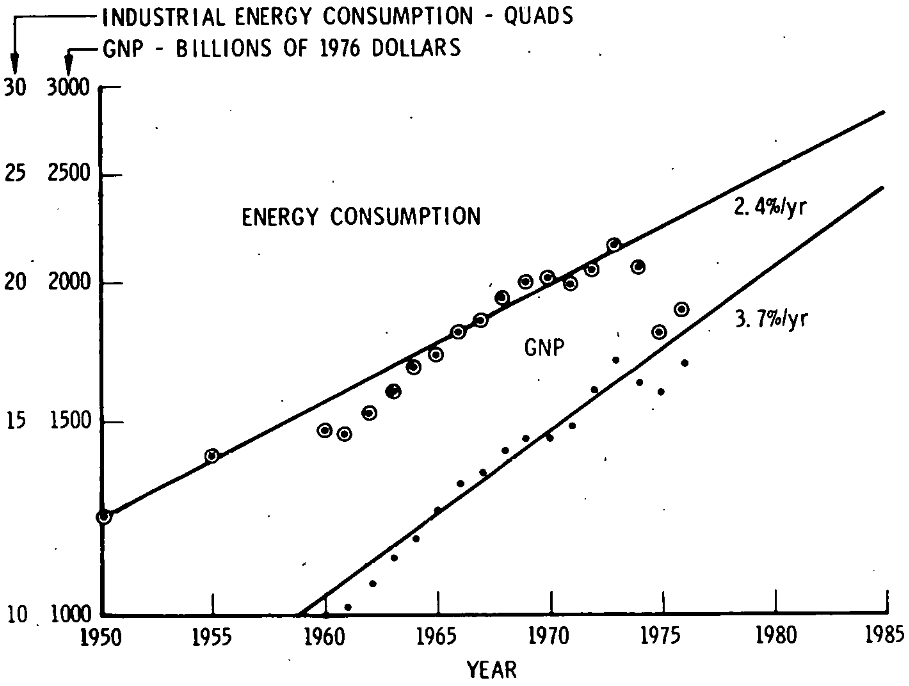


Figure 2-1. Industrial Energy Consumption - 1950-1976

has shown a 2.4% annual energy demand growth. The more interesting aspect of the data indicates that each decrease or increase in energy consumption is associated with a somewhat similar fluctuation in the gross national product, thus corroborating that a fair degree of correlation exists between industrial energy consumption and the nation's economy.

2. Industry's Portion of U. S. Energy

The industrial process heat market has been found to comprise approximately 25% of the current U. S. energy consumption. Recent references (5, 6, 7) show that approximately 69 x 10^{15} Btus (i.e., 69 Quads) were consumed in 1971 and the estimated current (i.e., 1977) annual use is approximately 75 to 80 Quads; the upper bound of which is compatible with the 2.4% annual energy demand growth.

The breakdown of 1971 energy consumption by market sector is shown in the left hand block of Table 2-1. Based on the U. S. net energy consumption (i.e.,

Table 2-1. Industrial Energy Consumption by Market Sector and Energy Use

Distribution of Energy Consumption[1] by Market Sector-1971

MARKET SECTOR	PURCHASED FUELS		PURCHASED FUELS & ELEC	
	QUADS	%	QUADS	%
HOUSEHOLD/ COMM	14.3	20.7	17.4	30.6
TRANSPORT	17.0	24.6	17.0	29.8
INDUSTRIAL	20.3	29.6	22.6	39.7
ELEC GEN	17.4	25.3	--	--
TOTAL	69.0	100.0	57.0	100.0

Industrial Energy Use[2] (percent)

PROCESS STEAM	40.6	68.4
DIRECT PROCESS HEAT	27.8	
ELECTRIC DRIVE	19.2	
ELECTRIC PROCESS	2.8	
FEED STOCK	8.8	
OTHER	0.8	
TOTAL	100.00	

1. Source: Energy Conservation in the Manufacturing Section - 1954-1990, Energy and Environmental Analysis, Inc., prepared for the Council on Environmental Quality, November, 1974.

2. Source: Analysis of The Economic Potential of Solar Thermal Energy to Provide Industrial Process Heat, Intertechnology Corporation, prepared for the Energy Research and Development Administration Division of Solar Energy, February 1977.

purchased fuels plus electricity), industry (shown shaded) requires approximately 39.7% of the energy.

A further breakdown of this industrial demand appears in the right hand block of Table 2-1. It is obvious from the data that the major portion of industrial energy is utilized in the form of thermal energy rather than in the form of power. Specifically, process steam and direct process heat total 68.4% of the industrial energy consumed (which translates to over 27% of U.S. energy consumption).

3. Consumption By Region and Fuel

An examination of the industrial energy consumption by region and fuel in 1972 (prior to the Arab Oil Embargo) is summarized in Table 2-2. The table shows that natural gas was the predominant fuel consumed by industry, furnishing nearly two-thirds (62.8%) of the industrial energy needs. Coal furnished 24% and oil the remaining 14%. The table further indicates that only in the Northeast and Northcentral regions does coal supply more than 40% of the regional industrial energy requirement. In fact, in the remaining five regions oil and gas combined supply about 90% of the industrial needs.

Table 2-2. Industrial Energy Consumption by Region and Fuel - 1972

REGION	10^{12} Btu			
	COAL	OIL	N. GAS	TOTAL
NORTHEAST	1067	487	774	2248
NORTHCENTRAL	1993	372	2281	4646
NORTHWEST	21	112	352	485
SOUTHEAST	361	219	544	1124
SOUTHCENTRAL	382	317	2163	2862
SOUTHWEST	134	818	3950	4902
NONCONTIGUOUS STATES	11	14	38	63
TOTAL	3970	2260	10120	16332
PERCENT	24.3	13.9	62.8	100

4. Fuel Conversion and Priorities

It is reasonably easy and economical to convert a natural gas boiler to burn oil, involving a change in the burner and the addition of oil storage tanks. However, the conversion from either oil or gas to coal normally requires an entirely new boiler, extensive coal handling equipment, and a large area of land to store the coal. Furthermore, if the industrial process is continuous, as most are, then the coal/boiler must have a backup oil burning capability and adjacent oil storage tanks to back up the coal system which is prone to periodic mechanical failures.

Consequently, industry has found that up to eight times the initial capital investment is required for a coal process heat plant than for an oil or natural gas system.

Subsequent to 1973, industry was assigned the lowest natural gas priority of all market sectors, and rather than switching from natural gas to coal as desired by the Government, industry has of necessity converted to oil because of this difficulty in switching to coal. Currently, coal supplies only 25% of industry's needs with the balance evenly split between oil and natural gas. With continuing Government pressure to convert to coal and the ever increasing oil and gas price spiral, industry is now becoming interested in the use of solar energy as a potentially attractive alternative.

B. PROCESS HEAT VERSUS TEMPERATURE RELATIONSHIPS

Relationships between industrial process heat utilization and the associated temperature are an additional categorization to define the role of process heat. Studies to date of such relationships provide insight to their significance, but further interpretation is necessary.

Four recent DSE studies (References 8, 9, 10, and 11), examined the industrial process heat requirements as a function of application temperature. Reference 3, which typifies these studies, presents a cumulative distribution of industrial process heat requirements as a function of the terminal temperature required for a process; this distribution curve is repeated in Figure 2-2 for convenience. Appendix A-1 presents a complete tabulation of these industrial process heat applications and annual energy requirements, as a function of terminal temperature, ranging from the highest application temperature requirement to the lowest.

The cumulative distribution in Figure 2-2 provides only a partial view of the situation. Most of these studies, including Reference 8, examined each process as if it were an individual plant application and not as it actually exists; i.e., as a subprocess of a much larger and more complex operation. In large complex efficient plants the waste heat from the highest temperature subprocess is normally utilized to satisfy the terminal temperature process heat requirement of

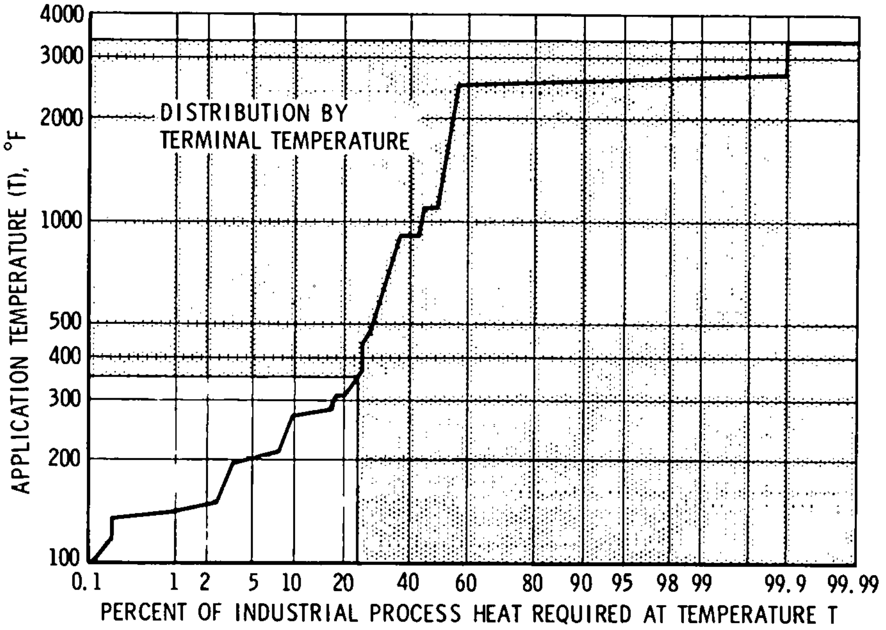


Figure 2-2. Cumulative Distribution of Process Heat Requirements

another lower temperature process; this technique is called cascading. This form of energy conservation will disguise the identification of many of the low-temperature individual plant applications that would correspond to the lower portion of the curve in Figure 2-2, which tends to shift the distribution of applications to the higher temperatures. Neglecting this potential shift, these current data show that DOE's Industrial Process Heat Program, which was aimed at delivering thermal energy at or below 350°F, would account for only 22% of the industrial process heat terminal temperature requirements. Moreover, the next 33% (i.e., 22 to 55 along Figure 2-2 axis) of the requirements fall in the 350°F to over 2000°F range and easily can be satisfied utilizing current state-of-the-art solar technology systems now completing development for the generation of electric power. The industrial process heat market in this 350°F to 2000°F range comprises approximately 8% to 9% of the current entire U. S. energy consumption.

C. SIGNIFICANT HIGH-TEMPERATURE PROCESS HEAT APPLICATIONS

Process heat applications of significance to solar are identified in this section from two perspectives. First, the results of prior DOE studies are summarized to highlight five industrial classifications and second, two other pertinent criteria are discussed.

1. Applications Derived from Prior DOE Studies

A key objective of the Industrial Process Heat Program is the development of solar systems that have the capability of capturing a significant portion of the industrial energy market. To assist in accomplishing this goal, DOE in previous studies (Section II A) has examined a wide variety of industrial processes and has identified the process heat temperature and energy requirements representative of the Standard Industrial Groups. Two of these studies were particularly pertinent regarding solar applications.

Table 2-3 summarizes the results of the two major studies. The results of these two surveys of energy consumption appear to be consistent even though each differed in data-gathering techniques and scope. Each study indicates that about 90% of the total process heat was consumed by industries identified in five standard two-digit industrial classification groups, and again these same five groups contained the major process heat users at temperatures above 350°F. These top five groups - Paper and Allied Products, Chemicals, Petroleum Products, Stone, Clay and Glass, and Primary Metals - along with their appropriate process heat requirements are highlighted by the shaded overlay in Table 2-3.

2. Other Pertinent Application Criteria

Two other criteria used in identification of significant high-temperature process heat applications are (1) availability of capital for new equipments, and (2) selection of process heat terminal temperature requirements that are within the current state of the art of solar equipments currently under development for solar electric applications. A brief discussion of these follows but future refinements of these identifications are appropriate.

Table 2-3. Summary of 1974 Process Heat Requirements Established by Analysis of Existing Processes

STANDARD INDUSTRIAL CLASSIFICATION GROUP	INDUSTRY	TOTAL PROCESS HEAT, 10^{12} Btu		PROCESS HEAT GREATER THAN 350°F, 10^{12} Btu	
		INTERTECHNOLOGY	BATTELLE	INTERTECHNOLOGY	BATTELLE
10-14	MINING	129	55	38	11
20	FOOD AND KINDRED PRODUCTS	319	555	48	115
21	TOBACCO PRODUCTS	1	-	0	-
22	TEXTILE MILLS	116	296	0	17
23	APPAREL	-	-	-	-
24	LUMBER AND WOOD PRODUCTS	172	210	0	74
25	FURNITURE	12	-	0	-
26	PAPER AND ALLIED PRODUCTS	1,093	559	349	94
27	PRINTING AND PUBLISHING	-	-	-	-
28	CHEMICALS	534	2,100	135	1,650
29	PETROLEUM PRODUCTS	2,637	3,100	2,480	2,960
30	RUBBER	10	-	3	-
31	LEATHER	3	-	0	-
32	STONE, CLAY AND GLASS	991	1,170	940	1,118
33	PRIMARY METALS	3,772	1,951	3,621	1,935
34	FABRICATED METAL PRODUCTS	0	-	0	-
35	MACHINERY	-	-	-	-
36	ELECTRICAL EQUIPMENT	2	-	2	-
37	TRANSPORTATION	23	47	23	2
38	INSTRUMENTS	-	-	-	-
39	MISCELLANEOUS	-	-	-	-
ALL	ROUNDED TOTALS	9,810*	10,040*	7,640	6,530

*Represents about 60% of the 16.6 Quads of process heat used by Industry in 1974

Planned capital spending by industry usually reflects expenditures either to replace obsolete equipments or to expand by tapping a new or previously unsatisfied market. Table 2-4 distributes the standard industrial classification groups into two major categories (i.e., durable and non-durable goods), and then adds a third category pertaining to non-manufacturing. The table includes a listing of process heat energy requirements, the process terminal temperature requirement, and the planned capital spending. Once again the previous five industrial groups identified in Table 2-3 appear to satisfy the planned capital spending criterion; and in addition, the three non-durable industrial groups - Paper and Allied Products, Chemicals, and Petroleum Products - satisfy the 350°F to 2000°F temperature criterion. However, most of the durable industrial groups, including Primary Metals, Stone, Clay and Glass, have much higher process heat temperature requirements. Consequently, most of these applications will not be able to utilize the solar electric equipments currently under development, but will probably require special very high-temperature solar hardware research and development.

Table 2-4. Industrial Process Heat Requirements and Capital Spending Patterns

INDUSTRY	PROCESS HEAT DATA BASE 10^{12} Btu	TYPICAL TERMINAL TEMP REQ-°F	1978 PLANNED CAPITAL SPENDING (billions of dollars)
IRON AND STEEL	3772	2700-900	4.28
NON-FERROUS METALS			2.48
ELECTRICAL MACHINERY	2	1700-350	2.98
MACHINERY	0	—	5.78
AUTOS, TRUCKS AND PARTS	23	2650-250	
AEROSPACE			0.90
OTHER TRANS EQUIP			0.32
FAB METALS AND INSTRUMENTS	0	—	3.69
STONE, CLAY AND GLASS	991	3300-1500	1.72
OTHER DURABLES	15	150-70	2.64
TOTAL DURABLES	4803	—	27.32
CHEMICALS	534	2200-300	7.94
PAPER AND PULP	1093	1900-280	3.08
RUBBER	10	450-280	1.66
PETROLEUM	2637	1600-250	12.56
FOOD AND BEVERAGES	319	1110-100	4.72
TEXTILES	116	300-200	0.72
OTHER NONDURABLES	173	300-212	1.49
TOTAL NONDURABLES	4882	—	32.17
ALL MANUFACTURING	9685	—	59.49
MINING	129	2500-150	5.07
RAILROADS	—	—	3.30
AIRLINES	—	—	0.88
OTHER TRANSPORTATION	—	—	2.52
COMMUNICATIONS	—	—	15.31
ELECTRIC UTILITIES	—	—	25.84
GAS UTILITIES	—	—	4.20
COMMERCIAL	—	—	22.45
ALL NONMANUFACTURING	129	—	79.57
ALL BUSINESS	9814	—	139.06

D. DEFINITION OF HIGH-TEMPERATURE PROCESS HEAT (SOLAR VIEWPOINT)

High-temperature process heat (i.e., above 350°F) as it pertains to solar thermal electric power generation is only recently being defined. The basis of such a definition comprises the basic concept of process heat in solar thermal electric power generation and the status of development of solar systems that can apply to process heat. These considerations are described next.

1. Basic Concept of High-Temperature Process Heat

The basic concept underlying high-temperature process heat in solar thermal electric power generation is the utilization of solar radiation (insolation) to heat a working fluid to a sufficient temperature so that it can be used two ways: (1) directly for one of the high-temperature industrial process heat applications, or (2) indirectly to most efficiently power a turbine, which will in turn drive an electric power generator.

Solar thermal energy systems to implement this concept were derived as a part of the DOE development activities. In late 1975 and early 1976 low-temperature (i.e., below 350°F) process heat studies and system developments were initiated by ERDA. These systems were aimed at the applications and prototype demonstrations leading to the early commercialization of low-grade thermal energy solar systems. The development of medium- and high-grade solar thermal energy hardware was channeled into similar hardware developments for the solar electric applications, which are pertinent to the high-temperature area.

2. Solar Concentrator Status

Many collector system configurations presently exist for obtaining thermal energy in quantities large enough and at temperatures high enough to efficiently support electric power generation or to satisfy the medium- and high-temperature industrial process heat application requirements. These are based on the principle that high-temperature solar energy systems require concentrated solar radiation, and to obtain concentrated solar energy, direct solar radiation is usually necessary (since diffused radiation cannot be focused), thus necessitating a focused collector configuration. In summary, higher temperature requirements require higher solar energy concentrations.

A complete listing of typical solar concentrators, method of concentration, usual range of concentration ratio, type of tracking, and focal zone (i.e., point, line, or area) is shown in Table 2-5. Concentration ratios of approximately 20 and above are generally applicable to high-temperature process heat.

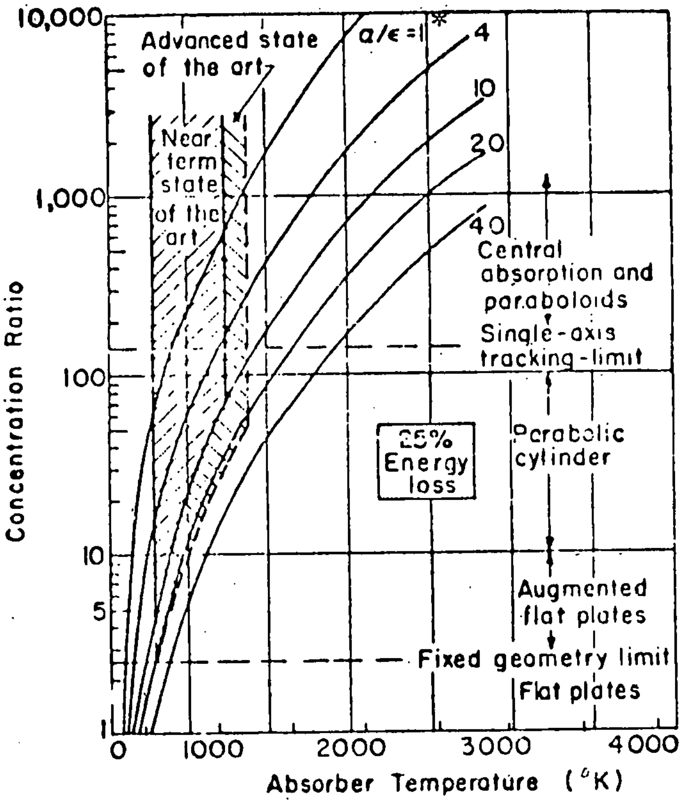
A summary of the expected performance of typical solar concentrating collectors is shown in Figure 2-3. Several of these medium- and high-temperature concepts (i.e., concentration ratio above 20) have been or are currently under development to satisfy the solar electric application requirements. Each of these systems requires implementation of the following functions: (a) collection of energy, (b) conversion of solar energy to thermal energy, (c) thermal energy transport, (d) energy storage or backup system to cover periods when insolation is not available, and (e) master control to regulate the supply to satisfy the demand.

Table 2-5. Typical Solar Concentrators

	Method of Concentration		Usual Range of Concentration Ratio *	Type of Tracking			Focal Zone			Comments
	Reflective	Refractive		None	One Axis	Two Axis	Point	Line	Area	
FLAT REFLECTORS										
Solar Ponds	X		1.0	X					X	Low cost, low temp.
Side Mirrors (north side of the absorber, noon reversible mirrors, "V" troughs, etc.	X		1.5-3.0	X					X	Not attractive for elec. power generation
Fixed Flat Mirrors, movable focus	X		20-50		X(absorber)			X		Low capital costs
Multiple Heliostats redirecting to a central absorber (central receiver)	X		100-1000 or more			X	X			More desirable at higher power levels, best for large systems
SINGLE CURVATURE REFLECTORS										
Truncated Cones	X		1.5-5	X	X		X			
Compound Parabolic Concentrator	X		3-10	X	X		X	X		Attractive as a secondary reflector
Parabolic Cylinder (E-W, N-S, or tilted axis)	X		10-30		X			X		Historical approach -- data exist
Reflecting Linear Fresnel	X		10-30		X			X		Similar to the parabolic trough
DOUBLE CURVATURE REFLECTORS										
Paraboloids	X		50-1000			X	X			Perhaps the best optical geometry
Hemispheres	X		25-500			X	X			Does not focus finely
Reflecting Circular Fresnel	X		50-500			X	X			Less expensive than paraboloid
REFRACTING LENSES										
Linear Fresnel		X	3-50	X	X			X		Focal line varies greatly with sun angle unless tracked
Circular Fresnel		X	50-1000			X	X			Focal length must be comparable to diameter to avoid excessive edge losses

Source: Los Alamos Scientific Laboratory, Solar Process Heat from Concentrating Flat-Plate Collectors, December 1976.

* Concentration ratios of approximately 20 and above are generally applicable to high-temperature process heat.



*α/ϵ = absorptivity/emissivity ratio

Figure 2-3. A Summary of Properties of Typical Solar Concentrating Collectors

A fairly complete treatment of the performance and attributes of the various collector systems is available in other DOE publications, so it will not be repeated here. It suffices to briefly summarize applicable portions of that treatment. Distributed collector systems of the parabolic trough or segmented mirror configuration are capable of satisfying the medium-grade thermal energy requirements and are currently available to deliver working fluid temperatures in the vicinity of 550-600°F. Moreover, linear distributor collectors can conceivably be made useful to about 900°F by the development of secondary concentrators which refocus the solar radiation, or by the development of solar absorber coatings with improved absorptivity over emissivity ratios approaching unity.

Two additional systems, the central receiver or central absorption and the parabolic dish or paraboloid, currently show the greatest promise in meeting the high-temperature performance requirements above 600°F. Parabolic dish systems and central receiver systems utilizing steam have been developed that are currently capable of operating to approximately 1000°F. Conceptual designs and analyses have been conducted for helium and air systems up to 2000°F and systems to 2700°F and higher have been considered. Table 2-6 presents the solar hardware development status of those systems to be utilized for industrial process heat applications. The solar hardware identified in the medium-, high-, and very high-temperature ranges are all included in the generation definition of high-temperature process heat above 350°F.

Table 2-6. Industrial Process Heat Solar Hardware Status

TEMPERATURE RANGE	COLLECTOR TYPE	DEVELOPMENT STATUS
LOW		
90-140°F UP TO 250°F UP TO 350°F	SOLAR PONDS FLAT PLATE LINEAR DISTRIBUTED	COMMERCIAL APPLICATION
MEDIUM		
UP TO 600°F UP TO 600°F	LINEAR DISTRIBUTED DISH DISTRIBUTED	LARGE SCALE EXPERIMENTS READY FOR COMMERCIAL APPLICATION
HIGH		
600-1100°F STEAM	CENTRAL RECEIVER DISH DISTRIBUTED	TECHNOLOGY AVAILABLE FOR LARGE SCALE EXPERIMENTS
VERY HIGH		
UP TO 2000°F HOT AIR	CENTRAL RECEIVER DISH DISTRIBUTED	TECHNOLOGY UNDER DEVELOPMENT BY EPRI
OVER 2000°F	CENTRAL RECEIVER DISH DISTRIBUTED	REQUIRES RECEIVER MATERIAL R&D

E. AGRICULTURAL AND INDUSTRIAL PROCESS HEAT BRANCH RESPONSIBILITIES

The Agricultural and Industrial Process Heat Branch has the complete responsibility for both the technology development and the commercialization for both low- and high-temperature process heat areas. At ERDA's inception in January 1975 the Agricultural and Industrial Process Heat Branch recognized that only low-temperature solar collectors under development at that time would be available to support the solar industrial process heat experimental demonstration and application efforts. Also in 1975, the required technology development of medium- and high-temperature solar thermal energy collection systems was assigned to the Solar Electric Applications Program, because of the similarities in hardware requirements and funding limitations.

At the present time many of the linear distributed collector systems and some of the parabolic dish systems have completed their technology development phase and are now available to support the solar industrial process heat experimental applications and demonstration efforts for medium-grade thermal energy applications. The Agricultural and Industrial Process Heat Branch is currently reviewing the technology development status of the high- and very high-temperature industrial solar thermal energy collector systems and is currently reassigning a portion of these activities to the Solar Energy Research Institute (SERI) in Golden, Colorado. A complete definition of these SERI responsibilities is not available at this time. The current Agricultural and Industrial Process Heat Branch program is contained in Appendix A-2.

III. ROLE OF SOLAR THERMAL POWER IN PROCESS HEAT

III. ROLE OF SOLAR THERMAL POWER IN PROCESS HEAT

The role of solar thermal power in high-temperature process heat is demonstrated in this section in terms of three example applications:

- Tank Farm Heating (350°F - 550°F)
- Central Steam Plant (550°F - 1000°F)
- Cement Manufacture (1500°F - 2000°F)

Each of these represents a significant, current fossil-fueled industrial process heat system identified as a possible candidate for solar thermal process heat systems. The three temperature ranges (i.e., 350-550, 550-1000, 1500-2000°F) were selected so that three types of solar hardware currently under development for solar electric applications could be reviewed for potential utilization to produce industrial process heat.

Each example is presented first in terms of a description of its current fossil fuel implementation, and second in terms of the potential solar thermal role. The fossil fuel discussions include advantages, market, and physical characteristics.

A. TANK FARM HEATING, 350°F TO 550°F

The tank farm heater is used to heat crude oil to obtain a proper viscosity for moving and processing the fluid. Such a system is shown schematically in Figure 3-1.

1. Fossil Fuel Implementation

The utilization shown in Figure 3-1 has several advantages in an industrial application of solar energy. First, there is an adequate area above the tank and inside the emergency containment levy for collection of the solar radiation. Obtaining sufficient collection area at an industrial site is often not possible for many alternate applications. A second advantage of this tank farm application is that there is sufficient natural mechanism for energy storage. This mechanism is the latent heat of the liquid stored in the tank. A third advantage is that in a refinery a tank heating system is already installed. This heating system could be used either during periods of extended bad weather or in the evenings to reduce temperature fluctuations.

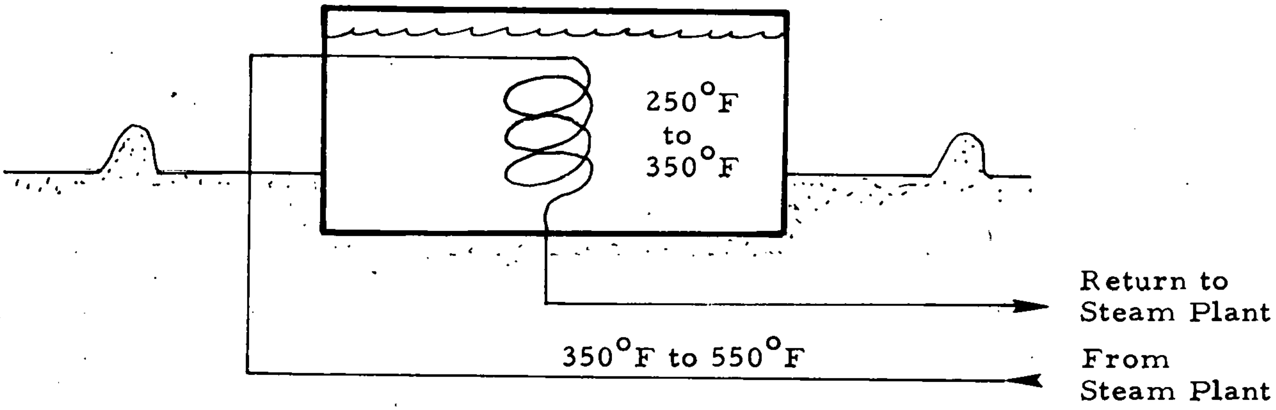


Figure 3-1. Tank Farm Heating System Schematic

The initial market potential for solar tank farm heaters is large, as indicated by the potential number of units in Table 3-1. These numbers were estimated for two markets: refineries and cement plants. Based on technical discussions at Continental Oil it was determined that in a refinery there are potential applications related to crude storage tanks and possibly one or two product tanks. Examples of the latter would be asphalt and bunker C fuel oil. The number of refineries in each geographic region was determined from Reference 12. It was conservatively assumed that each refinery would require a minimum of two solar tank heating units. The cement plants represent another possible oil tank heating application although this is outside the petroleum industry. Many cement plants are gradually converting to coal systems which are prone to occasional mechanical failure because of the mechanical complexity. In the continuous process pertaining to the cement plant, back-up fuel is required. It is assumed that each back-up coal plant will require one tank farm heater. Estimates of the number of refinery and coal units in areas of high insolation that correspond to the preceding criteria are those summarized in Table 3-1.

Table 3-1. Potential Tank Farm Heaters
Number of Units

Average Annual Insolation kW hr m^2	Units in the Area In Cement Plants	In Refineries Over 30,000 BBL/CD*
6-7	35	76
7-8	16	30
> 8	5	2

*Barrels of Crude Oil per Day

Continental Oil selected a typical tank unit for evaluation; it is described in Table 3-2. A tank diameter of 100 feet and a liquid height of 40 feet were assumed. It was further assumed that the average ambient temperature was 50°F, the wind was 10 mph, the liquid temperature in the tank was 250°F, and the above-the-ground surface area of the tank was 12,560 ft^2. Such a tank would be heated with a steam line from a central steam plant located a considerable distance from the tank farm. Steam is usually supplied between 350°F and 500°F with 450°F being a typical supply temperature. Steam is most always supplied at least 100°F above the required storage temperature to minimize the tank heat exchanger size.

The thermal analysis for this application was essentially carried out by Continental Oil in Ponca City, Oklahoma. Continental has computer programs set up to calculate the heat loss from the tanks under a number of different conditions. The heat loss from an uninsulated tank with the parameters of Table 3-2 would be 14.1×10^6 Btu/Hr. It is common practice to insulate tanks and typically this would

Table 3-2. Tank Farm Heater Parameters

Diameter	100 feet
Liquid Height	40 feet
Temperature	250° F
Insulation	1-1/2 inches
Ambient Conditions (Average)	50° F; 10 mph wind
Cooling Rate	18 BTU/HR/SQ.FT X12,560 SQ. FT. X 8760 = 1982 x 10^6 BTU/YR.
Available Solar Collection Area	10,000 SQ. FT.
Steam	350° F

involve installation of 1½ inches of polyurethane form, which according to Continental Oil would cost $2.50/ft^2. The K factor is 0.14 Btu/Hr ft^2 ^{o}F per inch and the emissivity is 0.9. This 1½ inches of insulation would reduce the inside surface temperature of the tank to 57^{o}F and reduce the heat loss to 0.23 x 10^6 Btu/Hr. Additional insulation can be considered; e.g., another 1½ inches would cost $1.25/ft^2, reduce the surface temperature to 53.6^{o}F and the heat loss to 0.12 x 10^6 Btu/Hr. Thus the corresponding additional energy savings would be 0.11 x 10^6 Btu/Hr. The total investment in the original insulation would be $31,400, and the incremental additional would be $15,700.

To evaluate such projects Continental Oil currently reports they would use an average projected fuel cost of $2.50 x 10^6 Btu and three and one-third years payout. However, Continental is considering shifting to a five-year payout in evaluating energy savings projects. Five years is also used by Shell (13), and that period has been recommended in the literature (14). However, using $2.50 x 10^6 Btu, the payout period for additional insulation would be six and one-half years; therefore, using a five-year payout period would not be economical.

2. Potential Solar Thermal Role

Using \$2.50 x 10^6 Btu and the five-year payout period recommended by Shell, the question is whether a solar boiler could economically supply the energy required for the refinery tank farm. A full discussion is included in Appendix B. A distributed collector system is considered that is under development for powering an irrigation pump. The collector system is an array of parabolic troughs. Two orientations can be considered. These are North-South and East-West. The latter arrangement, depicted in Figure 3-2, will collect less total energy over a year but steam generation will be more uniform through the seasons. In the first of three cases analyzed the collector must provide the total daily heat requirements of the tank in winter. The heat is stored in the tank and its temperature is allowed to fluctuate above a minimum. This is a worst case requiring the largest collector area. In this case the area required for the tank parameters considered above is 4600 ft^2 and available area is over 10,000 ft^2. This assumes an average of 1200 Btu/ft^2/day of radiant energy converted to heat with the collectors in the East-West orientation.

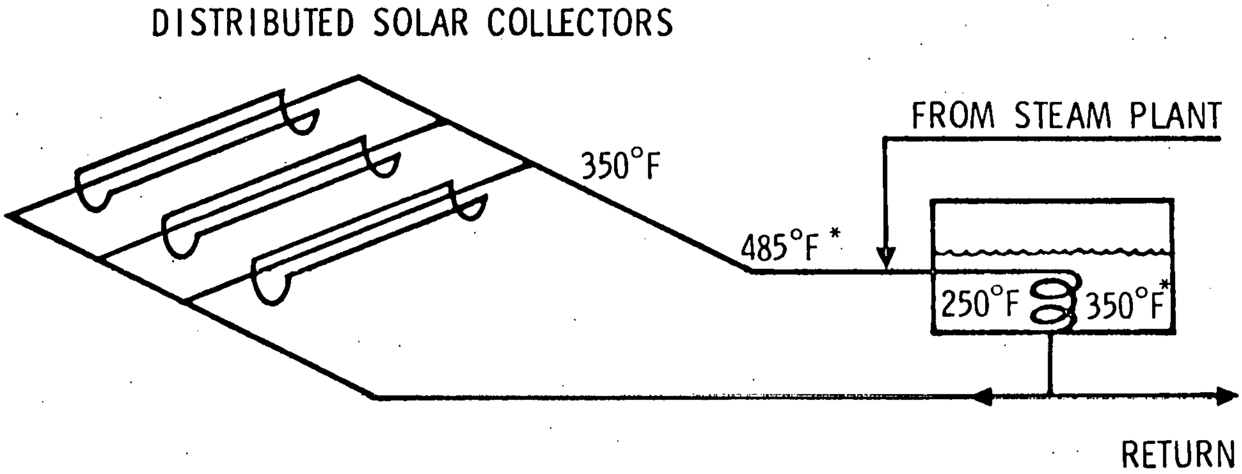


Figure 3-2. Supplemental Solar Steam
Tank Farm - Crude Oil
*Asphalt Storage

According to information from the Sandia Laboratories, Albuquerque, this collector system is currently available from Accurex Corporation at \$14.60/ft^2. At this price the solar collectors would cost \$67,160 and the payout would be 13.3 years. Projected cost reductions in the system and increased fuel prices would make this application economic.

In this first case all of the energy requirements of the tank are supplied by the solar unit. An advantage seen by Continental Oil is the saving in steam and condensate lines to the tank in a new installation. In some cases the investment in these lines might be \$10,000 to \$20,000 and this could be taken as a credit against the cost of the solar unit.

The second case is a modification of this first case. The same East-West collector orientation is still used but a smaller collector area is possible by supplying steam at night from the central steam plant. Also, this would have the advantage of reducing the temperature fluctuations in the tank. The magnitude of these fluctuations are discussed in Appendix B. The payout still would be 13.3 years based on \$14.60/ft^2 for the collector system. There would be no credit, however, for the steam and condensate lines running to the tank. Energy displacement would also be less. Assume that steam from the central plant is adjusted so as to maintain a uniform tank temperature. The solar capacity factor for the unit in a high insolation area is 56%. Thus the size of the unit for the tank conditions assumed above would be 2352 ft^2 or \$34,340 at current prices. Over a year of operation 56% of the required heat would be supplied by the solar unit.

A third case would involve a North-South orientation of the distributed collector system. In this case the steam generation capability would vary with the seasons. In the summer this would be 1880 Btu/ft^2-day so that a 2936 ft^2 system could supply the average daily requirements of the above tank. Over the period of a year the average steam generation would be 1400 Btu/ft^2-day. Thus the annual energy displacement would be 74%. This system would require steam from the central plant during the winter. It has the advantage of a shorter payout compared with the first two cases. However, if the credit for steam and condensate lines were sufficiently large, then the first case would have the advantage; but if a solar unit is to be added to an existing plant when the steam lines are already in place, then the third case would be the most advantageous.

As discussed in Section III A 1, the initial market potential in units for solar tank farm heaters was determined. Table 3-1 showed the number of potential tank farm heaters as a function of insolation intensity. To repeat, it was assumed that each refinery would require a minimum of two units and each cement plant one unit. Applications in higher insolation areas will become economic first. It is concluded that this application would be practical if fuel rose to \$3.50 x 10^6 Btu and solar equipment costs were \$8.90/ft^2.

B. CENTRAL STEAM PLANT FOR PETROLEUM AND CHEMICAL INDUSTRIES, 550°F TO 1000°F

In refineries or chemical plants there are requirements for process heat, process steam and pumping. The requirements for a number of different petroleum processes assuming steam driven pumps are shown in Table 3-3. In present refineries a good rule of thumb is that one-third of a barrel of crude is used for steam generation out of each ten barrels processed (Reference 15). In a chemical plant about 50% of the input energy requirements are for steam generation (Reference 16).

1. Fossil Fuel Implementation

Most existing steam plants for refineries or chemical plants are now gas-or-oil fired. Existing plants at several Shell Oil refineries are shown in Table 3-4. Steam temperatures of 750°F and pressures around 650 psig are typical of refinery use. Refinery and chemical operations are continuous, requiring steam 24 hours a day, 365 days a year. A list of major petroleum refineries, crude capacity, and estimated steam capacity in MWth is shown in Table 3-5.

An oil-fired steam plant of 100 million Btu/Hr capacity costs $1.8 to 2.5 million, fuel is priced at $2.50/million Btus and the plant efficiency is around 91 percent. The payout period for such a plant varies from 5 years for Shell and Exxon to a maximum of 17 years for Dow Chemical. The $2.50/million Btu was recommended by Continental Oil and corresponds to Continental's projected future cost of marginal fuel used in a refinery.

According to Shell, the initial capital investment for a coal-fired steam plant of 100 million Btu/Hr is $15 to $20 million. This covers the cost of the boiler, the coal unloading and handling equipment, the ball mill for pulverizing the coal, scrubbers to meet environmental requirements, and backup oil burning capability and oil storage. The coal is priced at $1.25/million Btu. The overall coal plant efficiency is still around 91% after allowance for the energy losses for handling and processing the coal, and heating the backup oil storage tank. The oil companies consider the total cost of operating a coal plant (capital, maintenance, and fuel) about equal to that of an oil plant.

Table 3-3. Steam Requirements for Different Petroleum Processes

	Unit consumption of steam, lb./bbl.		
		Process and Heat	
Process	Pumps	Range	Average
Topping--low API	15-21	25-35	30
Topping--high API	20-30	35-50	45
Desalting	—	1-13	2
Vac. flash:			
40 per cent	50-55	8-18	14
60 per cent	55-60	8-39	18
70 per cent	60-65	8-100	38
Thermal cracking	108-316	0-45	—
Thermal reforming	53-81	0-20	—
Thermal coking	62-176	44-190	110
Viscosity breaking	17-60	14-29	—
Cat. cracking:			
65 per cent	40	40-50	45
75 per cent	55	75-90	80
85 per cent	70	--	100
Cat. reforming	92-140	10-127	75
Asphalt mfr.	16-20	10-13	12
Polymerization	66-273	80-210	130
Alkylation	280-720	0-1,360	500
Hydrodesulfurization	96-250	8-45	25
Gasoline treating	12-23	2-75	10
Lube mfr.	1,100-1,300	900-1,500	1,200
Vac. dist.:			
40 per cent	70-76	16-180	56
60 per cent	76-84	18-220	85
70 per cent	84-90	20-260	100
Dewaxing	270-840	200-390	300
Solvent extraction	75-144	40-140	130
Rerunning	60-80	16-260	150
Deasphalting	96-230	70-140	120
Naph. solvent rerun	15-23	30-80	60
Acid treat. and contact	51-61	45-100	80
Clay contact alone	46-50	45-100	80
Hydrofinishing	30-85	8-20	17
Percolation	7-17	8-90	45
Wax mfr.	800-1,300	400-1,000	600
Deoiling	280-1,160	300-800	500
Acid. treat. and contact	51-61	50-120	100
Clay contact alone	46-50	50-120	100
Percolation	7-17	8-60	35
Solvent mfr.	40-70	10-40	25
Naphthenic lubes	250-400	300-450	350
Specialties	--	—	—

Reference: W. L. Nelson, "Refinery Complexity and Steam Requirements", Oil and Gas Journal, June 4, 1962, pg. 130

Table 3-4. Shell Oil Refineries

Site	Steam Generator No. Units–MMBtu/hr	Heat Medium No. Units–MMBtu/hr	Approx. Non-Process Acreage
Houston, TX	4 – 125 5 – 330 1 – 480 3 – 360 1 – 730 4 – 620	1 – 150 1 – 220	320
Los Angeles, CA	1 – 220 2 – 350	1 – 120	80
Odessa, TX	1 – 200		600
Ciniza, NM	1 – 200		150
Geismar, LA	2 – 290	1 – 150	200

It was assumed that steam generation with new technologies would only be applicable to refineries above a certain size. One reason is the availability of sufficient engineering staff to incorporate the new technology. Based on discussions with industry a minimum refinery size of 30,000 B/cd (barrels of crude oil per day) capacity was selected. Table 3-6 is a listing of all refineries greater than this size; also listed are their estimated steam requirements based on one-third barrel for steam generation per ten barrels capacity. These steam requirements are additionally correlated with insolation in Table 3-6.

Steam requirements in the chemical industry are shown in Table 3-7. These are taken as one-half the total energy requirement, which is consistent with other analyses in the industry (Reference 16).

It is concluded from Tables 3-6 and 3-7 that in both the chemical and petroleum industries the potential number of units is more than sufficient to justify development of a new technology of the solar type by private industry to supply the market.

Table 3-5. Petroleum Refineries

Company & Location	Insolation kWh m^2	Crude Capacity B/cd *	Estimated Steam Capacity MW Thermal
CALIFORNIA			
Atlantic Richfield Co., Watson	6-7	93,000	454
Gulf Oil, Santa Fe Springs	6-7	21,900	132
Mobil Oil, Torrance	6-7	95,000	338
Shell Oil, Wilmington	6-7	50,000	236
Standard Oil, El Segundo	6-7	120,000	550
Union Oil (Grande (Santa Marie Ref.)	6-7	1,500	96
Union Oil (Rodeo (Oleum Ref.)	6-7	37,000	165
Union Oil (Wilmington (L.A. Ref.)	6-7	83,000	286
DELAWARE			
Getty Oil, Delaware City	6-7	90,700	385
KANSAS			
American Oil, Neodesha	6-7	–	85
CRA, Inc., Coffeyville	6-7	8,000	85
Mobil Oil, Augusta	6-7	17,000	132
Natl. Coop. Ref., McPherson	6-7	–	121
Phillips Pet., Kansas City	6-7	15,000	234
Skelly Oil, El Dorado	6-7	20,000	179
MINNESOTA			
Great Northern Oil, Pine Bend			
MISSOURI			
American Oil, Sugar Creek	6-7	35,000	228
MONTANA			
Continental Oil, Billings	6-7	12,200	121
Humble Oil, Billings	6-7	13,000	107
WYOMING			
American Oil, Casper	6-7	11,800	93
Atlantic Richfield, Sinclair	6-7	14,200	90
NORTH DAKOTA			
American Oil, Mandan	6-7	–	137
OKLAHOMA			
Champlin Pet., Enid	7-8	22,000	102
Continental Oil, Ponca City	7-8	13,000	217
Sequoia Refining, Ponca City	7-8	10,500	96
Sun Oil, Duncan	7-8	17,000	126
Sun Oil, Tulsa	7-8	31,500	245
Texaco, West Tulsa	7-8	13,500	129

*** Barrels of Crude Oil per Day**

Table 3-5. Petroleum Refineries (Cont'd)

Company & Location	Insolation kWh m^2	Crude Capacity B/cd	Estimated Steam Capacity MW Thermal
TEXAS			
American Oil, Texas City	6-7	70,000	663
Atlantic Richfield, Houston	6-7	70,000	605
BP Oil Corp., Port Arthur	6-7	28,000	220
Chevron Oil, West. Div., El Paso	>8	24,600	179
Coastal States Petrochemical Corpus Christi	7-8	33,000	365
Cosden Oil & Chem., Big Spring	7-8	25,000	151
Crown Central Pet., Pasadena	6-7	38,000	231
Diamond Shamrock, Sunray	6-7	12,000	104
Gulf Oil, Port Arthur	6-7	158,100	904
Hess Oil & Chem., Corpus Christi	7-8	—	129
Humble Oil, Baytown	6-7	149,000	948
Marathon Oil, Texas City	6-7	20,000	118
Mobil Oil, Beaumont	6-7	103,000	866
Phillips Pet., Borger	7-8	—	234
Phillips Pet., Sweeny	6-7	—	234
Pontiac Ref., Corpus Christi	7-8	7,000	146
Shell Oil, Deer Park (Houston)	6-7	64,400	445
Signal Oil, Houston	6-7	21,000	198
Southwestern Oil, Corpus Christi	7-8	9,000	143
Suntide Ref., Corpus Christi	7-8	10,000	135
Texaco, Port Arthur	6-7	108,000	852
Texaco, Port Neches	6-7	22,000	124
Texas City Ref., Texas City	6-7	14,500	137
Union Oil of Calif., Nederland	6-7	39,000	288
UTAH			
American Oil, Salt Lake City	7-8	—	101
Chevron Oil, Western Div., Salt Lake	7-8	27,000	118
VIRGINIA			
American Oil, Yorktown	6-7	—	140

Table 3-6. Process Heat

Petroleum Refinery Statistics
Number of Units

Average Annual Insolation kWh m^{-2}	Estimated Steam Generation Capacity, MW Thermal 80-100	100-150	150-250	>250
6-7	5	11	10	13
7-8	1	9	3	2
>8	0	0	1	0

Table 3-7

Process Heat
Chemical Plants

State	Insolation kWh m^{-2}	Process Heat Capacity, MW	Solar Potential, MW
Nebraska	6-7	330	165
Kansas	6-7	1200	600
Maryland	6-7	775	387
Virginia	6-7	2500	1250
North Carolina	6-7	1260	630
South Carolina	6-7	1480	740
Georgia	6-7	780	390
Florida	6-7	1600	800
Arkansas	6-7	1370	685
Oklahoma	7-8	80	40
Texas	6-8	19600	9800
Idaho	6-7	150	75
Colorado	6-7	100	50
Arizona	>8	35	17
Utah	>7	35	17
Nevada	6-8	115	57
California	6-8	2000	1000

2. Potential Solar Thermal Role

The previous fossil fuel application section documented industry recommendations for plant size, potential market size, acceptable amortization periods, capital cost for gas, oil and coal plants, and projected fuel costs. This information was utilized as the basis for an equivalent cost analysis of four types of steam process heat systems: oil, natural gas, coal and solar. The analysis determines the real costs of delivering 1 million Btus of steam at 960°F and 1600 psia, after deleting the effects of general inflation. The solar plant selected for analyses was the McDonnell Douglas concept for the Central Receiver plant with 6 hours of thermal storage. MDAC costs and performance were used after deletion of the equipment peculiar to electrical generation. The study considered the annualized cost of process heat systems for two life cycle periods that typify the amortization periods recommended by industry; ten and twenty years. A single process heat plant delivering up to 100 million Btus per hour (29 MW_{th}) was evaluated.

Several conventional plants (coal, oil and gas) were compared with the solar thermal plant (heliostats and receivers) which included thermal storage. Southwestern U. S. insolation levels were used in the solar plant analyses. Annualized costs were calculated based on a present worth methodology. In summary, for a ten year life cycle, solar plants become competitive with coal process heat plants in 1994, and for a 20 year life cycle, the solar plant becomes competitive with a coal plant in 1989. Figure 3-3 summarizes the analyses for all four plants up to the year 2000. The complete study is presented in Appendicies B-3 and C.

C. CEMENT MANUFACTURE, 1500°F TO 2000°F

In 1972 there were 170 portland cement plants in the United States. The heavy weight of processed cement causes high shipping costs; consequently, plants are located near a source of raw materials and also near the market it supplies. In the U. S., the high shipping costs, local market size, and large distances between market areas dictate that plant size be limited to that plant capacity necessary to supply the local construction market. The name, location, and annual production capacity as of December 1975 are presented in Figure 3-4.

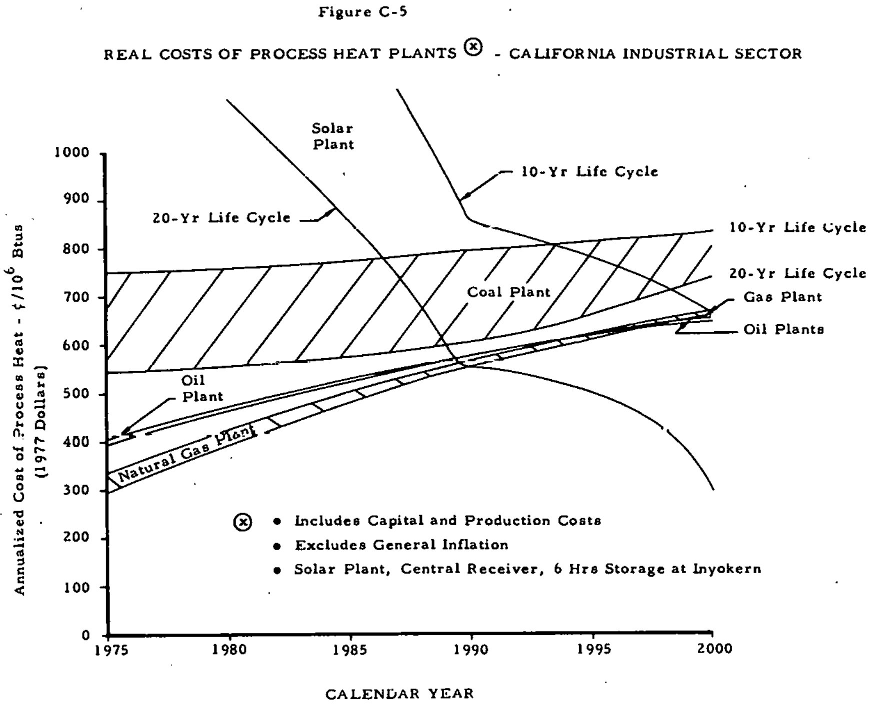


Figure 3-3. Real Costs of Process Heat Plants
California Industrial Sector

Cement raw materials are processed or blended by two basic procedures, "wet" or "dry" process. The basic differences between the two processes are in the kiln feed and the energy consumed per ton of cement processed. In the dry process, the feed enters the kiln as a free flowing powder with a maximum of about 7% moisture or as pellets with a maximum of 14%. In the wet process, raw materials usually are fed into the kiln as a free-flowing slurry with 24-48% moisture. Originally, the decision to build a wet-process or a dry-process plant was based primarily on the nature of the raw materials, although other considerations may also have affected the decision. There are some variations to the two basic processes; modifications designed to conserve energy. The semi-wet process and the suspension preheater are two of the more common variations. A schematic depicting the basic processes involved in the manufacture of cement are shown in Figure 3-5.

PORTLAND CEMENT PLANTS
BY PRODUCING CAPACITY
DECEMBER 31, 1975

ANNUAL PRACTICAL CAPACITY

- ● UNDER 400,000 Tons
- ● 400,000 to 700,000 Tons
- ● 700,000 to 1,000,000 Tons
- ● OVER 1,000,000 Tons
- • GRINDING ONLY

Source:

Economic and Market Research Department
Portland Cement Association
5420 Old Orchard Road
Skokie, Illinois 60076

Figure 3-4. Portland Cement Plants by Producing Capacity
December 1975

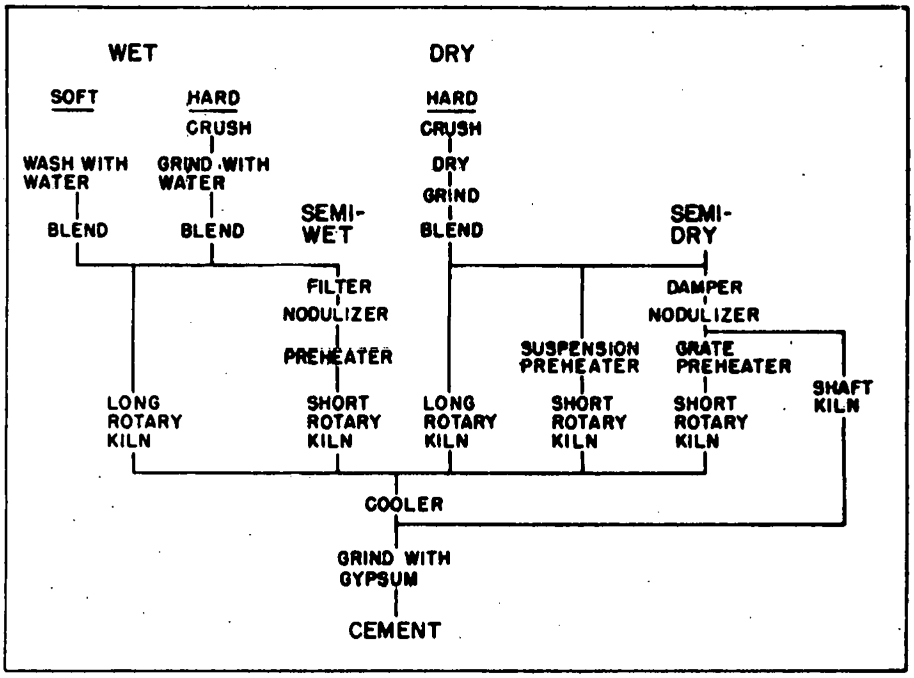


Figure 3-5. Processes Involved in the Manufacture of Cement

1. Fossil Fuel Implementation

Energy consumption for the various types of U. S. cement plants varies from around 12 x 10^6 Btu per ton of processed cement for the oldest operating cement plants which were constructed in 1920 to as low as 4.5 x 10^6 Btu for the most recently constructed suspension preheater plants. The newest Japanese and German plants are much larger and more energy efficient and use as little as 3.5 x 10^6 Btu/ton cement. Table 3-8 presents the average production and fuel energy usage statistics for wet and dry U. S. plants during 1972 while Table 3-9 shows the energy consumption by department (kiln, mills and drying) for the fourteen most energy efficient plants in the U. S. The information in the first table only includes fuel demand and does not include electrical energy requirements to rotate kilns or raw and finishing mills. Complete cement plant energy requirements are given in the latter table.

Table 3-8. 1972 U. S. Cement Industry Production/Fuel Usage

TYPE PLANT	NUMBER OF PLANTS	PRODUCTION 10^6 TONS (%)	FUEL USAGE, 10^{13} BTU (%)				10^6 BTU/TON
			COAL	OIL	NGAS	TOTAL	
WET	107	45.85 (59.2)	10.40 (21.9)	4.98 (10.5)	14.75 (31.0)	30.13 (63.4)	6.6
DRY	63	31.53 (40.8)	7.96 (16.7)	1.87 (03.9)	7.58 (16.0)	17.41 (36.6)	5.5
TOTAL	170	77.38 (100.0)	18.36 (38.6)	6.85 (14.4)	22.33 (47.0)	47.54 (100.0)	6.15

The economics of cement plants are dependent upon the available supply and cost of raw materials and the other competition in the region.

Energy usage information indicates that the U. S. cement industry can reduce its energy consumption if similar, older wet process plants are modernized, expanded and converted to either the suspension or grate preheater dry process. The major restriction preventing the cement industry from taking the necessary energy conservation measures is financial. The replacement of existing facilities dictates that the industry invest enormous amounts of capital in energy efficient technology. In 1974 a major cement equipment manufacturer costed the construction of a dry process plant incorporating a suspension preheater and rotor mill. It was assumed the plant would have a capacity of 2200 tons per day or 725,000 tons per year. The cost estimates in dollars are shown in Table 3-10. It was estimated that delivery time for this equipment is some 20-24 months assuming complete engineering information is available at the time of the order. Field work could start six months before delivery and require an additional 20-24 months. The total time from order date would range from 36-40 months. After initial start-up a period of 6-12 months to full production rate would be normal for a new plant or the installation of new equipment at an old plant. Downtime for installing a

Table 3-9. Energy Consumption by Department
Efficient Plants - U. S. Cement Industry

Plant No.	Production tons/year	Process*	Kiln: Fuel demand 10^6 btu/ton	Kiln: Electric kwh/ton	Kiln: Electric 10^3 btu/ton	Mills, Raw & finish grinding: kwh/ton	Mills, Raw & finish grinding: 10^3 btu/ton	Drying fuel 10^3 btu/ton	Total: 10^6 btu/ton	Total: kcal/kg
1	583,606	SP	3.360	31.1	330	74.2	786	94	4.570	1269
2	212,310	SP	3.915	12.5	133	88.9	942	-	4.990	1386
3	435,750	D	3.954	27.1	287	85.0	901	45	5.187	1441
4	864,584	D	4.230	22.2	235	68.0	721	11	5.198	1444
5	956,345	SP + D	3.947	39.1	414	79.0	837	6	5.204	1446
6	528,885	D	4.154	29.1	308	89.9	953	47	5.462	1517
7	515,550	SP + D	4.432	29.9	317	86.4	916	209	5.874	1632
8	555,945	D	4.278	20.9	222	98.0	1039	216	5.754	1598
9	535,500	D	4.333	29.3	311	90.8	962	115	5.721	1589
10	499,369	SP	[illegible]	27.0	286	91.2	967	323	5.974	1659
11	680,314	SP + D	4.542	22.0	233	105.7	1121	-	5.895	1638
12	988,575	W	4.684	25.3	268	78.5	832	-	5.784	1607
13	1,002,750	W	5.039	21.2	225	69.2	734	-	5.998	1666
14	499,831	D	4.845	29.6	314	81.2	861	163	6.183	1718

* D - Dry
SP - Suspension Preheater
W - Wet

Table 3-10. Estimated Cost of a 2200 Ton per Day Cement Plant Incorporating A Roller Mill and Suspension Preheater

Department	($1,000) Equipment	Installation	Total
Quarry equipment & amenities	$ 4,000	$ 300	$ 4,300
Limestone crushing	400	900	1,300
Limestone storage	500	1,150	1,650
Raw grinding (roller mill)	2,250	5,200	7,450
Additive & clay handling	600	1,400	2,000
Blending	600	1,400	2,000
Calcining	4,150	9,550	13,700
Clinker grinding & gypsum handling	1,700	3,900	5,600
Loadout & packing	600	1,400	2,000
Electrical distribution and central process control	1,600	3,700	5,300
Electric motors	1,200	2,750	3,950
Land (640 acres)	1,000		1,000
Storage facilities	1,000	3,000	4,000
Land improvements	1,000		1,000
Coal Equipment	1,250	1,250	2,500
Total	$ 21,850	$ 35,900	$ 57,750
Cost per ton of capacity			$80

Source: PCA Economic and Market Research Department.

suspension preheater is difficult to estimate; however, it is believed that 6-12 months would be required to replace an existing kiln with a suspension preheater under reasonably favorable site conditions. The schematic flow diagram of a rotary kiln and a suspension preheater with a flash furnace, typical of the cost data just presented, is shown in Figure 3-6.

Fuel conversion or the addition of new equipment to permit greater fuel flexibility may or may not be productive from a profit standpoint. In fact, many recent investments in new fuel equipment by cement companies can be attributed to supply limitations of natural gas and oil rather than to changes in the fuel prices

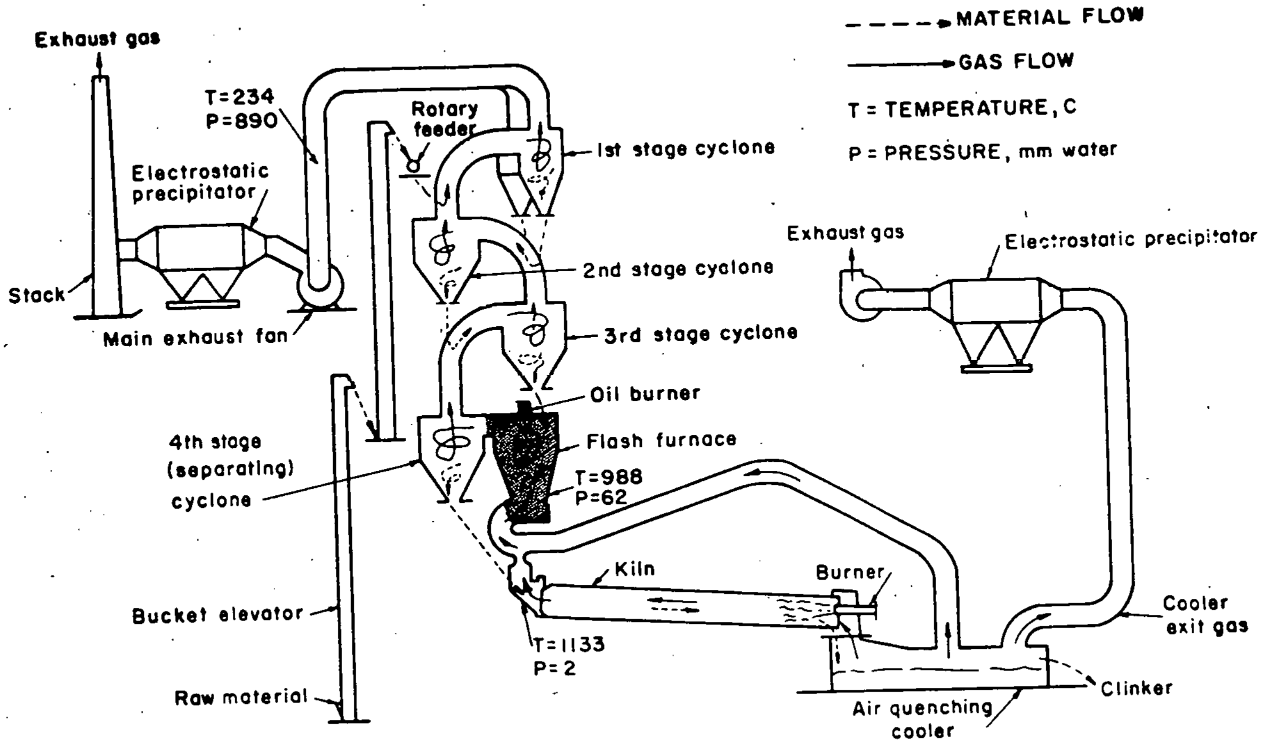


Figure 3-6. Schematic Flow Diagram of Rotary Kiln and Suspension Preheater With Flash Furnace (SF)

Source: Report of PCA Technical Mission to Japan, 1973

directly. Therefore, the decision to use a different kiln fuel may have to be handled separately from the decision to purchase new energy efficient technology which is cost saving or expansionary in nature.

Two questions plaguing the cement industry that must be answered to assess the longer term are: (1) how long to use existing equipment and escalated fuel prices, and (2) when to adopt new energy saving equipment.

Two examples have been chosen to indicate the sensitivity of an investment decision to: (1) change in fuel costs, (2) magnitude of initial capital costs, and (3) the discount factor that is chosen.

Example 1 - Minor Kiln Modifications A 400,000 ton per year plant using natural gas is considering adding additional chains inside the kilns to obtain a better heat transfer from the hot gas to the raw material. This is expected to decrease the energy demand by 0.3×10^6 Btu per ton. A chain system would require 20% of the initial capital cost each year for routine maintenance. The system would require 18 days of downtime to install the new equipment and one would expect 5 days per year additional downtime for maintenance. The sales price of the cement, fob at the mill, is \$30 per ton. The present energy cost is \$0.50 per million Btu. Assuming a 50% tax rate, Table 3-11 indicates the level of allowable investment for 50% and 100% increases in fuel price at 10% and 16% rate of return on investment. If the suggested change requires \$200,000, these chains would be advantageous if the price of gas rises to \$0.75 per million Btu. In 1974 when the fuel price more than doubled, cement plants implemented minor plant improvements such as the installation of chains because it was economically advantageous for such installations.

Table 3-11. Investment Matrix - Example 1

Fuel costs/ million Btu	Required return on investment	
	10%	16%
\$ .50	\$ 56,000	- 0 -
.75	388,000	\$278,000
1.00	722,000	558,000

Example 2 - Major Kiln Modifications A 500,000 ton per year plant using No. 6 fuel oil is considering converting its wet kiln to a dry process. This is expected to decrease the energy requirements by 1.3×10^6 Btu per ton. For such a system the yearly routine maintenance is expected to cost 10% of the initial capital investment. A 10% return on investment is acceptable to management, conversion will require 30 days of downtime to install the equipment, and 5 days per year will be lost due to maintenance. The sales price of the product is $36 per ton, the present fuel cost is $11.50 per barrel, which makes the effective energy cost $1.71 per million Btu. Assuming a 50% tax rate, Table 3-12 indicates the level for various fuel prices at 10% and 16% rates of return. Thus, if the price of oil increases to $14.50 per barrel, which is $2.16 per million Btu, the plant could justify spending almost $4 million on the new equipment for a 10% rate of return on investment. The actual cost of conversion would be in excess of $25 million; therefore, fuel price increases alone will not be sufficient to justify this major kiln modification.

Table 3-12. Investment Matrix (Example 2)

Fuel costs/ million Btu	Required return on investment	
	10%	16%
$1.71	$2,800,000	$1,930,000
1.93	3,360,000	2,340,000
2.16	3,920,000	2,770,000

The most significant energy savings to the cement industry will probably result in the adoption of preheater dry process kilns in conjunction with roller mill raw grinding departments. As indicated before the two examples were discussed, such an installation required a long construction time and cost in 1974 dollars of $80 per ton of installed capacity. Conversion from wet process to simple long-dry-process would cost $50 per ton and require an equally long construction period. Recognizing the fact that over half of the cement plants in the U. S. are wet-process plants that will require phasing out or conversion with the anticipated increased costs of fuel and using the $80/ton 1974 construction costs, the U. S. cement industry faces an enormous financial task. If the industry were to convert all existing wet-process plants and replace plants that are more than 40 years old, the capital cost would be in excess of $3 billion, which is greater than industries' present net worth. If all plants more than 15 years old were replaced, the capital cost would increase to $5 billion. Because industry is immediately faced with replacement of the older, less efficient wet-processing plants, they are willing to examine the feasibility of all types of new energy saving equipment, including solar, in order to assess and install those equipments that can best satisfy the industry's economic structure over the next 20 to 40 years.

2. Potential Solar Thermal Roles

Further discussion of solar thermal applications for cement plants are contained in Appendix B. Many of these applications have been suggested through interviews with members of the cement industry. In addition to the 1500°F and higher temperature application associated with the kilns, there are some lower temperature uses as well. California Portland Cement suggested a solar tank farm heater. This would be for residual fuel used as a backup for coal fired plants. Gifford-Hill in Dallas suggested using solar energy for drying wet raw material. This would be applied first to plants that have a wet quarry. An example is the Gifford-Hill plant in North Carolina. Solar drying in the open air would be the first approach. Also hot air could be produced in a solar unit such as those being developed for the Brayton cycle solar electric plant. An air temperature of 1800°F could be reached and this hot air combined with fossil fuel in a drying unit.

In drying operations, however, only a small fraction of the energy required for the plant can be displaced by solar. The Portland Cement Association has suggested that a solar unit be used for precalcining. Precalcining is an operation in which at least 40% of the fossil energy required can be displaced by solar. In a normal dry process plant in the United States calcining takes place in the kiln. This is the conversion of calcium carbonate to lime. This is the only endothermic reaction in the process for manufacturing portland cement. It occurs at a constant temperature of about 1560°F. It is followed in the kiln by the reaction of calcium oxide and silica to form calcium silicate. This is an exothermic reaction but takes place at 2300°F-2900°F. Kiln temperatures are too high for use of solar heat in this part of the cement making process. The calcining reaction, however, can be carried out prior to the solids being introduced into the kiln. This has the advantage of reducing the size and lowering the cost of the kiln required. The Portland Cement Association suggested converting the calcium carbonate to lime in a separate precalcining reactor and stockpiling the lime. This provides a natural storage mechanism. The temperature required is 1560°F which is compatible with the Brayton cycle units being developed. A suitable reactor configuration would have to be designed.

A second approach to precalcining was suggested by Arizona Portland Cement. In their plant they are now carrying out precalcining in the preheater by injection of natural gas. Air is passed over the clinkers coming out of the kiln. This cools the clinkers and heats the air to about 1000°F. The preheater is a column that is 218 feet high. The solids are raised to the top of the column mechanically. They then fall through the air. The hot air enters the bottom of the column and exits at the top. The solids are preheated to 1500-1600°F and about 40% calcination takes place in this column. The solids leaving the column enter the kiln directly. Additional precalcining can be effected by injecting natural gas at a height of about 150 feet. The gas burns on the surface of the solids.

It was suggested that at this same point in the column there could be direct introduction of radiant energy. The reaction mixture would move in a helical pattern through reactor tubes to get good heat transfer on the inside surface of these reactor tubes. The radiant energy would be reflected to the outside of the reactor tubes from a field of heliostats. Work would be required on reactor design and heat transfer to the solids. Injection of natural gas or other fossil fuel would have to be controlled so that the sum of the solar and fossil fuel inputs were constant.

In all of these cases the solar plant would displace fossil fuel. A payout of 8 years is typically used in this industry. Table 3-13 shows the maximum cost of the solar plant to achieve the 8 year payout: This cost is expressed on the basis of the square feet of collector field required. It is assumed that in a location with an insolation of 8 kW hr m^{-2} the average energy collected is 1400 Btu/ft^2-day.

Table 3-13. Cement Plant Solar Units
Allowable Costs

Average Annual Insolation KW Hr m^{-2}	Fuel $/MMBTU	Maximum Cost for 8 Yr. Payout $/$Ft.^2$
8	2.50	10.22
8	4.00	16.35
7	2.50	8.94
7	4.00	14.30
6	2.50	7.67
6	4.00	12.26

The suggestions that have been received for application of solar energy in the cement industry are summarized in Figure 3-7. The material flow in this figure is shown for a normal dry process cement plant. Only the dry process plant was considered because of the gradual converison of wet process plants to dry. The normal flow of material and heat in Figure 3-7 is shown in solid lines. Potential applications for solar heat are shown in dashed lines.

The first application would be in pre-drying. This would be applicable to those plants located at wet quarries. The second application also for some wet quarries is to provide solar input to the crusher-dryer in the form of hot air up to

1650°F. Some solar units are under development in the Federal program that will produce hot gas up to 1700°F. This material could be stockpiled or go directly to the preheater. Some of the air used to cool the clinkers could be passed through the preheater and then the solar heater to raise its temperature to 1650°F. Less input of gas or oil at the crusher-dryer would then required.

A third application suggested is preheating the solids before entering the kiln. Again air used to cool the clinkers could be heated to a higher temperature in a solar heater. This air would then be used in the preheater.

Far more energy could be introduced into the process through precalcining. Here there could be direct introduction of radiant energy into the precalcining reactor. The latter would be analogous to a solar boiler. Radiation would be

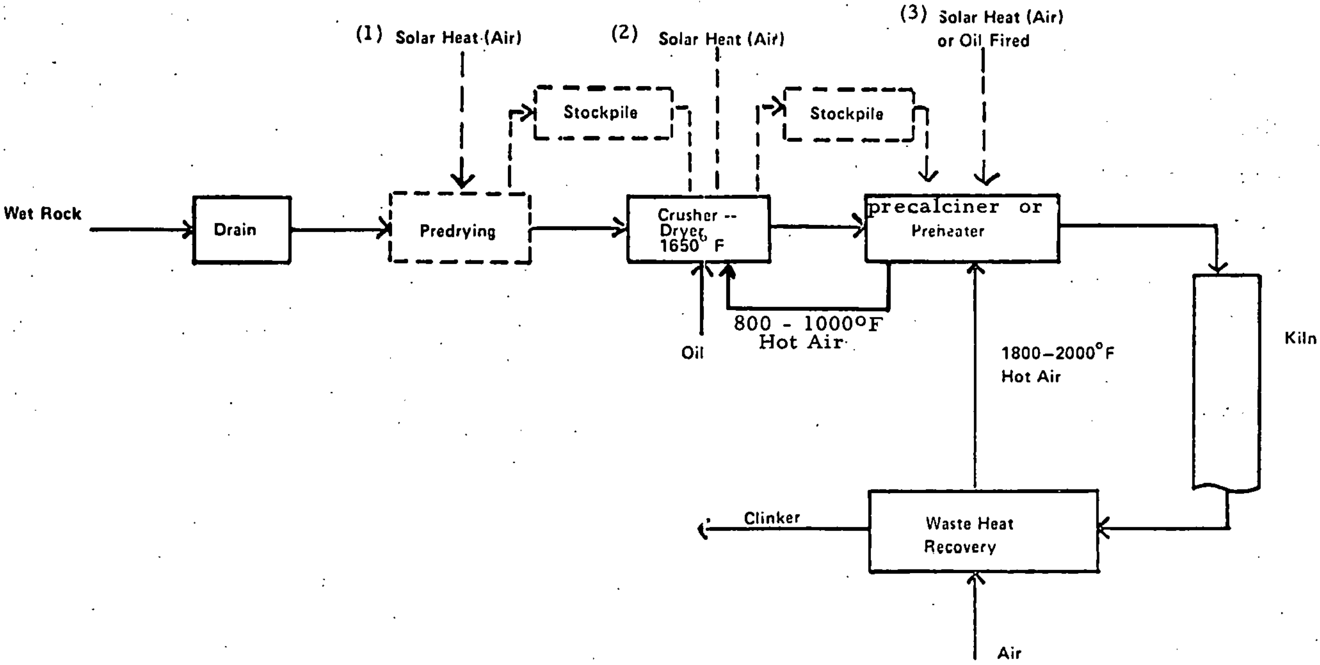


Figure 3-7. Cement Manufacture
Dry Process

received at the reactor from a field of heliostats. This radiation would be trapped in the receiver and eventually absorbed in the reactor tubes. The reaction, $CaCO_3 \longrightarrow CaO + CO_2$ would take place at a constant temperature of about 1560°F. In the analogous receiver discussed in the previous section water is converted into steam at the constant temperature of about 1000°F. Heat transfer from the outside wall of the reactor tube to the calcium carbonate on the inside would need investigation. The plant would have to operate continuously twenty-four hours a day. This means that an alternative fuel, such as gas, would have to be burned in the precalcining reactor. This would be done in a controlled manner so that the total heat input, radiant plus gas combustion, was always a constant.

Precalcining is a method of getting high quality solar heat into the reaction system directly with a minimum of equipment. Solar energy introduced at the precalcining step would displace coal or other fossil fuel introduced at the kiln. Also precalcining has the advantage of reducing the size of the kiln that is necessary. Alternatively in an existing plant it can allow production to increase within the same kiln.

A somewhat different approach to precalcining has also been suggested. In this, a separate unit would be involved and the lime from this precalcining unit would be stockpiled. This stockpile would serve as an energy storage mechanism. Material would be added to the stockpile when available radiant energy was above a minimum level required to operate the precalcining unit. Material would be removed from the stockpile continuously at a constant rate, preheated and introduced to the kiln. This approach has the advantage that greater energy displacement by solar is possible because of the energy storage mechanism. It has the disadvantage of requiring more equipment. Also the sensible heat of the lime in the stockpile may be lost. The amount lost would depend on the containment of the stockpile and its size. In a worst case where the material cools to ambient the loss would be about 20% of the energy introduced when the calcium carbonate was converted to lime. This last stockpile between the separate precalciners and preheaters is not shown in Figure 3-7.

Large solar hot air generators designed for utilities will use a field of heliostats. These reflect the direct insolation to the top of a tower where the solar boiler is located. A mechanism is provided with the heliostat so that its orientation can be continuously varied during the day to keep the reflected radiation on target at the top of the tower. A couple of receiver designs which contain the solar boilers are under development by Boeing and Black & Veatch.

These systems are being designed to use a Brayton cycle for the generation of electric power. This or similar equipment once developed could be used for producing hot gas in the cement plant for drying. Solar receiver capacities of 400 MW_{th} or 1365×10^6 Btu/Hr are under consideration for utilities. A typical cement plant might produce 600,000 tons per year and require for continuous operation a heat input rate of 360×10^6 Btu/Hr. If 50% of this heat input, 180×10^6 Btu/Hr, is provided by precalcining then the size of the solar unit required would be about 53 MW_{th}. This is only slightly larger than the 10 MW_e pilot plant now under construction.

The intensity of solar insolation varies with the time of day, the seasons, and weather conditions. In the above applications these fluctuations are countered by varying the input from fossil fuel. The exception would be in stockpiling the lime from a solar precalcining reactor. In the latter case the solar unit could be designed to provide the entire energy requirement for precalcining. This then could account for about 50% of the energy input into the plant. The heliostat field might be sized so as to provide the average requirement for the year. The average daily direct normal insolation in the southwestern U. S. is above 8 kW-hr m^{-2}. The minimum size for the heliostat field can now be estimated. A 600,000 ton/year cement plant would correspond to 180×10^6 Btu/Hr energy input to precalcining. This would require a solar collection area corresponding to 104 MW_{th} (36 MW_e). This size unit would correspond to a 36 MW_e intermediate load utility generating station.

Alternatively if stockpiling is not used, the size of the heliostat field would be such that during maximum insolation all energy requirements were being met by the solar unit. A larger size would be less economic and a smaller size would not have as great an energy displacement. This assumes that high-temperature thermal storage is not used.

A precise economic analysis of the cement applications is not possible because there are many rapidly changing costs involved. Solar boilers are now under development. Their costs are rapidly decreasing due to new technology and to normal learning curve effects.

However, to comment on the economic feasibility of the proposed applications, consider the case of precalcining and stockpiling. In the above example with a 600,000 ton/year cement plant the displacement of fossil fuel with solar energy would be 50%. The solar plant would correspond to a 36 MW_e (104 MW_{th}) electric utility unit in size. The relevant components of the latter are the heliostat field and solar receiver. Deleting the cost of storage from the preceding solar central receiver steam plant, the cost drops from \$514 to \$400/kW_{th} and projected investment would be about \$41.6 million. The allowable investment for a 50% displacement would be \$41.6 million assuming a 10 year payout and \$2.64 per million Btu. Thus it is concluded that if the Federal solar program related to electric utilities is economically successful then the above would represent a feasible application of the same components.

IV. RECOMMENDED PROGRAMMATIC APPROACH TO FURTHER SOLAR THERMAL APPLICATIONS

IV. RECOMMENDED PROGRAMMATIC APPROACH TO FURTHER SOLAR THERMAL APPLICATIONS

Definition of a programmatic approach is necessary to implement the role of solar thermal process heat applications addressed in Section III. Accordingly, an approach is recommended in this section which is a continuation and expansion of the present DOE Industrial Process Heat Program. Such an approach places increased and earlier emphasis on the high-temperature process heat users that are the current principal energy consumers.

The implementation of this approach is described briefly in the following paragraphs. First, an overview is provided to focus on Government and industrial coordinated involvement. Second, some recommendations are made to initiate a high-temperature program. Finally, a preliminary discussion is presented regarding content of DOE solicitation notices (e.g., RFPs) to implement the program and provide data on key technical issues.

A. OVERALL APPROACH TO MAXIMIZE INDUSTRIAL INVOLVEMENT

The key to successfully implementing the programmatic approach recommended here is to maximize the involvement of industry which is extremely diverse geographically and technically. This approach should accelerate commercialization of solar thermal high-temperature process heat systems despite limited Government investment and participation. It makes use of the fact that industry does have the technical expertise and financial means.

Several programmatic constraints will be required to accomplish this early industrial involvement. Focus must initially be on those industries that are the principal energy consumers. Multiple applications for high-quality heat must be identified early, as supplements to those of this report; and all such applications must be capable of utilizing equipments that are currently under development for the Solar Thermal Electric Program. Selection of these candidate applications must consider the ultimate user needs. Furthermore, the selection process should utilize the expertise of the most qualified user organizations.

This early industrial participation would lay the base for subsequent experimental and demonstration projects. These projects should be joint ventures sponsored by DOE but with up to 50% participation by industry. This approach should be attractive to industry and provide high confidence of early commercialization of solar high-temperature process heat.

B. INITIAL STAGES OF PROGRAM IMPLEMENTATIONS

The initial stages of the Solar Energy High-Temperature Process Heat Program again emphasize expanded industrial involvement sponsored by DOE. Sponsorship considerations and types of studies to be conducted are discussed next.

1. Initial DOE-Sponsorship Considerations

DOE can initiate this high-temperature program by giving grants to study, design, and evaluate specific solar process heat applications. Such grants would be to representative forms of the three industries studied in this report (i.e., cement, chemical, and petroleum), and of other industries which are large energy consumers (e.g., steel mills, pulp and paper mills, and lime production). Studies done within the solar equipment user industry would tend to be success oriented since the users would have a vested interest in the project.

An awareness of the particular industrial structure is important to the selection of firms. The significance of this involves the degree of technology sharing and power structure that exist within a given industry. For example, cement manufacturers allow extensive sharing compared to the closely guarded chemical industry; the steel industry is dominated by a few large firms compared to small family-owned foundries. The structure can determine the best way of introducing new technology and also key points for industry interviews.

It is also essential to be aware that industrial management time is at a premium and solar energy projects will be competing for their time. Accordingly, to gain management acceptance of solar energy the first applications should be less ambitious, such as a tank farm heater or small steam plant.

2. Near-Term Status and Development Plan

The following studies are projected for assessing the viability of solar thermal energy systems to supply industrial process heat. Appendix A-2 contains a more detailed description and summary of conclusions from DOE studies funded in Fiscal Years '75, '76 and '77.

a. Application Studies: The DOE economics and applications studies should be expanded in scope and task to the medium- and high-grade thermal energy needs. Studies should be conducted to define the requirements as functions of (a) scale, (b) temperature range, (c) dependability, (d) geographic distribution, (e) energy demand profiles and projections, (f) projections of cost and timing alternatives, and (g) energy suppliers. A rigorous assessment should be obtained regarding the role of solar thermal systems and the target performance requirements that the systems must achieve to be viable.

b. Reference Designs: In-depth analyses of the more promising system concepts and applications will be performed. These analyses need to emphasize the optimum integration of solar thermal systems into specific industrial applications, e.g., primary metals; stone, clay and glass; petroleum products; paper and allied products. The areas to receive special consideration should include practicability and reliability of design, environmental impacts, ease of maintenance, and solar system capability to meet demand profiles. In addition, the ability of a specific system to ameliorate or eliminate reliance on utility or conventional supplies for backup energy should be identified.

c. Major Assessments: As the studies of Section IV-2-a and parts of Section IV-2-b are completed, the more promising systems and applications offering the greatest market potential should be identified. These will necessitate contributions of industry, the technical and economic communities, and the solar equipment manufacturers. These assessments need time-phased efforts with initial medium-grade thermal energy system concepts available sometime in 1978. In subsequent years, high- and very high-grade energy systems should be identified. However, the exact planning needs to be phased with the completion times of the necessary economic applications and referenced solar thermal design studies.

d. Development Program Plan: Detailed program plans need to be prepared which include supporting applications of existing technology and continuing technological developments. These should be consistent with the boundary conditions that medium- and high-grade industrial process heat, retrofit, and integrally designed solar thermal industrial plants will be demonstrated to the industry by the early and late 1980's. Furthermore, these plans must be consistent with the goal that solar thermal energy for industrial process heat will be achieved economically to a maximum degree by the early 1990's. Costs and construction times for the major elements should be obtained from (a) the referenced solar thermal designs described in Section IV-2-b, (b) the systems already constructed, and (c) from the experience gained in the solar electric applications, total energy systems, and low-grade industrial process heat systems.

C. CONTENT OF INITIAL DOE SOLICITATIONS

DOE can utilize several forms of solicitation notices to accomplish the initiation of high-temperature program activities. Such forms include grants (discussed in Section IV-B), Program Opportunity Notifications (PONs), RFPs, and Program Research and Development Announcements (PRDAs).

Regardless of form, the content of these should be such that each is a well-defined part of an integrated program. Each solicitation should accordingly include the following information.

- Statement of Work (SOW) incorporating purpose and scope, task background (including program objectives), contractual organization/relationships, schedules and deliverable products (i.e., reports, drawings, hardware), and specific tasks to be performed.
- Requirements/specifications as appropriate to control technical and economical factors in terms of performance.

1. Industrial Planning Grants

Multiple (i.e., 10-20) industrial planning grants should be issued by DOE. These would each involve $25-50 ,000 funding over 3-6 months. Each would involve the considerations addressed earlier in this section; i.e., selection of ultimate users to accelerate commercialization, acquisition of ideas developed by industry as part of their conservation efforts, development of menus of potential applications, utilization of most qualified organizations, and establishment of a base for subsequent experimental and demonstration projects.

2. Program Opportunity Notifications

PONs may be issued to provide conceptual designs of "new process" type of applications. This form of solicitation will allow industry to jointly contribute funds and management, such as is being done in the 10 MW_e Solar Central Receiver Pilot Plant in Barstow, California.

3. Conceptual Study RFPs and PRDAs

RFPs and PRDAs may also be issued to perform conceptual studies of special requirements for industrial processes. Candidate studies pertain to very high-temperature regions, and continuous versus batch process implications.

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REFERENCES

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APPENDIX A

APPENDIX

A-I. INDUSTRIAL REQUIREMENTS

The domestic energy consumption by economic or market sector historically has been compiled by the Bureau of Mines, and more recently by the Federal Energy Administration. Table A-1 presents the domestic energy consumption by economic sector for the period 1950 to 1976. The energy consumption increased each year until the time of the Arab oil boycott in 1973. In 1976, the U. S. consumption equaled the 1973 consumption and it is projected to exceed 75 Quads in 1977. The industrial consumption, exclusive of purchased electricity, has shown a steady 3 percent annual energy demand growth. If the industrial demand in future years is projected from the present use at this continued percentile growth, then the industrial process heat requirements alone are projected to be 140 Quads by the year 2050.

Industrial use of energy for direct or indirect process heat occurs in a diversity of applications. Required temperatures range from close to ambient for low-pressure distillations to above 3000°F (1647°C) for refractory kilns. The energy source selected for a given industrial use must satisfy both the specific temperature requirement and specific performance criteria. For some processes, direct heating must be clean and free of pollutants (e.g., processes for heating textiles, bakery goods, and certain metals). Often, precise temperature control (variability and accuracy) is required. For most heating processes, dependability is an important factor, particularly in continuous processing. Another factor affecting the selection of an industrial energy source is the problem of treating residuals to meet environmental standards. This consideration

Table A-1

Domestic Energy Consumption by Economic Sector

Year	Total (Quads)	Percent of Total Commercial / Residential[a]	Industrial[a]	Trans-portation[a]	Electricity Generation[b]	Miscellaneous and unaccounted for[a]
1950	34.0	22.3	36.3	25.3	14.7	1.4
1955	39.7	21.6	35.2	24.8	16.6	1.8
1960	44.6	22.8	32.9	24.3	18.5	1.5
1961	45.3	22.9	32.3	24.2	18.8	1.8
1962	47.4	23.1	32.2	24.0	19.2	1.5
1963	49.3	22.3	32.3	24.3	19.6	1.5
1964	51.2	21.7	32.6	23.9	20.3	1.5
1965	53.3	22.2	32.2	23.8	20.8	1.0
1966	56.4	22.0	32.0	23.6	21.4	1.0
1967	58.3	22.3	31.3	24.1	21.8	0.5
1968	61.8	21.2	31.4	24.5	22.5	0.4
1969	65.0	20.9	30.9	24.3	23.5	0.4
1970	67.1	20.8	30.1	24.6	24.2	0.3
1971	68.7	20.7	29.1	24.8	25.1	0.3
1972	71.9	20.3	28.5	25.1	25.8	0.3
1973	74.7	19.1	28.6	25.3	26.6	0.4
1974	73.0	19.1	27.9	25.3	27.4	0.3
1975	70.6	19.2	25.4	26.3	28.7	0.4
1976	74.2	20.2	25.4	25.6	28.8	(2)

[a] Does not include electricity.

[b] Distributed throughout other sectors.

Sources: FEA, Energy in Focus, May 1977.

imposes restrictions on the choice of fuels not only from the varying requirements of different industrial processes, but also from the variable environmental conditions for each geographical location. In short, the ideal industrial energy source is not only economical, but is also dependable, clean, and easy to control.

In light of these factors, there are certain characteristics of solar energy which industrial users should find desirable. The primary attribute of solar energy is its cleanliness, both in conveying heat to the working material and the lack of residuals released to the environment. Solar energy should also be relatively easy to control if transformed to process steam or hot gaseous streams. The primary noneconomic drawback of solar energy use is the undependability of insolation. For many industrial heating applications, rapid response backup heating capability will be a necessary part of the solar system.

Solar energy will be of particular use in cases where intermittent supply is acceptable. At major facilities using continuous processing, a regular and dependable energy supply is a necessity, and storage and/or backup supply will be needed with any solar system. However, when intermittency is acceptable, the economics of solar technologies will be greatly improved.

Figure A-1 shows the cumulative distribution of industrial process heat requirements as a function of application temperature. These data show that the current industrial heat program, aimed at delivering thermal energy at or below 350°F, will account for 22 percent of industrial process heat used as a function of terminal process temperature, or 41 percent

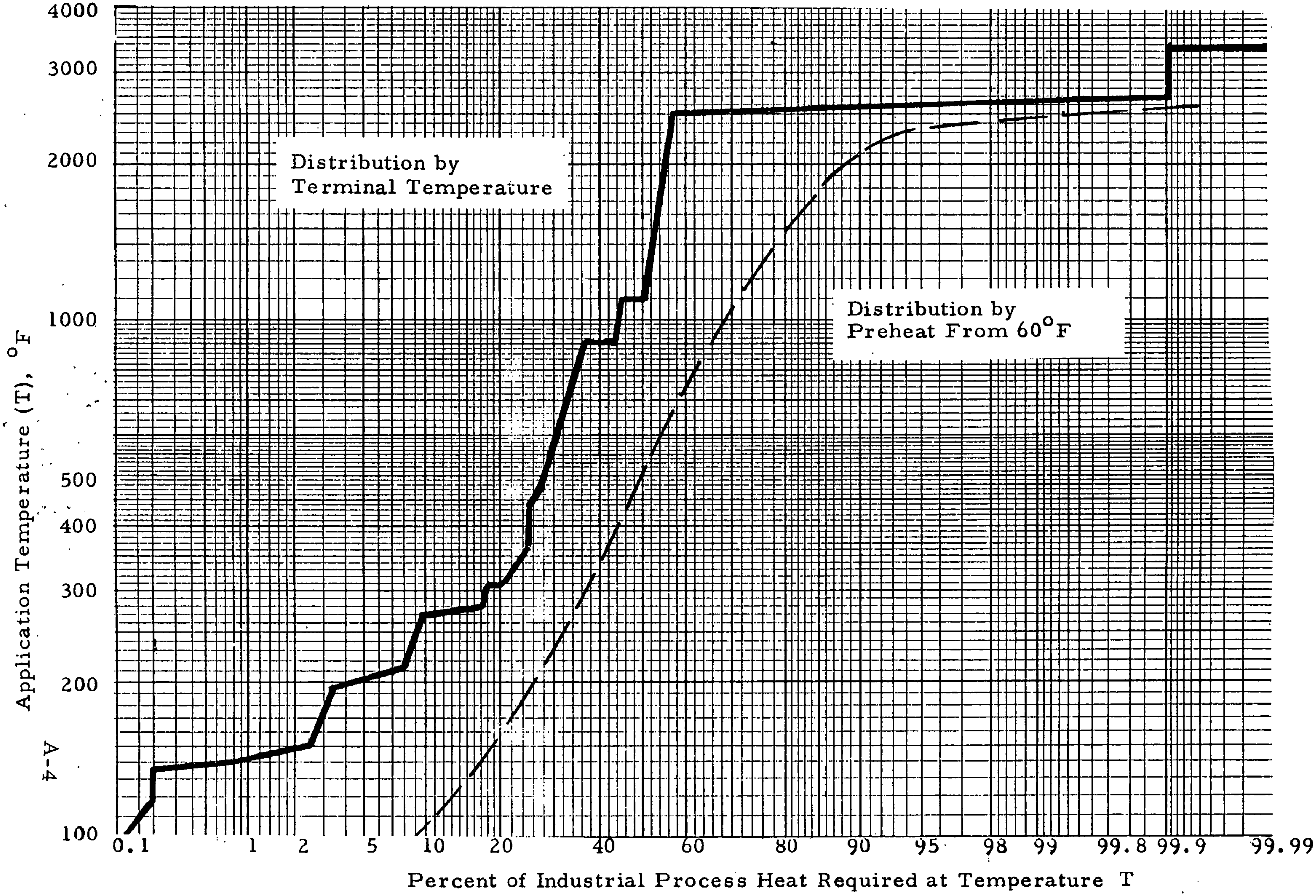


Figure A-1. Cumulative Distribution of Process Heat Requirements used as a function of preheat temperature process heat. The balance of the thermal energy requirements, 78 percent of the thermal energy needs or 59 percent of the preheat demand, remains to be satisfied.

Many surveys of energy consumption have been conducted recently. They appear to be consistent but differ in data-gathering techniques and scope. The industrial process heat requirements shown in Figure A-1 have been prepared from data extracted from Reference 3. This study appears to be the most comprehensive treatment of industrial thermal energy requirements in existing literature. Table A-2, also based on information from Reference 3 presents a tabulation of industrial process heat application and annual requirements for 1974, as a function of terminal temperature, starting with the highest application temperature requirement and concluding with the lowest temperature requirement. Information from this table was used to prepare Figure A-1.

Not all of the four digit standard industrial classification groups were included in the Reference 3 survey, there being over 450 in the mining and manufacturing categories. The final data sample included applications from 78 of the groups and these applications consume 9.8×10^{15} Btu's per year, about 59 percent of the estimated total amount of process heat used by industry. These data contain only the heat used in production processes in industry, and is not concerned with total energy consumption, use of electricity or fuels for power. This data base, the best currently available, is of course only a sample of the total use of process heat (requirements) by industry.

It is of interest also to look at the distribution of energy consumption for industrial process heat by states (Table A-3). The two states with the largest industrial energy consumption are Texas and Louisiana. In both of these states industry has been established to take advantage of the plentiful fossil fuels that exist there. It is anticipated that the projected thermal energy demands of the industrial sector will not follow the existing geographic consumptive patterns, but will probably of necessity relocate in regions that are most competitive in meeting future energy requirements. For solar demands the southwestern regions show the greatest potential.

Table A-2

Industrial Process Heat Application Annual Requirements for 1974
Application Terminal Temperature

Standard Industrial Classification	Industry and Process	Application Temperature Requirement, °F	Process Heat Used 10^{12} Btu/yr
3255	Clay Refractories; Firing	3300	9
3221	Glass Containers, Melting-Firing	2700-2900	99
3312	Blast Furnace & Steel Mills	2700	3300
3321	Ferrous Castings, Gray Iron Foundries, Cupola Melting	2700	107
3322	Ferrous Castings, Malleable Foundries, Cupola Melting	2700	24
3323	Ferrous Castings, Steel Foundries, Cupola Melting	2700	15
3711	Motor Vehicles, Casting Foundry	2650	23
3211	Flat Glass, Melting	2300-2700	50
3241	Hydraulic Cement, Calcining	2300-2700	468
3251	Brick & Structural Tile, Brick Kiln	2500	70
1011	Iron Ore, Pelletizing of Concentrates	2350-2500	37
3331	Primary Copper, Smelting & Fire Refining	2000-2500	33
3333	Primary Zinc, Pyrolytic Reduction	2400	1
28195	Alumina, Calcining	2200	35
3334	Primary Aluminum, Prebaking Anodes	2000	8
3221	Glass Containers, Conditioning	1500-2000	42
3211	Flat Glass; Fabrication, Tempering & Laminating	1470-2000	4

Table A-2 (Continued)

Industrial Process Heat Application Annual Requirements for 1974

Application Terminal Temperature

Standard Industrial Classification	Industry and Process	Application Temperature Requirement, °F	Process Heat Used 10^{12} Btu/yr
2661	Chemicals Recovery - Calcining	1900	96
3295	Kaolin, Calcining	1900	1
3295	Expanded Clay & Shale, Bloating Process	1800	29
3274	Lime - Calcinating	1800	130
3321	Ferrous Castings, Gray Iron Foundries, Heat Treatment & Finishing	900-1800	11
3322	Ferrous Castings, Malleable Iron Foundries, Heat Treatment & Finishing	900-1800	2
3323	Ferrous Castings, Steel Foundries, Heat Treatment & Finishing	900-1800	3
3621	Motors & Generators, Oxide Coat Laminations	1500-1700	1
3295	Treated Minerals, Expanded Perlite Expansion Process	1600	2
2911	Petroleum Refining, Hydrogen Plant	1600	124
1475	Phosphate Rock, Calcining	1400-1600	1
3621	Motors & Generators, Annealing	1500	1
3221	Glass Containers, Annealing	1200	13
3221	Glass Containers, Post Forming	1200	1
2911	Petroleum Refining, Olefins & Aromatics	1200	124
2911	Petroleum Refining, Catalytic Cracking	1125	447
2062	Cane Sugar Refining, Revivification	750-1110	4
3295	Treated Minerals, Fuller's Earth, Drying & Calcining	1100	6

Table A-2 (Continued)

Industrial Process Heat Application Annual Requirements for 1974 Application Terminal Temperature

Standard Industrial Classification	Industry and Process	Application Temperature Requirement, °F	Process Heat Used 10^{12} Btu/yr
2911	Petroleum Refining, Thermal Operations	555-1010	154
2046	Wet Corn Milling, Fiber Dryer	1000	3
2063	Lime Calcining	1000	3
3211	Flat Glass, Annealing	930	6
2911	Petroleum Refining, Catalytic Reforming	925	498
2911	Petroleum Refining, Delayed Coking	900	225
3479	Galvanizing, Melting Zinc	850	0.01
2911	Petroleum Refining, Hydrocracking	515-810	91
2911	Petroleum Refining, Vacuum Distillation	440-800	183
2911	Petroleum Refining, Catalytic Hydrorefining	700	52
2911	Petroleum Refining, Hydrotreating	700	124
2911	Petroleum Refining, Atmospheric Topping	650	275
2034	Dehydrated Fruits & Vegetables, Granule Flash Dryer	550	1
2823	Cellulosic Man-Made Fibers, Polyester	< 550	49
2823	Cellulosic Man-Made Fibers, Polyproplene	< 540	4
2823	Cellulosic Man-Made Fibers, Nylon	< 535	42
2013	Meat Packing, Sausages & Prepared Meats Singeing Flame	500	1
2841	Soaps, Spray Drying	500	0.001
2841	Detergents, High-Temperature Processes	500	0.001

Table A-2 (Continued)

Industrial Process Heat Application Annual Requirements for 1974

Application Terminal Temperature

Standard Industrial Classification	Industry and Process	Application Temperature Requirement, °F	Process Heat Used 10^{12} Btu/yr
2841	Detergents, Spray-Dried	500	0.02
2952	Asphalt Felts & Coatings, Saturator	400-500	2
2841	Soaps, High-Temperature Processes	490	0.002
3321	Ferrous Castings, Gray Iron Foundries, Mold & Core Preparation	300-475	86
3322	Ferrous Castings, Malleable Iron Foundries, Mold & Core Preparation	300-475	12
3323	Ferrous Castings, Steel Foundries, Mold & Core Preparation	300-475	20
2051	Bread & Baked Goods, Baking	420-460	6
1475	Phosphate Rock, Drying	450	11
3079	Plastics Products, High-Density Polyethylene	425	4
2048	Prepared Feeds, Alfalfa Drying	400	17
2082	Malt Beverages, Grain Dryer	400	9
2023	Condensed & Evaporated Milk, Spray Drying	350-400	4
2079	Shortening & Cooking Oil, Vacuum Deodorizer	300-400	0.4
2085	Distilled Liquor, Dryer (Grain)	300-400	2
2952	Asphalt Felts & Coatings, Coating	300-400	1
2952	Asphalt Felts & Coatings, Sealant	300-400	0.6
2873215	Urea, High-Pressure, Steam-Heated Stripper	375	5
2611	Pulp Mills, Pulp Digestion	370	253
3271	Concrete Block, Autoclaving	360	5
2952	Asphalt Felts & Coatings, Steam Drying	350	3

Table A-2 (Continued)

Industrial Process Heat Application Annual Requirements for 1974
Application Terminal Temperature

Standard Industrial Classification	Industry and Process	Application Temperature Requirement, °F	Process Heat Used 10^{12} Btu/yr
2034	Dehydrated Fruits & Vegetables, Flake Dryer	350	1
3621	Motors & Generators, Baking	350	0.1
2841	Detergents, Drum-Dried	350	0.3
2812	Alkalies & Chlorine, Diaphragm Cell	350	82
2865	Cyclic Intermediates, Ethylbenzene	350	3
2046	Wet Corn Milling, Steep Water Evaporator	350	4
2046	Wet Corn Milling, Germ Dryer	350	2
2046	Wet Corn Milling, Gluten Dryer	350	1
2075	Soybean Oil Mills, Meal Dryer	350	4
2077	Animal & Marine Fats, Fat	330-350	17
2653	Solid & Corrugated Fiber, Corrugating & Glue Setting	300-350	22
2865	Cyclic Intermediates, Styrene	250-350	35
2869	Organic Chemicals, NEC - Vinyl Chloride Monomer	250-350	9
2911	Petroleum Refining, Butadiene	250-350	60
2869	Organic Chemicals, NEC, Isopropanel	200-350	11
1477	Sulfur, Frasch Mining	325-340	60
3011	Tires & Inner Tubes, Vulcanization	250-340	6
2911	Petroleum Refining, Alkylation	45-340	59
3275	Gypsum, Kettle Calcining	330	10
2951	Paving Mixtures, Heating Asphalt	325	5
2951	Paving Mixtures, Aggregate Drying	275-325	88
3241	Hydraulic Cement, Drying	275-325	8

Table A-2 (Continued)

Industrial Process Heat Application Annual Requirements for 1974
Application Terminal Temperature

Standard Industrial Classification	Industry and Process	Application Temperature Requirement, °F	Process Heat Used 10^{12} Btu/yr
2085	Distilled Liquor, Cooking Spirits	320	6
2079	Shortening & Cooking Oil, Hydrogenation Preheat	300	0.4
3275	Gypsum, Wallboard Drying	300	11
2421	Sawmills & Planing Mills, Kiln Drying of Lumber	300	63
2892	Explosives, Drying	300	0.006
3711	Motor Vehicles, Baking-Prime & Paint Ovens	250-300	0.29
2611	Pulp Mills, Pulp & Paper Drying	290	383
2873215	Urea, Low-Pressure, Steam-Heated Stripper	290	0.89
2085	Distilled Liquor, Evaporation	250-290	2
2611	Pulp Mills, Black Liquor Treatment	280	164
28195	Alumina, Digesting, Drying, Heating	280	113
2063	Beet Sugar, Evaporation	270-280	31
2063	Beet Sugar, Pulp Dryer	230-280	17
2261	Finishing Plants, Cotton, Drying	275	22
2261	Finishing Plants, Synthetic, Drying & Heat Setting	< 275	23
2046	Wet Corn Milling, Sugar Hydrolysis	270	2
2079	Shortening & Cooking Oil, Dryer Preheat	200-270	0.60
2062	Cane Sugar Refining, Evaporator	265	26
2046	Wet Corn Milling, Sugar Evaporator	250	3
2435	Plywood, Drying	250	51
1021	Copper Concentrate, Drying	250	2

Table A-2 (Continued)

Industrial Process Heat Application Annual Requirements for 1974

Application Terminal Temperature

Standard Industrial Classification	Industry and Process	Application Temperature Requirement, °F	Process Heat Used 10^{12} Btu/yr
1474	Potash, Drying Filter Cake	250	1
2834	Pharmaceutical Preparations, Autoclaving & Cleanup	250	19
2834	Pharmaceutical Preparations, Tablet & Dry - Capsule Drying	250	1
2865	Cyclic Intermediates, Phenol	250	0.5
2023	Condensed & Evaporated Milk, Sterilization	250	0.5
2032	Canned Specialties, Processing	250	0.4
2869	Organic Chemicals, NEC, Cumene	250	1
2892	Explosives, Nitric Acid Concentrator	250	0.07
2823	Cellulosic Man-Made Fibers, Acrylic	<250	24
2085	Distilled Liquor, Distillation	230-250	8
2033	Canned Fruits & Vegetables, Commercial Sterilization	212-250	2
2869	Organic Chemicals, NEC, Ethanol	200-250	6
3295	Treated Minerals, Kaolin Drying	230	13
3295	Treated Minerals, Barium Drying	230	0.3
2075	Soybean Oil Mills, Evaporator	225	2
2111	Cigarettes, Drying	220	0.4
2111	Cigarettes, Rehumidification	220	0.4
2141	Tobacco Stemming & Redrying, Drying	220	0.50
1211	Bituminous Coal, Drying	150-220	18
2075	Soybean Oil Mills, Toaster Desolventizer	215	6
2821	Plastic Materials & Resins, Polymerizer Preheat	200-215	0.1

Table A-2 (Continued)

Industrial Process Heat Application Annual Requirements for 1974 Application Terminal Temperature

Standard Industrial Classification	Industry and Process	Application Temperature Requirement, °F	Process Heat Used 10^{12} Btu/yr
2063	Beet Sugar, Thin Syrup Heating	212	7
2075	Soybean Oil Mills, Stripper	212	0.3
2082	Malt Beverages, Coaker	212	2
2082	Malt Beverages, Brew Kettle	212	4
2085	Distilled Liquor, Cooking Whiskey	212	3
2262	Finishing Plants, Dyeing	212	15
2436	Veneer, Drying	212	58
2033	Canned Fruits & Vegetables, Sauce Concentration	212	0.4
2034	Dehydrated Fruits & Vegetables, Peeling Potatoes	212	0.3
2034	Dehydrated Fruits & Vegetables, Cook Potatoes	212	0.5
2824	Noncellulosic Fibers, Rayon	< 212	38
2824	Noncellulosic Fibers, Acetate	< 212	38
2023	Condensed & Evaporated Milk, Stabilization	200-212	3
2032	Canned Specialties, Precook Beans	180-212	0.4
2033	Canned Fruits & Vegtables, Blanching/ Peeling	180-212	2
2037	Frozen Fruits & Vegetables, Blanching	180-212	2
2032	Canned Specialties, Simmer Blend Beans	170-212	0.2
2037	Frozen Fruits & Vegtables, Cooking	170-212	1
3321	Ferrous Castings, Gray Iron Foundries, Pickling	100-212	110
3322	Ferrous Castings, Malleable Iron Foundries, Pickling	100-212	15

Table A-2 (Continued)

Industrial Process Heat Application Annual Requirements for 1974

Application Terminal Temperature

Standard Industrial Classification	Industry and Process	Application Temperature Requirement, ^{o}F	Process Heat Used 10^{12} Btu/yr
3323	Ferrous Castings, Steel Foundries, Pickling	100-212	26
2261	Finishing Plants, Cotton, Washing	200	15
2261	Finishing Plants, Cotton, Dyeing	200	5
2262	Finishing Plants, Synthetic, Washing	200	36
2892	Explosives, Wax Melting	200	0.1
2892	Explosives, Sulfuric Acid Concentrator	200	0.03
2892	Explosives, Nitric Acid Plant	200	0.2
2892	Explosives, Blasting Cap Manufacture	200	0.02
2079	Shortening & Cooking Oil, Cooking Oil Reheat	200	0.3
2037	Frozen Fruits & Vegetables, Juice Pasteurization	200	0.3
2033	Canned Fruits & Vegetables, Pasteurization	200	0.2
2033	Canned Fruits & Vegetables, Brine Syrup Heating	200	1
2821	Plastic Materials & Resins, Drying	200	0.03
2011	Meat Packing, Edible Rendering	200	0.5
2816	Inorganic Pigments - Drying Chrome Yellow	200	0.08
2821	Plastic Materials & Resins, Heating Wash Water	190-200	0.06
2022	Natural Cheese, Whey Condensing	160-200	10
2822	Synthetic Rubber, Cold SBR Latex Crumb Dryer Air Temperature	150-200	4
2822	Synthetic Rubber, Cold SBR, Oil-Carbon Black Masterbatch, Dryer Air Temperature	150-200	0.5

Table A-2 (Continued)

Industrial Process Heat Application Annual Requirements for 1974
Application Terminal Temperature

Standard Industrial Classification	Industry and Process	Application Temperature Requirement, °F	Process Heat Used 10^{12} Btu/yr
2822	Synthetic Rubber, Cold SBR, Oil Masterbatch Dryer Air Temperature	150-200	1
2063	Beet Sugar, Granulator	150-200	0.2
2062	Cane Sugar Refining, Melter	185-195	3
2037	Frozen Fruits & Vegetables, Citrus Juice Concentration	190	1
2032	Canned Specialties, Beans, Sauce Heating	190	0.2
2048	Prepared Feeds, Pellet Conditioning	180-190	2
3479	Galvanizing, Cleaning, Pickling	130-190	0.01
3273	Ready-Mix Concrete, Hot Water for Mixing	120-190	0.3
2063	Beet Sugar, Thin Juice Heating	185	3
2034	Dehydrated Fruits & Vegetables, Fruit & Vegetable Drying	165-185	6
2062	Cane Sugar Refining, Defecation	160-185	0.4
2063	Beet Sugar, Extraction	140-185	5
2841	Soaps & Detergents, Various Processes in Soap Manufacture	180	0.5
2841	Soaps & Detergents, Detergent Various Low-Temperature Processes	180	0.4
2082	Malt Beverages, Water Heater	180	0.5
2079	Shortening & Cooking Oil, Oil Heater	160-180	0.7
2079	Shortening & Cooking Oil, Wash Water	160-180	0.1
2082	Malt Beverages, Mash Tub	170	0.6
2086	Soft Drinks, Bulk Container, Washing	170	0.2

Table A-2 (Continued)

Industrial Process Heat Application Annual Requirements for 1974 Application Terminal Temperature

Standard Industrial Classification	Industry and Process	Application Temperature Requirement, ^oF	Process Heat Used 10^{12} Btu/yr
2086	Soft Drinks, Returnable Bottle Washing	170	1
2022	Natural Cheese, Pasteurization	170	1
2026	Fluid Milk, Pasteurization	162-170	1
2022	Natural Cheese, Process Cheese Blending	165	0.1
3271	Concrete Block, Low-Pressure Curing	165	12
2062	Cane Sugar Refining, Mingler	125-165	0.6
3295	Treated Minerals, Expanded Perlite Drying	160	0.2
2075	Soybean Oil Mills, Bean Drying	160	4
2023	Condensed & Evaporated Milk, Evaporation	160	5
2034	Dehydrated Fruits & Vegetables, Precook Potatoes	160	0.5
2011	Meat Packing, Sausages & Prepared Meats, Smoking/Cooking	155	1
2511	Wooden Furniture, Kiln Dryer & Drying Oven	150	4
2512	Upholstered Furniture, Kiln Dryer & Drying Oven	150	1
2611	Pulp Mills, Pulp Refining	150	175
2834	Pharmaceutical Preparations, Wet Capsule Formation	150	0.1
3621	Motors & Generators, Drying & Preheat	150	0.04
2822	Synthetic Rubber, Cold SBR Latex Crumb, Blowdown Vessels	130-145	0.9
2011	Meat Packing, Sausages & Prepared Meats Cleanup	140	44

Table A-2 (Continued)

Industrial Process Heat Application Annual Requirements for 1974 Application Terminal Temperature

Standard Industrial Classification	Industry and Process	Application Temperature Requirement, °F	Process Heat Used 10^{12} Btu/yr
2016	Poultry Dressing, Scalding	140	3
3111	Leather Tanning & Finishing, Retan, Dyeing, Fat Liquor	120-140	0.2
2822	Synthetic Rubber, Cold SBR Latex Crumb Monomer Recovery	120-140	4
2022	Natural Cheese, Starter Vat	135	0.02
2062	Cane Sugar Refining, Granulator	110-130	0.4
3111	Leather Tanning & Finishing, Chrome Tanning	85-130	0.06
3111	Leather Tanning & Finishing, Wash	120	0.03
2022	Natural Cheese, Whey Drying	120	3
2046	Wet Corn Milling, Starch Dryer	120	3
2046	Wet Corn Milling, Steepwater Heater	120	0.8
2046	Wet Corn Milling, Sugar Dryer	120	0.2
3111	Leather Tanning & Finishing, Drying	110	2
3111	Leather Tanning & Finishing, Finishing Drying	110	0.1
2022	Natural Cheese, Make Vat	105	0.5
2051	Bread & Baked Goods, Proofing	100	0.8
2022	Natural Cheese, Finish Vat	100	0.02
2822	Synthetic Rubber, Cold SBR Latex Crumb, Bulk Storage	80-100	0.2
2822	Synthetic Rubber, Cold SBR Latex Crumb Emulsification	80-100	0.1
2822	Synthetic Rubber, Cold SBR, Oil-Carbon Black Masterbatch, Oil Emulsion Holding Tank	80-100	0.03

Table A-2 (Continued)

Industrial Process Heat Application Annual Requirements for 1974 Application Terminal Temperature

Standard Industrial Classification	Industry and Process	Application Temperature Requirement, °F	Process Heat Used 10^{12} Btu/yr
2822	Synthetic Rubber, Cold SBR, Oil Masterbatch Oil Emulsion Holding Tank	80-100	0.09
3111	Leather Tanning & Finishing, Bating	90	0.09
2086	Soft Drinks, Nonreturnable Bottle Warming	75-85	0.4
2086	Soft Drinks, Can Warming	75-85	0.5
2511	Wooden Furniture, Makeup Air & Ventilation	70	6
2512	Upholstered Furniture, Makeup Air & Ventilation	70	1
2911	Petroleum Refining, Lubricants	Unavailable	25
2911	Petroleum Refining, Asphalt	Unavailable	96

Table A-3

Fuel Consumption by the Industrial Sector, 1972

STATE	COAL		PETROLEUM		NATURAL GAS		TOTAL FUEL
	10^3 Tons	10^{12} Btu	10^3 BBL	10^{12} Btu	10^6 SCF	10^{12} Btu	10^{12} Btu
Alabama	10,551	276.4	2,626	15.8	173,032	173.0	465.2
Alaska	416	10.9	1,068	6.4	37,596	37.6	54.9
Arizona	-	-	1,745	10.5	71,892	71.9	82.4
Arkansas	-	-	1,945	11.7	176,202	176.2	187.9
California	1,776	46.5	21,464	128.8	710,207	710.2	885.5
Colorado	1,628	42.7	1,753	10.5	96,734	96.7	149.9
Connecticut	55	1.4	5,681	34.1	21,144	21.1	56.6
Delaware	-	-	3,645	21.9	10,003	10.0	31.9
Florida	-	-	7,280	43.7	94,568	94.6	138.3
Georgia	398	10.4	6,192	37.2	164,514	164.5	212.1
Hawaii	-	-	1,266	7.6	-	-	7.6
Idaho	-	-	1,048	6.3	36,026	36.0	42.3
Illinois	8,319	218.0	16,887	101.3	415,094	415.1	734.4
Indiana	19,681	515.6	8,806	52.8	307,536	307.6	876.0
Iowa	1,449	38.0	4,782	28.7	106,350	106.4	173.1
Kansas	289	7.6	2,790	16.7	217,384	217.4	241.7
Kentucky	3,610	94.6	4,353	26.1	97,487	97.5	218.2
Louisiana	-	-	40,577	243.5	1,373,632	1,373.6	1,617.1
Maine	-	-	5,584	33.5	-	-	33.5
Maryland, D.C.	4,593	120.3	6,191	37.1	74,575	74.6	232.0
Massachusetts	108	2.8	5,883	35.3	38,696	38.7	76.8
Michigan	13,012	340.9	6,013	36.1	288,217	288.2	665.2
Minnesota	1,662	43.5	5,025	30.2	134,199	134.2	207.9
Mississippi	-	-	3,205	19.2	169,926	169.9	189.1
Missouri	2,000	52.4	2,175	13.1	123,992	124.0	189.5
Montana	318	8.3	1,856	11.1	42,750	42.8	62.2
Nebraska	-	-	1,113	6.7	75,613	75.6	82.3
Nevada	158	4.1	470	2.8	15,045	15.0	21.9
New Hampshire	29	0.8	1,174	7.0	3,691	3.7	11.5
New Jersey	42	1.1	13,263	79.6	97,106	97.1	177.8

Table A-3 (Continued)

Fuel Consumption by the Industrial Sector, 1972

	COAL		PETROLEUM		NATURAL GAS		TOTAL FUEL
STATE	10^3 Tons	10^{12} Btu	10^3 BBL	10^{12} Btu	10^6 SCF	10^{12} Btu	10^{12} Btu
New Mexico	7	0.2	1,721	10.3	148,654	148.7	159.2
New York	7,336	192.2	9,641	57.8	127,241	127.2	377.2
North Carolina	1,423	37.3	9,010	54.1	94,252	94.3	185.7
North Dakota	407	10.7	724	4.3	16,800	16.8	31.8
Ohio	24,321	637.2	9,006	54.0	462,674	462.7	1,153.9
Oklahoma	-	-	2,766	16.6	247,309	247.3	263.9
Oregon	-	-	3,686	22.1	67,274	67.3	89.4
Pennsylvania	28,592	749.1	15,182	91.9	395,951	396.0	1,237.0
Rhode Island	-	-	1,157	6.9	5,973	6.0	12.9
South Carolina	1,221	32.0	3,839	23.0	89,868	89.9	144.9
South Dakota	-	-	349	2.1	8,465	8.5	10.6
Tennessee	2,046	53.6	2,334	14.0	146,625	146.6	214.2
Texas	926	24.3	105,330	632.0	2,681,498	2,681.5	3,337.8
Utah	2,257	59.1	2,890	17.3	75,851	75.9	152.3
Vermont	-	-	388	2.3	-	-	2.3
Virginia	2,717	71.2	6,224	37.3	64,849	64.8	173.3
Washington	203	5.3	4,910	29.5	110,063	110.1	144.9
West Virginia	9,436	247.2	7,294	43.8	130,279	130.3	421.3
Wisconsin	3,309	86.7	2,191	13.1	150,989	151.0	250.8
Wyoming	209	5.5	1,558	9.3	74,256	74.3	89.1

APPENDIX A-II

INDUSTRIAL PROCESS HEAT PROGRAM SUMMARY

For the convenience of the reader the entire Industrial Process Heat Program Summary as of June 1977 is included here. The material was excerpted from Reference 1.

INDUSTRIAL PROCESS HEAT APPLICATIONS USING SOLAR ENERGY

ERDA's Agricultural and Industrial Process Heat Branch is working with ERDA laboratories and industry in the development of solar heat energy applications to industrial processes in three areas:

- o *Low temperature applications (below 212°F/100°C);*
- o *Intermediate temperatures (212°F/100°C to 350°F/176°C);*
- o *High temperature applications (above 350°F/176°C).*

The low temperature industrial process heat experiments and prototype systems include such uses of solar energy as dehydration of foods, curing of concrete blocks, the production of hot water for can washing, and similar applications in which temperatures under the boiling point of water are required. Low temperature technology is basically similar to that for the heating and cooling of buildings and agricultural applications.

Intermediate temperature process heat applications include production of low pressure steam for industrial uses, and various drying operations such as those employed in the food processing, textile, and paper and pulp industries. The technology for this portion of the program comes in part from the research and development conducted for the heating and cooling of buildings, and in part from the solar thermal electric programs directed toward the generation of electric power.

High temperature process heat experiments and prototype systems planned will include production of high pressure steam, heat for chemical processes, and other industrial uses of solar energy. The technology for these prototype systems will come primarily from research and development conducted for solar thermal electric generation systems.

Solar systems designed to supply industrial process heat must show economic viability, maintainability, reliability, and be capable of integration into existing industrial processes. To accomplish this, the industrial portion of the program has been planned to:

- o *Assess those processes in the various industries where solar energy can supply a significant amount of the process energy needs;*
- o *Design solar energy systems that can provide significant amounts of process heat;*
- o *Experiment with various system designs to determine the best method of deriving industrial process heat;*
- o *Demonstrate, by the installation of prototype systems, the capacity of solar energy to provide significant amounts of the process heat requirements of various industries.*

SUMMARY OF
INDUSTRIAL PROCESS HEAT PROJECTS
USING SOLAR ENERGY

TITLE: Feasibility Evaluation - Solar Heated Textile Process Water

PROJECT MANAGER: Charles Hester
Clemson University
Clemson, South Carolina
(803) 656-3139

ERDA FUNDING: $93,000 (1976)

START DATE: 6/1/75

PROJECT SUMMARY

A feasibility study was conducted to evaluate the technical and economic constraints associated with the use of solar heating to produce process water for the textile industry. The study developed energy-use data based upon actual plant processes to determine both the current water needs for the industry by temperature level and to assess the probable future impact of conservation schemes upon possible solar concepts. A realistic weather and solar flux environment definition was made based upon analysis of actual weather data for the southeast Piedmont region where most of the textile finishing plants are located.

Collector area requirements to meet textile water demand of varying amounts and temperatures were generated using assembled test data for six collector types ranging from simple flat plate areas to tracking concentrator configurations. Energy collection densities for various types of collectors, operating in a representative Southeast environment and producing process water of varying temperatures, were generated.

Using the assembled test data and performance predictions for various collector types and for various textile process water temperature levels, an after-taxes, rate-of-return economic analysis was performed to determine allowable installed collector costs per square foot.

Additionally, studies were conducted to determine the effects of possible federal inducements to solar conversion in the form of investment tax credit changes. Lastly, the effect upon economic viability of solar concepts due to the establishment of a leasing industry was evaluated.

INDUSTRIAL PROCESS HEAT SURVEYS AND WORKSHOPS

TITLE: Survey of the Applications of Solar Energy Systems to Industrial Process Heat

PROJECT MANAGER: Elton Hall
Battelle Columbus Laboratories
Columbus, Ohio
(614) 424-6424

ERDA FUNDING: $352,000

START DATE: 1/1/76

PROJECT SUMMARY

Battelle's Columbus Laboratories, with support from Honeywell, Inc., and Battelle's Pacific Northwest Laboratories as subcontractors, have completed a study of the potential for the application of solar thermal energy to supply industrial process heat requirements.

Process heat requirements of 20 industries were identified and characterized according to quantity, temperature range, and form. Concepts for solar thermal energy systems were evaluated with respect to expected performance and cost in industrial applications. A preliminary assessment was made of related nontechnical issues, i.e., economic, institutional, legal, and environmental.

The extrapolated data cover six 2-digit Standard Industrial Classifications (SIC's): food; textiles; lumber; paper; chemicals; and stone, clay and glass. Nine 4-digit SIC's include: coal mining and cleaning; sulfur mining; petroleum refining; blast furnaces and steel mills; primary copper; primary aluminum; and automobile and truck manufacturing. These SIC's, excluding coal and sulfur mining, consumed more than 80 percent of the fuels purchased in 1971 by the entire manufacturing sector (SIC's 20-39).

The extrapolated data show that today about 3.5×10^{15} Btu/year, or 35 percent of the total, is required at temperatures up to 350° F. The process heat above 350° F, about 65 percent of the total, is used largely in fuel-fired direct heaters in petroleum refining, in metallurgical furnaces, and in kilns.

The technical performance and cost of several different types of solar collectors and system concepts were analyzed. Experimental collector performance data were incorporated in a computerized model to evaluate annual collector performance as a function of temperature and geographic location through computer simulation using actual weather data.

TITLE: Analysis of the Economic Potential of Solar Thermal Energy to Provide Industrial Process Heat

PROJECT MANAGER: Malcolm Fraser
InterTechnology Corporation
Warrenton, Virginia
(703) 347-7900

ERDA FUNDING: $293,000

START DATE: 1/1/76

PROJECT SUMMARY

The objective of the study is to identify those applications of solar thermal energy for providing industrial process heat which are technically and economically feasible and can contribute significantly to the process heat requirements of industry in the U.S.

The process heat data base assembled as the result of this survey includes specific process applications from 78 four-digit Standard Industrial Classification (SIC) groups. These applications account for the consumption of 9.81 quadrillion Btu (10.4 quadrillion kJ) in 1974, about 59 percent of the 16.6 quadrillion Btu estimated to have been used for all process heat in 1974. About 7-1/2 percent of industrial process heat is used below 212°F (100°C), and 28 percent below 550°F (288°C).

In this study, the quantitative assessment of the potential of solar thermal energy systems to provide industrial process heat indicates that solar energy has a maximum potential to provide 0.6 quadrillion Btu (0.6 quadrillion kJ) per year in 1985, and 7.3 quadrillion Btu (7.7 quadrillion kJ) per year in 2000, in economic competition with the projected costs of conventional fossil fuels for applications having a maximum required temperature of 550° (288°C).

A wide variety of collector types were compared for performance and cost characteristics. Performance calculations were carried out for a baseline solar system providing hot water in representative cities in six geographical regions within the U.S. which were defined on the basis of a constant performance of the solar process heat system.

Specific industries which should have significant potential for solar process heat for a variety of reasons include food, textiles, chemicals, and primary metals. Lumber and wood products, and paper and allied products also appear to have significant potential. However, good potential applications for solar process heat can be found across the board throughout industry.

Finally, an assessment of nontechnical issues which may influence the use of solar process heat in industry showed that the most important issues are the establishment of solar rights, standardization and certification for solar components and systems, and resolution of certain labor-related issues.

TITLE: Industrial Process Heat Workshop

PROJECT MANAGER: D. Anand
University of Maryland
College Park, Maryland
(301) 454-2411

ERDA FUNDING: $30,000 (1976)

START DATE: June 28 & 29, 1976

WORKSHOP SUMMARY

The first Solar Industrial Process Heat Workshop, sponsored by the Energy Research and Development Administration, Division of Solar Energy, and coordinated by the University of Maryland, was held to assess the design and application of cost-effective solar energy systems for supplying industrial process heat.

The purposes of the workshop were (1) to bring together researchers, manufacturers, and users to assess the state of the applications of industrial process solar heat, (2) to examine concepts in industrial process solar heat that can be put to commercial use, (3) to facilitate the detailed interchange of information through survey presentations and intensive working group discussions, (4) to identify the direction of future efforts, and (5) to present results of related work in ERDA-funded projects.

The workshop was divided into two parts. The first part consisted of sixteen surveys and reports of on-going projects. The second part consisted of working groups whose task was to consider problems related to the introduction of solar energy into industry and to make a status report of their conclusions.

Participants were invited from universities, governmental agencies, and industry. A total of 140 persons attended the formal sessions as well as the working group meetings. The working groups were organized so as to enable all attendees to participate in the three specialty areas: Hot Air Applications, Hot Water Applications, and Steam Applications. Preliminary proceedings were distributed at the meeting.

SUMMARY OF 1977 PROJECTS IN INDUSTRIAL PROCESS HOT WATER

Four contracts were negotiated in 1976 for Phase I analysis and design studies of solar energy systems to provide industrial process hot water. Phase I effort was completed in January 1977. Major activities included (1) a solar impact analysis report based on detailed process analysis and solar system conceptual design, (2) a preliminary design and performance report for ERDA evaluation upon completion of 80% of Phase I, and (3) a final design and performance report. Based upon present funding, three firms have been contracted for Phase II, experiment fabrication, integration, and test.

A no-funds exchanged contract is also continuing in the area of shallow solar ponds for process hot water.

Specifics of the five Phase I hot water projects are described on the following pages.

INDUSTRIAL PROCESS HOT WATER

PROJECT

TITLE: Solar Industrial Process Hot Water as Used to Cure Concrete Blocks

CONTRACTOR: AAI Corporation
P.O.Box 6767
Baltimore, Maryland 21204

PROJECT MANAGER: H. Wilkening
(301) 666-1400

ERDA FUNDING:

PHASE I - $114,000 (1976)
PHASE II- $450,000 (1977) (estimated)

PROJECT START DATE: 4/7/76

CONTRACT NO.: E(04-3)1217

SOLAR SYSTEM

APPLICATION: Curing of Concrete Blocks

LOCATION: York Building Products Co.
Harrisburg, Pennsylvania

CONSTRUCTION START DATE: May 1977

COLLECTOR:

TYPE & SIZE: 24/1 Concentrating Collector
9200 ft^2
FLUID: Water
MAX. TEMP.: 180°F

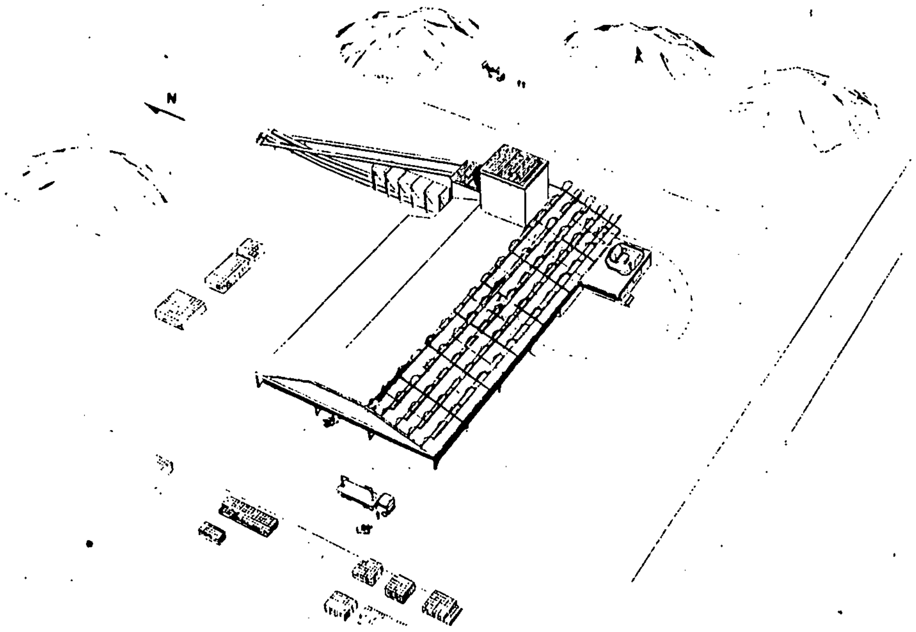
STORAGE: Circular Rotoclave Water Tank

PROCESS HEAT SUPPLIED: 1.5×10^9 Btu/yr

PERCENTAGE OF PROCESS: 35%

PROJECT SUMMARY

The AAI Corporation's concept requires their 24/1 concentrating collector to produce hot water to cure concrete blocks. This is a process requiring about 1500 Btu per block for curing at a temperature of 140° to 180°F. A circular underground curing tank will be the storage tank for the solar system. The solar hot water system for this process will be installed at a new plant being planned by the York Building Products Co. in Harrisburg, Pa. The plant is scheduled to begin operation in early 1978, with the solar hot water system providing about one-third of the block curing energy.



INDUSTRIAL PROCESS HOT WATER

PROJECT

TITLE: Application of Solar Energy to the Supply of Industrial Process Hot Water

CONTRACTOR:
Acurex Corporation
Aerotherm Division
485 Clyde Avenue
Mountainview, California 94042

PROJECT MANAGER: J. Vindum
(415) 964-3200

ERDA FUNDING:

PHASE I - $204,000 (1976)
PHASE II- $570,000 (1977) (estimated)

PROJECT START DATE: 3/29/76

CONTRACT NO.: E(04-3)1218

SOLAR SYSTEM

APPLICATION: Washing Food Cans

LOCATION: The Campbell Soup Co.
Sacramento, California

CONSTRUCTION START DATE: May 1977

COLLECTOR:

TYPE & SIZE: Flat Plate, 3900 ft^2 & Parabolic Tracking, 2700 ft^2
FLUID: Water
MAX. TEMP.: 195^0F

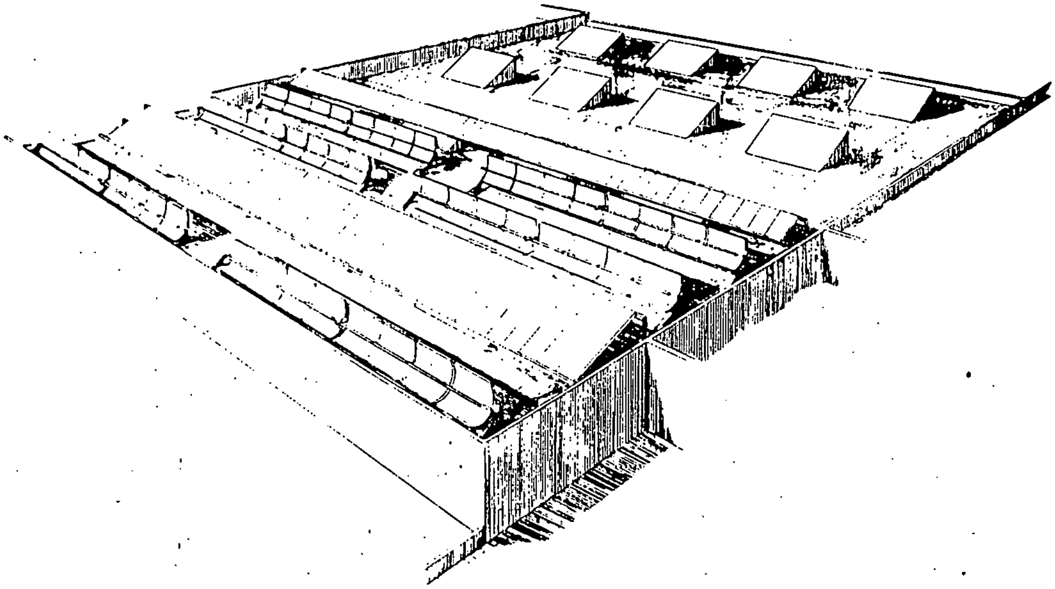
STORAGE: 17,000 gal. water storage tank

PROCESS HEAT SUPPLIED: 2.2×10^9 Btu/yr

PERCENTAGE OF PROCESS: 77%

PROJECT SUMMARY

The process selected by Acurex Corporation for analysis and design studies is the can washing operation which occurs as part of a soup manufacturing production line. The Campbell Soup Company plant in Sacramento, California, was selected as the site for the Phase I study. All of the production lines at the Campbell plant utilize potable water at 185^0 to 195^0F for empty can washing. Water will be heated first by flat plate collectors then by parabolic trough tracking concentrators. The flat plate collectors make up 59% of the heating system and the parabolic trough tracking concentrators make up 41% of the total 6620 sq. ft. solar system. The National Canners Association estimate that 1100 plants use hot water for can washing, yielding a potential solar energy impact of approximately 6.6×10^{12} Btu per year for this application alone. System construction will begin in mid-1977.



INDUSTRIAL PROCESS HOT WATER

PROJECT

TITLE: Applications of Solar Energy to the Supply of Hot Water for Textile Dyeing

CONTRACTOR: General Electric Company
Advanced Energy Programs
P. O. Box 8661
Philadelphia, Pennsylvania 19101

PROJECT MANAGER: J. Trice
(215) 962-1150

ERDA FUNDING:
PHASE I - $258,000 (1976)
PHASE II- $580,000 (1977) (estimated)

PROJECT START DATE: 4/5/76

CONTRACT NO.: E(04-3)1220

SOLAR SYSTEM

APPLICATION: Textile Dyeing

LOCATION: Riegel Textile Corporaton
La France, South Carolina

CONSTRUCTION START DATE: May 1977

COLLECTOR:
TYPE & SIZE: Evacuated tube modules, 6700 ft^2
FLUID: Ethylene Glycol/Water
MAX. TEMP.: 250°F

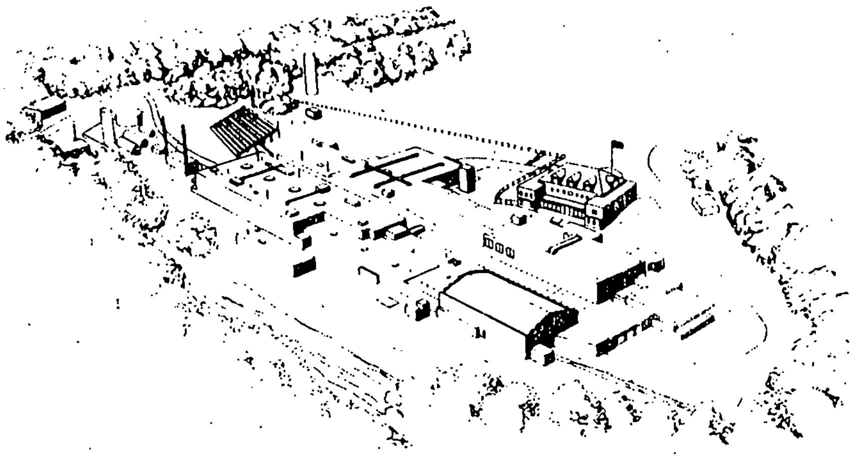
STORAGE: 8000 gal. water storage tank

PROCESS HEAT SUPPLIED: 1.4 x 10^9 Btu/yr

PERCENTAGE OF PROCESS: 50%

PROJECT SUMMARY

General Electric has selected the textile industry to evaluate the solar energy application to industrial process heat. This industry uses large quantities of process hot water, with a corresponding energy consumption of 50 x 10^{12} Btu per year. The La France, South Carolina plant of the Riegel Textile Corporation has been selected as the experiment site. The textile process selected is the dyeing and finishing operation, which consumes 90% of the industry process hot water. The specific application is the dyeing operation using process hot water at 180-200°F. Nearly 400 GE TC100 evacuated tube collector modules with a collector area of 6680 sq. ft. will be used. The dye process tank, or beck, and associated equipment is readily modified to accommodate the solar energy system hardware. The dye beck operation amounts to 40% of the total process heat load, which, projected over the textile industry, indicates a potential hot water energy savings of 20 x 10^{12} Btu per year.



INDUSTRIAL PROCESS HOT WATER

PROJECT

TITLE: Application of Solar Energy to the Supply of Industrial Hot Water

CONTRACTOR: Jacobs Engineering Co.
837 South Fair Oaks Avenue
Pasadena, California 91105

PROJECT MANAGER: B. Eldridge
(213) 449-2171

ERDA FUNDING:

PHASE I - $155,000 (1976)
PHASE II- Not funded (1977)

PROJECT START DATE: 3/31/76

CONTRACT NO.: E(04-3)1219

SOLAR SYSTEM

APPLICATION: Commercial Laundry

LOCATION: American Linen Supply
El Centro, California

CONSTRUCTION START DATE: Not Applicable

COLLECTOR:

TYPE & SIZE: Parabolic Trough Tracking, 3600 ft^2
FLUID: Water
MAX. TEMP.: Water 170°F

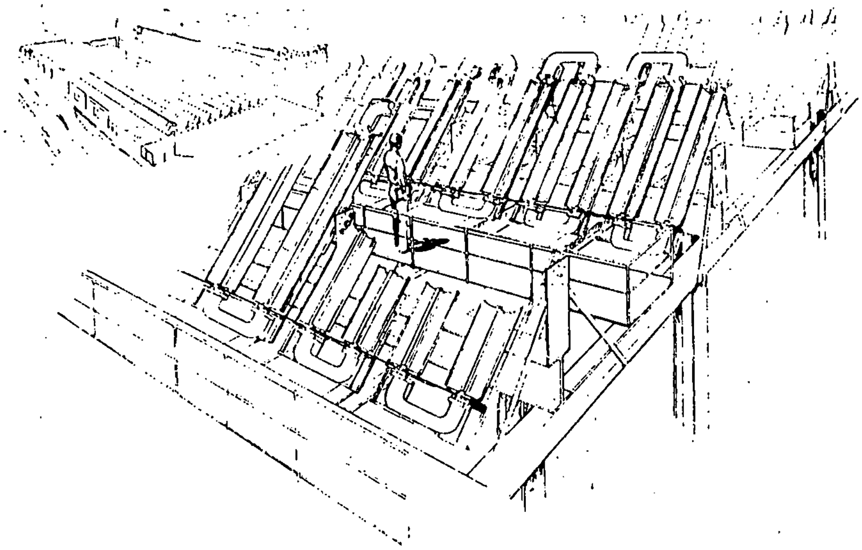
STORAGE: 15,000 gal. water storage tank

PROCESS HEAT SUPPLIED: 1.5 x 10^9 Btu/yr

PERCENTAGE OF PROCESS: 39%

PROJECT SUMMARY

The application of solar energy studied by Jacobs Engineering Company is to supply process hot water and steam for commercial laundry use at the American Linen Supply plant in El Centro, California. Average daily usage for process hot water at the plant is 35,150 gallons at 150-170°F. Daily requirements for steam are 11,360 lbs. at 100-125 psi. Primary emphasis of the Phase I study was the supply of process hot water, which is approximately 70% of the boiler output. The feasibility of providing for the plant's steam requirements with solar energy was also studied in Phase I. Typically, commercial laundry establishments use water at 150-170° F for washing operations, and steam at 100-125 psi for drying and finishing. It was contemplated that the solar energy system would be retrofitted into the plant's existing steam and hot water system, leaving the existing system intact for comparative evaluation and to serve as standby.



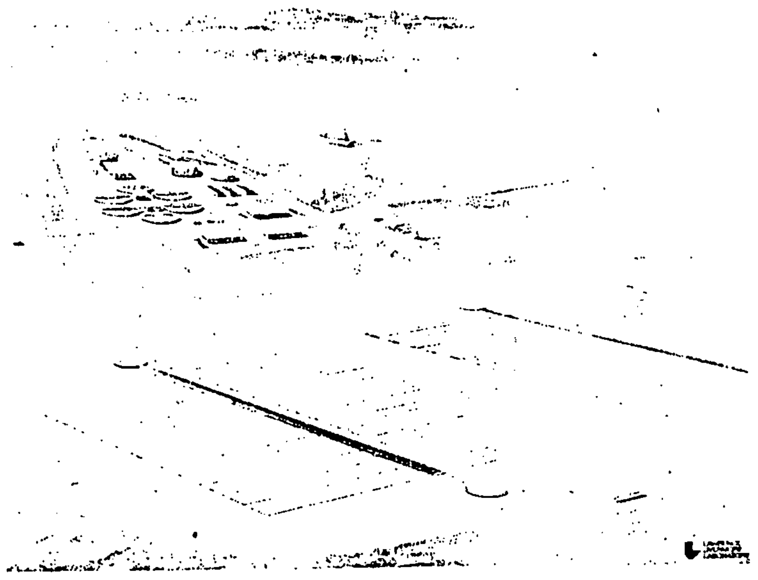
INDUSTRIAL PROCESS HOT WATER

PROJECT	
TITLE:	Performance of the SOHIO Solar Water Heating System Using Large Area Plastic Collectors
CONTRACTOR:	Lawrence Livermore Laboratory University of California P. O. Box 808 Livermore, California 94550
PROJECT MANAGER:	W. Dickinson (415) 447-1100
ERDA FUNDING:	
PHASE I -	N.A. (1976)
PHASE II-	N.A. (1977)
PROJECT START DATE:	1975
CONTRACT NO.:	E(04-3)1038

SOLAR SYSTEM	
APPLICATION:	Mining/Milling (Uranium)
LOCATION:	SOHIO Petroleum Co. Grants, New Mexico
CONSTRUCTION START DATE:	1975 (3 modules)
COLLECTOR:	
TYPE & SIZE:	Shallow Solar Ponds (30), 80,000 ft^2
FLUID:	Water
MAX. TEMP.:	130^oF
STORAGE:	350,000 gal. cold water 350,000 gal. hot water
PROCESS HEAT SUPPLIED:	25×10^9 Btu/yr
PERCENTAGE OF PROCESS:	50%

PROJECT SUMMARY

Under a no-funds-exchanged contract between the Sohio Petroleum Company and ERDA, the Lawrence Livermore Laboratory has designed a shallow solar pond (SSP) facility for the new Sohio uranium mining and milling complex near Grants, New Mexico. The objective of the ERDA-Sohio project is to design and build a system of SSP's to provide a substantial portion (approximately 50%) of the hot water required by the Sohio Petroleum Company. The hot water is used to accelerate the chemical leaching process by which the uranium ore is concentrated to U_3O_8. This process requires about 10^{11} Btu/year. Performance measurements on a prototype system yielded an annual average collection efficiency of about 45%. The pond design has been optimized and Sohio will soon go out to bid for construction of the first 30 module unit of this system.



SUMMARY OF 1977 PROJECTS IN INDUSTRIAL DRYING/DEHYDRATION PROCESSES

Six contracts were negotiated in 1976 for Phase I analysis and design studies of the application of solar energy to industrial drying/dehydration processes. Phase I effort was completed in March 1977. Major activities included (1) a solar impact analysis report based on detailed process analysis and solar system conceptual design, (2) a preliminary design and performance report for ERDA evaluation upon completion of 80% of Phase I, and (3) a final design and performance report. Based upon present funding, four firms will be contracted for Phase II, experiment fabrication, integration, and test.

Specifics of the six Phase I drying/dehydration projects are described on the following pages.

INDUSTRIAL DRYING/DEHYDRATION PROCESSES

PROJECT

TITLE: Application of Solar Energy to Industrial Drying/Dehydration Processes

CONTRACTOR: California Polytechnic State University
San Luis Obispo, California 93407

PROJECT MANAGER: E. Carnegie
(805) 546-2388

ERDA FUNDING:

PHASE I - $269,000 (1976)
PHASE II- $580,000 (1977) (estimated)

PROJECT START DATE: 6/1/76

CONTRACT NO.: E(40-1)5123

SOLAR SYSTEM

APPLICATION: Drying of Prunes and Raisins

LOCATION: Lamanuzzi & Pantaleo (Drying Facility)
Fresno, California

CONSTRUCTION START DATE: June 1977

COLLECTOR:

TYPE & SIZE: Single-glazed Flat Plate, 19,500 ft^2
FLUID: Air
MAX. TEMP.: 150°F

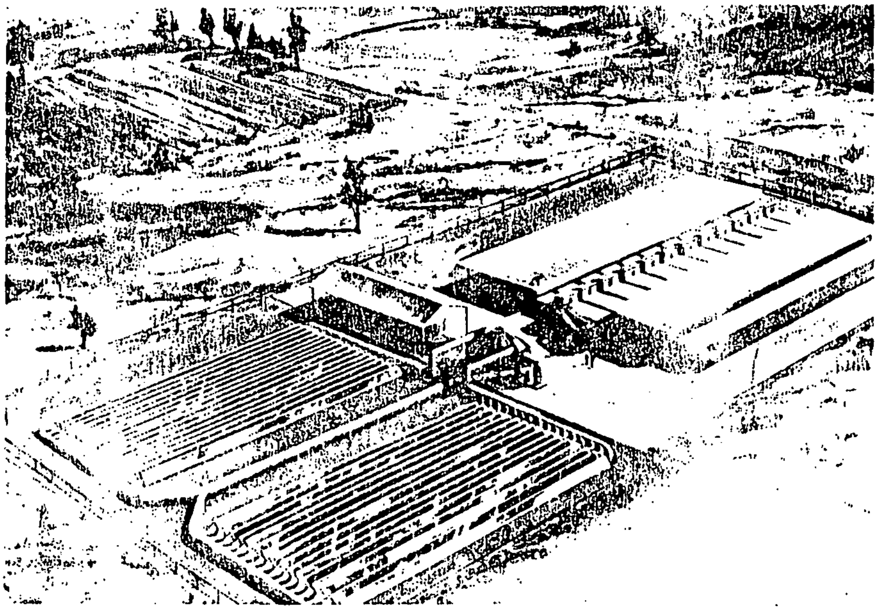
STORAGE: 12,000 cu. ft. rock storage unit

PROCESS HEAT SUPPLIED: 2.3x10^9 Btu/yr

PERCENTAGE OF PROCESS: 69%

PROJECT SUMMARY

Cal-Poly has completed Phase I analysis and design studies of a solar energy system intended to provide substantially all the hot air necessary to operate one tunnel of the dehydrating facility of Lamanuzzi and Pantaleo (L&P) located near Fresno, California. The system will deliver heated air to a tunnel dehydrator 54 feet in length, requiring approximately 1.4 million Btu per hour to dry raisins and prunes at 150° F. Dehydrators average 12 tunnels per unit. Energy requirements for food dehydration, based on 1970 estimates, are approximately 1.8 x 10^{14} Btu per year.



INDUSTRIAL DRYING/DEHYDRATION PROCESSES

PROJECT

TITLE: Textile Drying Using Solarized Cylindrical Can Dryers to Demonstrate the Application of Solar Energy to Industrail Drying or Dehydration Processes

CONTRACTOR: Honeywell, Inc.
Systems Research Center
2600 Ridgway Parkway
Minneapolis, Minn. 55413

PROJECT MANAGER: E. Zoerb
(612) 378-5737

ERDA FUNDING:

PHASE I - $146,000 (1976)
PHASE II- $640,000 (1977)

PROJECT START DATE: 6/1/76

CONTRACT NO.: F(40-1)5124

SOLAR SYSTEM

APPLICATION: Fabric Drying

LOCATION: West Point - Pepperell
Fairfax, Alabama

CONSTRUCTION START DATE: June 1977

COLLECTOR:

TYPE & SIZE: Parabolic Trough Tracking, 8313 ft^2
FLUID: Water (230 psig)
MAX. TEMP.: 380° F

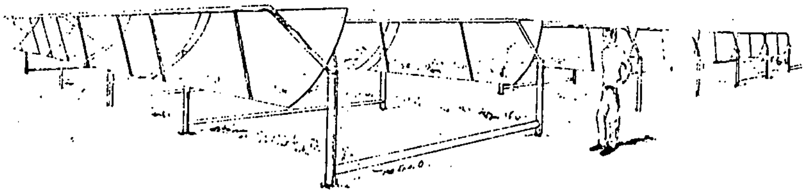
STORAGE: None

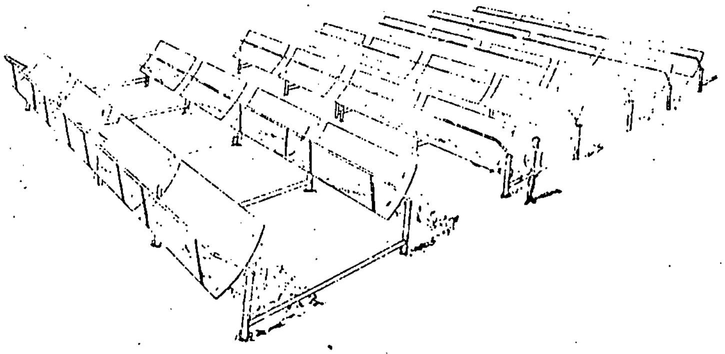
PROCESS HEAT SUPPLIED: 1.2 x 10^9 Btu/yr

PERCENTAGE OF PROCESS: 46%

PROJECT SUMMARY

Phase I design and analysis studies were conducted by Honeywell to provide a solar energy system for a textile fabric cylindrical (can) dryer. The system will be installed in the weaving process at the West Point-Pepperell facility in Fairfax, Alabama. The proposed collector system is designed to provide 70 psia/315° F steam required to operate the can dryer. In this application, hot water is generated at 380°F/230 psig by the solar collector field and fed to a hot water steam generator which then produces steam for the process. The drying process involves passing wet yarn over the outer surface of the steam heating can. On a national scale, this slashing process for broadwoven goods, requires 5×10^{12} Btu per year.





PROJECT

TITLE: Solar Industrial Process Heat for Kiln Drying Lumber

CONTRACTOR: Lockheed Missiles & Space Co., Inc.
P. O. Box 1103
Huntsville, Alabama 35807

PROJECT MANAGER: P. McCormick
(205) 837-1800

ERDA FUNDING:
PHASE I - $71,000 (1976)
PHASE II- $310,000 (1977)

PROJECT START DATE: 6/1/76

CONTRACT NO.: E(40-1)5042

SOLAR SYSTEM

APPLICATION: Lumber (Kiln Drying)

LOCATION: J. A. LaCour Kiln Service, Inc.
Canton, Mississippi

CONSTRUCTION START DATE: June 1977

COLLECTOR:
TYPE & SIZE: Double-glazed Flat Plate with Reflector, 2500 ft^2
FLUID: Water
MAX. TEMP.: 160°F

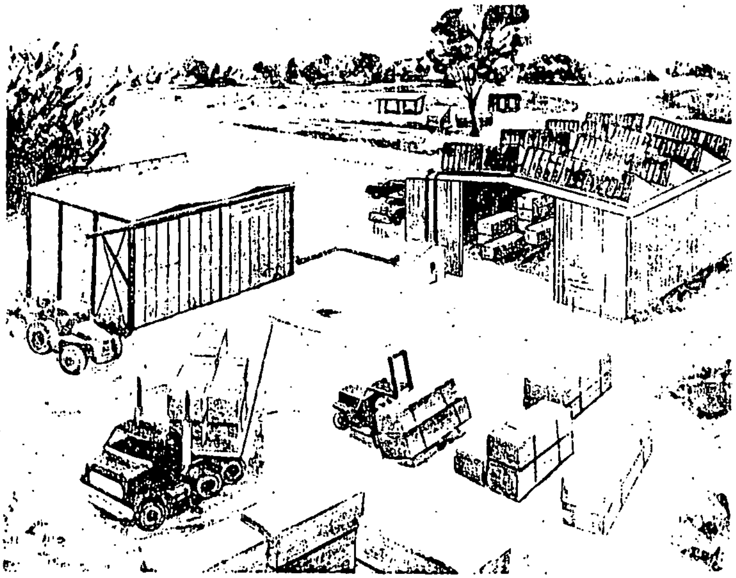
STORAGE: 4800 gal. water tank

PROCESS HEAT SUPPLIED: 9×10^5 Btu/yr

PERCENTAGE OF PROCESS: 44%

PROJECT SUMMARY

Lockheed has completed design and analysis studies of a solar heated kiln for commercial use in the drying of lumber. J.A. LaCour & Company, Canton, Miss., will provide the kiln, land, and operation at their hardwood lumber production facility. Approximately 85% of hardwoods and a higher percentage of softwoods require kiln drying at an energy consumption rate of approximately 1.4×10^{14} Btu annually for kiln dried lumber products. The proposed Lockheed system will generate hot water in the solar collector arrays and provide hot air for drying via an air/water heat exchanger. Depending on the initial moisture content of the wood, typical air drying temperatures for this application range from 110° to 160° F.



PROJECT

TITLE: Application of Solar Energy to Industrial Drying of Soybeans

CONTRACTOR: Teledyne - Brown Engineering
Cummings Research Park
Huntsville, Alabama 35807

PROJECT MANAGER: P. Fisher
(205) 532-1402

ERDA FUNDING:
PHASE I - $287,000 (1976)
PHASE II- $730,000 (1977) (estimated)

PROJECT START DATE: 5/26/76

CONTRACT NO.: E(40-1)5122

SOLAR SYSTEM

APPLICATION: Soybean Drying

LOCATION: Gold Kist, Inc. (Soybean Plant)
Decatur, Alabama

CONSTRUCTION START DATE: June 1977

COLLECTOR:
TYPE & SIZE: Single-glazed Flat Plate, 13,100 ft^2
FLUID: Air
MAX. TEMP.: 160°F

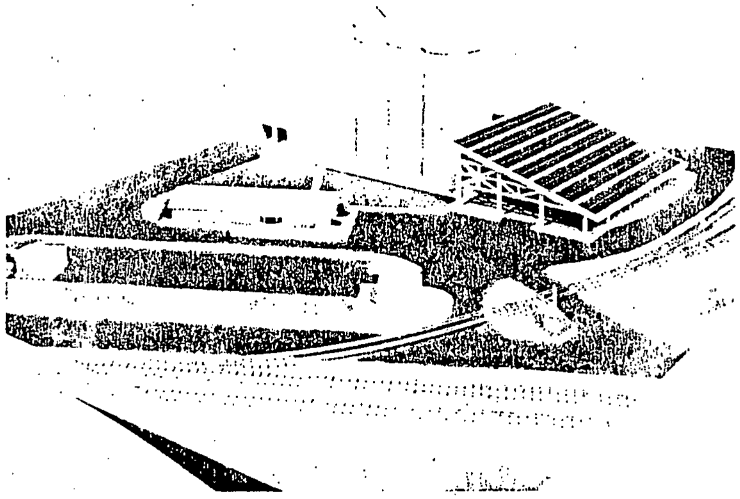
STORAGE: None

PROCESS HEAT SUPPLIED: 3.7x10^9 Btu/yr

PERCENTAGE OF PROCESS: 52%

PROJECT SUMMARY

Teledyne-Brown Engineering has completed Phase I design and analysis studies of a solar energy drying process applied to soybeans. A conventional grain dryer will be used to process the soybeans; however, it will derive the energy required to heat the air principally from a flat plate air solar collection system. Conceptually, the system will be integrated into the Gold Kist soybean processing plant at Decatur, Alabama, to be operated by them as part of their routine processing operations. Current estimates of energy requirements for soybean drying are on the order of 5 x 10^{14} Btu per year. Maximum recommended air drying temperature is 160° F.



PROJECT

TITLE: Application of Solar Energy to Industrial Drying or Dehydration Processes

CONTRACTOR: Midwest Research Institute
425 Volker Blvd.
Kansas City, Missouri 64110

PROJECT MANAGER: J. Bradley
(816) 561-0202

ERDA FUNDING:

PHASE I - $64,000 (1976)
PHASE II- Not funded (1977)

PROJECT START DATE: 5/26/76

CONTRACT NO.: E(40-1)5121

SOLAR SYSTEM

APPLICATION: Alfalfa Drying

LOCATION: Western Alfalfa Corp.
Lawrence, Kansas

CONSTRUCTION START DATE: Not Applicable

COLLECTOR:

TYPE & SIZE: Flat Plate, 5700 ft^2 and Tracking Concentrator, 5800 ft^2
FLUID: Air
MAX. TEMP.: 400°F

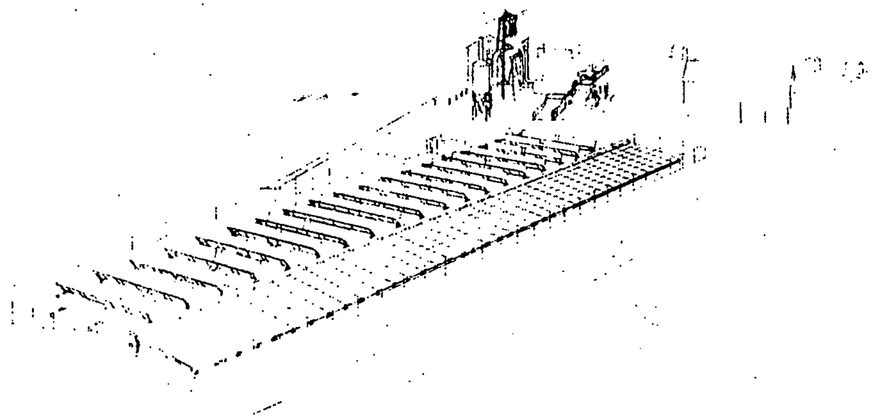
STORAGE: None

PROCESS HEAT SUPPLIED: 2×10^9 Btu/yr

PERCENTAGE OF PROCESS: 13%

PROJECT SUMMARY

Midwest Research Institute has completed the Phase I design and analysis studies for the application of solar energy to rotary drying and dehydration processes. The specific application is the drying of alfalfa in the rotary dryers of the Western Alfalfa Corporation facilities in Lawrence, Kansas. The design approach is a collector array consisting of 304 flat plate collectors and 38 focusing collectors. The selected alfalfa dehydrating process requires the heating of air from ambient conditions to approximately 1800°F. The proposed solar system will provide preheated air at 300°-400°F to the rotary flame furnace. MRI data indicates that energy consumption of rotary drying equipment used in processing a wide range of industrial and agricultural products exceeds 1.5×10^{15} Btu/year, which includes 2.13×10^{13} Btu per year for alfalfa drying alone.



PROJECT

TITLE: Application of Solar Energy to Continuous Belt Dehydration

CONTRACTOR: Trident Engineering Assoc., Inc.
48 Maryland Avenue
Annapolis, Md. 21401

PROJECT MANAGER: R. Wagner
(301) 267-8128

ERDA FUNDING:

PHASE I - $226,000 (1976)
PHASE II - Not Funded (1977)

PROJECT START DATE: 5/25/76

CONTRACT NO.: E(40-1)5119

SOLAR SYSTEM

APPLICATION: Onion Drying

LOCATION: Gilroy Foods, Inc.
Gilroy, California

CONSTRUCTION START DATE: Not Applicable

COLLECTOR:

TYPE & SIZE: Evacuated Tube, 5900 ft^2

FLUID: Water
MAX. TEMP.: 210°F

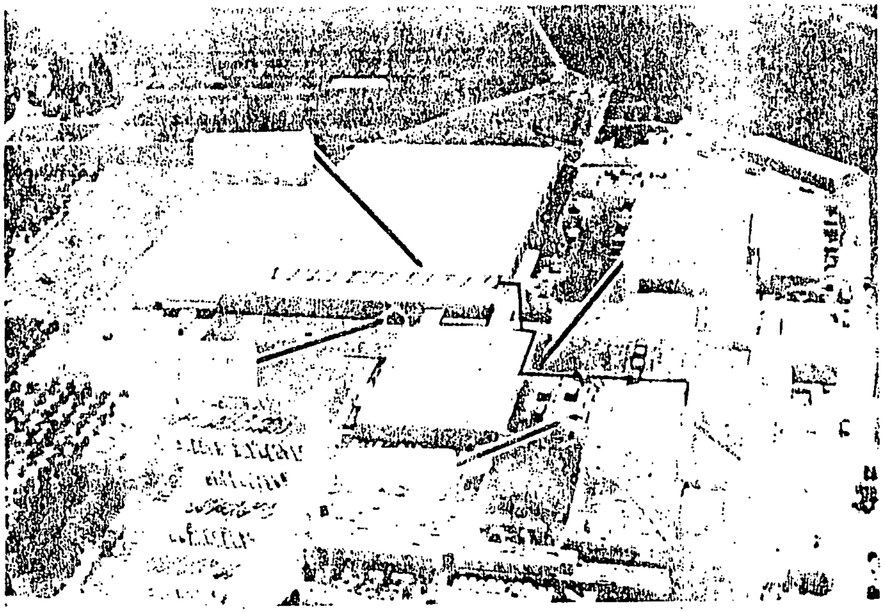
STORAGE: None

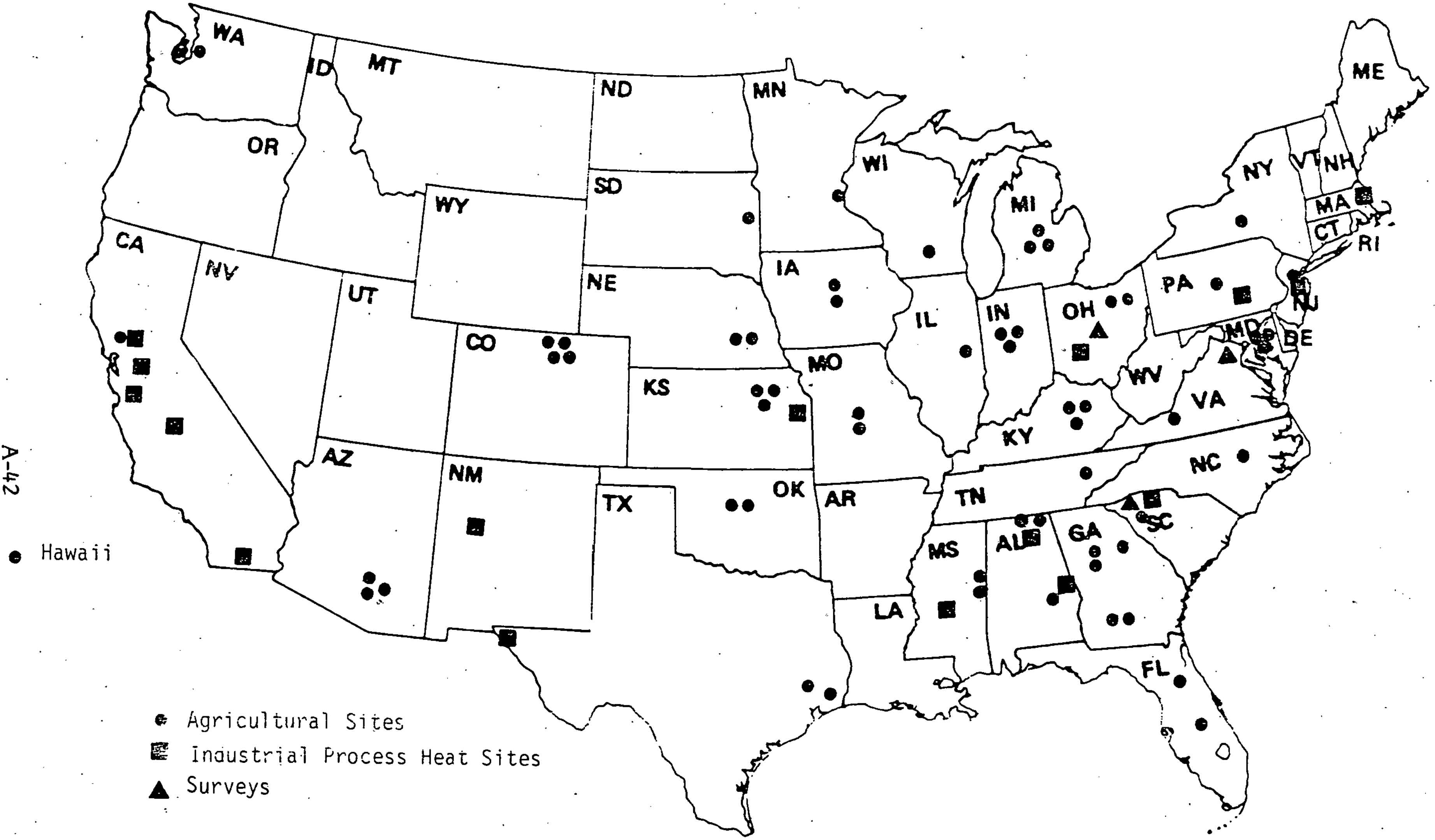
PROCESS HEAT SUPPLIED: 2.3×10^9 Btu/yr

PERCENTAGE OF PROCESS: 2%

PROJECT SUMMARY

Trident Engineering has completed the Phase I design and analysis studies for the application of solar energy to drying and dehydration processes. The application selected is the dehydration of onions and garlic on a continuous belt, gas fired, conveyer system at the Gilroy Foods plant, a subsidiary of McCormick & Company. Evacuated tube collectors provide 200°F preheated air, through a water/air heat exchanger, to the dryer burner inlet section. During the period outside the drying season, October through March, the collected energy will be used to preheat boiler condensate water.





LOCATION OF AGRICULTURAL AND INDUSTRIAL PROCESS HEAT PROJECTS

A-III. MAJOR RELATED EFFORTS

A. ECONOMIC, ENVIRONMENTAL AND APPLICATION STUDIES

The text that follows contains brief summaries of the more significant study results and conclusions.

1. Patterns of Energy Consumption in the United States (Source 1, Table 2-1)

The total energy consumption in the United States increased from 43.1 quadrillion Btu in 1960 to 60.5 quadrillion Btu in 1968; the 1960-68 growth rate (compounded) was 4.3% per year.

The breakdown by broad sector was:

	Consumption (quadrillion Btu)		Growth Rate	Percent of Total	
	1960	1968	(percent)	1960	1968
Residential	8.0	11.6	4.8%	18.6%	19.2%
Commercial	5.7	8.8	5.4	13.2	14.4
Industrial	18.3	25.0	3.9	42.7	41.2
Transportation	11.0	15.2	4.1	25.5	25.2
Total	43.1	60.5	4.3%	100.0%	100.0%

The growth rates vary from a low of 3.9% per year for the largest sector--industrial--to a high of 5.4% per year for the smallest sector--commercial. But industrial use still remained the dominant use of energy, at over 40% of the nation's total consumption.

Transportation is growing almost as rapidly as the total, and continues to account for about one-quarter of total energy consumption.

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*Because of rounding off, totals do not necessarily add.

Residential consumption has been increasing at 4.8% per year, above the overall average, and accounts for almost 20% of the total.

2. Solar Program Assessment: Environmental Factors, Solar Agriculture and Industrial Process Heat (Reference 17).

Since many of the solar process heating concepts funded by the Energy Research and Development Administration (ERDA) are still largely in the developmental phase, the potential environmental issues presented in this report are based essentially on a review of technical subsystems studies and extrapolation of similar situations. The completion in the near future of the ERDA design experiments in this area, as well as projects using similar solar system components to provide heating and cooling and/or electricity, should provide the basis for a more detailed and precise assessment of the environmental impacts of agricultural and industrial process heating via solar energy use. The four environmental and safety issues considered were: land requirements, glare and misdirected light, product contamination, and handling and disposal of system wastes.

3. Analysis of the Economic Potential of Solar Thermal Energy to Provide Industrial Process Heat (Reference 8)

This quantitative assessment of the potential of solar thermal energy systems to provide industrial process heat indicates that solar has a maximum potential to provide 0.6 quadrillion Btu (0.6 quadrillion kJ) per year in 1985, and 7.3 quadrillion Btu (7.7 quadrillion kJ) per year in 2000 in economic competition with the projected costs of conventional fossil fuels -- for applications having a maximum required temperature of 550°F (288°C).

Solar process heat at temperatures up to 550°F (288°C) provided by a tracking parabolic trough collector might be cost-effective now in competition with oil heat in the region of the country with the highest insolation. By 1985, solar process heat should be cost competitive with: (a) oil in all locations for producing steam for indirect heat and in some locations for direct heat, and (b) gas in some situations. By 2000, solar process heat should be able to compete with the fuel cost of oil and gas anywhere in any application below 550°F (288°C).

The process heat data base assembled as the result of this survey includes specific process applications from 78 4-digit SIC groups. These applications account for the consumption of 9.81 quadrillion Btu (10.4 quadrillion kJ) in 1974, about 59 percent of the 16.6 quadrillion Btu estimated to have been used for all process heat in 1974. About 7-1/2 percent of industrial process heat is used below 212°F (100°C), and 28 percent below 550°F (288°C).

4. Survey of the Application of Solar Thermal Energy Systems to Industrial Process Heat (Reference 9)

Process heat requirements of 20 industries were identified and characterized according to quantity, temperature range, and form. Concepts for solar thermal energy systems were evaluated with respect to expected performance and cost in industrial applications.

The detailed findings are as follows: (1) Process heat requirements are distributed across the full range of temperatures and energy forms. Up to 35 percent is used at temperatures of 350°F or less. (2) Industry investment criteria and attitudes as related to solar thermal energy system implementation seriously impact the viability of the concept. (3) Solar thermal systems can provide 100,000 to 500,000 Btu/ft^2/year. (4) Shallow solar ponds nearly meet today's investment criteria; other systems currently are too costly. (5) Current tax structure provides a disincentive for the industrial application of solar energy. Tax parity with fossil fuel deduction is needed. (6) Roof-top installations will not provide more than 5 or 10 percent of the requirement of process-heat-intensive plants. Large ground-based collector installations must be developed. (7) Relative costs of collectors versus piping and ancillary components indicates the need for large collector modules. (8) Large-module flat plate collectors for Northern climates (glass-type or shallow pond) need to be developed. (9) Development of a low-cost large-module steam system is needed. (10) Hot-air collectors probably will be limited to small installations. (11) Measured data on direct versus diffuse radiation is needed.

5. Mission Analysis of Photovoltaic Solar Energy Conversion, Major Missions for the Mid-Term (1986-2000) (Reference 10)

Volume III evaluates the use of photovoltaic total energy systems (i.e., photocells supply d.c. electrical energy and the waste heat from cooling the photocells is utilized for industrial processes). The study surveyed the industrial process heat requirements and found that a surprisingly large fraction of the industrial process heat used in the United States is used at temperatures below 250°C, i.e., at temperatures that may be compatible with the operation of GaAs solar cells. (GaAs cells have been operated at 300°C, and it is expected that arrays will be developed that are capable of prolonged operation, without appreciable reduction in usable life, at temperatures in the 200-250°C range). A summary is presented of U.S. industrial process heat requirements, with emphasis on these lower-temperature applications.

6. Solar Process Heat from Concentrating Flat Plate Collectors (Reference 5)

The potential impact of solar process heat on the United States gross energy input (GEI) has been analyzed. At temperatures up to 250°C the maximum contribution is 38.6% of the GEI or 14 million equivalent barrels of oil per day in 1975. At 800°C the potential impact approaches 50%. Clearly, if an inexpensive high-temperature solar collector were available, solar process heat could have a significant role in achieving energy independence.

7. Solar Thermal Mission Analysis (Reference 11)

The distinguishing feature of a Total Energy system is its on-site generation of electricity with recovery and reuse of turbine waste heat for space heating, water heating, space cooling, process heat, etc.

Conventional Total Energy systems proved to be economically competitive as an alternative to the use of utility supplied energy for two reasons; the elimination of electric power transmission losses and costs, and the superior efficiency (about 60% average) with a TE system relative to electric utility supplied energy at about 30% average. Thus, the stage was set for the introduction of TE systems into the market place.

A computer program has been developed (and tested) which simulates a STE system operation based upon hourly insolation and demand for 365 days operation. The program allows for the evaluation of thousands of different STE applications and configuration by trading off a wide variety of component and subsystem sizes, efficiencies and costs.

The computer simulation program was also utilized for the analysis of three real applications; a concrete block plant in central Arizona, a fluid milk plant in New Mexico and a department store in California. The results of the analysis of the concrete block and fluid milk plants are encouraging insofar as installing STE systems, because they have process heat temperature requirements easily attainable by solar systems, attractive demand ratios, synergistic potential from related base products, economic viability relative to fossil fueled alternatives and could achieve a net energy reserve equivalent of 2.05 Quads or 360 million barrels of oil. This represents approximately 1.25 percent of the total current U.S. oil reserves or 12.5 percent of the current total U.S. yearly oil production.

Considering that such encouraging results are exhibited by only two industries which comprise only 5.6 percent of the total industrial process heat required with temperatures below 350°F, the potential for STE applications appears promising from an energy standpoint.

8. Industrial Applications of Solar Energy (Reference 4)

The objective of this program was to define solar energy systems that are technically and economically feasible, can satisfy all or part of selected industry demands, and to determine the market potential of such systems. The primary emphasis was placed on the application of total energy systems where the industrial process heat, electrical demands, and space heating and cooling are satisfied at maximum possible efficiency.

Industrial energy usage was first determined, leading to a survey of those which were energy-intensive. The survey yielded the necessary industrial demand data to allow first-level designs to be accomplished. Concurrently with the industry survey, subsystem methodology was established in the areas of insolation data retrieval, collector performance and sizing, thermal storage, energy conversion, and heat transport. In excess of 40 first-level designs were generated, allowing for a preliminary ranking and selection of industries for the conceptual design phase. These industries with Standard Industrial Classification (SIC), were: Meat Packing (SIC 2011), Fluid Milk (SIC 2026), Sugar Beets (SIC 2063), Asphalt Materials (SIC 2951), and Concrete Block (SIC 3272).

Conceptual designs were then generated for each primary location for these industries and three additional locations as dictated by previously determined industrial influence zones. These designs were then used to determine system economics and ultimately the market penetration. All of the selected industries yielded positive returns on investment (ROI) in the small central receiver configuration, thereby validating the selection.

B. INDUSTRIAL EXPERIMENTAL PLANTS AND DEMONSTRATIONS

Industrial manufacturing applications of solar energy are quite varied. For integrated manufacturing facilities, no two locations have identical energy demands and associated economic considerations. Below is a description of applications of solar energy to industrial manufacturing where demonstrations have been jointly undertaken by industry and the Division of Solar Energy. These projects are in addition to those projects listed in Appendix A-II.

1. Steam Projects

In May 1977, ERDA issued a Request for Proposal (RFP) for solar production of industrial process steam (Reference 3). The objective of the procurement was the determination of the technical and economic feasibility of producing low-pressure steam (212°F - 350°F, 14.7 - 135 psi) for industrial process heat by solar energy.

2. Industrial Total Energy Projects

In April 1977, a textile mill in Shenandoah, Georgia was selected for the first large-scale industrial total energy experiment. The total energy system will supply electrical energy, process heat and satisfy heating and cooling requirements. Conceptual design contracts have been awarded to Acurex-Aerotherm, General Electric Company and Stearns-Roger Engineering Company. Georgia Power Company will act as site coordinator and project integrator.

Sandia Laboratories at Albuquerque, New Mexico, has designed, constructed and is currently operating a solar total energy test facility for component and subsystem evaluation, and for supplying electrical, heating and cooling loads for a Sandia office building. The collector array is made up of four quadrants for evaluation of different types of linear distributed collectors. Four collector types are currently under test and others under consideration.

C. SOLAR THERMAL ELECTRIC POWER GENERATION

In January 1975, parallel, competitive contracts were awarded for subsystem research experiments and preliminary design of 10 MW_e Central Receiver Solar Thermal Electric Power Pilot Plant. The contractor teams are as follows: (a) McDonnell Douglas, Stearns-Roger, Sheldahl, Rocketdyne and West Associates; (b) Martin Marietta, The Bechtel Corporation, Engineering Experiment Station Georgia Institute of Technology, and Foster Wheeler; (c) Honeywell, Black and Veatch, Babcock and Wilcox, and Northern States Power Company; and (d) Boeing.

Subsystem research experiments were carried out for collector, receiver and thermal storage subsystems. All of the experiments were successful, and selection of best system and subsystems is currently in process.

Southern California Edison Company, the City of Los Angeles, and the State of California have been selected as partners in construction and operation of the 10 MW_e Pilot Plant which will be constructed at a desert site near Barstow, California. The plant is planned to be operational, supplying power to the utility grid in the late 1980 or early 1981 time period.

A-IV. DEVELOPMENT MILESTONES AND COMMERCIALIZATION POTENTIAL

A. CRITICAL RD&D AND COMMERCIALIZATION MILESTONES FOR MEDIUM- AND HIGH-TEMPERATURE PROCESS HEAT

	Year
Major milestones preceeding scientific feasibility demonstration	
Application Analyses	1975-1980
Market Analyses	1975-1980
Selection of Demonstration Projects	1975-1980
Scientific feasibility demonstration	
Medium Temp Collector Experiments	1976-1977
High/Very High Temp Central Receiver Experiments	1976-1980
High/Very High Temp Parabolic Dish Experiments	1977-1981
Decision to proceed with engineering demonstration	
Medium Temp Demonstrations	1977
High Temp Demonstrations	1979
Very High Temp Demonstrations	1980
Completion of total plant engineering demonstration operation, 1-5 MW_{th} size	
Medium Temp	1978
High Temp	1980
Very High Temp	1981
Decision to proceed with prototype (commercial-scale)	
Medium	1979
High	1981
Very High	1982
Completion of prototype demonstration of commercial-scale, 5-100 MW_{th} size	
Medium	1980
High	1983
Very High	1986
Commitment to first commercial installation	
Medium	1981
High	1985
Very High	1989

B. MAXIMUM POTENTIAL DEPLOYMENT SCHEDULE

YEAR	ELECTRICITY	RESIDENT/COMMERCIAL		INDUSTRIAL		TRANSPORT
		HEAT	AIR COND.	HEAT*	FEEDSTOCK	FUEL
1975				0		
1985				0.6		
1990				2.7		
1995				4.4		
2000				7.3		
2010				12.0		
2020				18.5		
2030				30.0		
2040				48.0		
2050				70.0		

Assumptions:

1. 1974 was utilized as a base year with 16.6* Quads of industrial process heat which represented 68.4 percent of the 24.3 Quads of energy consumed by industry. In 1974, industry used 40.5% of the total U.S. energy consumption of 60 Quads. A breakdown of the total industrial use in 1974 appears below:

Process Steam	40.6%	(16.6 Quads)
Direct Process Heat	27.8%	
Electric Drive	19.2%	
Electric Process	2.8%	
Feed Stock	8.8%	
Other	0.8%	
	100.0%	(24.3 Quads)

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*Quads thermal delivered.

Assumptions (Continued)

2. Industry has shown a steady 3% annual energy growth. Industrial process heat demand in future years was projected from 1974 use of 16.6 Quads (thermal) and continued 3% annual growth.

3. Installed cost and collector efficiencies were then used to project the market capture potential of solar systems. This was done on a regional basis, for six regions of uniform insolation utilizing regional fuel costs and industrial process heat consumption by temperature in each region. Initial penetrations will be rapid in the south and western U. S. and then more gradual penetration in other regional markets. Analysis was carried out for 1985 and 2000. It showed solar capturing 2.6% of the new market in 1985 and 20% in 2000 using only low- and medium-temperature heat collectors. With the low-temperature collector penetration beyond 2000 and with high-temperature collectors to capture additional markets, it is assumed that 50% of the new process heat market can be captured by 2050.

APPENDIX B

Prepared by

W. H. CLINGMAN & CO.

MANAGEMENT and TECHNOLOGY CONSULTANTS

APPENDIX B-I

High Temperature Solar Process Heat
Market Potential of Selected Applications

Introduction

In a previous project several industrial interviews were carried out to identify potential applications of solar steam plants. These are discussed in the report, "Early Utilization of Solar Steam Plants", June 27, 1976. The interviews that were carried out are listed in Table 1. The present project is a continuation of this earlier effort. The objective has been to find additional markets for some or all of the components being developed in the solar thermal program.

The previous project was principally concerned with identification of opportunities. Several constraints were applied. Applications were sought for high quality heat so that components could be used that are being developed in the ERDA solar thermal conversion program. Applications were sought in the Southwestern United States in order to benefit from the high insolation there. Focus was on the industries that are the principal energy consumers. Opportunities for solar process heat were identified in the cement, petroleum refining, and chemical process industries.

In the present project the focus has been on analyzing the market opportunities for the applications identified in the previous study. These are the heating of tank farms in petroleum refineries, central steam and utility plants in the petroleum and chemical industries, precalcining feed in the cement industry and drying feed materials in the latter. The interviews in the present project have confirmed that these applications appear the most promising. Analysis of the market opportunities has involved three steps. These are: the refinement of the feasibility analysis for each proposed application; the identification of application sites so that available insolation can be compared with need; and feedback from industry.

The refinement of the feasibility analysis was done primarily by those in industry. In the first phase of the present project six industrial interviews were carried out. Two types of information were requested. First were the minimum parameters required for a specific application to be feasible. These parameters included temperatures and required energy inputs. Second was information on the number of potential sites for each application discussed. Here questions such as land availability were considered, particularly within the firm being interviewed.

The report of this first phase is included in the appendix. Additional interviews were carried out in the cement industry after the report was completed and all interviews related to feasibility analysis are listed in Table 2. Those interviewed were asked to provide the minimum technical parameters that would be required for a particular application to be feasible. These parameters included required payout, size, and projected cost of fuel displaced. The utility of a solar plant was also discussed. Information was obtained from Aerospace on insolation statistics and the performance of equipment being produced in the solar thermal program. This information was combined in memoranda with that obtained from industrial interviews. These memoranda are in the appendix and were used to obtain feedback from industry.

The second step in analyzing market opportunities was to correlate the potential industrial application sites with insolation intensity. One objective of the study has been to determine those factors which will be important as incentives in stimulating applications. A potential application should have certain characteristics to stimulate investment on the part of a manufacturer. One such characteristic is the existence of a large number of prospects for the initial unit of an application. With a new technology such as solar steam plants the initial sale that doesn't have government financial incentives may be the most difficult. If there are a large number of potential sites for that sale then this will increase the probability of success. Also the larger the unit market the smaller will be the cost of building the first unit relative to the total market size.

A second desireable characteristic of an application is that industrial firms easily recognize the utility of the solar device. For example, if the solar unit provides process heat in an area that is equally well served by a waste heat recovery system, then the solar unit would be viewed as having limited utility. For management to perceive utility readily the solar unit must be compatible with the existing plant structure. Application of the initial solar units should not involve redesigning other parts of the plant.

It was desired to achieve this characteristic for the applications analyzed in the present project. To do this industry representatives were used. They first identified the applications in gross terms and then defined more specifically the limits on design parameters that would be necessary. During the feedback step, which is discussed below, another reason for having those in the industry define their own requirements was identified. A distrust of federal government analyses related to their own industry was expressed. This is particularly true in the discussion of new applications or market analyses of new products. This point is also considered below in the recommendations for further pursuit of the applications discussed in this report.

To analyze the first characteristic a determination of the potential unit market was carried out. This is discussed in the next section. Published statistical information was used to determine the number of application sites and units as a function of geographic location. This distribution can then be compared with the distribution of insolation. The variation in insolation above some minimum essentially will vary the timing as to when the application will be economic in each region. With fuel costs rising and solar equipment costs falling solar units will become economically competitive in different insolation intensity areas at different times. The most significant data will be the number of unit applications available in the highest insolation areas. Also significant is the number of units in medium insolation areas in order that there be a future market once the product is established in the higher insolation locations.

The third step in analyzing market opportunities was to obtain industry feedback. This was done in two ways and is discussed in the next section. First two presentations were made to the Industrial Boiler Committee of the American Boiler Manufacturers Association. Material was presented that had been obtained from the end user interviews. Both the nature of the applications and the economic feasibility were discussed. At the first presentation Howard Webb of the Aerospace Corporation also gave a status report on the solar thermal program. After the second presentation there were questions and comments from the committee members. This provided an opportunity to determine some of their reactions to the proposed applications.

The second method of obtaining feedback was to send a summary description of each application to industry people for comments. This was done. Their comments are discussed below and have been incorporated into the application descriptions that are in the appendix.

The next section discusses the market analysis of the application opportunities. This is followed by a separate discussion of the information that was obtained in the feedback process. Then conclusions and recommendations are presented at the end of the report.

Market Analysis of Opportunities

Solar Tank Farm Heaters:

A summary of this potential application is given in the appendix. The application was initially suggested in interviews with Continental Oil Company. It has also been independently suggested by California Portland Cement Company. The application at cement plants would be to heat a tank of residual fuel to 150°F. Such a tank is always present at coal-fired plants as a backup fuel supply. The reason is the frequent breakdown and maintenance required for the coal handling equipment. When this happens the kiln cannot be shut down except with severe economic penalties. Thus a backup fuel is required.

The thermal analysis for this application was essentially carried out by A. Joe Mitchell, Jr. in the Central Engineering Department of Continental Oil Company in Ponca City, Oklahoma. They have computer programs set up to calculate the heat loss from tanks under a number of different conditions. The first step was to determine the heat loss from the tank under a set of typical conditions. For this purpose Mr. Mitchell assumed a 100 ft. diameter tank and a liquid height of 40 ft. It was further assumed that the average ambient temperature was 50°F, the wind was 10 m.p.h. and the liquid temperature in the tank was 250°F. The heat loss from an uninsulated tank with these parameters would be 14.1 MMBTU/HR. It is thus common practice to insulate tanks and typically this would involve application of 1-1/2 inches of polyurethane foam. According to Mr. Mitchell this would cost $\$2.50/\text{ft.}^2$ The K factor is 0.14 BTU - in/ft.^2 - °F - hr and emissivity is 0.9. This then would reduce the surface temperature of the tank to 57°F and reduce the heat loss to 0.23 MMBTU/HR. Now one can consider adding additional insulation. Another 1-1/2 inches would cost $\$1.25/\text{ft.}^2$ and reduce the surface temperature to about 53.6°F and the heat loss to 0.12 MMBTU/HR. Thus energy savings would be 0.11 MM BTU/HR. The total investment in the original insulation would be $31,400 and in the incremental addition would be $15,700.

To evaluate such projects Continental Oil would use an average projected fuel cost of $2.50 per MMBTU and 3-1/3 years payout. They will probably shift to a 5 year payout in evaluating energy saving projects. Five years is also used by Shell[1] and has been recommended in the literature.[2] Using $2.50 per MMBTU the payout for the additional insulation would be 6.5 years. It thus would not be economic.

The next question is whether a solar boiler could supply the energy required for the tank. This is discussed in the memorandum in the appendix. A distributed collector system is considered that is under development for powering an irrigation pump. The collector system is an array of parabolic troughs. Two orientations can be considered. These are North-South and East-West. The latter arrangement will collect less total energy over a year but steam generation will be more uniform through the seasons. In the first case analyzed the collector must provide the total daily heat requirements of the tank in winter. The heat is stored in the tank and its temperature is allowed to fluctuate above a minimum. This is a worst case requiring the largest collector area. In this case the area required for the tank parameters considered above is 4600 $ft.^2$ and available area is over 10,000 $ft.^2$ This assumes an average of 1200 $BTU/ft.^2$ day of radiant energy converted to heat with the collectors in the East-West orientation.

According to information from the Aerospace Corporation this collector system is currently available from one manufacturer at $14.60/$ft.^2$ installed. At this price the solar collectors would cost $67,160 and the payout would be 13.3 years. Projected cost reductions in the system and increased fuel prices would make this application economic.

In this first case all of the energy requirements of the tank are supplied by the solar unit. An advantage seen by Mr. Mitchell is the saving in steam and condensate lines to the tank in a new installation. In some cases the investment in these lines might be $10,000 to $20,000 and this could be taken as a credit against the cost of the solar unit.

A modification of this first case is to use the same East-West collector orientation but to supply steam at night from the central steam plant. This would have the advantage of reducing the temperature fluctuations in the tank. The magnitude of these fluctuations are discussed in the appendix. The payout still would be 13.3 years based on $14.60/ft.^{2} for the collector system. There would be no credit, however, for the steam and condensate lines running to the tank. Energy displacement would also be less. Assume that steam from the central plant is adjusted so as to maintain a uniform tank temperature. The solar capacity factor for the unit in a high insolation area is 56%. Thus the size of the unit for the tank conditions assumed above would be 2352 ft.^{2} or $34,340 at current prices. Over a year of operation 56% of the required heat would be supplied by the solar unit.

A third case would involve a North-South orientation of the distributed collector system. In this case the steam generation capability would vary with the seasons. In the summer this would be 1880 BTU/ft.^{2}-day so that a 2936 ft.^{2} system could supply the average daily requirements of the above tank. Over the period of a year the average steam generation would be 1400 BTU/ft.^{2}-day. Thus the annual energy displacement would be 74%. This system would require steam from the central plant during the winter. It has the advantage of a shorter payout compared with the first two cases. If the credit for steam and condensate lines were sufficiently large, however, then the first case would have the advantage. If a solar unit is to be added to an existing plant when the steam lines are already in place, then the third case would be the most advantageous.

Next the initial market potential in units for solar tank farm heaters was determined. From discussions at Continental Oil it is assumed that in a refinery there is a potential application with the crude storage tank and possibly one or two product tanks. Examples of the latter would be asphalt and bunker C fuel oil. In Table 3 is shown the number of potential tank farm heaters as a function of insolation intensity. The geographic distribution of insolation was taken from Figure 1. The number of refineries in each geographic region was determined from reference (3). The distribution of cement plants was obtained for the Portland Cement Association. These are given in Table 4. All cement plants are gradually converting to coal and it is assumed that each will require one tank farm heater. It is assumed that each refinery would require a minimum of two units. Those applications in the higher insolation areas will become economic first. It is concluded that this application would be practical if fuel rose to $3.50/MMBTU and solar equipment costs were $8.90/ft.^{2}.

Solar Steam Plants:

This application is discussed in the appendix. In a refinery or chemical plant there are requirements for process steam, heat, and pumping. The requirements for a number of different petroleum processes assuming steam driven pumps are shown in Table 5. In present refineries a good rule of thumb is that one-third of a barrel of crude is used for steam genration out of each ten barrels processed.[4] In a chemical plant about 50% of the input energy requirements are for steam generation.[5]

The steam plants that are now used are gas or oil fired. The existing plants for all Shell Oil refineries are shown in Table 6. The trend in the industry is to move toward coal-fired plants that produce both steam and electric power. Commitments are already being made toward this end according to Mr. Beyer, at Exxon. For example, they have a 200 MWE unit planned for Baton Rouge, Louisiana. This will supply only part of their electrical requirements. They will have excess steam at the turbine outlets that they will sell to neighboring industry.

The 10 MWE pilot plant now under developement in the solar thermal program would be compatible in size with some of these requirements. The steam temperature from thermal storage, however, is 550° F and this is below the 750° F, 650 psig steam now used in a refinery.

In Table 7 are shown the projected costs for solar power plants that have been analyzed by Aerospace Corporation. The solar capacity factor has been used to calculate the fuel displacement that would result in a petroleum refinery or chemical plant. At $2.50/MMBTU this then allows calculation of the payout. The figure, $2.50/MMBTU, is that recommended by Continental Oil and corresponds to the future cost of the marginal fuel used in a refinery. This cost is higher than the cost of coal which would be the fuel for major new installations. The higher figure, however, is more realistic for solar units installed as fuel savers. The payout is longer than the 5 years used to justify such plants in the industry. It is thus concluded that direct application of central receiver technology as it is being developed for utilities will be delayed beyond these utility applications because of the higher requirements for return on investment in industry.

A second method of generating steam would be with a distributed collector system. These would be the type of units discussed in the previous section. They would be used as a fuel saver. The orientation would be North-South to maximize energy displacement over a year. The unit would be designed to produce steam at 600°F, and 1120 BTU/ft.^{2}-day would be the average annual capacity. This is 20% less than for 400°F steam. The payout at a current cost of $14.60/ft.^{2} and a cost of $2.50/MMBTU for the displaced energy would be 14.3 years. At projected costs of $10/ft.^{2} the payout in high insolation areas would be 9.8 years. In Table 8 the maximum cost for a payout of 5 years is shown as a function of insolation. Applications in the high insolation areas will take place first.

The next step was to examine the question of land availability. In Table 9 are the available acreage at all of the Shell Oil refineries in the United States. The distributed collector system will supply varying amounts of steam generation capacity per acre depending on geographic location. This is shown for the Shell refinery in the same table. Then finally is shown the maximum steam generation possible with a distributed collector system as a percent of total steam requirements.

It is assumed that such steam generation would only be applicable in refineries above a certain minimum size. One reason is the availability of a sufficient engineering staff to incorporate the new technology. The engineering staff must also arrange to control the conventional steam plant so that total steam production, solar plus conventional, is a constant. Based on personal knowledge of refineries in the Texas City, Texas area I have somewhat arbitrarily chosen this cutoff at 30,000 B/cd capacity. In Table 10 is a listing of all refineries greater than this size. Also listed is their estimated steam requirements based on one-third of a barrel for steam generation per ten barrles capacity. The steam requirements are correlated with insolation in Table 11.

Steam requirements in the chemical industry are shown in Table 12. These are taken as one-half the total energy requirement, which is consistent with other analyses in the industry.[5] The data are limited to those areas with an insolation above 6 KW hr m^{-2}.

It is concluded that in both the chemical and petroleum industry the potential number of units is more than sufficient to justify development of the market on the part of private industry.

Cement Plants:

Application for cement plants are discussed in the appendix. These have been suggested by those interviewed. California Portland Cement suggested a solar tank farm heater. This would be for residual fuel used as a backup for coal fired plants. Mr. Earhart at Gifford-Hill in Dallas suggested using solar energy for drying wet raw material. This would be applied first to plants that have a wet quarry. An example is the Gifford-Hill plant in North Carolina. Solar drying in the open air would be the first approach. Also hot air could be produced in a solar unit such as those being developed for the Brayton cycle. An air temperature of 1800°F could be reached and this hot air combined with fossil fuel in a drying unit.

In drying operations, however, only a small fraction of the energy required for the plant can be displaced by solar. Mr. N. R. Greening of the Portland Cement Association has suggested that a solar unit be used for precalcining. This is a mechanism by which at least 40% of the energy required can be displaced by solar. In a normal dry process plant in the United States calcining takes place in the kiln. This is the conversion of calcium carbonate to lime. This is the only endothermic reaction in the process for manufacturing portland cement. It occurs at a constant temperature of about 1560°F. It is followed in the kiln by the reaction of calcium oxide and silica to form calcium silicate. This is an exothermic reaction but takes place at 2300°–2900°F. Kiln temperatures are too high for use of solar heat at this part of the process. The calcining reaction, however, can be carried out prior to the solids being introduced into the kiln. This has the advantage of lowering the cost of the kiln required. Mr. Greening suggested converting the calcium carbonate to lime in a separate precalcining reactor and stockpiling the lime. This provides a natural storage mechanism. The temperature required is 1560°F which is compatible with the Brayton cycle units being developed. A reactor configuration needs to be designed.

A second approach to precalcining was suggested by Arizona Portland Cement. In their plant they are now carrying out precalcining in the preheater by injection of natural gas. Air is passed over the clinkers coming out of the kiln. This cools the clinkers and heats the air to about 1000°F. The preheater is a column that is 218 feet high. The solids are raised to the top of the column mechanically. They then fall through the air. The hot air enters the bottom of the column and exits at the top. The solids are preheated to 1500–1600°F and about 40% calcination takes place in this column. The solids leaving the column enter the kiln directly. Additional precalcining can be effected by injecting natural gas at a height of about 150 feet. The gas burns on the surface of the solids.

It was suggested tht at this same point in the column there could be direct introduction of radiant energy. The reaction mixture would move in a helical pattern through reactor tubes to get good heat transfer on the inside surface of these reactor tubes. The radiant energy would be reflected to the outside of the reactor tubes from a field of heliostats. Work would be required on reactor design and heat transfer to the solids. Injection of natural gas or other fossil fuel would have to be controlled so that the sum of the solar and fossil fuel inputs were constant.

In all of these cases the solar plant would displace fossil fuel. A payout of 8 years is typically used in this industry. Table 13 shows the maximum cost of the solar plant to achieve the 8 year payout. This cost is expressed on the basis of the square feet of collector field required. It is assumed that in a location with an insolation of 8 KW hr m^{-2} the average energy collected is 1400 BTU/ft.^{2}-day.

Feedback:

Two approaches were used to obtain feedback. First presentations were made to the Industrial Boiler Committee of the American Boiler Manufacturers Association on Jan. 19, 1977 and June 22. These were presentations of the results of the industrial interviews used to identify and refine solar application opportunities. The interviews were discussed in the previous section. At the first meeting Mr. Howard Webb of the Aerospace Corporation also presented a status report on the solar thermal program. At the completion of the second presentation there was time for discussion and comment. A list of the committee members is in Table 14.

The principal comment was on the requirements for economic feasibility of the solar tank farm heater. The comment was made that the federal government and their contractors are always presenting data that is misleading to justify their programs. The specific objection was not including the cost of backup steam lines to a tank in the cost of a solar tank farm heater. This bias was sufficiently strong that it was difficult to make the group understand that what I was presenting were Continental Oil calculations and the price which they would pay for a solar tank farm heater.

There were a few other questions from the group. Their interest, however, was limited compared to that of the utility boiler people to whom a presentation had been made previously. There was a preoccupation of the committee with the changing government regulations controlling the fuel that can be burned in an industrial boiler. What questions I did receive were from representatives of the larger firms such as Foster Wheeler.

The feedback obtained from end user interviews has been primarily to confirm the data used in the preparation of the summary memoranda in the appendix. The interviews are listed in Table 1 . All of the comments have been incorporated into those memoranda. In particular the interviews were used to confirm the way in which a solar project would be evaluated. Figures used for payout and cost of fuel displaced were discussed. In the petroleum and chemical industries these were 5 years and $2.50/MMBTU respectively. In the cement industry they were 8 years and $2.50/MMBTU. Payout over a longer number of years was discussed in some depth and would not be feasible.

Mr. Mitchell at Continental Oil recommended that no specific numbers be given on future costs of the solar unit. Otherwise people will try to disprove the figures to show that the solar unit is really not as good as reported in the memorandum. I think this is part of the same attitude as found with the industrial Boiler Committee. It was agreed that the only specific numbers on the solar units that would be given would be those related to an existing unit. A statement would then be made that the proposed application would become economic as costs come down.

Further information also was obtained in these interviews on the number of solar units that might be installed in a refinery. This was particularly true for the solar tank farm heaters. Correlations between steam generation requirements and refining capacity have been published.[4] There is also a correlation in a chemical plant between steam requirements and total energy input.[5] These correlations were used to analyze the potential market for solar units and were confirmed in the interviews.

Conclusions

From the feedback information it is concluded that the applications identified are close to optimum from the standpoint of the objectives of the study. In each industry the focus has been on those applications that can produce a major impact on energy consumption. These are the steam generator in petroleum and chemical plants and a solar precalcining unit in cement plants. In order to gain management acceptance of solar energy the first applications may be less ambitious, such as a solar tank farm heater. Even in this case, however, the need has been pointed out by industry management. This is important. Even in the experimental stage a solar project will compete with other projects for management time.

The detailed economic and engineering analysis of these applications should be done by industry. This might involve using a federal grant to partially offset the cost. If a detailed analysis is made by a government contractor outside of the industry then this would not carry as much weight. Based on comments during the feedback phase the reaction may be negative to an outside contractor. This would run counter to the objective of stimulating investment from the private sector in developing the proposed applications. If the studies are done within the end user industry then they would have a vested interest in the project.

In general the application projects studies will require a short payout. Both the literature and interviews show that in most cases petroleum companies will use five years. The same would probably be true for long term projects in the chemical industry and the cement industry would use eight years. These are not the lifetimes expected for a new unit but are the numbers used to select between alternative technologies. In some cases a premium would be paid for the solar unit as a hedge against fuel price increases after the five year period. In any case the rate of return in the industrial application will have to be higher than in the case of utilities.

Fuel costs are rising and solar equipment costs are falling. The solar units considered would all prove economic in time if cost goals are met. This is assuming a five year payout in the petroleum and chemical industry and an eight year payout in the cement industry. Those applications which would become economic first are the tank farm heater and small steam plants using a distributed collector system. Using a projected cost of $10/ft.^{2} the latter would show a payout of five years when the marginal fuel cost reaches $4.90 per MMBTU. This is in a high insolation area with an annual average daily insolation of 8 KW hr m^{-2}. This should happen in the 1980's. Both of these applications have the advantage that they can be sized to be small initially. Thus management can gain confidence with a trial installation and minimize their risk.

In the case of precalcining in a cement plant the payout reaches 8 years for a projected equipment cost of $8.80/ft.^{2} and a fuel cost of $2.50/MMBTU. This may also happen in the 1980's, but an installation could require a major process modification on the part of the cement manufacturer. This is true because precalcining is not now used in the United States. Also technical studies are required on the direct introduction of radiant energy into a precalcining reactor. Initial applications in the cement industry would probably be less ambitious. They might involve drying or tank farm heating.

The final applications to become economic will be those involving central receiver steam plants. Industry is moving toward plants which produce both steam and electric power. The central receiver pilot plant being developed in the solar thermal program is compatible with this trend. It is also the same order of magnitude in size as many industrial boilers. Two factors, however, will delay its application. One is the shorter payout of capital investment that will be required in the chemical and petroleum industry as compared to utilities. The other is the requirement in industry for continuous twenty-four hour output from the plant. Continuous operation is required during extended periods of bad weather. This means that capacity displacement for the solar unit would be essentially zero and its entire cost would have to be paid from fuel savings. This situation could be alleviated to some extent if there were a way of combining the solar and conventional boilers so as to reduce equipment cost below that for two separate units.

Our final conclusion is that initial projects should establish the solar unit as a viable technology in the opinion of management. This will require projects that are of interest but involve little risk. The solar tank farm heater would be an example.

Recommendations

One conclusion from the present study is that there are significant industrial applications for solar, high temperature, process heat. The study has been confined to only three industries, chemical, cement, and petroleum. It is proposed to expand this study to include many other industries which are large energy consumers. Examples are steel mills, pulp and paper mills, and the lime industry.

In this expanded study industrial inputs to the analysis would play an important role. The structure of each industry relative to the influx of new technology would first be determined. In some cases, such as for cement manufacturers, technology is evaluated on an industry-wide basis. In this case the Portland Cement Association is the technical arm of the industry. There is extensive technology sharing. The chemical industry, on the other hand, represents a very different structure. Process information is closely guarded by each firm. There is no general sharing of technology. Another characteristic of the industry structure is the percent of the market held by the largest firms. For example, the steel industry is dominated by a few firms. These would have the financial resources and technical expertise to introduce new technology where appropriate. Foundries, on the other hand, tend to be small firms, many family owned, and introduction of solar technology would be more difficult. The structure can determine the best way of introducing new technology and also key points for industry interviews.

The structure would be determined by talking with trade and technical associations within the industry. Government statistics would also be consulted as well as industry specialists within the Department of Commerce. Following this key technical people within the industry would be interviewed to establish the feasible applications for solar process heat. These could then be analyzed at the Aerospace Corporation and then feedback from the industry obtained.

A second conclusion from the present study is that the end user should participate in or carry out the detailed design of a solar unit. Also manufacturing costs must come down before the potential applications are economically feasible. One way of achieving these ends would be to establish an initial industrial market through federal incentives. Preliminary to this representative firms in each industry could be given a grant to design and evaluate specific solar process heat specifications. In an expanded study including additional industries it is proposed to identify such projects.

References

1. Interview with E. H. Mergens, Shell Oil Company, Houston, Texas.
2. Henry Duckham and James Fleming, "Better Plant Design Saves Energy", Hydrocarbon Processing, July 1976, pg. 78.
3. "Worldwide Direction, Refining and Gas Processing 1970/71".
4. Warren E. Danekind, "Steam Management in a Refinery", Hydrocarbon Processing, December, 1976, pg. 71.
5. E. H. Mergens, Hydrocarbon Processing, July, 1977.

TABLE 1

Initial Industrial Interviews
for
Identification of Opportunities
(Prior to June, 1976)

Continental Oil Company, Ponca City, Oklahoma
    D'Arcy Shock, Research & Development Department

Continental Oil Company, Houston, Texas
    K. R. Gerhart, Director, Internal Energy Conservation

Continental Oil Company, Ponca City, Oklahoma
    Mr. Hugh Barnes, Central Engineering

Gifford-Hill Portland Cement Co., Dallas, Texas
    James W. Porter, Executive V. P., Gifford-Hill Industries
    K. L. Earhart, Vice President
    Roe Evans, Technical Director

Portland Cement Association, Skokie, Illinois
    Dr. E. Hognestad, Director of Technical and Scientific Development
    Dr. N. R. Greening, Director of Basic Research

Babcock and Wilcox, Barberton, Ohio
    W. H. Jackson, V. P. of Marketing
    Dave Walker, Industrial and Marine Division Engineering

TABLE 2

Interviews Related to the Feasibility Analysis

Gifford-Hill Portland Cement Co., Dallas, Texas

Portland Cement Association, Skokie, Illinois

Arizona Portland Cement, Tucson, Arizona

California Portland Cement, Los Angeles, California

Dow Chemical Company, Freeport, Texas

Exxon Company, U.S.A., Houston, Texas

Shell Oil Company, Houston, Texas

Continental Oil Company, Ponca City, Oklahoma

Figure 1

Average Daily Direct Normal Insolation

(kWhr m^{-2})

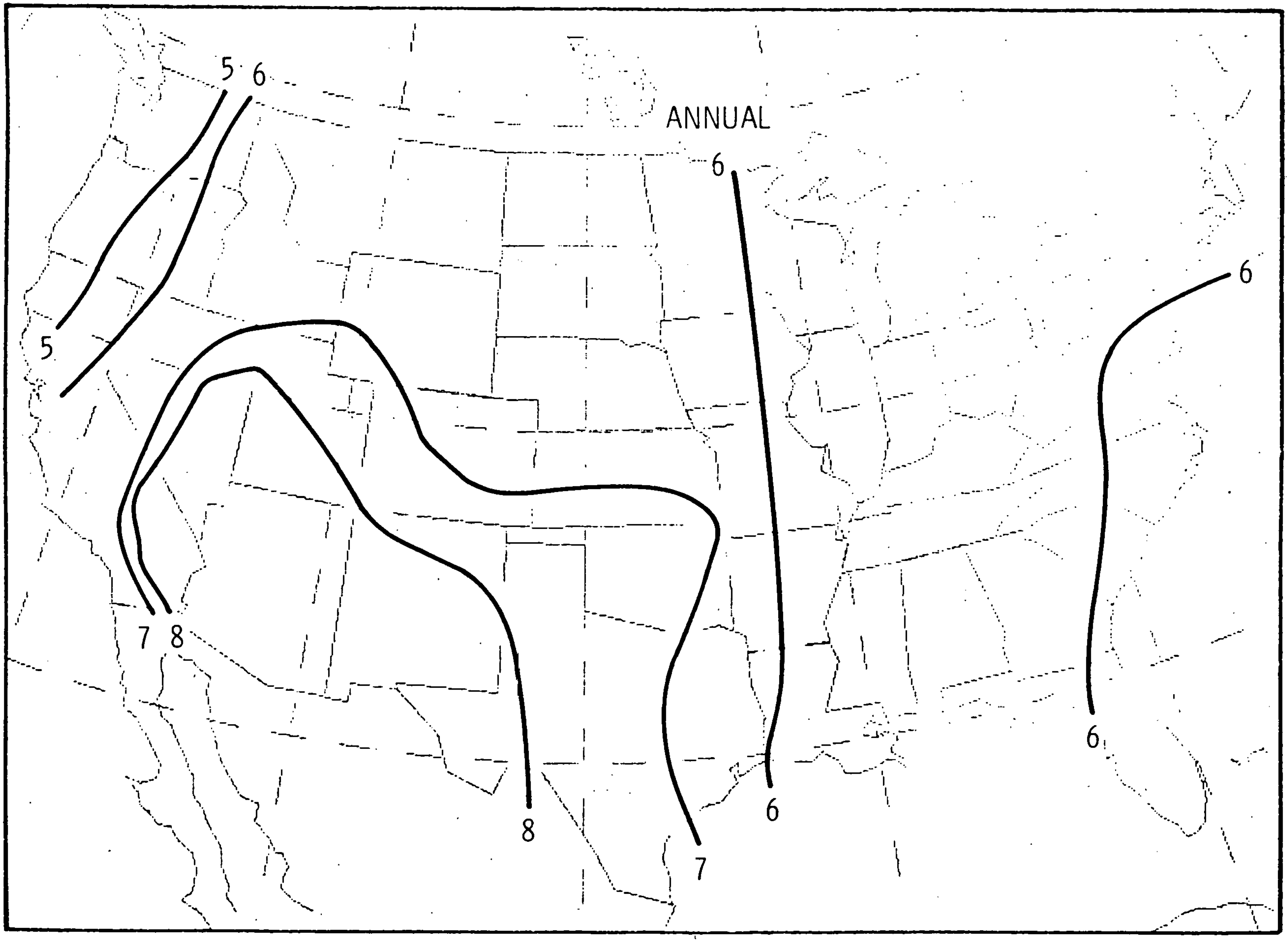


TABLE 3

Potential Tank Farm Heaters

Average Annual Insolation KW Hr m^{-2}	In Cement Plants	In Refineries Over 30,000 BBL/CD
6-7	35	76
7-8	16	30
>8	5	2

TABLE 4

Cement Plants

	Annual Capacity MM Tons	Insolation Kwhrm^{-2}	Wet	Maximum Solar Plant Site MW Thermal
FLORIDA				
General — SE Div.	>1.0	6-7		>90
General — SE Div.	0.4-0.7	6-7		30-60
Maule	>1.0	6-7	X	>90
Lehigh	0.4-0.7	6-7		30-60
National Portland	>0.4	6-7		>30
Fla. Mining & Mineral	0.4-0.7	6-7		30-60
SOUTH CAROLINA				
Gifford-Hill	0.4-0.7	6-7		30-60
Giapt	0.4-0.7	6-7		30-60
Santee	>1.0	6-7		>90
NORTH CAROLINA				
Ideal	0.7-1.0	6-7		60-90
VIRGINIA				
Citadele	0.4-0.7	6-7		30-60
MARYLAND				
Alpha	0.4-0.7	6-7		30-60
Lehigh	0.7-1.0	6-7		60-90
TEXAS				
Ideal	0.4-0.7	6-7	X	30-60
Lone Star	0.4-0.7	6-7	X	30-60
General (Trinity Division)	0.4-0.7	6-7	X	30-60
Coast	0.4-0.7	6-7	X	30-60
Alpha	>0.4	6-7	X	>30

	Annual Capacity MM Tons	Insolation Kwhrm^{-2}	Wet	Maximum Solar Plant Site MW Thermal
TEXAS				
Kaiser	0.7-1.0	7-8	X	60-90
San Antonio	0.4-0.7	7-8	X	30-60
Capitol Aggregates	>0.4	7-8	X	>30
Lone Star	0.4-0.7	7-8		30-60
Southwestern	>0.4	7-8	X	>30
Texas Industries	>1.0	6-7	X	>90
Universal Atlas	0.4-0.7	6-7	X	30-60
Gifford-Hill	0.7-1.0	6-7	X	30-60
General (Trinity Division)	0.4-0.7	6-7	X	30-60
General (Trinity Division)	0.4-0.7	6-7	X	30-60
Southwestern	>0.4	>8		>30
Southwestern	>0.4	>8		>30
OKLAHOMA				
Ideal	0.4-0.7	7-8		30-60
Martin-Marietta (Western Div.)	0.4-0.7	7-8		30-60
OKC (Oklahoma)	0.4-0.7	7-8		30-60
MISSOURI				
Missouri Portland	>0.4	6-7		>30
ARKANSAS				
Arkansas	0.7-1.0	6-7		60-90
Ideal	>0.4	6-7		>30
IOWA				
Penn-Dixie	0.4-0.7	6-7		30-60
Marquette	0.4-0.7	6-7		30-60
Lehigh	0.4-0.7	6-7		30-60
Northwestern States	0.4-0.7	6-7		30-60

	Annual Capacity MM Tons	Insolation Kwhrm^{-2}	Wet	Maximum Solar Plant Site MW Thermal
UTAH				
Ideal	>0.4	7-8		>30
Utah	>0.4	7-8		>30
COLORADO				
Ideal	0.4-0.7	6-7		30-60
Ideal	0.7-1.0	6-7		60-90
Martin-Marietta (Western Div.)	0.4-0.7	6-7		30-60
NEW MEXICO				
Ideal	0.4-0.7	>8		30-60
ARIZONA				
Amcord (Phoenix)	0.4-0.7	>8		30-60
California Portland (Arizona)	>1.0	>8		>90
CALIFORNIA				
Kaiser	>1.0	7-8		>90
Northwestern	>1.0	7-8		>90
Amcord (Riverside)	>1.0	7-8		>90
Amcord (Riverside)	0.7-1.0	7-8		60-90
California Portland	>1.0	7-8		>90
California Portland	0.4-0.7	7-8		30-60
Monolith	0.4-0.7	6-7		30-60
General (California Div.)	0.4-0.7	6-7		30-60

	Annual Capacity MM Tons	Insolation Kwhrm^{-2}	Wet	Maximum Solar plant Site MW Thermal
SOUTH DAKOTA				
South Dakota	0.7-1.0	6-7		60-90
NEBRASKA				
Ash Grove	0.7-1.0	6-7		60-90
Ideal	>0.4	6-7		>30
KANSAS				
Lone Star	>0.4	6-7		>30
Monarch	0.4-0.7	7-8		30-60
Ash Grove	0.4-0.7	7-8		30-60
General (Trinity Division)	>0.4	7-8		>30
Universal Atlas	0.4-0.7	7-8		30-60
MONTANA				
Kaiser	>0.4	6-7		>30
Ideal	>0.4	6-7		>30
WYOMING				
Monolith	>0.4	6-7		>30
WASHINGTON				
Lehigh	>0.4	6-7		>30
OREGON				
Oregon	>0.4	6-7		>30
IDAHO				
Oregon (Idaho Division)	>0.4	6-7		>30

TABLE 5

Steam Requirements for Different Petroleum Processes

Process	Unit consumption of steam, lb./bbl. Pumps	Process and Heat Range	 Average
Topping—low API	15-21	25-35	30
Topping—high API	20-30	35-50	45
Desalting	—	1-13	2
Vac. flash:			
40 per cent	50-55	8-18	14
60 per cent	55-60	8-39	18
70 per cent	60-65	8-100	38
Thermal cracking	108-316	0-45	—
Thermal reforming	53-81	0-20	—
Thermal coking	62-176	44-190	110
Viscosity breaking	17-60	14-29	—
Cat. cracking:			
65 per cent	40	40-50	45
75 per cent	55	75-90	80
85 per cent	70	—	100
Cat. reforming	92-140	10-127	75
Asphalt mfr.	16-20	10-13	12
Polymerization	66-273	80-210	130
Alkylation	280-720	0-1,360	500
Hydrodesulfurization	96-250	8-45	25
Gasoline treating	12-23	2-75	10
Lube mfr.	1,100-1,300	900-1,500	1,200
Vac. dist.:			
40 per cent	70-76	16-180	56
60 per cent	76-84	18-220	85
70 per cent	84-90	20-260	100
Dewaxing	270-840	200-390	300
Solvent extraction	75-144	40-140	130
Rerunning	60-80	16-260	150
Deasphalting	96-230	70-140	120
Naph. solvent rerun	15-23	30-80	60
Acid treat. and contact	51-61	45-100	80
Clay contact alone	46-50	45-100	80
Hydrofinishing	30-85	8-20	17
Percolation	7-17	8-90	45
Wax mfr.	800-1,300	400-1,000	600
Deoiling	280-1,160	300-800	500
Acid. treat. and contact	51-61	50-120	100
Clay contact alone	46-50	50-120	100
Percolation	7-17	8-60	35
Solvent mfr.	40-70	10-40	25
Naphthenic lubes	250-400	300-450	350
Specialties	—	—	—

Reference: W. L. Nelson, "Refinery Complexity and Steam Requirements", Oil and Gas Journal, June 4, 1962, pg. 130

TABLE 6

Shell Oil Refineries

Site	Steam Generator No. Units—MMBTU/hr	Heat Medium No. Units—MMBTU/hr	Approx. Non-Process Acreage
Houston, TX	4 – 125 5 – 330 1 – 480 3 – 360 1 – 730 4 – 620	1 – 150 1 – 220	320
Los Angeles, CA	1 – 220 2 – 350	1 – 120	80
Odessa, TX	1 – 200		600
Ciniza, NM	1 – 200		150
Geismar, LA	2 – 290	1 – 150	200

TABLE 7. CENTRAL RECEIVER COST ESTIMATES

Plant Subsystem	MDAC Cost Estimate (1977 x 10^6 Dollars)				ERDA GOAL
	10 MW_e PP	100 MW_e			100 MW_e
		1st	20th	80th	Nth Plant
Collector[1]	18.28	105.88	76.20	61.72	56.50*
Receiver[1]	7.80	17.48	12.58	10.19	10.19
Tower	0.63	11.68	11.68	11.68	11.68
Thermal Storage	4.05	20.28	20.28	20.28	8.40**
Solar Sub-total	30.76	155.32	120.74	103.87	86.77
Land Preparation[2]	0.65	1.53	1.32	1.07	1.07
Buildings[2]	2.44	4.81	4.12	3.34	3.34
~~Turbo/Generator~~[2] Feed pumps, cond., etc.	~~5.05~~ 2.00	~~22.84~~ 5.14	~~19.57~~ 3.70	~~15.85~~ 3.00	~~15.85~~ 3.00
~~Electrical Plant Equip~~ & M.C.[2]	~~4.91~~ 1.91	~~8.28~~ 3.43	~~7.09~~ 2.47	~~5.74~~ 2.00	~~5.74~~ 2.00
Sub-total Bal. of Plant	~~13.05~~ 7.00	~~37.46~~ 14.91	~~32.10~~ 11.61	~~26.00~~ 9.41	~~26.00~~ 9.41
Distributables[3]	2.85	8.10	5.59	2.51	2.51
Indirect[3]	10.78	17.50	11.38	5.42	5.42
TOTAL PLANT DIRECT COSTS	~~57.44~~ 51.39	~~218.38~~ 195.83	~~169.81~~ 149.32	~~137.80~~ 121.21	~~120.70~~ 104.11
Contingency	5.03	N/A	N/A	N/A	N/A
Design & Tooling	8.75	2.89	2.89	2.89	2.89
1 DC & ESC	N/A	N/A	N/A	N/A	N/A
TOTAL CAPITAL COSTS	~~71.22~~ 65.17	~~221.27~~ 198.72	~~172.70~~ 152.21	~~141.00~~ 124.10	~~123.60~~ 107.00

Notes

* $\$65/m^2$

** $\$20/kW_e$ h

1 0.90 Learning Curve

2 0.95 Learning Curve

3 31% Reduction from 1 Unit Due to Larger Cost Base for 20 Units
69% Reduction from 1 Unit Due to Larger Cost Base for 80 Units

Lined out changes convert the MDAC Solar Electric Plant Costs to Solar Thermal Process Heat Plant Costs.

TABLE 8

Solar Steam Generators
Distributed Collector System Allowable Costs

Average Annual Insolation KW Hr m^{-2}	Fuel $/MMBTU	Maximum Cost for 5 Yr. Payout $/ft.^{2}
8	2.50	5.10
8	4.00	8.16
7	2.50	4.46
7	4.00	7.14
6	2.50	3.83
6	4.00	6.12

TABLE 9

Shell Oil Refineries

Site	Non-process Acreage	Insolation KW Hr m^{-2}	Potential Solar Steam Generation % of Total Steam
Houston, Tex.	320	6-7	8.1%
Los Angeles, Ca.	80	6-7	15.2%
Odessa, Tex.	600	7-8	525.0%
Ciniza, N.M.	150	>8	150.0%
Geisman, La.	200	<6	–

TABLE 10

Petroleum Refineries

Company & Location	Insolation Kwhrm^{-2}	Crude Capacity B/cd	Estimated Steam Capacity MW Thermal
CALIFORNIA			
Atlantic Richfield Co., Watson	6-7	93,000	454
Gulf Oil, Santa Fe Springs	6-7	21,900	132
Mobil Oil, Torrance	6-7	95,000	338
Shell Oil, Wilmington	6-7	50,000	236
Standard Oil, El Segundo	6-7	120,000	550
Union OIl (Grande (Santa Marie Ref.)	6-7	1,500	96
Union OIl (Rodeo (Oleum Ref.)	6-7	37,000	165
Union OIl (Wilmington (L.A. Ref.)	6-7	83,000	286
DELAWARE			
Getty Oil, Delaware City	6-7	90,700	385
KANSAS			
American Oil, Neodesha	6-7	–	85
CRA, Inc., Coffeyville	6-7	8,000	85
Mobil Oil, Augusta	6-7	17,000	132
Natl. Coop. Ref., McPherson	6-7	–	121
Phillips Pet., Kansas City	6-7	15,000	234
Skelly Oil, El Dorado	6-7	20,000	179
MINNESOTA			
Great Northern Oil, Pine Bend			
MISSOURI			
American Oil, Sugar Creek	6-7	35,000	228
MONTANA			
Continental Oil, Billings	6-7	12,200	121
Humble Oil, Billings	6-7	13,000	107
WYOMING			
American Oil, Casper	6-7	11,800	93
Atlantic Richfield, Sinclair	6-7	14,200	90
NORTH DAKOTA			
American Oil, Mandan	6-7	–	137
OKLAHOMA			
Champlin Pet., Enid	7-8	22,000	102
Continental Oil, Ponca City	7-8	13,000	217
Sequoia Refining, Ponca City	7-8	10,500	96
Sun Oil, Duncan	7-8	17,000	126
Sun Oil, Tulsa	7-8	31,500	245
Texaco, West Tulsa	7-8	13,500	129

Company & Location	Insolation $Kwhrm^{-2}$	Crude Capacity B/cd	Estimated Steam Capacity MW Thermal
TEXAS			
American Oil, Texas City	6-7	70,000	663
Atlantic Richfield, Houston	6-7	70,000	605
BP Oil Corp., Port Arthur	6-7	28,000	220
Chevron Oil, West. Div., El Paso	>8	24,600	179
Coastal States Petrochemical Corpus Christi	7-8	33,000	365
Cosden Oil & Chem., Big Spring	7-8	25,000	151
Crown Central Pet., Pasadena	6-7	38,000	231
Diamond Shamrock, Sunray	6-7	12,000	104
Gulf Oil, Port Arthur	6-7	158,100	904
Hess Oil & Chem., Corpus Christi	7-8	—	129
Humble Oil, Baytown	6-7	149,000	948
Marathon Oil, Texas City	6-7	20,000	118
Mobil Oil, Beaumont	6-7	103,000	866
Phillips Pet., Borger	7-8	—	234
Phillips Pet., Sweeny	6-7	—	234
Pontiac Ref., Corpus Christi	7-8	7,000	146
Shell Oil, Deer Park (Houston)	6-7	64,400	445
Signal Oil, Houston	6-7	21,000	198
Southwestern Oil, Corpus Christi	7-8	9,000	143
Suntide Ref., Corpus Christi	7-8	10,000	135
Texaco, Port Arthur	6-7	108,000	852
Texaco, Port Neches	6-7	22,000	124
Texas City Ref., Texas City	6-7	14,500	137
Union Oil of Calif., Nederland	6-7	39,000	288
UTAH			
American Oil, Salt Lake City	7-8	—	101
Chevron Oil, Western Div., Salt Lake	7-8	27,000	118
VIRGINIA			
American Oil, Yorktown	6-7	—	140

TABLE 11

Process Heat

Petroleum Refinery Statistics

Average Annual Insolation $KwHrm^{-2}$	Estimated Steam Generation Capacity MW Thermal			
	80-100	100-150	150-250	>250
6-7	5	11	10	13
7-8	1	9	3	2
>8	0	0	1	0

TABLE 12

Process Heat

Chemical Plants

State	Insolation KW Hr m^{-2}	Process Heat Capacity MW	Solar Potential MW
Nebraska	6-7	330	165
Kansas	6-7	1200	600
Maryland	6-7	775	387
Virginia	6-7	2500	1250
North Carolina	6-7	1260	630
South Carolina	6-7	1480	740
Georgia	6-7	780	390
Florida	6-7	1600	800
Arkansas	6-7	1370	685
Oklahoma	7-8	80	40
Texas	6-8	19600	9800
Idaho	6-7	150	75
Colorado	6-7	100	50
Arizona	>8	35	17
Utah	>7	35	17
Nevada	6-8	115	57
California	6-8	2000	1000

TABLE 13

Cement Plant Solar Units

Allowable Costs

Average Annual Insolation KW Hr m^{-2}	Fuel $/MMBTU	Maximum Cost for 8 Yr. Payout $/Ft.^{2}
8	2.50	10.22
8	4.00	16.35
7	2.50	8.94
7	4.00	14.30
6	2.50	7.67
6	4.00	12.26

TABLE 14

INDUSTRIAL BOILER COMMITTEE
H. Massey, Jr., Co-chairman
R. W. Precious, Co-chairman
J. C. Wilcox, Jr., Co-chairman

ABCO Industries, Incorporated
  B. E. Boyce, Vice President

Babcock and Wilcox Company
  W. H. Jackson, Vice President, Group Marketing
  J. C. Wilcox, Jr., Manager of Industry Sales

The Bigelow Company
  E. C. Crotty, President
  T. A. Gregeau, Vice President

Cleaver Brooks Division
  E. L. Weaver, Product Manager

Combustion Engineering, Incorporated
  H. Massey, Jr., Vice President
  J. P. Tully, Vice President

Energy Division of Zurn Industries, Incorporated
  C. L. Hedrick, Group Vice President

Foster Wheeler Energy Corporation
  A. F. Downham, Sales Manager, Industrial Equipment

International Boiler Works Company
  R. Imbt, Jr., Executive Vice President
  F.W. Taylor, President

E. Keeler Company
  R. J. Engler, President and General Manager

Lasker Boiler and Engineering Corporation
  F. A. Lasker, President

Nebraska Boiler Company, Incorporated
  D. T. Scully, President
  R. L. Swanson, Vice President, Manufacturing

Riley Stoker Corporation
  J. E. Hicinbothem, Vice President, Marketing
  R. E. Stough, Director Boiler Engineering

The Trane Company
  M. D. Farrell, Product Engineer
  H. J. Michaels, Sales Manager, Boiler and Combustion Products

Henry Vogt Machine Company
  R. W. Precious, General Manager, Boiler Division

APPENDIX B-II

Solar Tank Farm Heaters

Introduction

The federal solar energy program has many components. These range from the heating and cooling of homes and buildings to the generation of electric power by utilities. Several technologies are involved including wind power and photovoltaic solar cells. The technology closest to practical utilization on a large scale, however, is solar thermal conversion. In this the solar radiation is first converted to steam. Some or all of the steam is fed to a thermal storage unit. The remainder is fed to a turbine to generate electricity in the usual way. Steam is also generated in the thermal storage unit and supplies the balance of the driving force for the turbine. A ten megawatt pilot plant is being built by a group of utilities in Southern California and ERDA using this technology. Components for use in this plant and larger ones have been under development for several years by a number of ERDA contractors. The federal government is now identifying potential industrial applications that could use these same components.

The industries which are the primary energy consumers are petroleum refining, chemical, cement, and primary metals. A comparison of annual energy consumption is shown in Table 1. Thus applications for solar energy in these industries have been purposely sought out by ERDA. One application that has been suggested by many firms interviewed is supplying heat for tank farms. This summary report discusses the feasibility of a solar tank farm heater. In particular an approach is examined that can use the equipment being developed for utilities in the ERDA solar thermal conversion program.

The tank farm heater has several advantages as an initial industrial application of solar energy. First of all, there is an area above the tank for collection of the solar radiation. Obtaining sufficient collection area on the ground at an industrial site is often not possible for many applications. One of the questions discussed in this report is whether the area above a tank is sufficient for the tank heating requirements. Another advantage of this application is that there is a natural mechanism for energy storage. This is in the latent heat of the liquid stored in the tank. A point discussed below is the temperature fluctuation that would occur if solar energy were the only source of heat for the tank. A third advantage is that in a refinery there is already installed a heating system for the tanks that could be used during periods of extended bad weather. It could also be used in the evenings to reduce temperature fluctuations.

In this report the equipment and solar heating system are first described. Then the thermal characteristics of the system are discussed. These include the temperature fluctuations and the solar collector area requirements. Finally the economic trade-offs are discussed.

System Description

The solar tank farm heaters would be an auxillary steam generator that would complement the steam now being used to heat the tanks. Many different designs are possible and only one approach is discussed here. In this a distributed solar collection system would be erected above the tanks. This would consist of rows of cylindrical troughs with the boiler tubes supported along the focal line of each trough. The latter serves as a reflector to concentrate the radiant energy. A typical component under development by ERDA is shown in Figure 1. Orientation of the trough is typically north-south with the collector rotating during the day to follow the sun. Steam temperatures of 600-700°F can be obtained with these components. In tank farm heaters the required steam temperatures are not expected to exceed 450°F. This will allow some trade-offs in design to achieve lower cost.

Steam would exit from the collectors into the existing manifold for heating the contents of the tank. Condensate would be pumped back into the collectors. A control means would be provided to switch between the main steam plant and the solar boilers. At night steam from the main plant would be used according to the tolerance for temperature fluctuations.

There is another type of collector also under development. This is a flat plat collector. It has the advantage of using diffuse as well as direct insolation. Since the cylindrical collector is a focusing device it can produce higher temperatures than the flat plate collector. In the tank farm heating application, however, this may not be necessary.

Thermal Analysis

The heat loss from a tank depends upon a number of parameters. Since our concern is with assessing the feasibility of a solar heater rather than a detailed design nominal values have been assumed for the parameters. These are listed in Table 2 along with the corresponding heat loss.

We can now compare this heat loss to the available solar energy. The intensity of solar insolation varies with the time of day, the seasons, and weather conditions. The way in which these variables are taken into account depends upon the strategy that is used for a back-up energy supply. First assume that the solar boiler is the only source of steam in fair weather. That is, steam is generated at a maximum rate during daylight hours, raising the temperature of the liquid in the tank. At night no steam is generated and the temperature falls. The calculation of temperature loss is illustrated in Table 3. This, of course, assumes that the fluid remains at a uniform temperature. Actually the temperature drop would be greater at the sides of the tank.

The above is a worst case situation for calculating the area of solar collectors required. If a smaller temprature fluctuation were desired then steam from the central plant could be used at night or even continuously so that the heat input to the tank was uniform. In these cases the solar boiler would be smaller but less fossil fuel would be displaced.

Figure 2 shows the twenty-four hour average insolation at different times of the year. Let us calculate the collector area for an average insolation of 4 KW hr. m^{-2}. This would allow application of the solar unit in the Texas Gulf Coast and California in the winter. These are major centers for petroleum refining. The required area for this average insolation is 8558 ft.^{2}, assuming 50% efficiency for the collectors. The area above the 100 foot tank is 10,000 ft.^{2} so the required area is available.

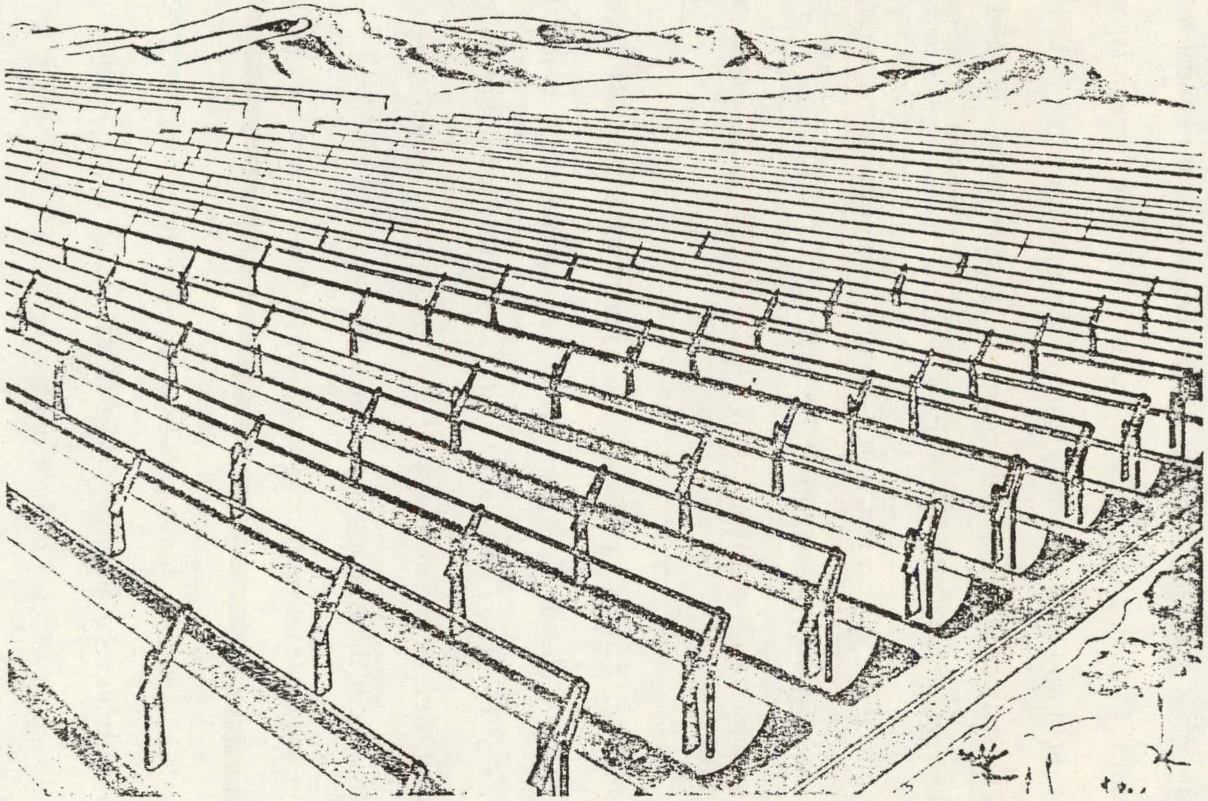
Economic Analysis

A precise economic analysis of this application is not possible because there are many rapidly changing costs involved. Solar boilers are now under development. Their costs are rapidly decreasing due to new technology and to normal learning curve effects. The cost of steam from the central steam plant is rapidly going up due to the rising cost of fossil fuel. In discussions with representative firms in the petroleum industry different opinions were obtained on the energy cost that should be used in making future economic analyses. In this report a projected cost of \$3.50 per million BTU has been chosen. The solar boiler disucssed above would displace 1982 x 10^6 BTU per year. Thus the yearly energy saving would be equivalent to \$6937. Assume that the payout of the solar boiler is in 3.3 years. Also assume that initial applications are in a region with average daily insolation of 7 KWHR/M^2. The required area is then about 4600 ft.^{2}. Then the allowable investment cost would be \$22,892 or \$4.98 per square foot of collector.

Another approach to conserving energy is to increase insulation. It is assumed in the above analysis that this has already been optimized. For example the heat loss was estimated assuming 1-1/2 inches of insulation costing \$2.00/ft.^{2}. The total insulation cost was \$25,120 and the outside tank surface temperature was 57° F. Doubling the insulation would add an investment of \$25,120 and cut the heat loss approximately in half. At \$3.50 per million BTU and 3.3 years payout the allowable investment would be \$11,446. This is not enough to justify adding the additional insulation.

The allowable investment for the solar heater as calculated above is expressed as dollars per square foot. It must include all costs, however, associated with the solar system. These would include the piping, valves, and control units as well as the mechanism for orienting the collectors. Projected cost goals for cylindrical collectors being developed in the ERDA program are \$5-6/ft.^{2}. The requirement from the above analysis is consistent with this. Thus it is concluded that as these components become developed for use in electric power generation they also would be applicable to solar boilers in tank farm heaters, assuming fuel costs rise to \$3.50 per million BTU.

Figure 1



General Atomic Distributed Collector Deployment Concept

Figure 2A

Average Daily Direct Normal Insolation

(kWhr m^{-2})

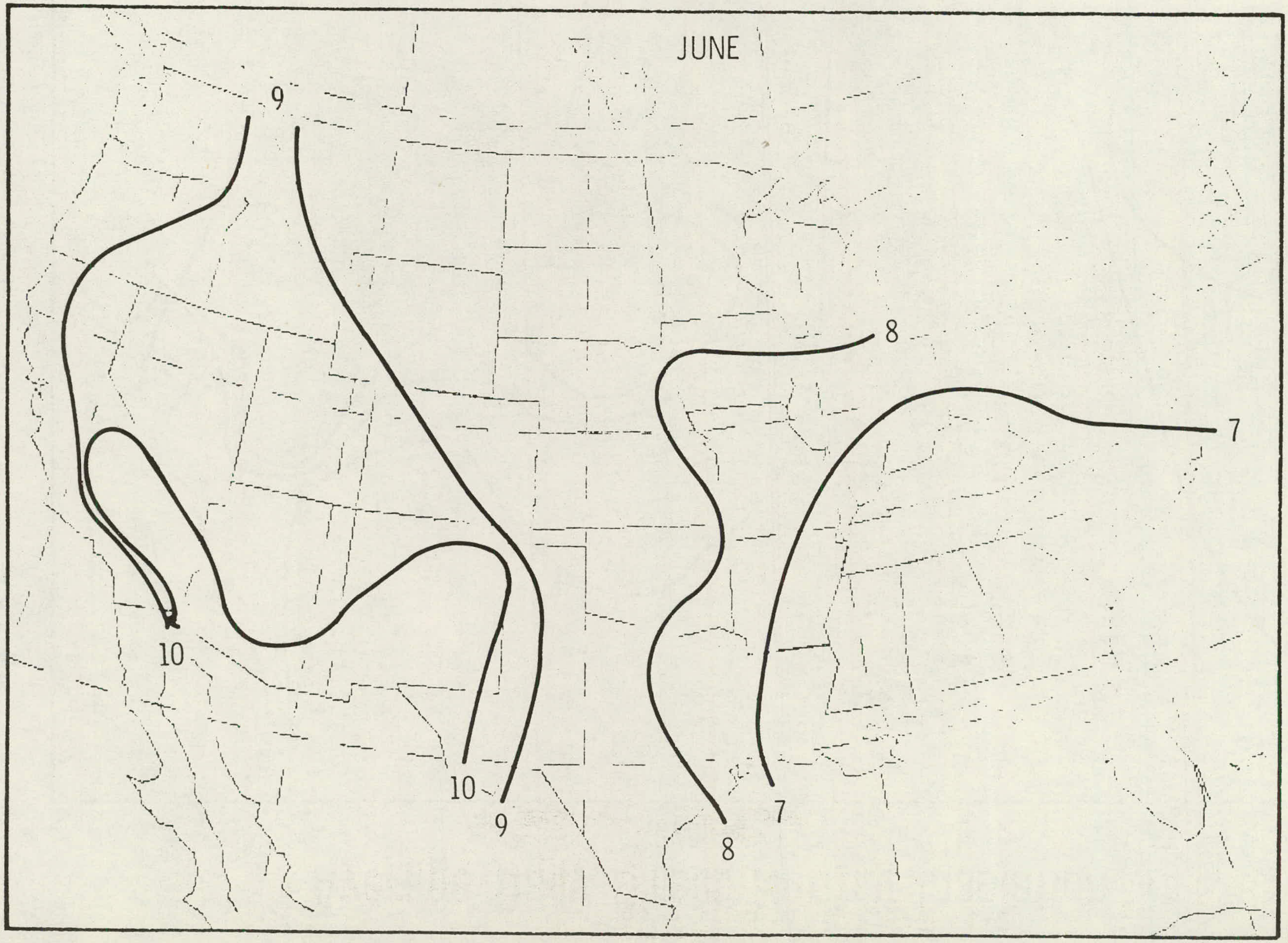


Figure 2B

Average Daily Direct Normal Insolation

(kWhr m^{-2})

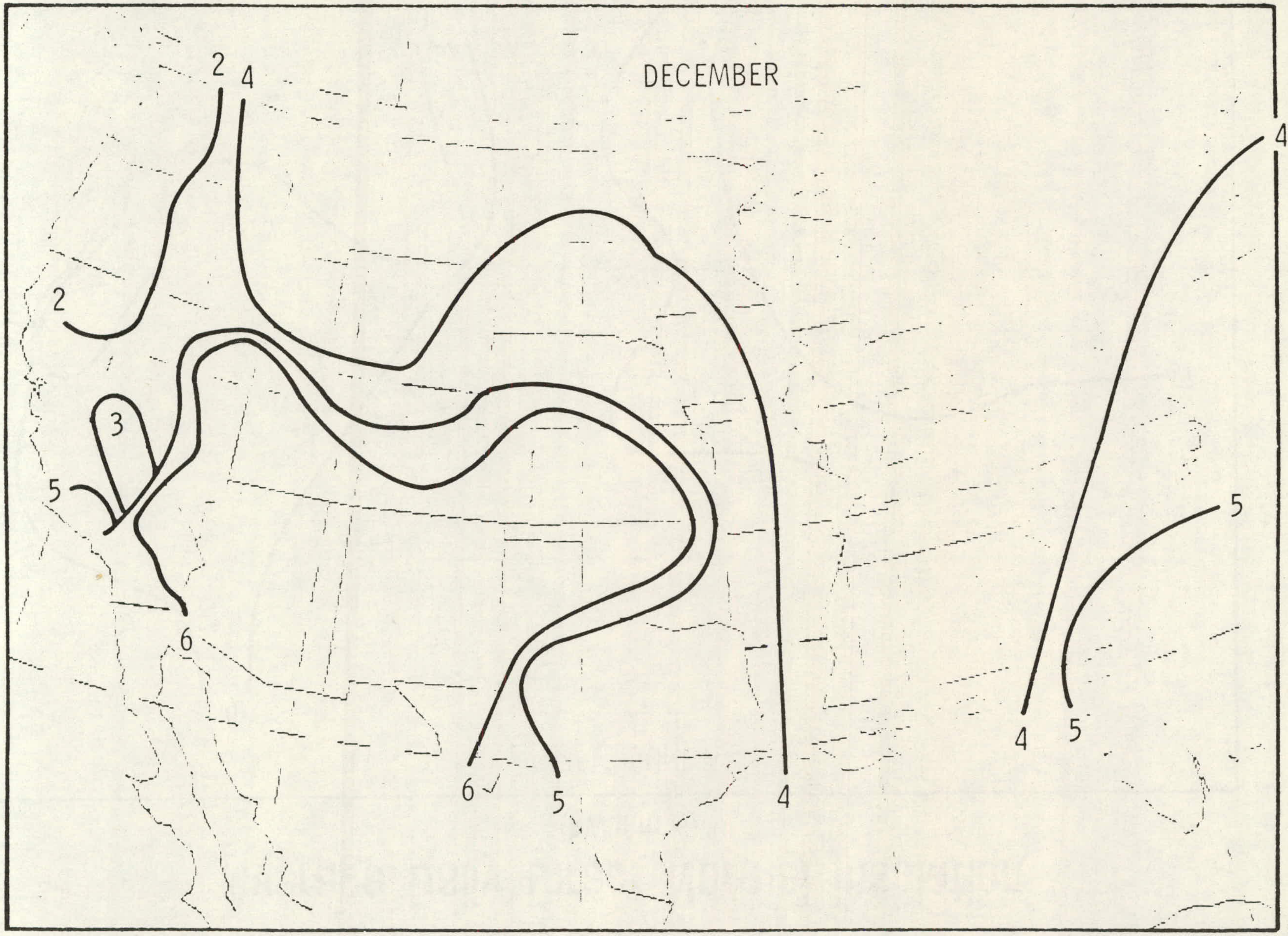


TABLE 1

ENERGY CONSUMING INDUSTRIES

SOUTHWEST

	OIL (1000 Barrels)	COAL (Short Tons)	GAS (Billion cu.ft.)	ELECTRIC (Billion KWH)
CHEMICAL	347	--	611	225
PETROLEUM	1669	--	927	287
STONE, CLAY, GLASS	1191	1	197	66

TABLE 2

Tank Farm Heater Parameters

Diameter	100 feet
Liquid Height	40 feet
Temperature	250°F
Insulation	1-1/2 inches
Ambient Conditions	50°F; 10 mph wind
Cooling Rate	18 BTU/HR/SQ.FT.- 12,560 SQ. FT. = 1982 x 10^6 BTU/YR.
Available Solar Collection Area	10,000 SQ. FT.
Steam	350°F

TABLE 3

Estimate of Temperature Loss

Assume worst case — no solar input

Cooling Rate	18 BTU/HR/SQ. FT.
Area	12,560 SQ. FT.
Total Cooling Rate	0.23×10^6 BTU/HR
Heat Capacity	0.4 BTU/lb./°F
Specific Gravity	0.7
Liquid Volume	314,000 Cu. Ft.
Temperature Loss	0.04°F/HR

APPENDIX B-III

Solar Steam Plants

Introduction

The federal solar energy program has many components. These range from the heating and cooling of homes and buildings to the generation of electric power by utilities. Several technologies are involved including wind power and photovoltaic solar cells. The technology closest to practical utilization on a large scale, however, is solar thermal conversion. In this the solar radiation is first converted to steam. Some or all of the steam is fed to a thermal storage unit. The remainder is fed to a turbine to generate electricity in the usual way. Steam is also generated in the thermal storage unit and supplies the balance of the driving force for the turbine. A ten megawatt pilot plant is being built by a group of utilities in Southern California and ERDA using this technology. Components for use in this plant and larger ones have been under development for several years by a number of ERDA contractors. The federal government is now identifying potential industrial applications that could use these same components.

The industries which are the primary energy consumers are petroleum refining, chemical, cement, and primary metals. A comparison of annual energy consumption is shown in Table 1. Thus applications for solar energy in these industries have been purposely sought out by ERDA. Much of the process heat requirement is supplied by steam rather than direct firing. The steam has the advantage of good thermal characteristics in addition to safety. A leak does not bring about a fire hazard as with other heat transfer fluids.

The components for generating this steam in a large solar unit are already being developed as a part of the ERDA solar thermal conversion program. This equipment is discussed further below. Also discussed is the proposed hybrid operation of the steam plant so that a continuous output is possible twenty-four hours a day. The components are being developed for utility application. Additional industrial applications of the same components would increase the total market size. This could introduce economies of scale in manufacturing and benefit both the utility and industrial application.

Description of Equipment

Large solar steam generators designed for utilities will use a field of heliostats. These reflect the direct insolation to the top of a tower where the solar boiler is located. A mechanism is provided with the heliostat so that its orientation can be continuously varied during the day to keep the reflected radiation on target at the top of the tower. A couple of receiver designs which contain the solar boilers are shown in Figures 2 and 3. These are under development by Foster Wheeler and Babcock & Wilcox respectively. In the Foster Wheeler design radiant energy enters the boiler from one side whereas in the second design it is trapped in a cylindrically symmetric configuration. The steam produced in the solar boiler moves to a thermal storage unit or a turbine generator.

A hybrid industrial steam plant is shown graphically in Figure 4. Here all of steam generated in the solar boiler would go to thermal storage. Two approaches have been examined for the latter. One is a bed of rock; the other is a molten salt utectic. In the hybrid steam plant direct heating of the thermal storage unit with oil or gas would also be possible. Process steam would then be generated within boiler tubes placed in the thermal storage medium. This plant would generate steam at a constant rate over a twenty-four hour period. Input of energy into the thermal storage unit would vary with time. The mixture of fossil fuel and solar energy would depend on the time of day and weather conditions.

Typical size parameters for such a unit are shown in Figure 6. These sizes correspond to a 100 MWE utility solar power plant with an efficiency of about 36%. This would be the next step beyond the current pilot plant project. From the table it can be seen that one of the major questions is availability of space for the heliostat field. This would be particularly true for refineries in major metropolitan areas. One source of space, however, is the tank farm. If the heliostats were supported above the tanks then this space could be utilized. The area required for 200 MMBTU/HR of steam generation capacity would be about 50 acres.

There is also an alternative technology to using heliostats and a central receiver. This alternative is to use a cylindrical trough as shown in Figure 5. This concentrates the direct insolation along the focal line where the boiler tube is located. The maximum steam temperature from these units would be about 700°F but this is adequate for most process heat applications. An advantage of the cylindrical trough is that orientation can be simpler and is less critical than with the heliostat field. The orientation sensitivity of the heliostat is due to the long path length of the light after initial reflection.

Thermal and Economic Analysis

In a hybrid solar steam generator as discussed above there are various trade-offs in design that can be considered. First of all, it is assumed that the output of process steam is continuous over a twenty-four hour period. The greater the thermal storage capacity the greater will be the percent of the energy output supplied by solar. Solar input will vary during the day. Let us further assume that direct heating of the storage medium by fossil fuel occurs at a uniform rate but only during the evening or bad weather conditions. This rate would be that required when no solar insolation was available for an extended period. In other words it would equal the output requirement of the plant plus losses. This would correspond to the minimum acceptable investment in the fossil fuel heater. The minimum storage requirement would be that to handle fluctuations in the solar heating rate during the day. Based on studies of utility plants this would be about 6 hours of storage capacity for an optimum case.

With these assumptions a rough economic analysis can be carried out. The hybrid solar steam plant is an energy saving unit. The extra capital investment for the solar components would be justified on the basis of the fossil fuel displaced. The units with 6 hours storage that are planned for utilities have projected cost goals of about $1360 per kilowatt electric installed. This corresponds to about 9500 BTU/HR of steam generation. The projected investment cost for just the steam generation part of the plant is 80% of the total. In an electric utility these units would be used for intermediate load applications. In operation as a steam generator the steam would be generated continuously in the thermal storage unit. During periods of high insolation at midday energy is delivered to the thermal storage unit in excess of requirements. This excess solar energy is then used for additional steam generation later in the day before direct firing is initiated. In the Southwest such a plant would be expected to get 47% of its energy input from solar. This figure is the annual average from available weather data.

The above data have been developed by the Aerospace Corporation for a hypothetical plant at Inyokern, California. Average daily direct insolation is shown in Figure 1 as a function of geographic location. Along the Texas Gulf Coast the displacement of fossil fuel by solar energy would be reduced by about 25%. A $1360 investment would result in an annual average of 3350 BTU/HR of solar steam generation. This is 35% of the total of 9500 BTU/HR. Payout of the investment would be 13 years at $3.50/MMBTU.

TABLE 1

ENERGY CONSUMING INDUSTRIES

SOUTHWEST

	OIL (1000 Barrels)	COAL (Short Tons)	GAS (Billion cu.ft.)	ELECTRIC (Billion KWH)
CHEMICAL	347	––	611	225
PETROLEUM	1669	––	927	287
STONE, CLAY, GLASS	1191	1	197	66

Figure 1

Average Daily Direct Normal Insolation

(kWhr m^{-2})

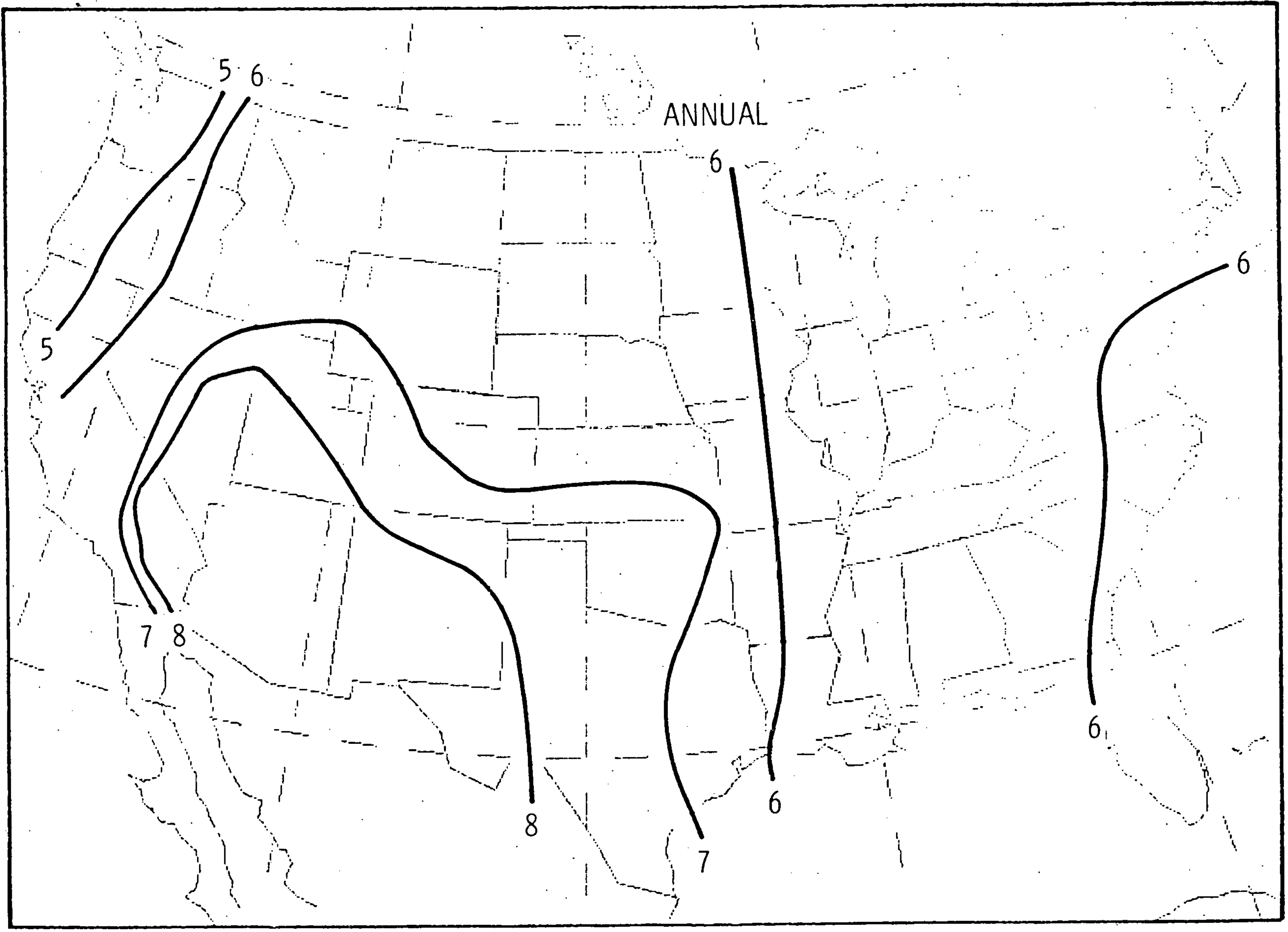


Figure 2

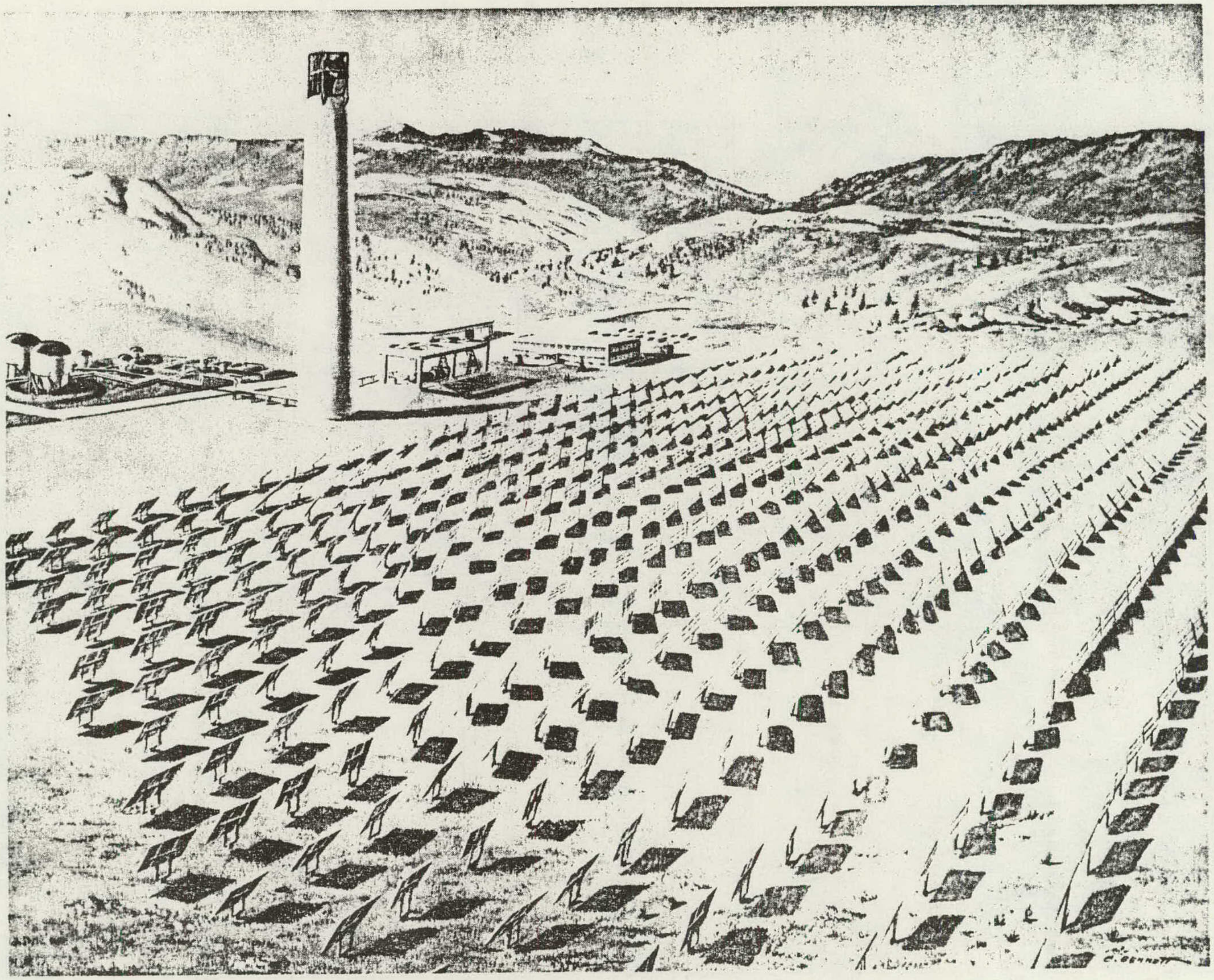


Figure 3

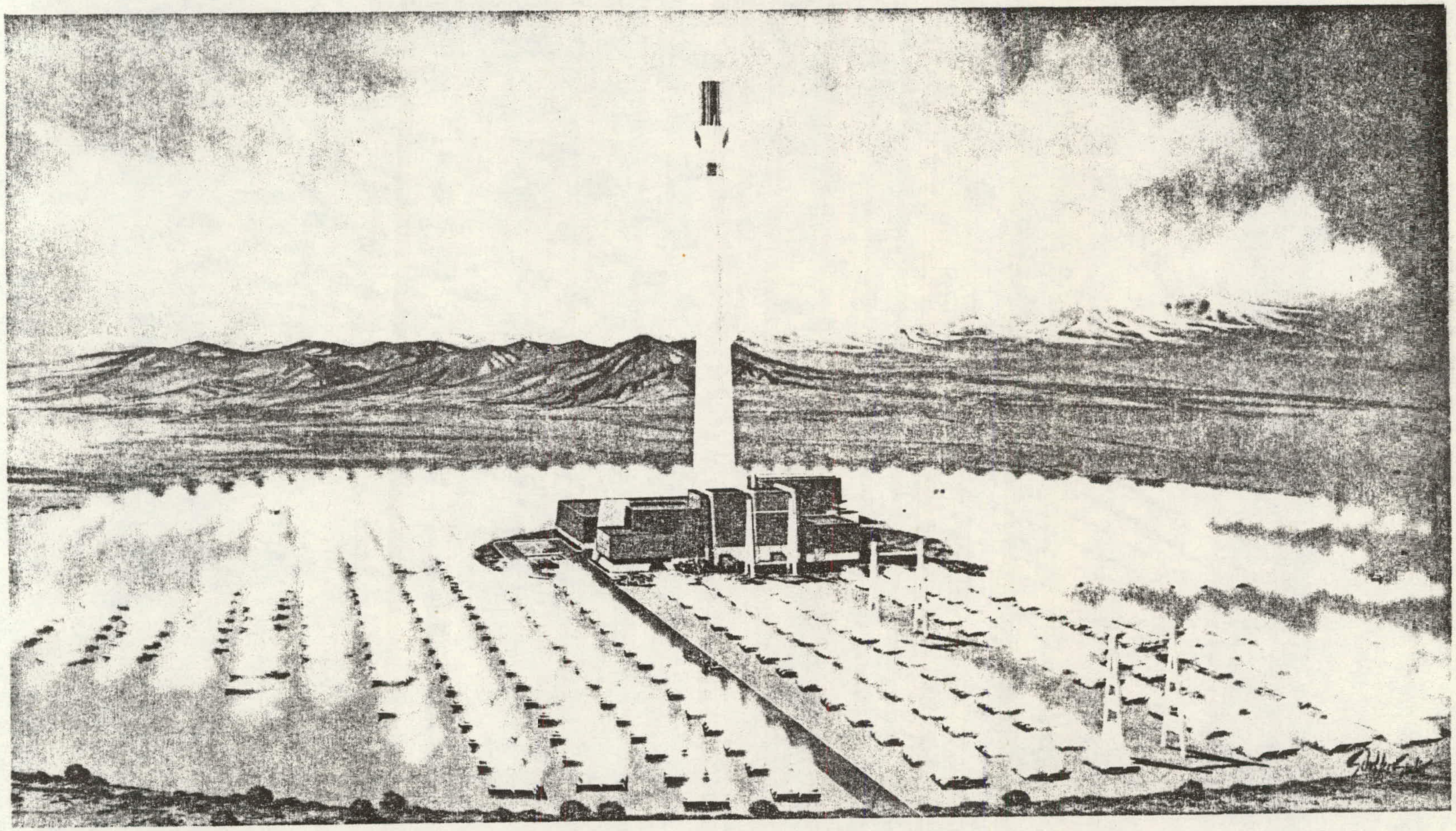


Figure 4

HYBRID STEAM PLANT

CENTRAL TOWER

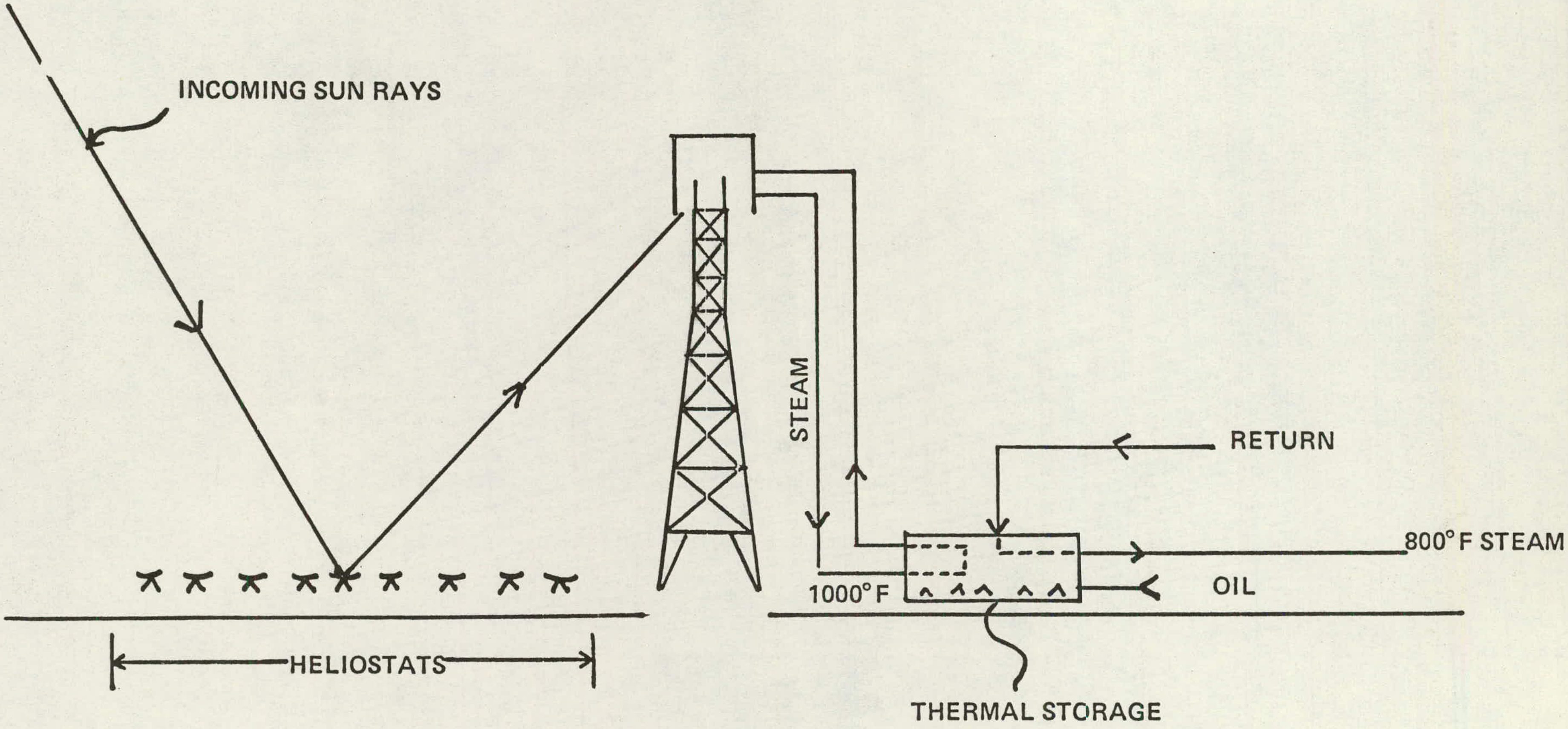
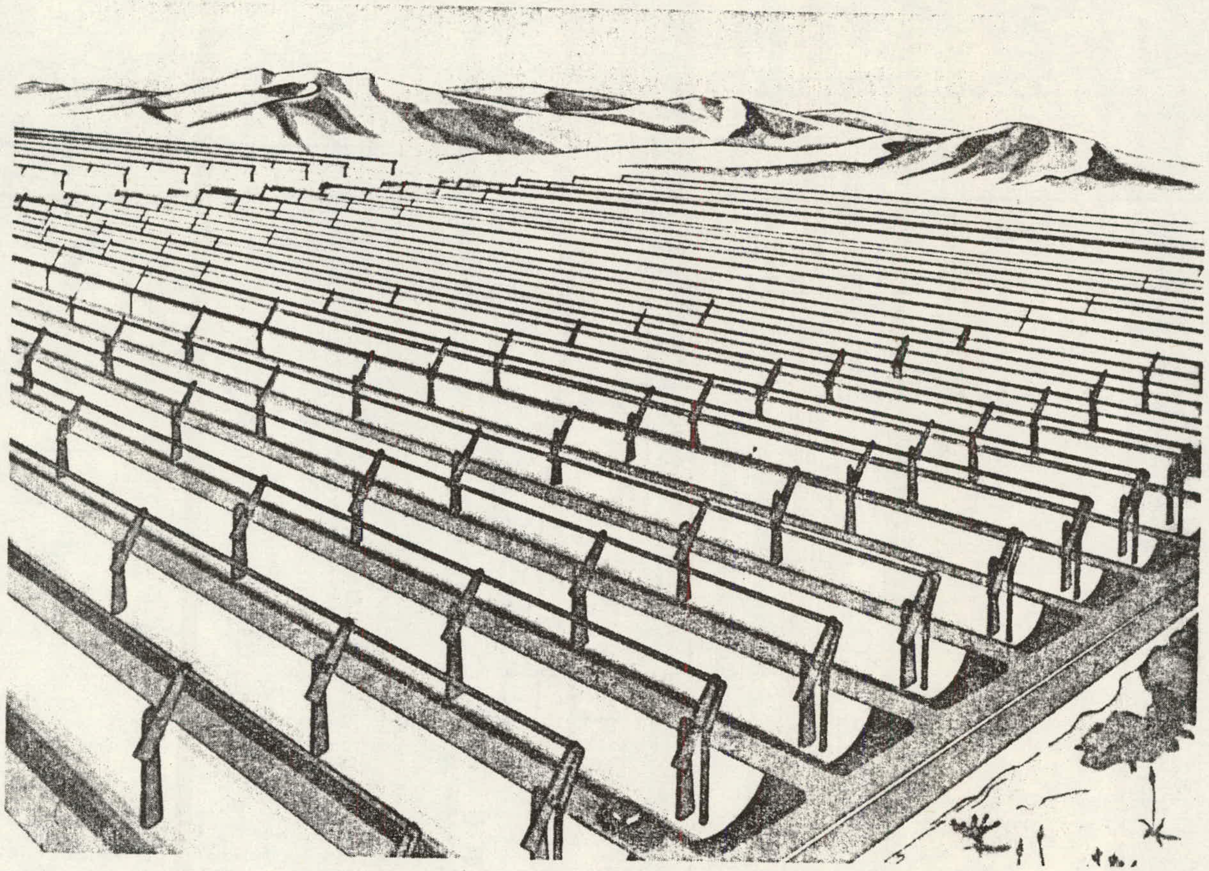


Figure 5

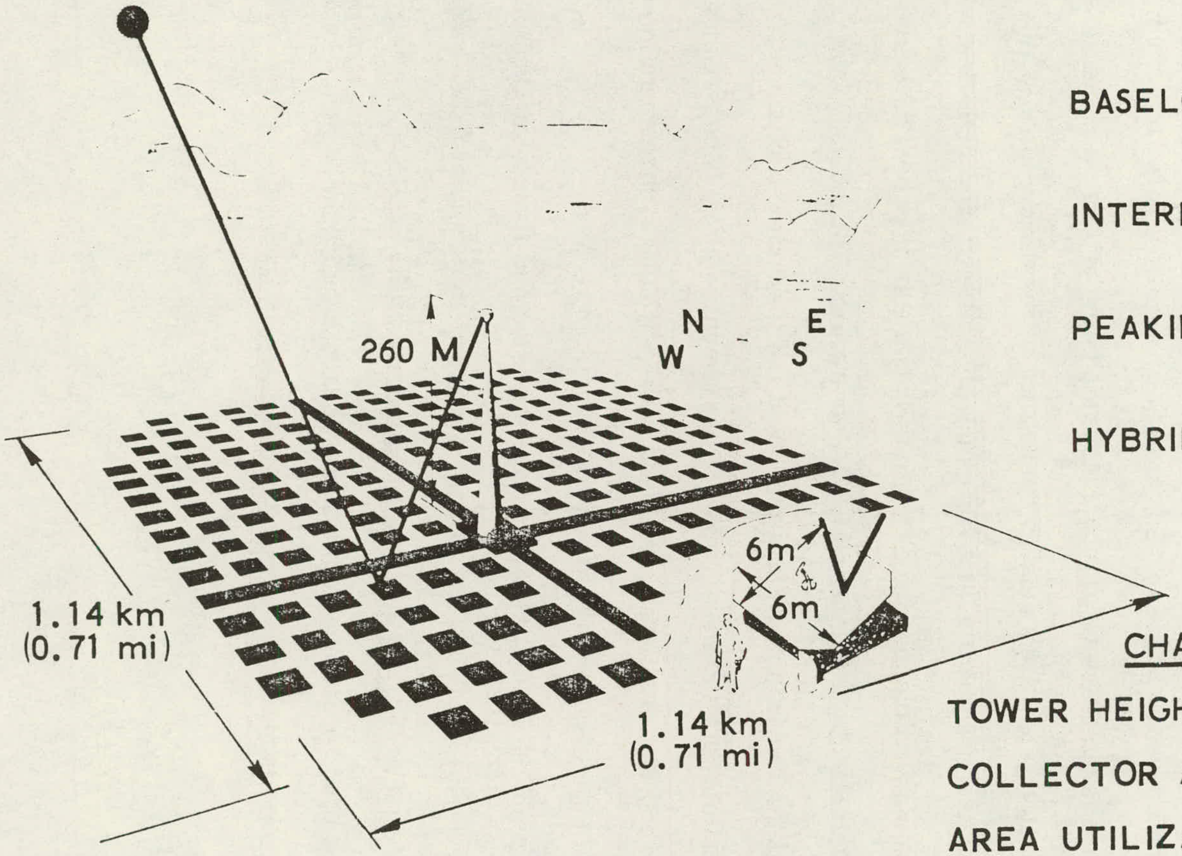


General Atomic Distributed Collector Deployment Concept

Figure 6

Solar Thermal Conversion

CENTRAL RECEIVER CONCEPT



100 MW_e PLANT

BASELOAD	3 MODULES (12 hr storage)
INTERMEDIATE	2 MODULES (6 hr storage)
PEAKING	1 MODULE (3 hr storage)
HYBRID	1 MODULE (1/2 hr storage)

CHARACTERISTICS

TOWER HEIGHT	260 m
COLLECTOR AREA	0.5 km^2/MODULE
AREA UTILIZATION	38.6%
TOTAL LAND AREA	1.3 km^2/MODULE
No. OF COLLECTORS	15,400/MODULE
SIZE OF COLLECTORS	32.4 m^2

APPENDIX B-IV

Report on Cement Plants

Introduction

The federal solar energy program has many components. These range from the heating and cooling of homes and buildings to the generation of electric power by utilities. Several technologies are involved including wind power and photovoltaic solar cells. The technology closest to practical utilization on a large scale, however, is solar thermal conversion. In this the solar radiation is first converted to steam. Some or all of the steam is fed to a thermal storage unit. The remainder is fed to a turbine to generate electricity in the usual way. Steam is also generated in the thermal storage unit and supplies the balance of the driving force for the turbine. A ten megawatt pilot plant is being built by a group of utilities in Southern California and ERDA using this technology. Components for use in this plant and larger ones have been under development for several years by a number of ERDA contractors. The federal government is now identifying potential industrial applications that could use these same components. Major industrial users of process heat are shown in Table 1. The cement industry is one of these. It is for this reason that several discussions have been held with individuals in the cement industry to explore the feasibility of using solar energy for process heat.

Several potential solar applications were suggested and these have been summarized in the next section. Following this a description is given of the equipment being developed in that part of the federal program that is related to electric utility applications. Much of this equipment could be used to implement the suggestions received. Finally in this report the thermal and economic aspects of using solar energy are discussed.

Solar Application Opportunities

The suggestions that have been received for application of solar energy in the cement industry are summarized in Figure 1. There material flow is shown for a normal dry process cement plant. Only the dry process plant was considered because of the gradual conversion of wet process plants to dry. The normal flow of material and heat in Figure 1 is shown in solid lines. Potential applications for solar heat are shown in dashed lines.

The first application would be in drying. This would be applicable to those plants located at wet quarries. The solar input to the drying step could be in the form of hot air at less than 1500°F. Some solar units are under development in the federal program that will produce hot gas up to 1700°F. This is illustrated in the next section. Some of the air used to cool the clinkers could be passed through the preheater and then the solar heater to raise its temperature to 1500°F. Less input of gas or oil at the dryer would then be required.

A second application that has been suggested is in preheating the solids before entering the kiln. Again air used to cool the clinkers could be heated to a higher temperature in a solar heater. This air would then be used in the preheater.

Far more energy could be introduced into the process through precalcining. Here there could be direct introduction of radiant energy into the precalcining reactor. The latter would be analogous to a solar boiler. Radiation would be received at the reactor from a field of heliostats. This radiation would be trapped in the receiver and eventually absorbed in the reactor tubes. The reaction, $CaCO_3 \longrightarrow CaO + CO_2$ would take place at a constant temperature of about 1560°F. In the analogous receiver shown in Figure 2 water is converted into steam at the constant temperature of about 1000°F. Heat transfer from the outside wall of the reactor tube to the calcium carbonate on the inside would need investigation. The plant would have to operate continuously twenty-four hours a day. This means that an alternative fuel, such as gas, would have to be burned in the precalcining reactor. This would be done in a controlled manner so that the total heat input, radiant plus gas combustion, was always a constant.

Precalcining is a method of getting high quality solar heat into the reaction system directly with a minimum of equipment. Solar energy introduced at the precalcining step would displace coal or other fossil fuel introduced at the kiln. Also precalcining has the advantage of reducing the size of the kiln that is necessary. Alternatively in an existing plant it can allow production to increase within the same kiln.

A somewhat different approach to precalcining has also been suggested. In this a separate unit would be involved and the lime from this precalcining unit would be stockpiled. This stockpile would serve as an energy storage mechanism. Material would be added to the stockpile when available radiant energy was above a minimum level required to operate the precalcining unit. Material would be removed from the stockpile continuously at a constant rate, preheated and introduced to the kiln. This approach has the advantage that greater energy displacement by solar is possible because of the energy storage mechanism. It has the disadvantage of requiring more equipment. Also the sensible heat of the lime in the stockpile may be lost. The amount lost would depend on the containment of the stockpile and its size. In a worst case where the material cools to ambient the loss would be about 20% of the energy introduced when the calcium carbonate was converted to lime.

Thermal Analysis

The intensity of solar insolation varies with the time of day the seasons, and weather conditions. In the above applications these fluctuations are countered by varying the input from fossil fuel. The exception would be in stockpiling the lime from a solar precalcining reactor. In the latter case the solar unit could be designed to provide the entire energy requirement for precalcining. This then could account for about 50% of the energy input into the plant. The heliostat field might be sized so as to provide the average requirement during the winter months. The average daily direct normal insolation is shown in Figure 4 for the winter. Consider those geographic areas where this number is above 4 Kw-hr m^{-2}. This area would include the Southwestern United States. The minimum size for the heliostat field can now be estimated. A 600,000 ton/year cement plant would correspond to 180 MM BTU/HR energy input to precalcining. This would require a solar collection area of about 0.84 Km^2 assuming 38% area utilization for the heliostats. This size unit would correspond to an 84 MWE intermediate load utility generating station.

Alternatively if stockpiling is not used the size of the heliostat field would be such that during maximum insolation all energy requirements were being met by the solar unit. A larger size would be less economic and a smaller size would not have as great an energy displacement. This assumes that high temperature thermal storage is not used. Assume a summer peak of about 0.7 Kwm^{-2}. In the case of our example above the heliostat field for this plant would be 0.075 Km^2. This corresponds to an electric utility plant rated at 7.5 MWE. Energy displacement in this case would be 4.5% instead of 50%.

Economic Analysis

A precise economic analysis of this application is not possible because there are many rapidly changing costs involved. Solar boilers are now under development. Their costs are rapidly decreasing due to new technology and to normal learning curve effects. The units that are planned for utilities have projected cost goals of $60/M^2 of collector surface. Adding in the cost of the solar receiver, $90/M^2 of collector surface is assumed below.

This number can now be used to comment on the economic feasibility of the proposed applications. First consider the case of precalcining and stockpiling. In the above example with a 600,000 ton/year cement plant the displacement of fossil fuel with solar energy would be 50%. The solar plant would correspond to an 84 MWE electric utility unit in size. The relevant components of the latter are the heliostat field and solar receiver. Collector area would be 0.32 Km^2 and projected investment would be about $28.8 million. The allowable investment for a 50% displacement would be $31.5 million assuming a 10 year payout and $2.00 per million BTU. Thus it is concluded that if the federal solar program related to electric utilities is economically successful then the above would represent a feasible application of the same components.

Next consider the application where there is no storage of energy. In the above example the size of the solar plant was equivalent to a 7.5 MWE power generation plant. The projected cost of the relevant components would be $2.6 million. The energy displacement would be 0.14 x 10^6 million BTU per year, and the calculated allowable investment is $2.8 million. Again the conclusion is that the application will be feasible if the plants being developed for electric utilities become economically successful.

Description of Equipment

Large solar steam generators designed for utilities will use a field of heliostats. These reflect the direct insolation to the top of a tower where the solar boiler is located. A mechanism is provided with the heliostat so that its orientation can be continuously varied during the day to keep the reflected radiation on target at the top of the tower. A couple of receiver designs which contain the solar boilers are under development by Foster Wheeler and Babcock & Wilcox respectively. In the Foster Wheeler design radiant energy enters the boiler from one side whereas in the second design it is trapped in a cylindrically symmetric configuration. The steam produced in the solar boiler moves to a thermal storage unit or a turbine generator.

The part of this system which would be applicable to the cement plant would be the heliostat field and central receiver. In one of the potential applications the latter would be modified so that it was a precalcining reactor rather than a boiler. It is envisioned, however, that the design would be similar. Temperature control would come from the constant temperature reaction taking place. If radiant energy is being received then the reactants must be present or the tube walls in the receiver would become overheated.

A modification of the receiver is being developed in the federal solar thermal conversion program for the production of hot gas. The latter would be used by a Brayton cycle for the generation of electric power. This or similar equipment once developed could be used for producing hot gas in the cement plant for drying. Solar receiver capacities of 400 megawatts thermal or 1365 MMBTU/HR are under consideration for utilities. A typical cement plant might produce 600,000 tons per year and require for continuous operation a heat input rate of 360 MMBTU/HR. If 50% of this heat input is provided by precalcining then the size solar unit required would be about 53 megawatts thermal. This is only slightly larger than the pilot plant now under construction.

Figure 1

CEMENT MANUFACTURE

DRY PROCESS

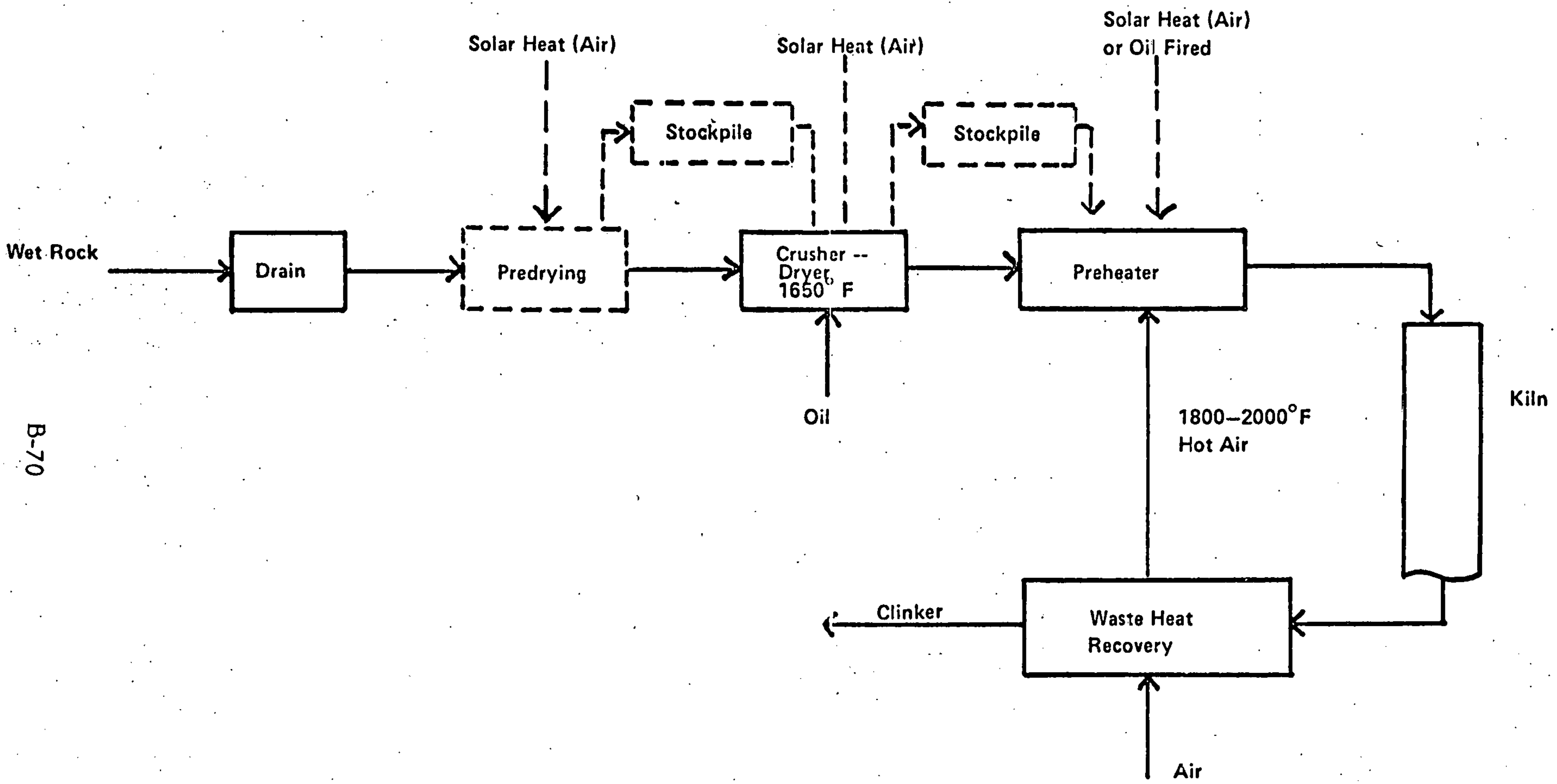
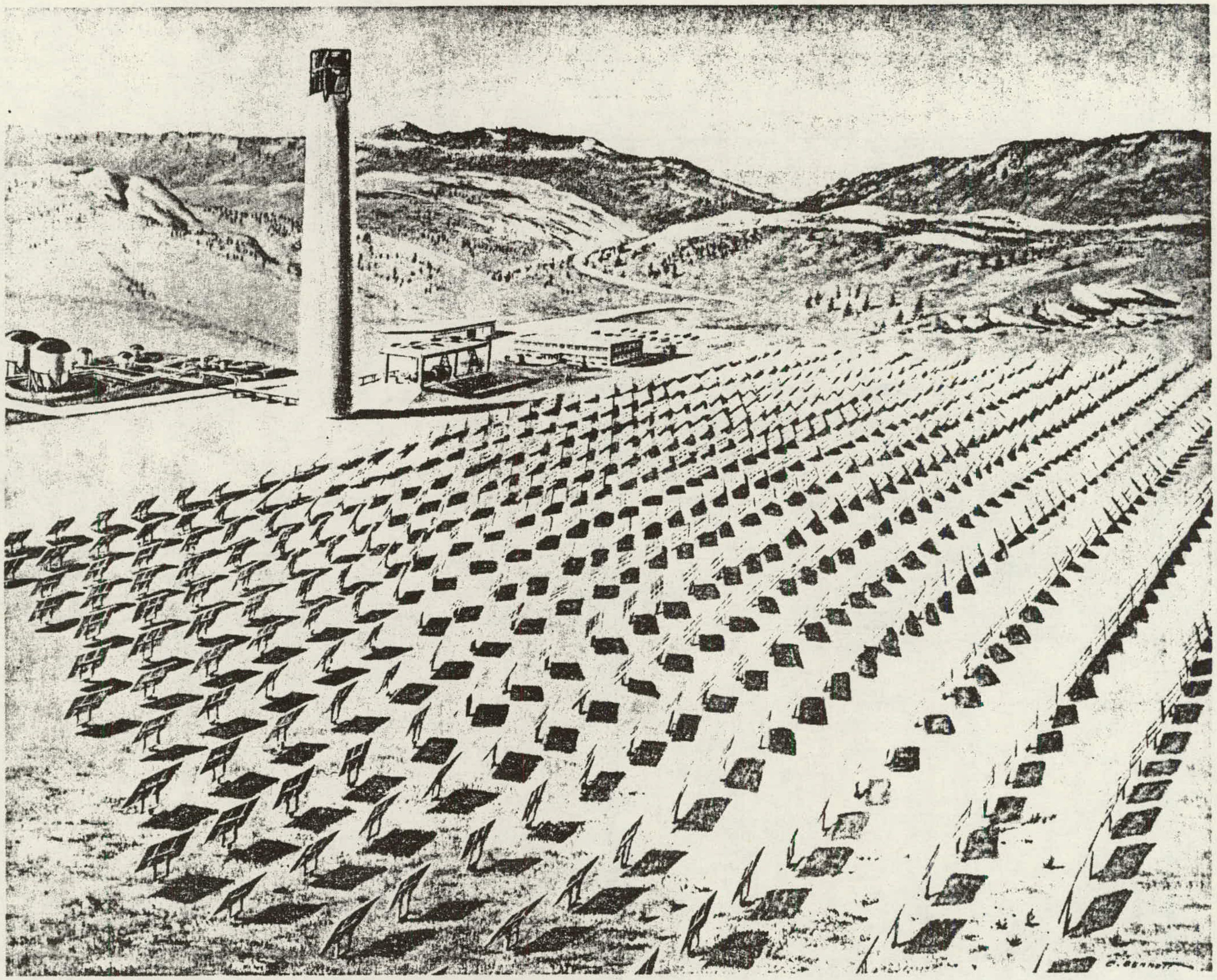


Figure 2



ARTIST'S CONCEPT OF THE MARTIN MARIETTA 10 MWe PILOT PLANT

Figure 3

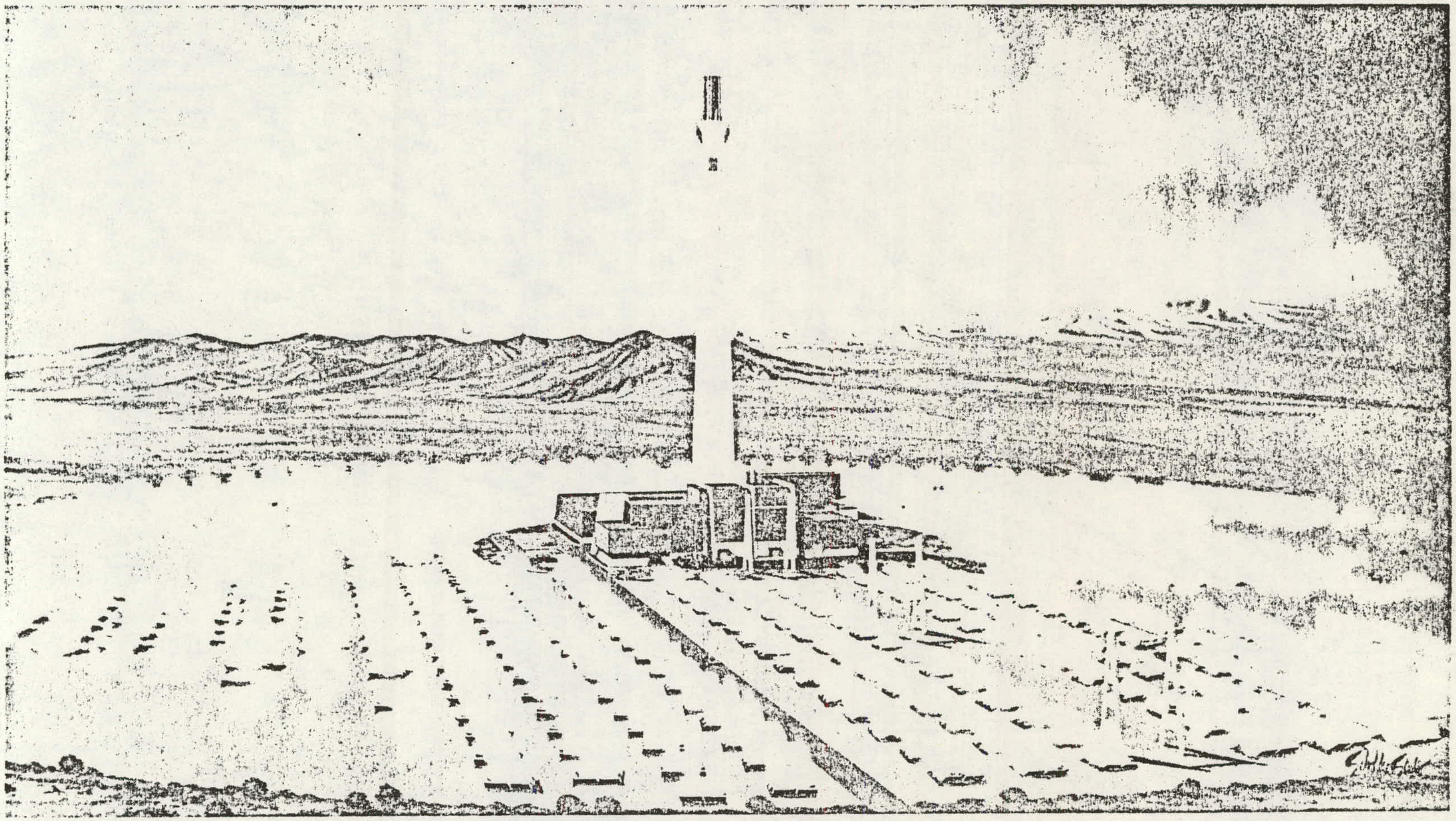
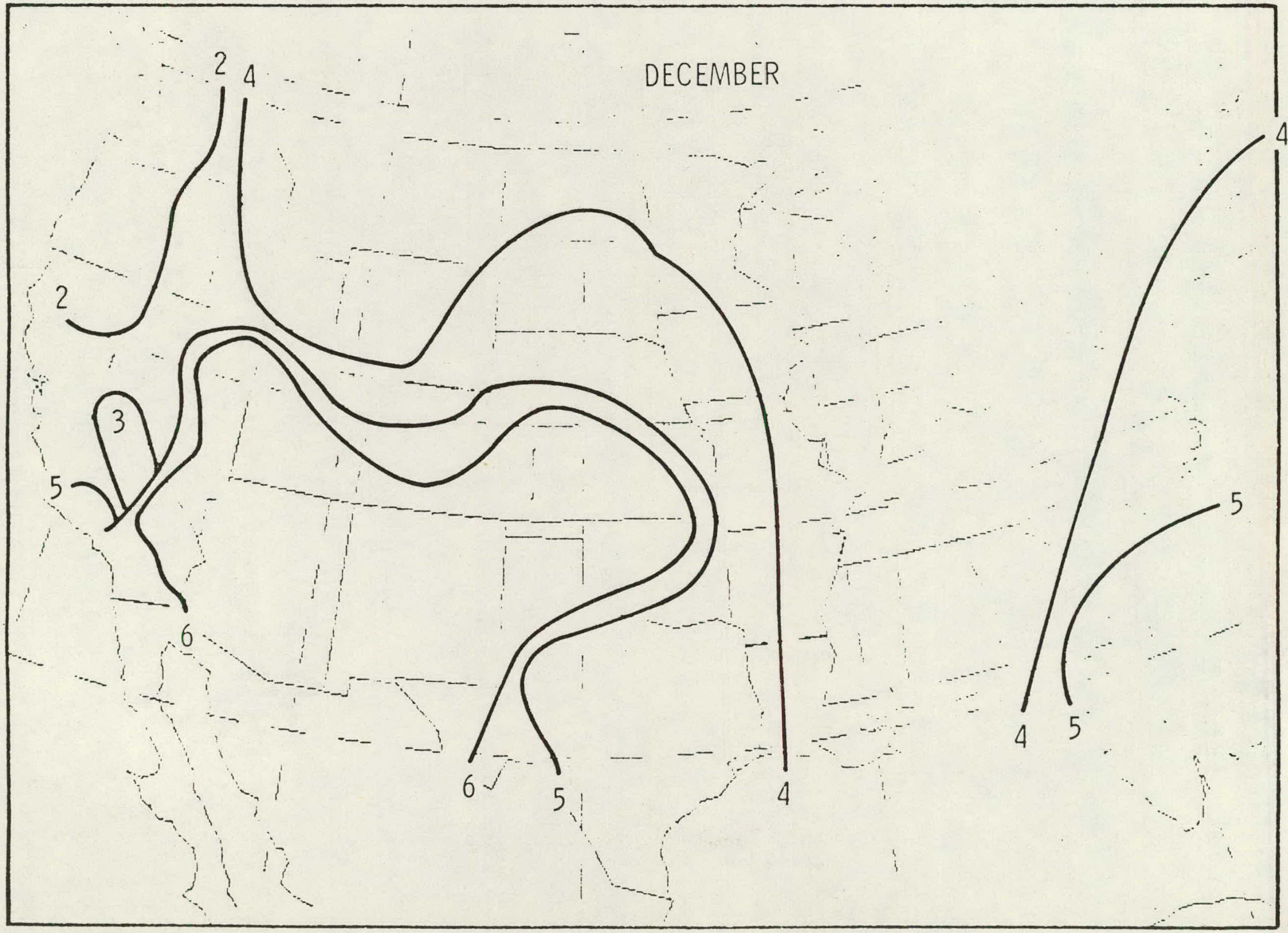


Figure 4

Average Daily Direct Normal Insolation

(kWhr m^{-2})



APPENDIX C

APPENDIX C

EQUIVALENT COST OF PROCESS HEAT SYSTEMS

The following analysis determined the real costs (per 10^6 Btus) for process heat plants, after deleting the effects of general inflation.

The study considered the annualized cost of process heat systems for two life cycle periods; 10 and 20 years. A single process heat plant delivering up to 100×10^6 Btus per hr (29 MW_{th}) was evaluated. Several conventional plants' concepts (coal, oil and gas) were compared with a solar thermal plant (heliostats and receiver) which included thermal storage. Annualized costs were calculated based on a present worth methodology for the California Industrial Sector. In summary, for a 10-year life cycle, solar plants become competitive with coal process heat plants in 1994, and for a 20-year life cycle, the solar plant becomes competitive with the coal plant in 1989.

The figures and tables that follow present the data sources, data base, ground rules and results. Table C-1 defines the task and summarizes the results; Table C-2 lists the data references; Table C-3 presents the study ground rules, plant size and plant costs; and Table C-4 gives the financial data base. Figure C-1 documents the industrial fuel prices in California; Figure C-2 presents the real costs of thermal energy in California, annualized over 30 years; Figure C-3, real cost of process heat plants with a 10-year life cycle; Figure C-4, real cost of process heat plants with a 20-year life cycle; and finally, Figure C-5, real cost of process heat plants showing both 10- and 20-year cycles.

TABLE C-1

TASK

- DETERMINE THE ANNUALIZED COST PER 10^6 BTUs OF PROCESS HEAT PLANTS FOR LIFE CYCLES OF 10 AND 20 YEARS. EVALUATE BOTH FOSSIL FUEL AND CENTRAL RECEIVER PLANTS IN TERMS OF LIFE CYCLE FINANCIAL COSTS (CAPITALIZATION AND PRODUCTION)

SUMMARY

- FOR THE CALIFORNIA INDUSTRIAL SECTOR SOLAR PLANTS BECOME COMPETITIVE WITH FOSSIL PLANTS AT THE FOLLOWING TIME PERIODS:

PROCESS HEAT PLANTS	10 YEARS	20 YEARS
COAL PLANTS	1994	2989
OIL PLANTS	1999	1990
GAS PLANTS	2000	1990

TABLE C-2
DATA REFERENCES

- ENERGY PRICES BY STATE
  - SHERMAN H. CLARK ASSOCIATES REPORT OF FUEL PRICE PROJECTION FOR THE UNITED STATES - RECEIVED 1978 (TO BE PUBLISHED)
- HELIOSTAT COST ESTIMATE BY TIME PERIOD
  - MDAC FIRST QUARTERLY PROJECT REVIEW (JANUARY 10, 1978)
- FOSSIL FUEL PROCESS HEAT PLANT COST ESTIMATE
  - SHELL OIL COMPANY - H. WEBB'S CONTACT WITH ED MERGEN AT HOUSTON OFFICE (NOVEMBER 23, 1977)

TABLE C-3

STUDY GROUND RULES AND DATA BASE

GROUND RULES

- PROCESS PLANT CONSISTS OF FUEL STORAGE, FUEL TRANSPORT AND BOILER ELEMENTS
- FINANCIAL ANALYSIS TO COMPARE ANNUAL COST PER UNIT ENERGY DELIVERED TO APPLICATION PROCESS. METHODOLOGY BASED ON PRESENT VALUE ANALYSIS ANNUALIZED OVER OPERATIONAL LIFETIME
- NO INFLATION, PRICES BASED ON 1977 DOLLARS
- CALIFORNIA INDUSTRIAL SECTOR

PLANT SIZE

- 100×10^6 BTUs/HR OR 29 MW_{TH}
- CENTRAL RECEIVER PLANT HAS 6 HOURS OF THERMAL STORAGE

PLANT COSTS

COAL PLANT	512 $\$/KW_{TH}$,	PCF = .85
OIL PLANT	103 $\$/KW_{TH}$,	PCF = .85
NATURAL GAS PLANT	70 $\$/KW_{TH}$,	PCF = .85
SOLAR PLANT (@91 $\$/m^2$)	514 $\$/KW_{TH}$,	PCF = .50

TABLE C-4

FINANCIAL ANALYSIS DATA BASE
PROCESS HEAT ANALYSIS

		LIFE CYCLE, VALUES		
YEARS	=	30	20	10
CAPITAL RECOVERY FACTOR	=	6%	8.7	13.5
TAX RATE	=	50%	50	50
FIXED CHARGE RATE	=	12%	17.4	27.0
DISCOUNT RATE	=	6%	6	6

PRIVATELY OWNED PLANT, INDUSTRIAL SECTOR

ANNUALIZED COST FOR 10 AND 20 YEARS OF LIFETIME OPERATION

HELIOSTATS LOCATED AT INYOKERN CALIFORNIA

HELIOSTAT CONVERSION EFFICIENCY = 54%

Figure C-1

INDUSTRIAL FUEL PRICES IN CALIFORNIA

Ref: Sherman H. Clark Associates - 1978
MDAC Central Receiver Project Review 1/10/78

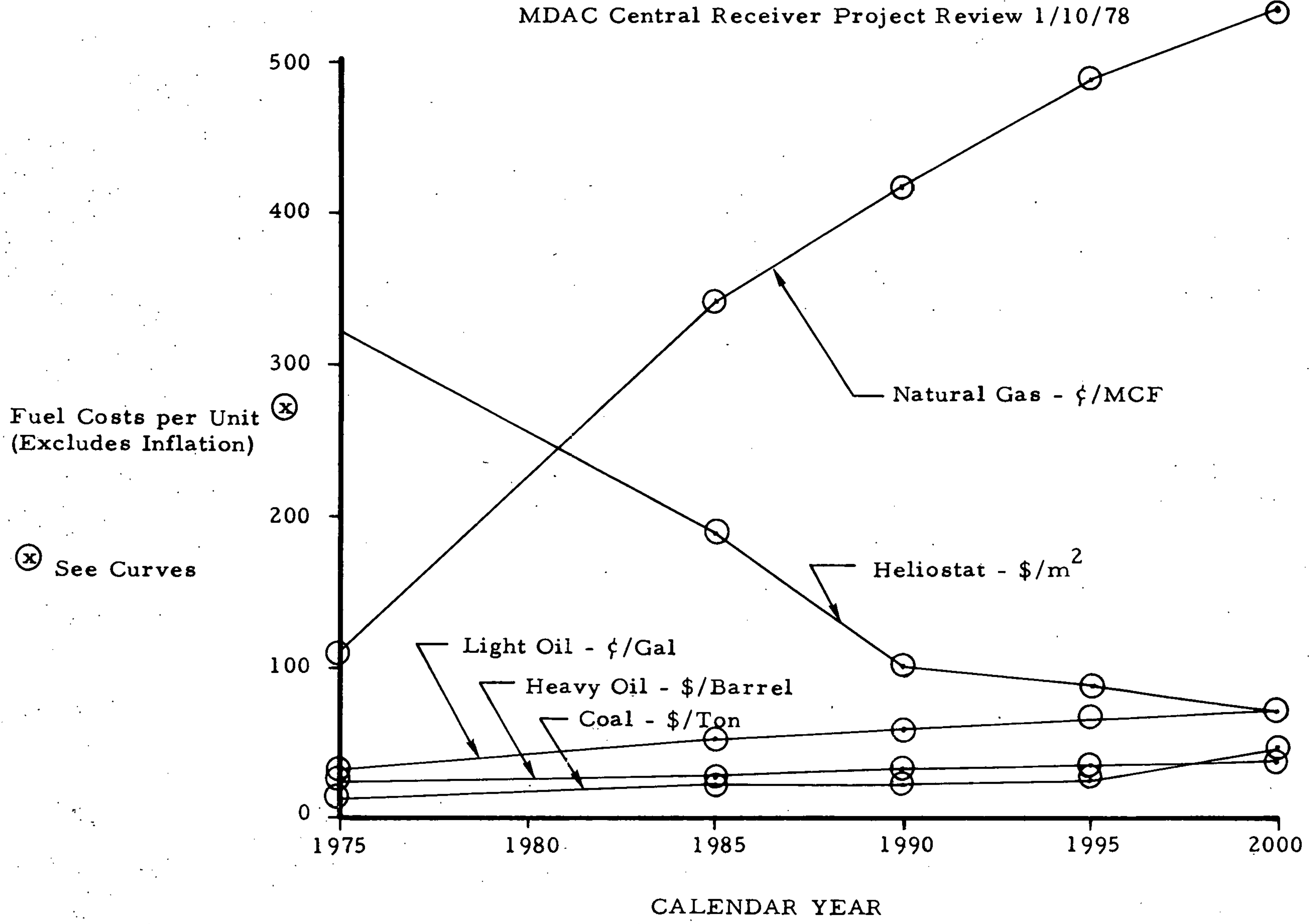


Figure C-2

REAL COSTS OF THERMAL ENERGY ANNUALIZED OVER 30 YEARS
CALIFORNIA INDUSTRIAL SECTOR

Note:
- o Excludes Inflation
- o Excludes Fuel Transport, Fuel Storage, Boiler Equipment
- o Includes Heliostat Equipment

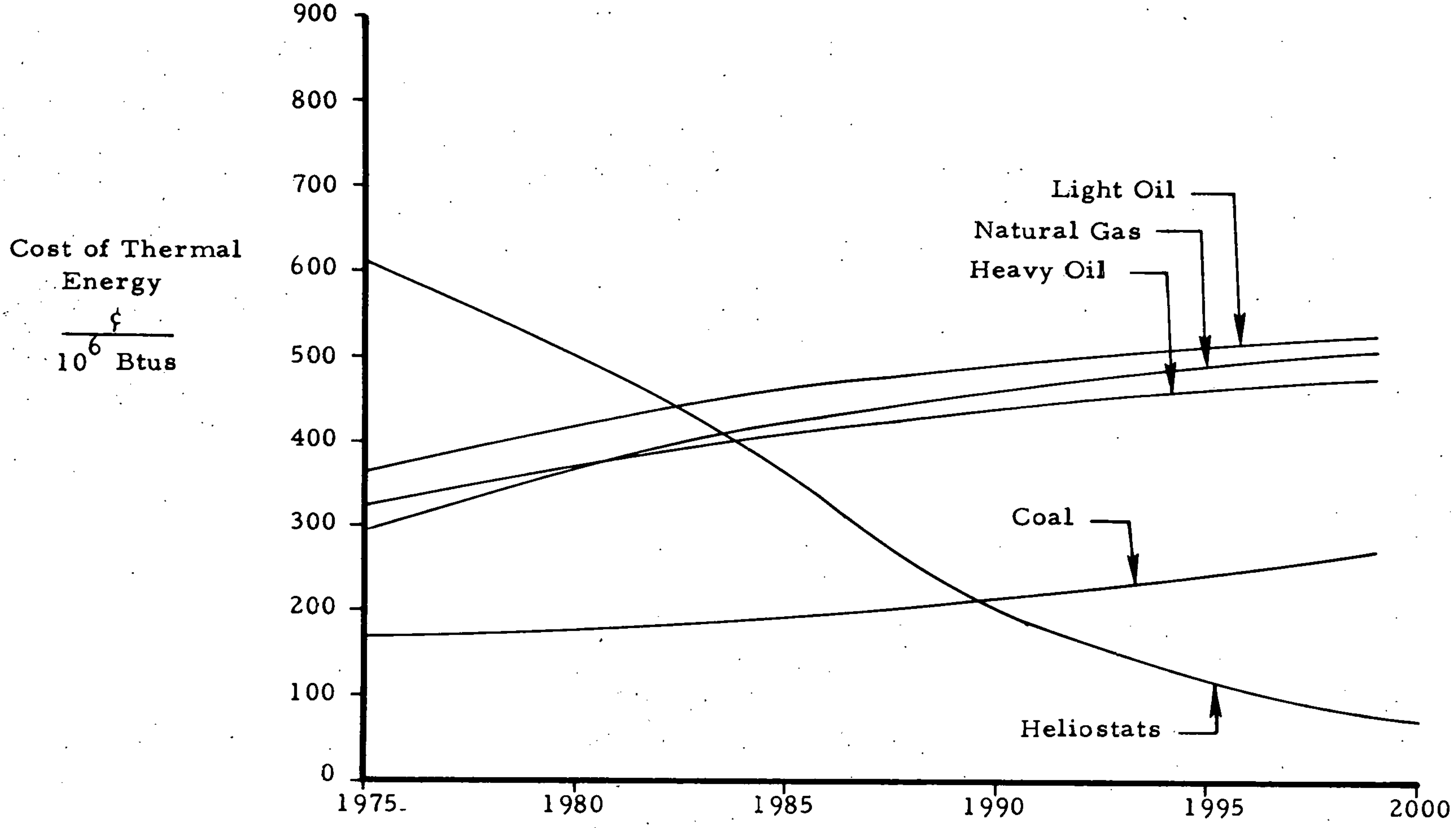


Figure C-3

REAL COSTS OF PROCESS HEAT PLANTS

- 10-Year Life Cycle
- California Industrial Sector
- No Inflation
- Discount Rate 6%
- Fixed Charge Rate 27%
- Capital Recovery Factor 13.5%

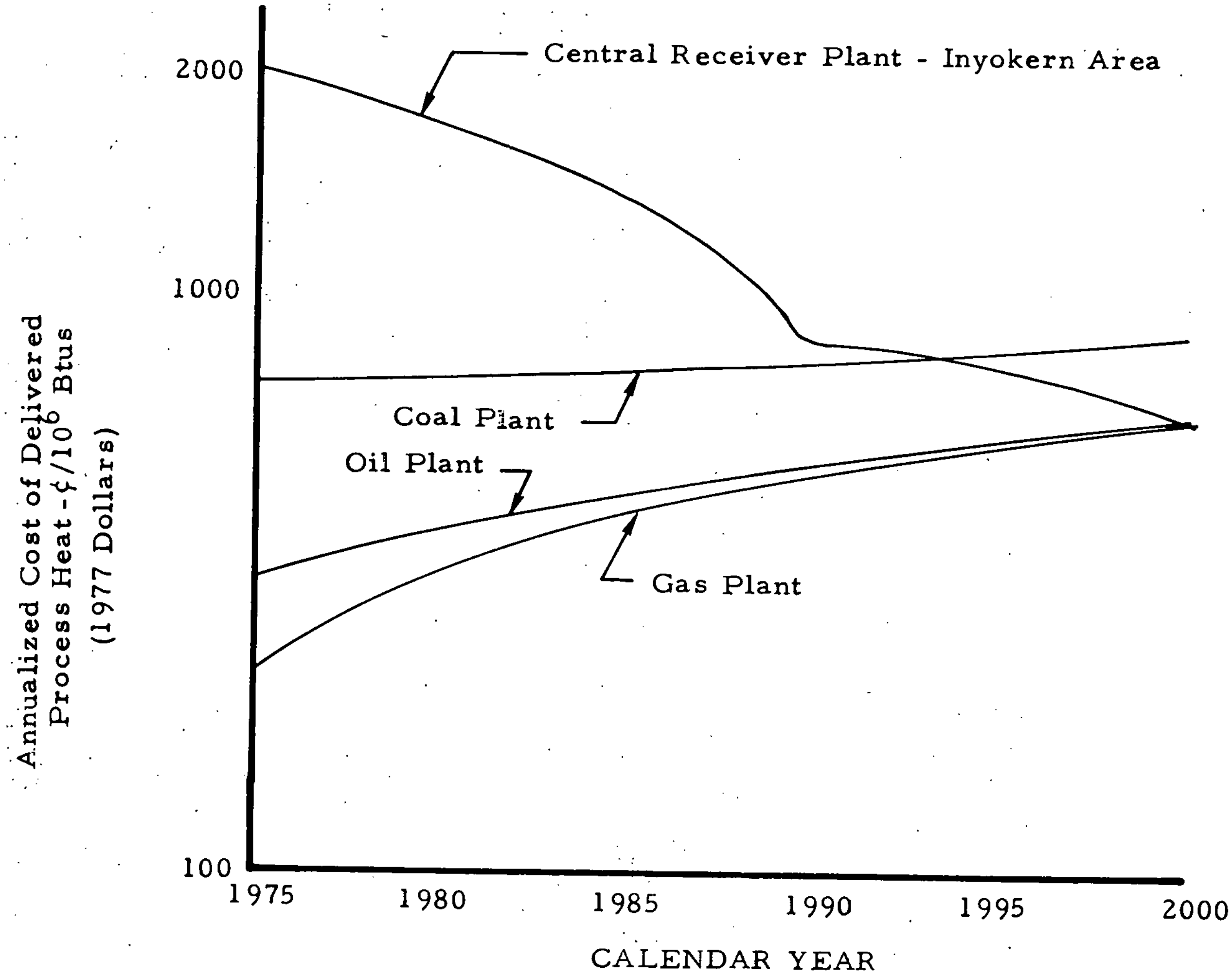


Figure C-4

REAL COSTS OF PROCESS HEAT PLANTS

- 20-Year Life Cycle
- California Industrial Sector
- No Inflation
- Discount Rate 6%
- Fixed Charge Rate 17.4%
- Capital Recovery Factor 8.7%

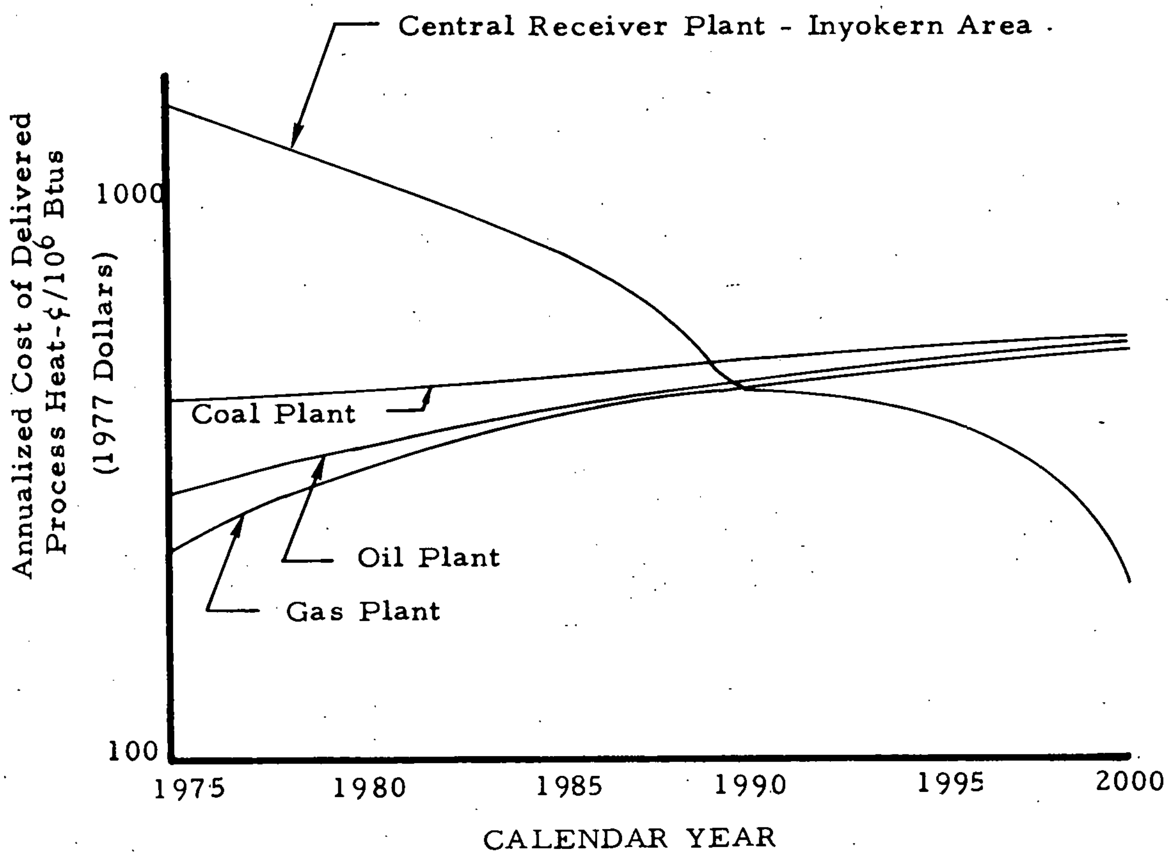
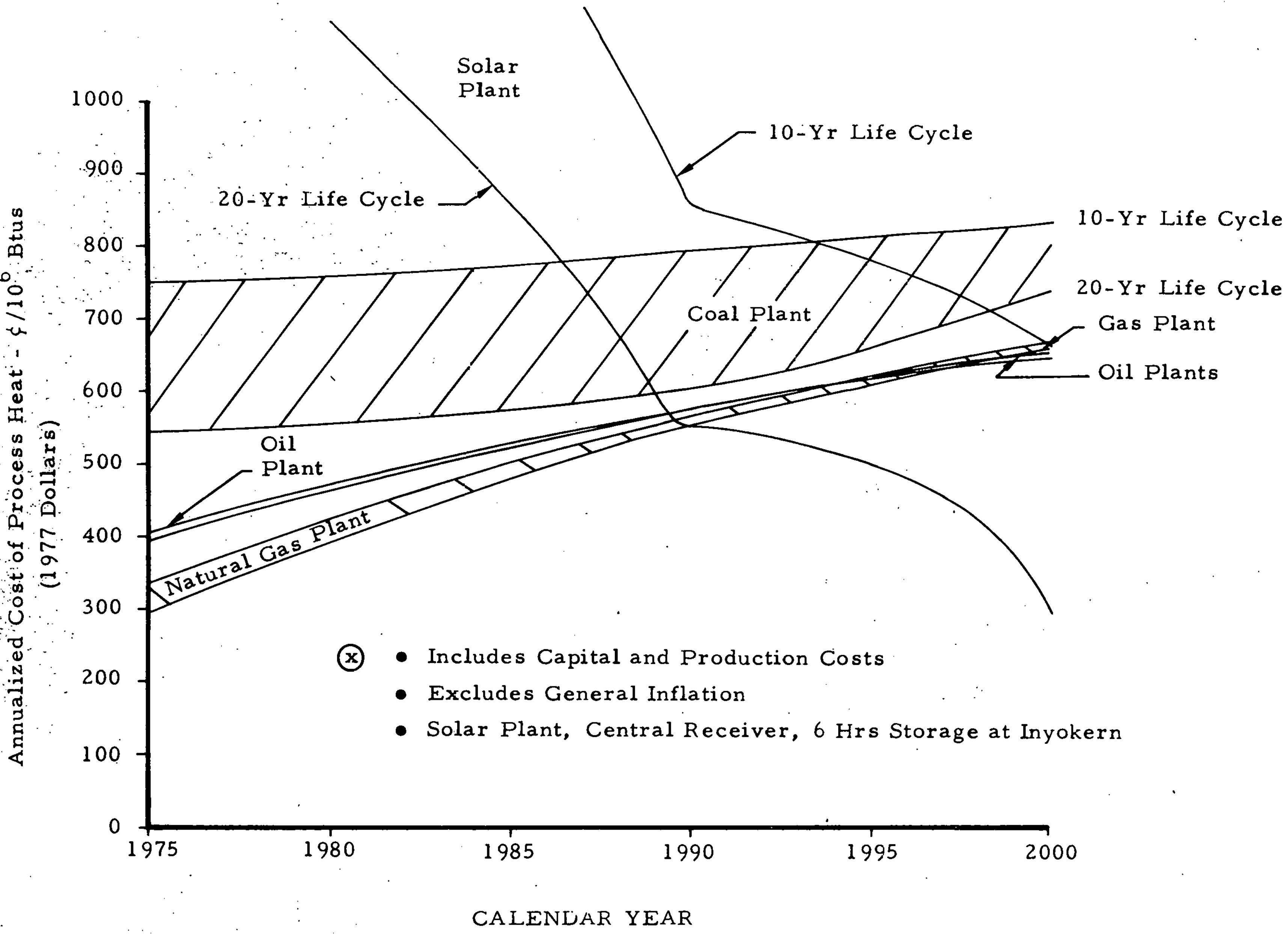


Figure C-5

REAL COSTS OF PROCESS HEAT PLANTS ⓧ - CALIFORNIA INDUSTRIAL SECTOR



ⓧ
- Includes Capital and Production Costs
- Excludes General Inflation
- Solar Plant, Central Receiver, 6 Hrs Storage at Inyokern