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Process Heat in California: Applications and Potential for Solar Energy in the Industrial, Agricultural and Commercial Sectors

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FOREWORD

The work documented by this report was performed by the Systems Division of the Jet Propulsion Laboratory, California Institute of Technology, for the Solar Energy Office of the Alternatives Implementation Division of California Energy Resources Conservation and Development Commission. Technical direction by the Solar Energy Office of the work documented in this report was the responsibility of Alexander Jenkins, Leigh Stamets, Matthew Ginosar and Martin Murphy.

The authors wish to extend their appreciation to the many people who contributed to the survey. In particular, the cooperation and assistance of many individuals in the industrial, agricultural and commercial communities, and from various governmental entities was valuable. A complete list of these individuals is included in the Appendix. Special thanks is given to the following:

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(6) Nanci Phillips and Jane Okano for preparing this document.

The many people interviewed expressed considerable interest in solar energy and it is hoped that this report will provide a basis for more complete and definitive work. The opinions, findings and conclusions in this report are those of the authors and do not necessarily represent the views of the California Energy Resources Conservation and Development Commission.

ABSTRACT

A summary of the results of a survey of potential applications of solar energy for supplying process heat requirements in the industrial, agricultural and commercial sectors of California is presented. Technical, economic and institutional characteristics of the three sectors are examined. Specific applications for solar energy are then discussed. Finally, implications for California energy policy are disucssed along with recommendations for possible actions by the State of California.

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SECTION I

INTRODUCTION, SUMMARY, AND RECOMMENDATIONS

A. INTRODUCTION

This report documents a survey of California commerce, industry and agriculture which investigated the potential for utilization of solar energy for process heating in these business sectors. The survey was conducted for the California Energy Resources Conservation and Development Commission as part of the California Solar-Thermal Applications Planning Study. The purpose of the survey was to determine applications for solar energy which would have both near-term feasibility and large energy displacement potential. Specific objectives were to:

(1) Identify the low-temperature thermal requirements (those with nearest-term solar opportunities) of California commerce, industry and agriculture.

(2) Determine which specific industries or businesses could utilize low-temperature solar energy for process heat and define solar energy applications.

(3) Describe the technical, economic and institutional characteristics of these industries or businesses which could influence the potential for solar energy to be widely used in these applications.

(4) Estimate the amount of energy which might be displaced by solar.

(5) Recommend actions for California policies and actions which could promote the wide-spread adoption of solar energy systems for process heat applications.

In order to achieve these objectives, the survey built on information already in existence. Table 1-1 gives energy consumption figures for California in 1975. These figures show that California consumed approximately 5200×10^{12} Btu in 1975 of which 34 percent was direct thermal energy. This is significantly less than for the U.S. in general, where colder weather makes thermal energy consumption approach 50 percent (Ref. 1).

Table 1-1 shows that the industrial, commercial and agricultural sectors consume a large percentage of California's thermal energy and therefore should provide a large opportunity for solar energy. Active solar energy programs are being conducted in the residential sector for space heating and domestic water heating for buildings. More recently at the federal level, the Department of Energy has been assessing the potential for

Table 1-1. Energy Consumption in California, 1975

SECTOR	SIC CODE	TOTAL ENERGY CONSUMPTION 10^{12} BTU/YR	%	TOTAL THERMAL ENERGY CONSUMPTION 10^{12} BTU/YR	%
Residential	---	853	16	665	33
Commercial	50-89	401	8	232	12
Industrial	20-39	965	19	813	42
Agricultural	01-09	119	2	25	1
Mining	10-14	19	---	9	-
Construction	15-17	7	---	2	-
Transportation	40-48	1940	37	16	1
Electric Utilities	49	851	16	224	11
Other	---	46	1	0	-
Total		5200	100	1990	100

SOURCE: A. D. Little, Inc., Energy Shortage Contingency Plan: Technical Appendix: A Report for the California Energy Resources Conservation and Development Commission, October 1975.

NOTE:
1. Numbers do not add up due to rounding.
2. Energy consumption is referenced to the point of delivery to the consuming sector.
3. SIC Code is Standard Industrial Classification Code as defined by the Department of Commerce (Ref. 1, Section III).

solar energy applied to process heat and this information was used to support the survey (Refs. 2 and 3). Unfortunately, much of this work is not directly applicable to California. For example, the differences between California and the rest of the U.S. in climate, crops and farming practices required additional analysis to determine how solar energy could be applied to California agriculture. In the industrial sector, where the primary survey effort was concentrated, the balance of industrial types, the kinds of fuel used, and the air pollution standards differ between California and the rest of the nation. Therefore, a specific, California-oriented survey was necessary.

There were certain constraints which emerged during the course of the survey which impacted the resulting analysis. Most industries know how much energy is consumed in their plant. However, they often do not know how the energy is used within the various stages of the production processes. Therefore, the calculations of thermal energy consumed in the various industries and for particular solar applications should be considered as best estimates, given the present state-of-knowledge at the plant level.

As will be discussed later, California has a greater percentage of low-temperature applications under $212^{\circ}F$ than occurs nationally. A major reason is the concentration of food production, an industry where few processes exist that are greater than $212^{\circ}F$. Furthermore, flat plate collector technology was recognized as being the closest to commercial availability. Therefore, in order to determine the nearest-term applications of solar, survey efforts were be concentrated on those applications under $212^{\circ}F$. In fact, the design/cost studies performed after the completion of this survey (Ref. 4) suggest that concentrating solar collectors may be nearly as economical as the flat plate collectors. Consequently, applications between $212^{\circ}F$ and $350^{\circ}F$ may be as attractive in the near-term as those under $212^{\circ}F$.

Within these constraints the survey was able to develop considerable information relevant to the utilization of solar process heat in California.

B. INDUSTRIAL SECTOR

1. Energy Consumption

The 33 highest energy consuming industries in California accounted for approximately two-thirds of the total thermal energy use in 1975: the top ten accounted for nearly one-half. Where the required temperature is above 350°F, it is usually above 1000°F. These industries include petroleum refining, organic chemicals, cement and blast furnaces. Lower temperature needs in these industries are either very small or are met with waste heat from higher temperature operations.

The top energy consuming industries with temperature requirements under 212°F are primarily in the food processing industry. The energy is used to heat products, to heat water for cleaning and to heat air for dehydration of products. The paper products, metal plating and soap industries also have most of their process temperatures below 212°F. Even when the process temperature is relatively low (below 150°F) it is common to find the heat supplied through a boiler producing steam of 350°F.

Table 1-2 presents the results of applying industry by industry scaling factors (derived from Refs. 2 and 3) to nation-wide and California (Ref. 5) data to determine energy use by temperature range within California. Some significant differences are apparent. Uses under 212°F are more extensive in California (12 percent) than in the total country (2.8 percent). However, in the 212°F to 350°F range, energy use in California (17 percent) is much less extensive than in the nation as a whole (32 percent).

2. Technical Characteristics

In California, natural gas is still the primary fuel source and in industries with high energy use, steam is the most common energy transport medium. Steam boilers can readily be converted to use fuel oil and those plants with interruptible natural gas supplies have definite plans to convert to allow the use of either fuel. Many have already done so. Those plants that cannot switch to fuel oil have firm gas supply commitments. All industries expect to pay an increasing price for oil and natural gas but perceive near term supplies to be adequate. Pollution controls associated with conversion to fuel oil did not seem to be of concern at the individual plant level in 1977.

Table 1-2. Thermal Energy Use in the Industrial Sector

	U.S.	California		Top 33 California Energy Consuming Industries	
Thermal Energy Requirements	% of Total Industry Thermal Use	10^{12} Btu/yr	% of Total Industry Thermal Use	10^{12} Btu/yr	% of Total Industry Thermal Use
Under 212°F	3	99	12	63	7
212 to 350°F	32	137	17	85	11
Subtotal	35	236	29	147	18
Greater than 350°F	65	577	71	365	45
Total	100	813	100	512	63
Notes	1	2	2	3	

NOTES

1) Dickinson, William C., "Solar Energy for Industrial Process Heat," _Solar Age_, August 1977, pp. 29-33.

2) This is a rough estimate of the temperature distribution of energy use for process heat in California obtained by scaling the distribution for the top 33 industries totalling 512 X 10^{12} BUT/yr to 813 X 10^{12} BTU/yr. It assures that the distribution of energy use in industry ranking 34 and below is the same as the top 33.

3) Summarized from Table 3-3.

While the application of solar energy is technically feasible for most thermal energy requirements under 212^{o}F, the complexity of the solar energy design (and therefore cost) are site specific and will vary considerably with the age, size, location and energy requirements of each operation. Certain issues are common to all industries investigated and will have to be addressed in any solar energy application. These are listed below:

(1) Many plants, which use large amounts of thermal energy and are therefore good candidates for solar energy in terms of potential fuel savings have limited space available for solar collector arrays. Roofs are typically cluttered with mechanical equipment and exhaust vents and ground space is often reserved for future expansion of production.

(2) Most existing buildings will require structural reinforcement to support solar collectors: this problem was encountered in all the specific design cases studied (Ref. 4). In some applications, it may be possible to obtain a building code variance to assign a portion (about 1/3) of the design "live" load to the "dead" load of the collectors.

(3) Existing operations are in varying degrees of obsolence and are often-not energy efficient. Management is aware of this problem and is in general rectifying it as capital becomes available. It does not make technical sense, (even if one ignores the economic issues) to use solar for 70 percent of today's energy use when conservation will soon reduce that use by 50 percent.

(4) It is relatively simple to provide for use of solar energy in the design and construction of new buildings. Even if a solar energy system is not initially installed, structural allowances, energy storage locations and pipe chases could be provided at minimal cost.

3. Economic Characteristics

Most solar energy applications are not economically competitive today with conventional energy sources. Industry typically requires a three to five year payback period* criteria on capital expenditures. However, several firms indicated that they were willing to consider up to ten years for viable energy options. Solar energy systems must not only compete with available fossil fuels but they must also compete for capital with other improvements in production facilities. If solar can meet the investment decision-making criteria of industry, capital will be available for those investments. However, capital investments which increase productivity are generally given higher priority.

The most important application characteristic affecting economic viability is the number of days that the process needs energy. Production lines which operate 12 months per year will be the first to find solar energy attractive.

There are a number of specific situations which may make solar energy attractive to industry long before it is generally viewed a good investment. These include:

(1) Installing a solar energy system to avoid the high cost of expanding remote facilities or to avoid a high cost of conversion to fuel oil.

(2) Using solar energy to maintain higher priority for available natural gas by staying under a critical usage breakpoint (100 Mcf/day).

(3) Using solar energy where long term security of supply is important.

(4) Using solar energy as a gesture of goodwill. This is especially attractive to industries with high public visibility and under government regulation.

*Payback period = $\dfrac{\text{initial investment}}{\text{net annual savings in the first year}}$

C. COMMERCIAL SECTOR

1. Energy Consumption

Almost all the thermal energy used in the commercial sector goes for space heating of buildings and domestic hot water. These uses were not included in the present survey. Commercial process heat is estimated to be about one percent of the total energy used in this sector or 2.8×10^{12} Btu in California in 1975.

Only three areas with potential applications for solar energy emerged in the survey; laundries, restaurants and film processing. Laundries, including those at hospitals and hotels as well as independent operations, are the largest users.

2. Technical Characteristics

Where process heat is used in the commercial sector it is commonly supplied as hot water which is combined with the space heating or domestic hot water system. In those cases it would not be treated differently by the solar energy system designer and, because energy use in Btu per square foot of facility is low, no special technical problems were found.

The larger laundries are a separate class and are essentially similar to industrial users. All the comments made in relation to industrial process heat above also apply to the large laundries. They typically use wash water at 180°F for heavily soiled industrial clothing and rags.

At least one hotel* has found 90°F water to be adequate for their internally operated laundry. By covering all available roof space with solar collectors, enough energy can be obtained for that use.

3. Economic Characteristics

Capital investment criteria in the commercial sectors are also in the 3 to 5 year payback range.

In the restaurant and hotel industries a very small percentage of total budget goes to the cost of energy. The possibility of using solar to save a small fraction of a small budget item is not likely to arouse much enthusiasm. However, some sensitivity was found to the public relations benefits of equiping facilities with solar energy.

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*Disneyland Hotel, Anaheim, California

D. AGRICULTURAL SECTOR

1. Energy Consumption

Thermal energy at less than 212°F is being used "on-the-farm" in five principle applications: Greenhouses, crop drying, brooding, and hot water in dairies. The total energy consumption for these applications is estimated to be 15.3×10^{12} Btu/yr.

2. Technical Characteristics

Greenhouses are, in fact, solar collectors and are not candidates for further solar use. Insulation or increased mass (storage) would be useful.

Crop drying is a very seasonal use, typically less than three months of the year. This greatly increases the cost of energy from capital intensive solar energy systems. It is also accompanied by large quantities of airborne dust which reduces the effectiveness of solar collectors.

Poultry brooding is perhaps the most viable application of solar energy. Required temperatures are low (95°F) and use is year round.

Hot water for dairies is very much like a domestic hot water application in commercial or residential buildings. There is usually ample space for solar collectors. One factor which will delay significant use of solar energy in this application is the availability of sufficient heat from nearby refrigerator condensors.

3. Economic Characteristics

Most agricultural thermal processes use either natural gas or LPG. In the crop drying application, oil is not felt to be a feasible substitute in direct fired driers because of product contamination.

Reliability of the energy service is critical because of the risk of spoilage.

Farms often have skilled full-time employees whose work load is intermittent. They could install solar energy systems at a considerable savings in cost compared to industrial commercial and residential applications.

E. INFORMATION DISSEMINATION

The technical capability to make use of solar energy is widely available in industry. However, at the time of the survey, use of solar energy was primarily associated with residential applications by most of the commercial and industrial people interviewed.

When solar energy systems can be shown to be attractive in industrial applications, the rate of adoption could be very rapid. Information travels fast in industry. Industries and commercial enterprises made up of a large number of small industries have strong trade organizations. Some good examples are:

(1) Canners League of California.
(2) American Meat Institute.
(3) National Forest Products Association.
(4) Rubber Manufacturer's Association.

These trade organizations perform both a lobbying function and an information dissemination function. The experience of an innovating firm will be rapidly shared with others through trade magazines and journals.

Agricultural is a special case of small industry. The Cooperative Extension Service not only disseminates information but also is involved in solving problems in the field.

Other special cases are the fast food chains and franchise operations. Central management support could play an important role in getting solar energy systems adopted once they have been shown to be economically attractive.

At the other end of the commercial/industrial spectrum are the industrial giants: The auto industry, the oil industry, the soap packaging industry, the vertically integrated supermarket chains. In these industries the trade organizations play a minor role in information dissemination. While antitrust laws and proprietary processes limit the communication between the large companies, internal information can have a large impact within a single organization. Also, these firms have strong in-house engineering and evaluative capability. All of the firms in this category contacted in the course of the survey had someone investigating solar energy for their own use. In these firms, a decision to begin using solar energy could have a large impact.

Whether or not an industry's trade organization plays a major role in information dissemination, all industry is linked through the professional journals and organizations. Examples of journals cutting across industries include:

(1) ASHRAE Journal
(2) Power Engineer
(3) Food Engineering
(4) Chemical Engineering

F. POLICY PERSPECTIVE

1. Overview

The findings concerning application of solar energy in the industrial, commercial, and agricultural sectors must be put in context. To do this, a number of comparisons can be made with the application of solar energy in these sectors, each of which will be discussed below in turn.

(1) The energy conservation potential of industrial applications of solar energy is significant when compared to all residential electric water heating, any single LNG supply project, or all current use of natural gas for residential domestic water heating.

(2) The capital investment per unit of energy conserved is lower for typical industrial applications of solar energy than for most residential applications.

(3) The tax credits currently available or under consideration have a much smaller effect on the cost of using solar energy for process heating than for residential applications.

(4) The business investment criteria are less favorable toward using solar energy than investment criteria appropriate to a homeowner because of differences in taxation policy and risk.

(5) The speed of market development, once economic solar energy systems are demonstrated, in the process heat sector is likely to be faster than in the building sector.

(6) Federal and state environmental policy prohibiting further environmental degradation will motivate industrial investment in solar energy long before it has any direct effect on homeowner decisions to invest in solar energy.

These insights suggest that there is much to be done in both the areas of policy formulation and technology development to bring process heat into commercial use.

2. Energy Conservation Potential

On an absolute scale the application of solar energy for process heat under 212°F in the industrial, commercial, and agricultural sectors is large in California. Approximately 100 x 10^{12} Btu/yr is consumed in this range and approaches 50 percent of the energy used for residential gas water heating or 2.5 times the energy used for heating water electrically. Practicality and cost aside, conversion of all existing industrial needs for low temperature thermal energy to solar energy would displace approximately 70 x 10^{12} Btu/yr - an amount of energy roughly comparable to 1/2 of a typical South Alaska LNG Project. (See Table 1-3 for more detail).

3. Capital Investment Index

In the present era of large investments for new energy resources, the effectiveness of deploying capital has become a significant concern. Capital is a scarce resource; the use of which must be balanced against the use of our natural resources and economic well-being. The deployment of capital in the industrial, commercial and agricultural sectors is influenced by tax policies which are very different from the policies influencing the residential sector. Furthermore, the risk associated with investment in industry is admittedly greater than the risk in the residential sector. Therefore, it is important to separate and compare each of the components influencing investment decisions between the commercial sectors and the residential sector.

Fundamental to the efficiency of capital investment is the ratio of the initial investment to the annual energy delivered to the load. As long as the options being compared have similar risk, operations and maintenance cost, and life, valid comparisons can be drawn at this level. By this measure, many industrial applications for solar energy are more attractive than residential space heating and water heating applications. The most attractive applications are in new processing lines with 6 day per week energy demands and where energy storage is already provided in the processing equipment. The best industrial applications are slightly more attractive by this simplistic measure than single family water heating, and considerably more attractive than space heating in single family dwelling. (See Table 1-4.)

Table 1-3. Energy Ranking of Industrial, Commercial and Agricultural End-Uses by Thermal Energy Consumption

Rank	Market Segment (Industrial, Commercial & Agricultural)	Energy Consumption 10^{12} Btu/yr	Item as Percentage of Consumption in Sector				
			Residential	Commercial	Industrial	Agriculture	State
1	Residential Gas Space Heating	354	43	--	--		6 8
2	TOTAL INDUSTRIAL PROCESS HEAT <350°F (d)	236	--	--	25		4 6
3	Residential Gas Water Heating	228	28	--	--		4 4
4	Commercial Gas Space Heating	180	--	46	--		3 5
5	TOTAL INDUSTRIAL PROCESS HEAT <212°F (a)	99	--	--	10		1 9
6	FOOD PROCESSING (b)	41 8	--	--	4 2		0 80
7	Commercial Electric Water Heating	35 4	--	9 1	--		0 68
8	Commercial Gas Air Conditioning	27 5	--		--		0 53
9	Residential Oil Space Heating	23 2	2 8	--	--		0 45
10	Industrial Gas Space Heating	22 5	--	--	2 3		0 43
11	AGRICULTURAL PROCESS HEAT <212°F	16 0				13	0 31
12	Commercial Gas Waterheating	14 6	--	3 8	--		0 25
13	Residential Electric Water Heating	13 9	1 7	--	--		0 27
14	Residential Electric Space Heating	13 2	1 6	--	--		0 28
15	Commercial Electric Air Conditioning	10 9	--	2 8	--		0 21
16	Residential Electric Air Conditioning	9 27	1 1	--	--		0 18
17	Industrial Oil Space Heating	8 28	--	--	0 9		0 16
18	GREENHOUSES (c)	7 75				6 5	0 15
19	Industrial Electric Air Conditioning	7 61	--	--	0 8		0 15
20	PAPER PRODUCTION <212°F (b)	7 00	--	--	0 7		0 14
21	Residential Oil Water Heating	6 62	0 8	--	--		0 13
22	Commercial Oil Space Heating	5 63	--	1 5	--		0 11
23	AGRICULTURAL DRYING/DEHYDRATING (c)	4 78				4 0	0 09
24	Commercial Electric Space Heating	4 30	--	1 1	--		0 08
25	VEHICLE MANUFACTURING <212°F (b)	3 50	--	--	0 4		0 07
26	SAWMILLS <212°F (b)	3 00	--	--	0 3		0 06
27	SOAP MANUFACTURING <212°F (b)	2 90	--	--	0 3		0 06
28	COMMERCIAL PROCESS HEAT <212°F	2 80		0 7			0 05
29	PLASTICS <212°F (b)	1 70	--	--	0 2		0 03
30	METAL PLATING <212°F (b)	1 5	--	--	0 2		0 03
31	BROODING HOUSE HEATING (c)	1 5				1 3	0 03
32	CONCRETE & ALLIED PRODUCTS <212°F (b)	1 1	--	--	0 1		0 02
33	Commercial Oil Water Heating	0 99	--	0 3	--		0 02

SOURCE Adapted from Hirshberg, Alan S , Davis F S (An), Solar Energy in Buildings Implications for California Energy Policy, JPL Document 5040-42, March 1977, Table III-2, p 3-14

NOTES
a) Included in "Industrial Process Heat<350°F "
b) Included in "Industrial Process Heat<212°F "
c) Included in "Agricultural Process Heat "
d) Summarized from Table 3-4

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Table 1-4. Ratio of Initial Cost to Annual Energy Delivered to the Load for Selected Applications of Solar Energy

	Single Family Water Heating	Single Family Space Heating	Mult. Family Water Heating	Industrial with Storage (Carnation Milk Co.)	Industrial no Storage (Crown Zellerbach)	Insulation (Pacific Veg. Oil) for Reference
PARAMETERS						
Solar Collection Btu/ft^2 /day	555	555	555	606	514	NOT APPLICABLE
Solar Duty Cycle Days/yr	365	200	365	312	312	
System Size - Collector ft^2	31	117	273	3100	65000	
Annual Solar Collected - 10^6 Btu/ft^2/yr	202	111	.202	189	160	
% of Load Supplied by Solar	66	66	68	77	17	
Installed Cost \$/ft^2						
New	33	38	26	31	24	
Retro	38	32	34	55	32	
RATIO OF COST TO ENERGY \$/10^6 Btu/yr						
New	163	250	128	164	150	
Retro	188	285	168	291	200	60

Note: All costs are in 1977 dollars and reflect estimates for the cost of construction in 1977 with technology available in the market.

4. Tax Credits

California tax law currently allows a credit of up to 55 percent of the cost of installing a solar energy system to be taken by individual and corporations, on their State income tax. For systems scaled to process heat applications, the credit is limited to 25 percent of the cost, because these systems will usually cost more than $12,000 (Ref. 6). Since the State tax credit increases a corporation's Federal tax liability, the tax credit reduces the cost of corporate use of solar energy by only 13 percent.*

A property tax exemption will be available from 1970 through 1983 for use of solar energy in buildings if the voters approve Proposition No. 3 in June of 1978. This property tax exemption apparently does not apply to process heat applications for solar energy (Ref. 7).

5. Business Investment Criteria

Business will evaluate solar energy as an investment which will reduce operating costs through reduction in fuel costs. A discounted cash flow analysis of the solar alternative will be a major factor in the decision. In a discounted cash flow analysis, capital investment and energy savings are combined with pertinent financial factors to put alternative choices on a common basis for comparison. This study uses a discounted cash flow method called "levelized energy cost". (Ref. 8). The "levelized energy cost" method allows the cost of solar energy to be examined separately, and then compared to the cost of fuel alternatives. The critical parameter in this analysis is the ratio of the annual cost of owning and operating solar equipment to the initial investment.

The adage that "the consumer ultimately pays the bill" can be used to structure a comparison of investments in solar energy by businesses and investments in solar energy by homeowners. For home heating or water heating systems, the consumer pays for the solar energy directly. For commercial systems the consumer pays for solar energy indirectly as part of the price of the manufactured product or part of the rent for property.

* 25% (1-.48) = 13% where .48 equals the federal tax rate for corporations.

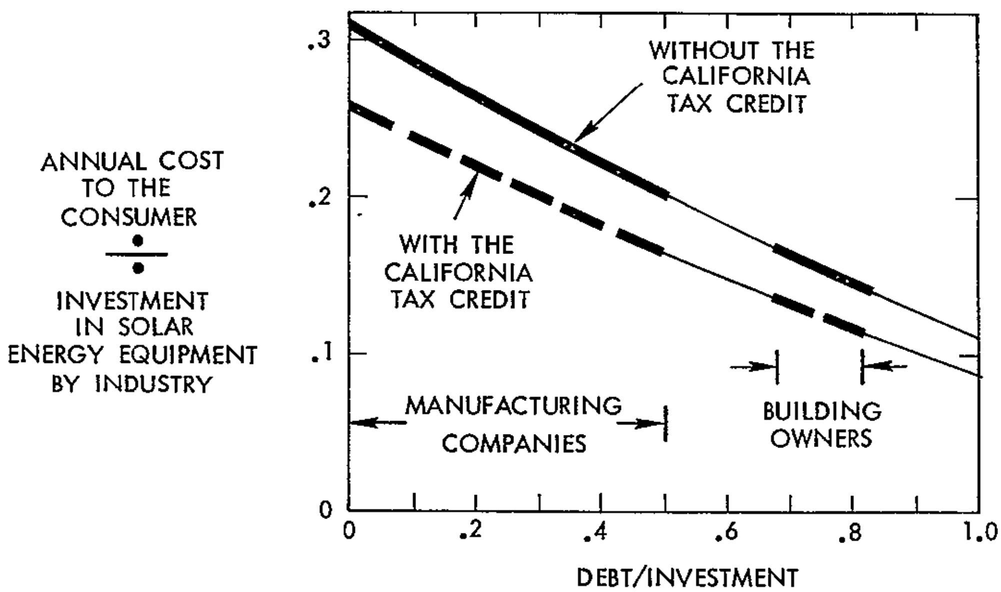
To make a comparison between the direct and indirect cost of solar energy to a consumer, it will be assumed that the cost of solar energy or fuel to the business is included dollar for dollar in the selling price of the product or service. In other words, cost of solar energy is "flowed through" to the consumer. In effect, we will be imagining that the energy content of a product can be purchased separately so that the price to the consumer can be compared with the direct cost of solar energy to a consumer owning his own equipment.

This, of course, means that the business can and does adjust the price of its product to the consumer to maintain a constant return on invested capital. In the case of fuel or purchased power, each dollar increase in cost would be reflected as a dollar increase in product price to the consumer. Thus the before tax profit is unaffected and there is no change in the tax liability of the business. Since the cost of fuel is also "flowed through" to the consumer, its deductibility is of no consequence to the price ultimately paid by the consumer. This allows the price of fuel to industry to be compared directly with the price of fuel to consumers.

With this conceptual background, it is possible to make a quantitative comparison of the use of solar energy in businesses to the use of solar energy in homes. For commercial solar energy systems the "annual cost to the consumer ÷ the initial investment in solar energy" equipment depends most strongly on the risk associated with the specific enterprise involved. This risk is reflected in the financing terms that are available to the firm. The lower the risk associated with an enterprise, the larger the share of debt finances available at a favorable interest rate.

The ratio of "the annual cost of solar energy to the consumer ÷ the investment in solar energy" is plotted vs. the amount of debt financing in Figure 1-1.

For the consumers, the range of financial risk is bounded by two categories of risk: the risk associated with loans secured by a home mortgage and consumer credit loans based solely on the ability to repay. Since interest is deductible, the ratio of "the annual cost of solar energy to the consumer ÷ the investment in solar energy" is a strong function of the particular consumer's income tax bracket. This function is plotted in Figure 1-2.

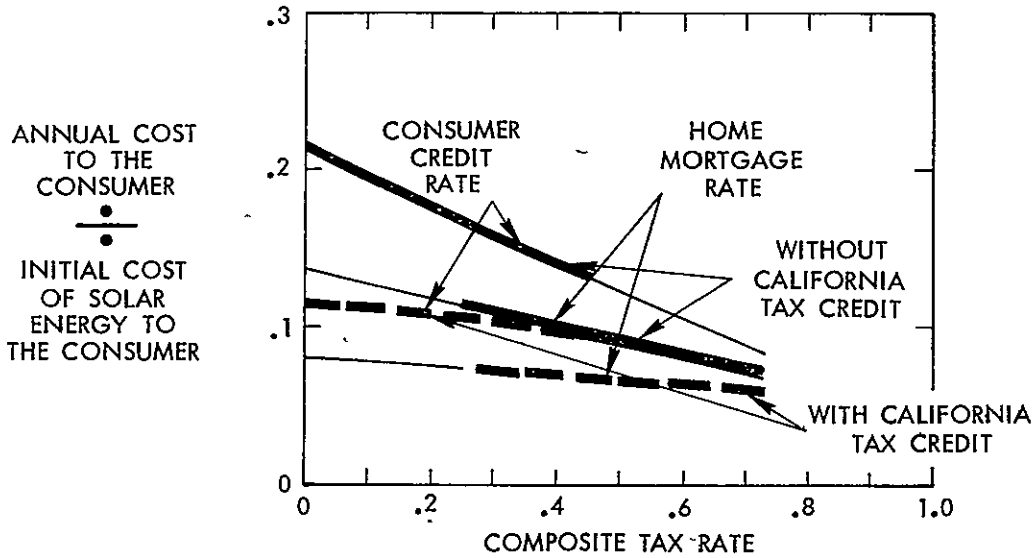


NOTES

1. PARAMETERS USED:

SYSTEM LIFE	20 YRS.
STATE INCOME TAX RATE	.09
FEDERAL INCOME TAX RATE	.48
INVESTMENT TAX CREDIT	.10
STATE TAX CREDIT	.25/.0
ANNUAL MAINTENANCE COST ÷ INVESTMENT	.01
ANNUAL PROPERTY TAX ÷ INVESTMENT	.02
INTEREST ON DEBT	.09
RETURN ON EQUITY	.18

Figure 1-1. Annual Cost of Solar Energy Flowed Through to Consumers By a Business Using Solar Energy Equipment



NOTES

1. PARAMETERS USED:

SYSTEM LIFE	20 YEARS
ANNUAL MAINTENANCE COST ÷ INVESTMENT	.01
ANNUAL PROPERTY TAX ÷ INVESTMENT	.02
INTEREST ON DEBT	.09/.18
STATE TAX CREDIT	.0 / .55

Figure 1-2. Annual Cost to Consumers for Consumer Ownership

A comparison of Figures 1-1 and 1-2 reveals a strong bias toward consumers using solar energy directly. This bias stems totally from difference in the perceived risk and taxation policies and is in no way inherent either to the technology, or to the physical characteristics of industrial compared to the residential applications. The technological and applications characteristics are all accounted for in the ratio of "initial cost to annual energy delivered" (See Table 1-4). Consumers with high incomes (and corresponding high composite tax rates) that can finance solar energy systems through home mortgages, perceive the lowest annual cost for a solar energy system. From Figure 1-2, the annual cost to a homeowner in the 50 percent composite tax bracket is less than 10 percent of the initial investment per year, without the California tax credit. With the 55 percent California tax credit this cost drops to 7 percent of the initial cost per year.

For a technically equivalent application, the annual cost of solar energy to a business is considerably higher. From Figure 1-1, the annual cost to business with a conservative level of debt (e.g., debt ÷ investment = 0.3) is about 24 percent of the initial cost per year without the California tax credit. With the 25 percent tax credit available to businesses in California, the cost of solar energy drops to 19 percent of the initial cost per year. Therefore, homeowner use of solar energy systems is more favorable to consumers than use of solar energy by business by more than a factor of two. The appropriateness of the differences in taxation policy and assignment of risk to these two applications of solar energy needs further investigation.

Although the cost of using solar energy directly in the home is less, it is likely that the cost of fuel to the homeowner will not rise as much as to industry. Homeowners in California are likely to see a gradual rise in price of natural gas over the long-term, while industry will be forced either to shift to fuel oil or pay the full (i.e., incremental) price for new sources of natural gas. (Preparation for the shift to fuel oil has been going on for several years in California.) Hence, while the cost of solar is lower to the homeowner, the cost of current fuels is held down so that he has less incentive to shift away from them.

The final decision between solar energy and the use of fuel will be made by comparing the levelized cost of solar energy with the levelized cost of fuel. The levelized cost of solar energy is tabulated in Table 1-5 for 3 applications: (1) A representative, good industrial application for solar

Table 1-5. Levelized Cost of Solar Energy

	(Initial Investment) ÷(10^6 Btu/yr), ($ 1977)	Levelized Charge Rate for Solar Investment, $\frac{\$\text{Annual Cost}}{\$\text{ First Cost}}$	Levelized Solar Energy Cost, $\frac{\$\ 1977}{10^6\ \text{Btu}}$
WITH CALIF. TAX CREDIT			
Commercial/Industrial D/I = .3, k = .1388 (Note 1.)	150	.1976	29.64
Apartment - Water Heating D/I = .8, k = .0701	130	.1164	15.13
Homeowner - Water Heating τ = .5 k = .0449	163	.0731	11.92
WITHOUT CALIF			
Commercial	150	.2385	35.82
Apartment	130	.1424	18.51
Homeowner	163	.0967	15.76
Notes	2	3	4

NOTES:

1. D/I = Debt ÷ Total Investment

   k = After tax cost of capital, fraction/year

   τ = Marginal tax rate, fraction

2. See Table 1-4 in Section I for values used here.
3. See Figures 1-1 and 1-2 to determine values used here.
4. $$\left[\text{Solar Energy Cost}\right] = \frac{\left[\text{Initial Investment}\right]}{\left[\text{Annual Energy Produced}\right]} \times \left[\text{Levelized Charge Rate}\right]$$

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energy, (2) hot water heating in a commercial apartment building and (3) hot water heating in a single-family home. Each of these applications is considered with and without the existing California tax credit for solar energy.

The levelized cost of fuel over the 20-year life of a solar energy system is estimated in Table 1-6 and compared to the cost of solar energy in Table 1-7.

For the representative industrial application, a solar energy cost of \$29.64 per 10^6 Btu is compared to a levelized fuel cost of \$7.48 to 9.47 per 10^6 Btu. The choice is obvious to the cost conscious manager - use fuel.

If fuel costs escalate at 3 percent above the general inflation rate, then the best commercial and industrial applications are more than a decade away from looking attractive to management as a capital investment. Meanwhile the investment minded homeowner is likely to find solar energy attractive in approximately two years (i.e., by 1979), even if natural gas is available to him.

If the tax credit for solar energy systems is not extended past 1980, there will be a two or three year interval when natural gas will be the preferred option to this same investment minded homeowner.

6. Speed of Market Development

The development of the industrial, commercial and agricultural markets for solar energy systems can be thought of in three dimensions: (1) a market start time, (2) a rate of adoption, and (3) the total market potential which was discussed earlier in this section. Without changes in current policies affecting the attractiveness of solar energy as an investment, the start of the industrial market for solar energy is estimated to be several years behind the residential markets. However, information dissemination channels are stronger in these sectors, and once solar energy becomes attractive, the normal rate of acceptance is expected to be much faster than in the housing industry. Many of the current government actions are aimed at accelerating the "normal rate of acceptance" by the housing industries. These include: information dissemination, large numbers of similar demonstrations, federally funded product testing, market research, state funded development of laboratory certification and testing procedures, and state tax credits.

Table 1-6. Levelized Cost of Fuel Over 20-Years

	Current or Near Future Fuel Cost, $/10^6 BTU	End Use Efficiency	Expected Fuel Cost Inflation Rate (Current Dollars), Percent/Year		Fuel Escalation Rate Factor		Levelized Cost of Useful Heat to the User, $/10^6 BTU	
			High	Low	High	Low	High	Low
WITH CALIF TAX CREDIT Commercial/Industrial D/I = 3, k = 1388 (Note 1)	3 40	7	9%	6%	1 95	1 54	9 47	7 48
Apartment - water heating D/I = .8, k = 0701	2 00	6	9%	6%	2 31	1 71	7 70	5 70
Homeowner - water heating τ = 5, k = .0449	2 00	.5	9%	6%	2 44	1 78	9 74	7 11
NOTES	2	3	4	5	6	6	7	7

NOTES

1) D/I = the ratio of Debt to Investment

   k = the weighted after tax cost of capital

   τ = the marginal tax rate

2) From California Public Utilities Commission Staff Report Case No 10342, Vol I, Sept 30, 1977

   a) Average system rate in 1977:

      for SCGC = $1 76/mcf

      for PG&E = $2.20

      Therefore assume 2.00 $/10^6 Btu for the average rate in California.

   b) Gas from new sources charged to industrial users.

      1) SCG/Transwestern

	'80	'85	'90
New Gas	1.95	2.15	2 37
Transmission	82	1 10	1 13
Distribution	.75	98	1 26
Total	3.52	4.23	4.76
Fuel Cost Escalation Rate (Constant Dollars) 5 yr	3 7%/yr	2 3%/yr	
10 yr	3 0%/yr		

      2) PG&E/Canadian

	'80	'85	'90
Canadian	2 56	2 56	2 56
Distribution	55	65	1.20
Total	3 11	3 21	3 76
Fuel Cost Escalation Rate 5 yr	0 6%/yr	3 2%/yr	
10 yr	1 92%/yr		

   c) Fuel Oil

      Current price (1977) = 17 00 $/Bbl

      at 6 X 10^6 Btu/Bbl = 2 83 $/10^6 Btu

3) Rough estimates of boiler efficiency reflecting improved efficiency with larger size. Industrial boiler can achieve 80% operating efficiency when operating at rated capacity

4) Assumes that fuel escalates at 3% above the inflation rate (See Note 2.)

5) Assumes a general inflation rate equal to 6% and that fuel escalates at the general inflation rate

6) The fuel escalation factor, FEF, levelizes the cost of fuel over the life of the investment The formula for the fuel escalation factor is

$$FEF = \left(\frac{1+r}{r-k}\right)\left[\left(\frac{1+r}{1+k}\right)^N - 1\right]\left[\frac{k(1+r)^N}{(1+k)^N - 1}\right]$$

where

   r = fuel escalation rate, fraction/year
   k = after tax cost of capital, fraction/year
   N = project life, years

The high and low estimates assume that r = 9% and 6% per year respectively.

7) Calculated from the following formula

$$\left[\begin{matrix}\text{Levelized Cost}\\ \text{of Useful Heat}\end{matrix}\right] = \frac{\left[\begin{matrix}\text{Near Team}\\ \text{Fuel}\\ \text{Cost}\end{matrix}\right] \times \left[\begin{matrix}\text{Fuel}\\ \text{Escalation}\\ \text{Factor}\end{matrix}\right]}{\left[\text{End of Efficiency}\right]}$$

Table 1-7. Comparison of Using Solar Energy to Using Fuel

	Levelized Solar Energy Cost $\frac{\$1977}{10^6 BTU}$	Levelized Cost of Useful Heat $\frac{\$1977}{10^6 BTU}$		Minimum Time to Become Competitive Years
		High	Low	
WITH CALIF. TAX CREDIT Commercial/Industrial D/I = .3, k = .1388	29.64	9.47	7.48	13.2
Apartment - Water Heating D/I = .8, k = .0701	15.13	7.70	5.70	7.8
Homeowner - Water Heating τ = .5, k = .0449	11.92	9.74	7.11	2.34
WITHOUT CALIF. TAX CREDIT Commercial	35.82	9.47	7.48	15.94
Apartment	18.51	7.70	5.70	10.1
Homeowner	15.76	9.74	7.11	5.6
Notes	1	2	2	3

NOTES:

1. From table 1 - 5.

2. From table 1 - 6.

3. If the fuel cost experience the highest rate of inflation, solar energy will become competitive soonest. Therefore, the minimum time to become competitive is estimated by the following formula:

$$\text{Minimum Time*} = \frac{\left[\mathrm{LN}\ \dfrac{\text{Solar Energy Cost}}{\text{1977 Levelized Cost of Heat}}\right]}{\mathrm{Ln}\ (1.09)}$$

*for 9% expected rate of inflation in fuel cost and assuming that solar energy price remain constant in current dollars.

A more limited role for government is indicated for the industrial, commercial and agricultural sectors. One of a kind demonstrations are probably adequate, information need only be directed at trade organization, industry can evaluate the quality of hardware without special government assistance, and finally government funded market research is probably inappropriate.

7. Federal and State Environmental Policy

The EPA has taken the position that allowing industrial expansion in areas exceeding the ambient air quality standards is in violation of the Clean Air Act. However, many labor and business groups are opposing this position calling it a "no growth" policy. The Clean Air Act Amendment of 1970 did not specify how this conflict was to be resolved. Although the conflict is still not completely resolved, the EPA ruled, in 1976, that industrial expansion would only be allowed if it resulted in a net reduction in emissions. Thus, an air pollution trade-off policy was established which permitted elimination or reduction of emissions from existing sources to offset emissions from new plants in the New Source Review Procedure. Meanwhile in California, the State Air Resources Board adopted New Source Review Regulations for the South Coast Air Quality Management District that allow air pollution trade-offs between different companies. Since all major populated areas of California also exceed the EPA ambient air quality standards, offsetting emission control measures are likely to be required to accomodate future industrial growth in California.

The use of solar energy systems as a pollution offset measure could accelerate its use. Industry could either purchase solar energy systems for its own use or share in the purchase of solar energy systems for others as a means of achieving a required pollution offset. A pollution offset credit of several dollars per square foot of collector may be justified for using solar energy.* This credit will increase with time as other mitigation measures reach the limit of their potential to reduce emissions. This area requires further study to determine the impact on industrial interest in solar energy.

G. RECOMMENDATIONS

1. A "go slow" posture is recommended for California regarding incentives for industrial applications of solar energy. State corporation tax credits get diluted by the increase in the federal tax liability and even at a level of 55 percent would not be adequate to make solar energy attractive to most industrial managers. Property tax exemptions while a positive step, would be inadequate to make a major difference to industrial use of solar energy in the near term.

2. California should conduct a more detailed study to evaluate the effect of tax policy and risk assigned on industry's propensity to adopt solar energy and other capital intensive energy conservation measures. This study puts in question the social wisdom of current taxation and risk assignment policy.

3. In a companion study, California should investigate the risk and usefulness of alternate forms of financing industrial applications of solar energy systems.

4. California should investigate the use of solar energy as a pollution offset measure. The value of solar energy in this regard needs to be established by application, pollutant, and geographical area within California. It is likely that continual updating of this data will be needed as the cost of direct pollution control technology increases.

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*One can explore the scale and significance of such a pollution offset credit by recognizing that burning natural gas in residential applications results in about 70 tons of emissions per bdf of natural gas burned.

If the cost of alternative pollution abatement measured is $10,000 per ton, then a rough estimate for the magnitude of pollution credit justified for installing a solar energy system is:

$$3.00\ \$/\text{ft}^2 = \frac{10{,}000\ \frac{\$}{\text{Ton}} \times \frac{(250{,}000\ \text{Btu/yr/ft}^2)}{(0.6\ \text{Efficiency})} \times \frac{70\ \text{tons}}{10^9\ \text{CF}} \times \frac{1\ \text{CF}}{10^3\ \text{Btu}}}{0.1\ \frac{\$\ \text{Annual Cost}}{\$\ \text{First Cost}}}$$

5. The state should monitor and evaluate ongoing Federal R&D programs in solar energy applications for all temperature ranges. The federal government is sponsoring a vigorous research, development and demonstration program in solar energy totaling over $300M in FY78. This program will produce new information, new hardware, and new ideas well into the future and these could change the outlook for industrial applications.

6. The state should support and encourage the University of California, the state university system and the community college system to develop curriculum and conduct research in the applications of solar energy to commercial, industrial, and agricultural processes. Although these applications currently appear to be more than 10 years from being attractive to management, this situation could be changed by the success of current Federal R&D, changes in taxation policy, or more rapid escalation of fuel prices than currently expected.

SECTION II

SURVEY METHODOLOGY

A. ASSUMPTIONS AND CONSTRAINTS

The study of solar energy for processs heat had not been previously examined to nearly the extent that it has for solar energy use in buildings. Two general studies were performed for the Energy Research and Development Administration (now the Department of Energy) (Refs. 1 and 2). Both were national in scope and did not address issues peculiar to California industry. The two studies were also done concurrently with this study and therefore, their results were not available as input to this work. Thus the base of knowledge for solar energy use for industrial processes was lacking.

Technical and economic requirements for process heat in industry, agriculture, and commerce are far more diverse than the requirements for residential buildings. Therefore, to stay within the scope and resources of the present study, certain simplifying assumptions and constraints were made. These assumptions and constraints are as follows:

(1) Process heat is defined to exclude space heating and cooling of industrial, agricultural, or commercial buildings and domestic water heating except where such uses are part of the production process: e.g., space heating of livestock shelters is included. It also excludes electrical power generation and transportation.

(2) The energy use figures in Ref. 3 were taken as sufficiently accurate to permit ranking of industrial, agricultural, and commercial process heat uses in terms of their energy requirements. It was important to identify the highest energy users so that their potential for solar energy could receive the most attention. In this way it was possible to investigate the users of all but about 10 percent of the total thermal energy use in California.

(3) The Standard Industrial Classification (SIC) Code was used to obtain and classify the data. Table 2-1 lists the SIC divisions and two-digit code subdivisions investigated in the course of the study. Those not listed were of such a nature that there appeared to be no possible application of solar energy or were not significant energy consumers in California.

Table 2-1. SIC Code Divisions and Major Groups Investigated

Major Group	Name
Division A	Agriculture, forestry, and fishing
01	Agricultural production - crops
02	Agricultural production - livestock
Division B	Mining
	None
Division C	Construction
	None
Division D	Manufacturing
20	Food and kindred products
24	Lumber and wood products, except furniture
26	Paper and allied products
28	Chemicals and allied products
29	Petroleum refining and allied industries
30	Rubber and miscellaneous plastic products
32	Stone, clay, glass, and concrete products
33	Primary metal industries
34	Fabricated metals
37	Transportation equipment
Division E	Transportation, communication, electric, gas, and sanitary services
49	Electric, gas, and sanitary services
Division F	Wholesale trade
	none
Division G	Retail trade
	none
Division H	Finance, insurance, and real estate
	none
Division I	Services
70	Hotels, rooming houses, camps, and other lodging places
72	Personal services
Division J	Public administration
	none
Division K	Nonclassifiable establishments
	none

(4) Certain SIC code major groups were eliminated in the initial screening because of excessive temperature requirements. Other groups bearing a strong resemblance to these were also eliminated with a minimum of investigation. For example, blast furnaces were found to require excessive temperatures and smelting was automatically eliminated because it appeared to require the same range of temperatures. The applications eliminated in this way were small energy users in California and accounted for only about 5 percent of the state's process heat.

(5) Since the purpose of the study was to locate near-term applications, only process temperatures of 350°F or less were investigated. Since flat plate collector technology was determined to be the nearest to commercial and economic viability, processes within their range of performance were examined in the most detail. Therefore, nearly all the effort was concentrated on applications with temperatures of 212°F or less.

(6) The SIC major groups are subdivided into three-digit codes and further subdivided into four-digit codes. In the major groups investigated, most three-digit code categories were investigated in some detail. Selected four-digit categories were investigated where they appeared promising because of significant process heat requirements. It was not possible to deal with all the four thousand or more four-digit categories. Therefore, the screening process may have eliminated some applications with potential for solar energy. It is not likely that any would be large energy users, however.

(7) Applications that were found were generally one part of an entire production operation. Other parts of the same operation may not have been suitable for solar energy. Therefore, it was desirable to breakdown the energy consumption by individual process. In most cases, the breakdown of energy use within the operation was not known and only estimates could be made of the amount of energy suitable for solar energy application.

B. THE SURVEY PROCESS

The sequence of steps in the survey was as follows:

(1) Identify the large energy users in California; investigate their specific end uses and rank them by their energy consumption.

(2) Determine, (where possible), the process heat energy use by SIC code of the industrial, agricultural, and commercial sectors of the California economy.

(3) Eliminate those end uses for which solar energy is not feasible in the near-term because of high temperature requirements or because surplus energy is available at the site.

(4) Conduct telephone interviews with industry representatives.

(5) Make site visits to representative companies appearing to have candidate solar applications.

(6) Make rough design-cost analyses and assessments of potential energy displacement. Define potential applications and rank by attractiveness.

(7) Broaden the survey to other companies in the potentially attractive SIC code groups to determine the breadth of applicability and the potential market.

(8) Analyze, organize, and structure the survey data to provide inputs to the design-cost studies.

(9) Evaluate the barriers and incentives to the widespread diffusion of solar energy applications in the industrial, commercial and agricultural sectors. Suggest possible options for State actions to promote the use of solar in the three sectors.

The initial data gathering was by literature search and telephone contact, to provide as much background data as possible for selection of those SIC categories to be interviewed or visited. The results of the literature search are incorporated in the sector and industry descriptions in Section III, below.

The major sources of data on thermal energy use were Ref. 3 and 4, which provided data for 1972-73. Current fuel use has certainly changed but, since the main use of the data was to rank different applications relative to one another, these figures were considered adequate. Thermal energy use was initially taken as total energy minus electrical energy, but it was found that natural gas use yielded the same ranking and this parameter was used instead.

Table 2-2 lists the top 33 of the 99 SIC code categories used in preparation of this report; these include all categories using more than 3×10^{12} Btu of gas per year. This summary table is presented to indicate the nature of the largest energy users and the procedure by which process heat users were ranked and identified for further investigation. Most of the categories which were lower on the list than the 33 shown and which had a potential for solar process heat, were various types of food processing (subcategories of SIC Code 20). In some cases, it was necessary to interview a representative of the type of company involved in order to determine whether or not the process temperature was too high to be a candidate for solar energy.

On the basis of the information in Table 2-2, companies to be initially interviewed were identified. A total of 24 SIC code categories were covered by interviews, plus five industry organizations. The trade organizations were willing to help, but some were more helpful than others because of their size and influence. Most were able to provide lists of California operations in their industry and production figures for the industry. Many were beginning to gather data on energy use, but except for a few large groups participating in federal programs, the data was not yet available.

A standard interview form was used to collect the data for the survey. Major headings and types of questions were as follows:

Technical Data

1. Process energy uses (process flow showing steps where process energy is used, with temperatures and amounts).
2. Energy consumption (forms of energy or fuel, with amounts, percent of total heat used at less than $350^{o}F$, less than $212^{o}F$).

Physical Data

1. Available roof or other area for collectors, capability of carrying collector load.
2. Orientation of potential collector area
3. Special concerns (computer rooms, labs, etc.)
4. Conservation measures taken or planned
5. Capability for maintenance of solar energy system.

Manufacturing Process

1. Identification of each process step with peak and average production rate, energy consumption rate, operating temperature, and duty cycle.

Table 2-2. Top Thermal Energy Consumers by 3-Digit SIC Code, California 1975

Thermal Energy Rank	SIC Code	Classification	Thermal Energy Consumption Btu x 10^{12}
1	291	Petroleum refining[a]	168
2	281	Industrial organic chemicals[a]	56
3	324	Hydraulic cement[a,b]	45
4	331	Blast furnaces[a,b]	31
5	206	Sugar products	23
6	203	Processed vegetables/fruits	22
7	322	Glassware[a,b]	18
8	327	Concrete and allied products[a]	16
9	263	Paperboard mills	15
10	209	Miscellaneous food products	12
11	329	Nonmetallic minerals	8
12	335	Nonferrous rollings mills[a]	8
13	325	Structural clay[a,b]	8
14	208	Beverages	7
15	262	Paper mills	7
16	289	Miscellaneous chemical products	7
17	371	Vehicle manufacturing	7
18	282	Plastics[a]	6
19	242	Sawmills[b]	6
20	202	Dairy products	5
21	339	Miscellaneous metal products[a]	5
22	372	Aircraft manufacture	5
23	344	Structural metal[a]	4
24	301	Tires[a]	4
25	295	Paving/roofing	4
26	284	Soap	4
27	201	Meat Products	4
28	205	Bakery products	4
29	332	Iron & Steel	4
30	265	Paper containers	3
31	347	Metal coating, engraving	3
32	204	Grain mill processing	3
33	307	Miscellaneous plastics[a]	3

Source:

A. D. Little, Inc , Energy Shortage Contingency Plan: Technical Appendix: A Report for the California Energy Resources Conservation and Development Commission, October 1975.

Notes:

a. Industries where temperature requirements do not appear to be suitable for low temperature solar applications.

b. Industries where surplus low-temperature heat or available waste heat appear to exist.

2. Identification of steps where fuel substitutions are not feasible.

Economic Data

1. Energy sources (fuel types and prices, availability, expected future prices, energy costs as percentage of total operating costs).
2. Energy planning, investment criteria, depreciation method.
3. Incentives required to cause selection of a solar energy system; kind of government participation felt desirable.

Institutional Data

1. Identification of influential trade organizations and journals.
2. Identification of influential leaders in the industry.

The interview form was completed by each person participating in the survey, and was used for in-person interviews, telephone interviews, literature searches and simple telephone contacts. In this way, all data was in a standard format and could be readily organized for later summary and analysis.

Interviews were scheduled roughly in order of energy use rank, after elimination of industries on the basis of literature review or telephone contacts.

The survey provided data to the analysis tasks, especially to the design-cost studies. These studies required not only the technical and economic data gathered in the survey, but also some ranking of the potential solar applications in order of attractiveness. The ranking involved ease of application of solar energy, probability of acceptance by the industry, and payoff in terms of total energy displaced if solar energy were widely adopted in the industry. It was planned that the survey would provide data from which the state could make an assessment of the market penetration potential of solar energy for process heat.

Interviews on site visits were generally conducted by two people, a design engineer and a systems analyst. The interviews were arranged through telephone contacts. Several contacts were usually made before a cooperative and available interviewee was found. As much information was obtained beforehand through the literature to maximize the effectiveness of the interviews. Plant engineers were the best source of technical and process information. Economic and financial information was usually obtained from corporate officers although plant engineers generally knew the investment requirements for plant equipment. During the site visits, company personnel were very cooperative and helpful. Although their knowledge of solar energy was often simplistic, their response to the possibility of solar energy was generally favorable.

From information gained in the survey, the survey teams reviewed and assessed the data. A consensus was reached on the most appropriate and attractive candidates for detailed design-cost studies. Included in the selection criteria was the desire for a range of applications and complexity of solar installations in order to evaluate a variety of generic system designs. The results of this analysis and selection process are listed in Table 2-3.

The scope of this study included estimates of the potential for solar energy in the industrial, agricultural and commercial sectors. Although information gathered in this survey was sufficient for a rough-cut analysis, insufficient information existed to perform the types of analyses necessary to precisely evaluate the market penetration potential. Firms were unable to provide the necessary detailed information. Either the information was not available, such as the thermal energy consumption breakdowns within the production process itself, or a specific design was required to provide other than general criteria. In addition, with process energy consumption breakdowns not known, it was difficult to evaluate with any precision the "typicalness" of the industrial process surveyed or the solar potential when only one part of a particular process had an application. Hot air, hot water, and process steam are common to many processes. The potential for solar in these generic approaches to solar were not examined. They are often supplemental to the production process itself e.g. clean-up, and are more wide-spread than this survey indicates. In other words, industries with no process requirements under 350°F were eliminated from this survey effort; although a more thorough examination would probably disclose clean-up operations under 350°F in many of them.

Steam boilers are a common source of process heat in many industries. Even when the process temperature is low, steam is often chosen as a means of distributing heat around a factory. No evaluation was made of the implications of integrating solar energy with steam generation or of the impact of its use on the design of a central energy system. The problems associated with storage of steam or storage of energy at temperatures adequate to produce steam on demand have not been solved. The large latent heat of water makes steam transport attractive but also makes the use of solar energy

Table 2-3. Design/Cost Studies Applications

Process	SIC Code	Thermal Energy Use Rank of SIC Code	Application
Storage of vegetable oils prior to processing*	207	75th	Heating of storage tanks up to $120^{\circ}F$+ to keep liquid. No storage, simple controls, simple collector installation.
Paper pulping prior to paper making	262	16th	75% batch pulping of paper at $180^{\circ}F$ remainder at $45^{\circ}F$. Water recycled after each batch. Solar to provide make up heat from ~ $100^{\circ}F$ to $180^{\circ}F$. Simple controls and collectors, use of existing storage.
Beer Pasteurization	208	15th	Very large system with sophisticated controls due to small temperature tolerance of pasteurization. Storage is a significant segment. Pasteurization at $145^{\circ}F$.
Soap Manufacture	284	27th	Neutralize fatty acids at $130^{\circ}F$ and maintain neat soap at $130^{\circ}F$ for pumping. Storage required.
Truck Washing at Fluid Milk Plant (old)	202	21st	Preliminary rinse of milk tank trucks at $110^{\circ}F$. Difficult site, long pipe runs, storage required, simple controls.

*On site Design/Cost study not performed. Estimated costs extrapolated from other design/cost studies based on comparable characteristics.

+Process temperatures, not collector temperatures.

difficult. Where steam condensate is returned to the boiler, make up water is 5-10 percent of the steam generation rate and to preheat this water to 212°F with solar energy would impact fuel consumption by less than one pecent.

SECTION III

INDUSTRIAL PROCESS HEAT SURVEY

A. INTRODUCTION AND GENERAL FINDINGS

1. General Sector Characteristics

The industrial sector, as defined in this report, consists of all manufacturing industries classified in major groups 20 to 39 in the Standard Industrial Classification (SIC) Code (Ref. 1). In that code, major groups 10 to 17 and 40 to 49 are also classed as industrial; however, since these groups (mining, construction, and transportation) use insignificant amounts of process heat they have not been included here. Space heating and cooling and non-process water heating for buildings are also excluded from this discussion. The SIC codes covered in this survey are listed in Table 3-1 with their respective numbers of employees, values of shipments, and energy consumption. California establishments in SIC 20 to 39 number over 35,700 and 11,000 of them employ more than 20 people. Total California employment is 11.1 million, with a value of shipments of nearly $63 billion. It is readily seen from Table 3-1 that there is no relation between the energy use of a group and its contribution to either employment or value of shipments. The top ten California energy users among the two-digit SIC code industries are listed in Table 3-2, together with their respective ranks by value of shipments and employment. These ten industries contribute 77 percent of the total value of shipment, with the top six using 75 percent of the energy to produce only 38 percent of the value. These characteristics, are necessarily inherent in the nature of the respective industries and do not necessarily reflect differences in efficiency of energy use.

2. Energy Utilization and Requirements

The top ten industrial energy users in California identified above are not necessarily the largest users of process heat. We saw in Section II which industrial users ranked highest in use of thermal energy. We have also seen that the industrial sector uses about 18 percent of the total energy in California, with over 80 percent of this being process heat. It can be noted here that in California, natural gas is the predominant fuel used in manufacturing, contributing nearly 60 percent of the total energy consumed and nearly all of the process heat. Any use of solar energy for process heat is

Table 3-1. Characteristics of California Industries by 2-digit SIC Code *

SIC Code	Classification	Employees (000)	Value of Shipments ($millions)	Total Energy Use (10^9 kWH
20	Food and kindred	1,181	11,794	27.2
22	Textile mills	132	543	1.4
23	Apparel	1,020	1,855	1.3
24	Lumber and wood	612	2,620	6.5
25	Furniture and fixtures	516	1,149	1.1
26	Paper and allied products	305	1,674	10.6
27	Printing and publishing	783	2,542	2.3
28	Chemicals	457	3,180	16.9
29	Petroleum and coal	72	3,398	48.6
30	Rubber and miscellaneous plastics	476	1,683	3.9
31	Leather	60	+	0.2
32	Stone, clay, and glass	461	1,923	29.3
33	Primary metals	353	2,170	17.6
34	Fabricated metals	1,183	4,215	9.1
35	Machinery	1,036	4,426	3.7
36	Electrical machinery	895	5,344	5.1
37	Transportation equipment	591	11,992	8.3
38	Instruments	335	1,423	1.0
39	Miscellaneous	313	953	0.9
20-39	TOTAL	11,160	62,976	194.8

*References: U.S. Bureau of the Census, Census of Manufacturers, 1972, Area Series - California, MC72(3)-5, U.S. Government Printing Office, Washington, D.C., 1975.

U.S. Bureau of the Census, Census of Manufacturers, 1972, Special Report Series: Fuels and Electric Energy Consumed, MC72(SR)-6, U.S. Government Printing Office, Washington, D.C., 1973.

+Information witheld to avoid disclosing figures for individual companies.

Table 3-2. Top Ten Energy Consuming Industries in California, 1974*

SIC Code	Classification	Rank In Energy Use	Rank In Employment	Rank In Shipment
29	Petroleum and coal	1	18	6
32	Stone, clay, and glass	2	11	11
20	Food and kindred	3	2	2
33	Primary metals	4	13	10
28	Chemicals	5	12	7
26	Paper and allied products	6	16	13
34	Fabricated metals	7	1	5
37	Transportation equipment	8	8	1
24	Lumber and wood	9	7	8
36	Electrical machinery	10	5	3

*Source: U.S. Bureau of the Census, Census of Manufacturers, 1972, Area Series - California, MC72(3)-5, U.S. Government Printing Office, Washington, D.C., 1975.

U.S. Bureau of the Census, Census of Manufacturers, 1972, Special Report Series: Fuels and Electric Energy Consumed, MC72(SR)-6, U.S. Government Printing Office, Washington, D.C., 1973.

therefore almost certain to displace natural gas, although some fuel-oil use might be displaced. Very little process heat is supplied by electricity, and little displacement of electric power use by solar energy appears likely. Where electricity is used for heating, however, there appears to be a good solar application because of the relatively high cost of electric energy.

Process heat in industry is often supplied by process steam, although many applications such as blast furnaces or kilns use air directly heated by combustion. The suitability of any industrial application for solar energy, at least on the basis of current technology, is largely a function of process temperature, as discussed below, although other factors will influence the cost of solar and its viability as a supplement energy source.

3. Technical Characteristics

Characteristics of industrial processes vary widely. Process temperatures and duty cycles are different as are the means for providing those temperatures. Process heat is used in the form of hot water, steam or heated air and is applied directly or through heat exchangers. The quality of the energy supply is important to those industries where contamination of the product is a possibility e.g., drying of food products.

Natural gas is the primary industrial fuel in California with fuel oil back-up. Because of the natural gas priority system in the state, most firms have begun conversion of their operations to fuel oil. Most large energy consumers have boilers or other equipment which can be dual fired or converted without considerable difficulty. Adequate on-site fuel oil storage facilities have not generally been constructed, although many are planned. The addition of pollution control equipment necessary for the conversion from natural gas to fuel oil is not perceived to be a problem by most industries surveyed. Greater concern is expressed by those industries with package boilers, presently fired by natural gas. These boilers cannot be modified to burn fuel oil and, therefore, replacement would be required to accomplish the change. While most of these users are small energy consumers and consequently have a higher natural gas priority rating, they are more concerned about future energy supplies than many larger energy consumers. Since the survey sample was not large, it was difficult to accurately measure how wide-spread and accurate this conversion situation is.

All of the interviews and plant visits were made to existing facilities. Solar energy systems would have to be retrofitted to these installations. Retrofitting is more difficult for several reasons. It involves a greater cost for installing the systems. Reinforcement of existing structures is often required to accommodate solar collector arrays. This problem was encountered in all of the specific design cases studied (Ref. 2). Also, existing operations are in varying stages of obsolescence. By current standards, they are often less energy efficient than new plants. Management will question the logic of placing a capital intensive investment on a plant that may soon be obsolete. There must be negligible disruption to the plant operation which can also make retrofitting more complex and expensive.

The integration of solar energy systems into new plant design is more desirable economically, most feasible technically, and most acceptable to management. Even if a solar energy system is not installed immediately, the mechanical and structural requirements for it can be incorporated into the original plant design at minimal additional cost and it can later be installed at considerably less cost than a retrofit. Management, however, will have to be assured that the solar energy system will have the same life-expectancy as the new plant facility.

4. Economic Characteristics

The economics of the industrial sector were fairly consistent with regard to capital investments and the potential for solar energy systems. The solar energy systems must compete with all other investments for the capital dollars. Industry typically has three to five year payback periods* but may be willing to accept up to ten years for viable energy options. Return on investment (ROI)** ranged from the prime rate (primarily regulated or price supported industries) to over 30%. This range reflects in large part the amount of risk the various industries are willing to assume. The higher the risk, the higher the return on investment required. Solar is generally considered a moderately high risk. However, if solar can meet the investment decision-making criteria of industry, it appears that the capital will be available for those investments.

$$\text{*Payback} = \frac{\text{Capital Investment}}{\text{Annual Savings}}$$

**ROI = the discount rate which makes the net present value of an investment equal to zero.

Solar energy systems are not economically competitive today with conventional energy sources. Conventional fuel prices are such that the low operating cost of solar energy systems do not offset the high capital costs of the systems. Additionally, there are still conservation measures today which are more cost-effective than solar and which would be taken prior to any investment in solar energy.

State natural gas priorities have been established and clearly imply possibility of interruption of supplies. However, many companies interviewed do not seem overly concerned about this situation. Fuel oil is perceived to be sufficiently plentiful even though more expensive. Many of the lower-priority boilers have been converted to burn either gas or oil, and more are in the process of conversion. Oil energy is currently about twice the price of natural gas energy, and this should improve the competitive position of solar energy where oil is being used. On the other hand, energy costs in the industries surveyed are in the range of 1 to 5 percent of total operating costs and therefore, increased fuel costs may not be viewed as a serious threat to profitability.

There are factors other than system cost, however, that could positively impact decisions to adopt solar. Food processing industries, for example, require an adequate and reliable fuel supply. The products are highly perishable and delays in acquiring adequate fuel supplies when needed could cause irreparable and unrecoverable product loss with severe economic penalties. If solar can help insure an adequate and reliable fuel supply, either by supplying the energy or by reducing the demand for conventional fuels so that higher natural gas priorities could be obtained, solar energy systems will be more favorably evaluated by management.

5. Institutional Characteristics

If the economic and technical criteria can be met, there are few institutional barriers to the user of solar energy in the industrial sector. There is sufficient engineering expertise in most plants to be able to understand, operate and maintain any solar energy system. Dissemination of information on solar energy applications is crucial to the widespread adoption of these systems. Active industry and professional organizations and widely read publications exist in most industries so that information can be easily transferred from one plant to another, and from one industry to another.

Many industries that do not participate in industry organizations are of sufficient size that research on solar is often done internally and dissemination of information is not a problem.

The one barrier to the dissemination of information is where proprietary processes exist. If the solar energy system is integrated into the proprietary part of the process, information dissemination will be difficult. If it does not involve the proprietary process itself, no difficulty will exist.

Another barrier is the narrow framework within which industry views solar energy. Management's knowledge of solar energy tends to be of systems for domestic hot water and space heating, not for solar energy systems capable of meeting thermal energy requirements of industrial processes. Industry, in general, is not willing to experiment with solar energy systems.

Demonstrations will be required to prove to industry the technical and economic viability of these systems. They may be willing to cost share in a solar energy system demonstration, but their share of the cost will still have to meet their economic criteria for capital investments.

Another institutional consideration of importance is that the high capital cost of solar energy systems can increase property tax assessments to the point where any life-cycle cost savings due to solar energy systems are nullified. This factor has been partially responsible for the cancellation of some solar projects, and the threat of assessment allegedly killed one project before it got started. It appears that a property tax exemption will be required to make solar energy systems economically attractive to most industrial users.

On the other hand, the high first cost of solar energy systems is not as much of a barrier as in the case of residential installations. Industrial plants are used to making large capital investments that pay back over a period of years, and the original investor is the same entity as the one that will own and operate the system over its lifetime. This simplifies the process of comparing solar energy systems with other energy sources. A major requirement is that the comparison show on a life-cycle costs basis, that solar energy must be economically competitive with alternatives. And, as noted above, industry must have confidence in designers and in the technical performance and reliability of solar energy systems.

6. Potential for Solar Energy

The nearest-term applications for solar energy are for processes with thermal energy requirements under 212°F. This potential for energy displacement is quite significant. If all 1975 thermal process energy requirements under 212°F were met by solar energy, roughly 99 trillion Btus or 2% of total California energy consumption could be displaced (Table 3-3).

Applications between 212°F and 350°F have the potential for even greater energy displacement. These medium temperature applications may in some cases be as competitive as lower temperature ones. Approximately 137 trillion Btu's are available in this temperature range. Thus an upper limit displacement potential by solar for thermal processes under 350°F could be in the range of 236 trillion Btus based on 1975 requirements.

California's top 33 thermal energy consumers account for approximately two-thirds of 1975 industrial thermal energy consumption. The top 10 alone account for nearly 50%. As stated in the assumptions and constraints, the internal energy consumption breakdowns are rough estimates. However, they should give a feeling of the relative nature of energy consumption in the various industries. Table 3-4 gives the breakdown for each of the top 33 SIC codes. For industries with energy requirements over 350°F, the largest generally use heat in excess of 1000°F. For industries with capabilities of waste heat utilization, cascading, or co-generation, no near-term solar applications were identified and no further investigations were undertaken.

Table 3-5 gives a breakdown by thermal energy requirements of industries which appear to have potential applications for solar energy and which were interviewed during the course of this survey. The top energy consuming industries with thermal requirements under 212°F are primarily in the food processing industry. The energy is used to heat products, to heat water for product processing, clean-up and sanitation, or to heat air for drying and/or dehydration of product. Although hot water and air can be produced directly, these requirements are generally met by producing steam at 100 to 150 psi (325-350°F).

Table 3.3. Energy Consumption in the Industrial Sector of California by Thermal End-Use Requirements

Thermal Energy Consumers	Thermal Energy Consumption							
	Under 212°F		212°F to 350°F		Over 350°F		Total	
	10^{12}Btu per yr	% of Sector Total	10^{12}Btu per yr	% of Sector Total	10^{12}Btu per yr	% of Sector Total	10^{12}Btu per yr	% of Sector Total
Top Ten (a)	37	4	45	6	293	36	375	46
Top 11-33 (b)	26	3	40	5	72	9	138	17
Top 33	63	7	85	11	365	45	512	63
Remaining Users (b)	36	5	52	6	212	26	301	37
TOTAL	99	12	137	17	577	71	813	100

Notes:

a.) Based on Table 3-4

b.) See notes to Table 3-4

Table 3-4. Thermal Energy End-Use Requirements of Top Thermal Energy Consumers by 3-Digit SIC Code, California 1975.

THERMAL ENERGY RANK	SIC CODE	CLASSIFICATION	THERMAL ENERGY CONSUMPTION 10^{12} BTU	Thermal Energy End Use Requirements (a)					
				Under 212°F		212°F to 350°F		Over 350°F	
				10^{12} BTU	% of Total Thermal	10^{12} BTU	% of Total Thermal	10^{12} BTU	% of Total Thermal
1	291	Petroleum Refining(b)	168	0	0	8.4	5	160	95
2	281	Industrial Organic Chemicals	56	0	0	0	0	56	100
3	324	Hydraulic Cement(b)	45	0	0	9	2	44.1	98
4	331	Blast Furnaces(b)	31	0	0	0	0		100
5	206	Sugar Products	23	5.0	22	16.8	73	1.2	5
6	203	Preserved Vegetables/Fruits (c)	22	16.9	77	3.7	17	1.3	6
7	322	Glassware(b)	18	0	0	0	0	18.0	100
8	327	Concrete and Allied Products	16	1.0	7	2.1	13	12.8	80
9	263	Paperboard Mills	15	5.0	33	10.0	67	0	0
10	209	Miscellaneous Food Products	12	9.0	75	3.0	25	0	0
11	329	Nonmetallic Minerals	8	0	0	2.0	25	6.0	75
12	335	Nonferrous Rolling Mills	8	0	0	2.0	25	6.0	75
13	325	Structural Clay(b)	8	0	0	0	0	8.0	100
14	208	Beverages(c)	7	2.2	31	12.9	41	1.9	28
15	262	Paper Mills(c)	7	2.0	33	5.0	67	0	0
16	289	Miscellaneous Chemical Products	7	0	0	5.2	75	1.8	25
17	371	Vehicle Manufacturing	7	3.5	49	1.1	16	2.4	34
18	282	Plastics	6	1.7	29	2.9	48	1.4	23
19	242	Sawmills(b)	6	3.0	50	3.0	50	0	0
20	202	Dairy Products(c)	5	4.3	86	0.1	2	0.6	12
21	339	Miscellaneous Metal Products	5	0	0	0	0	5.0	100
22	372	Aircraft Manufacture	5	0	0	0	0	5.0	100
23	344	Structural Metal	4	0	0	0	0	4.0	100
24	301	Tires	4	0	0	4.0	10	0	0
25	295	Paving/Roof	4	0	0	3.8	96	0.2	4
26	284	Soap	4	2.9	72	1.0	26	0.1	2
27	201	Meat Products(c)	4	3.9	98	0	0	0.1	2
28	205	Bakery Products(c)	4	0.5	12	0	0	3.5	88
29	332	Iron and Steel	4	0	0	0	0	4.0	100
30	265	Paper Containers	3	0	0	3.0	100	0	0
31	347	Metal Coating, Engraving(c)	3	1.5	50	0	0	1.5	50
32	204	Grain Mill Processing(c)	3	0	0	3.0	100	0	0
33	307	Miscellaneous Plastics	3	0	0	3.0	100	0	0

SOURCE A. D. Little, Inc., Energy Shortage Contingency Plan, Technical Appendix, A Report for the California Energy Resources Conservation and Development Commission, October 1975

NOTES a) Thermal end-use temperature breakdown is adapted from data in Intertechnology Corporation (ITC) "Analysis of the Economic Potential of Solar Thermal Energy to Provide Industrial Process Heat," Final Report, Volume I, II, Washington, D.C., Government Printing Office, February 1977, with modifications based on this California survey effort

b) Industries with processes where excess low-temperature thermal energy appears to exist or wasteheat appears to be available

c) Industries in which on-site visits were made

Table 3-5. Process Heat Requirements for Industrial Applications Surveyed in California, 1974

Industry by SIC Group		Application Temperature Requirement (°F)	Medium
20.	Food and Kindred Products		
2011	Meat Packing		
	Scalding, Carcass Wash, and Cleanup	140	Hot Water
	Singeing Flame	500	--
	Edible Rendering	200	--
2013	Meat Processing[a]		
	Smoking/Cooking	155	Hot Air
	Cleanup	160[c]	Hot Water
2026	Fluid Milk/Ice Cream[a]		
	Pasteurization	162-185[c]	Steam
	Truck/Tank Wash[b]	110-170	Hot Water
	Cleanup	160-180	Hot Water
2033	Canned Fruits and Vegetables[a]		
	Blanching/Peeling	180-212	Hot Water/Steam
	Pasteurization	200	Hot Water
	Brine Syrup Heating	200	Steam
	Commercial Sterilization	212-250	Steam/Hot Water
	Sauce Concentration	212	Steam
	Can Washing	180-190[c]	Hot Water
2037	Frozen Fruits and Vegetables[a]		
	Blanching	180-212	Steam/Hot Water
	Warehouse Floor Heating	90[c]	Hot Water/Hot Air
2048	Prepared Feeds[a]		
	Pellet Conditioning	180-190	Steam
	Alfalfa Drying	400[d]	Hot Air

Table 3-5. Process Heat Requirements for Industrial Applications Surveyed in California (Cont'd)

Industry by SIC Group	Application Temperature Requirement (^{o}F)	Medium
20. Food and Kindred Products		
2051 Bread and Baked Goods[a]		
Sponge Mixing[c]	75[c]	Warm Air
Proofing	105-115	Steam Heated Air
Baking	400-425	Hot Air
Cleanup-Basket Washing	165[c]	Hot Water
2079 Shortening and Cooking Oil[a]		
Seed Conditioning	180[c,e]	Steam
Stack Cooker	280[c,e]	Steam
Oil Storage	100-120[c]	Steam
Fatty Acid Removal	180[c]	Steam
Vacuum Bleaching	220[c]	—
Hydrogenation	380[c]	Steam
Deodorization	500[c]	—
2082 Malt Beverages[a]		
Cooker	212	Steam
Water Heater	180	Steam
Mash Tub	170	Steam
Grain Dryer	400[e]	Steam
Brew Kettle	212	Steam
Can/Bottle Washing	140-160[c]	Hot Water
Can Pasteurization	145[c]	Hot Water
2086 Soft Drinks[a]		
Fructose Storage	90[c]	Steam
Returnable bottle washing	170-190	Hot Water
Can Warming	130-140[c]	Hot Water
Clean up	140-170[c]	Hot Water

Table 3-5. Process Heat Requirements for Industrial Applications Surveyed in California (Cont'd)

Industry by SIC Group	Application Temperature Requirement (^{o}F)	Medium
20. Food and Kindred Products		
24. Lumber and Wood Products		
2421 Sawmills		
Kiln drying of lumber	110-180[c]	Hot Air
26. Paper and Allied Products		
2621 Paper Mills[a,b]		
Pulping[f]	120-180[c]	Hot Water
Paper drying	290-600[c]	Steam
28. Chemicals and Allied Products		
2841 Soaps and Detergents		
Soaps (Mazzoni Process)[a]		
Fatty Acid Preheat	130[c]	Steam Jacket
Mixing Tank	180[c]	Steam Jacket
Dryer		Steam
Detergents[a]		
Crutcher (mixer)	180[c]	Steam
Spray Dryer	500	Hot Air
34. Fabricated Metal Products		
3479 Galvanizing		
Metal	130-180	Electric Coils
Galvanizing Plating baths[g,a]	850	--
49. Electric Gas and Sanitary Services		
Sewage Treatment[a]		
Sludge Digesters		
Mesophyllic	95[c]	Steam
Thermophyllic	120[c]	Steam

Table 3-5

Source:

Adapted from Intertechnology Corporastion, (ITC) "Analysis of the Economic Potential of Solar Thermal Energy to Provide Industrial Process Heat," Final Report, Volume I, II, Washington, D.C., Government Printing Office, February 1977.

Following notes are variations from ITC data.

Note:

a) Plant visit made.

b) Design/cost study performed.

c) Variation from or addition to ITC daa.

d) There is a time/temperature tradeoff. Lower temperatures can be used but drying time will increase.

e) Only occurs when seed crushing is done.

f) Pulping refers to preparation of purchased pulp for paper-making operation.

g) There are similar operations in other SIC Code classifications, but no estimate could be made of the extensiveness of the application in the other industries.

B. SPECIFIC APPLICATIONS

In the industrial sector of California, potential solar energy applications were selected for investigation in the following major groups and will be discussed in this section:

(1) Food and Kindred Products (SIC 20).

(2) Paper and Allied Products (SIC 26).

(3) Chemicals and Allied Products (SIC 28).

(4) Fabricated Metals (SIC 34).

These industries were selected because of their importance as energy users in California and their use of thermal energy is appropriate for solar energy applications. In Section C, other industries with significant energy usage but higher temperature requirements, are discussed.

1. Food and Kindred Products (SIC 20)

Food and kindred products is divided into nine subcategories. Table 3-6 lists those subcategories and their thermal energy consumption.

Table 3-6. California Energy Consumption of Subcategories of Food and Kindred Products (SIC 20) (Btu x 10^{12})

SIC Code	Classification	Thermal Energy Consumption
201	Meat Products	4.2
202	Dairy Products	4.6
203	Preserved Fruits and Vegetables	21.8
204	Grain mill processing	3.2
205	Bread, cake, and related products	3.6
206	Sugar refining	22.8
207	Fats and Oils	0.9
208	Beverages	7.3
209	Miscellaneous	11.9

Reference:

A.D. Little, Inc., Energy Shortage Contingency Plan; Technical Appendix, A Report for the California Energy Resources Conservation and Development Commission, October 1975.

Food products differ from most other manufactured products in that they are purchased almost daily by the consumer. The result is constant public awareness of prices and price changes. Also, competition within the industry is keen. As a consequence, there is continual pressure to keep prices down and profit margins tend to be low. Therefore, even though energy costs are a small percentage of total operating costs they can be important enough to make the difference between operating at a sufficient profit and not doing so. With the generally low process heat temperatures in food processing, this industry is very attractive for investigation of potential application of solar energy.

Food distribution follows two different paths. In one case, independent processors manufacture a product and market it to retail outlets. In the other, large chains manufacture their own products and distribute them through their own retail outlets. For anti-trust reasons, the larger chains are often not allowed to participate in industry meetings and generally refrain from contact with competitors in food processing. This can limit the dissemination of solar energy information between the two types of distributors, but should not constitute a major impediment.

a. Meat Products. This group is divided into plants where animals are slaughtered and meat prepared for distribution to retail outlets, and those where meat products (sausages, etc.) are manufactured from purchased meats. Some integrated plants perform both functions. In California there were 283 plants in 1972, 228 of which were engaged in meat packing and processing. The remainder of the plants in this category were engaged in poultry dressing and poultry and egg processing, but their energy use is so small in relation to the others that they were not investigated.

There is a wide variation in the amount of energy used per unit of output; this parameter appears to be related primarily to the size of the plant. The base load (for lights and refrigeration) may be very small in small plants where energy use is dependent almost entirely on the production volume, while in large plants it may be as much as 85 percent of total energy consumption. For thermal energy, natural gas is the dominant energy source; nine-tenths of the thermal energy is used as boiler fuel, with the remainder used for direct processing. Oil can be substituted as a boiler fuel, but not in the direct processing applications (such as smoking meats). The meat products plants tend to be much more energy intensive than slaughtering plants, as would be expected; smoked products in particular require roughly ten times the energy per pound of finished product that is required by the products of meat packers.

Meat packing plants use very high volumes of hot water, typically at 100°F, 140°F and 180°F. Many plants use a fourth to a half of the boiler fuel to heat water. Heat recovery techniques (waste heat from refrigeration compressors, for example) are being developed, and are in direct competition with solar energy systems for capital dollars. In addition to the hot water, certain processes such as rendering use steam at atmospheric pressure. About half of the national meat packing industry is engaged in a federally sponsored energy conservation effort; energy reductions of about 7 percent have been achieved.

In meat processing plants, hot water is also used in large quantities for cleanup, but there are added requirements for steam and hot air for cooking and smoking.

The meat packing industry made a special study of industry energy uses and published the results in 1976 (Ref. 3). The study results indicated that energy costs were rising rapidly and by 1978 would amount to about two-thirds of the net profit levels. This result suggests that there may be economic incentive for the adoption of cost competitive solar systems to stabilize costs. Less expensive energy conservation measures will, of course, be the first priority, and even these will have to compete for capital funds. Profit levels are low enough that large amounts of capital are not available for new investment in either conservation or solar energy systems.

The meat packing industry is well represented by industry organizations that have played a major role in examining energy use in the industry. Some trends that are of concern to the industry are:

(1) Present and prospective limitations on the use of natural gas, combined with threats of restriction on the only alternative, petroleum products

(2) The trend toward increased popularity of portion-controlled meats for use by restaurants, institutions, fast-food chains, and hotels. The addition of more processing at the plant level increases energy use in plants

(3) The rigid operating framework resulting from union contracts and federal inspection requirements

There appears to be a good potential for the use of solar energy in providing a large part of the hot water requirements of the meat packing and processing plants; smoking and cooking operations do not seem to be adapted to solar energy at this time. Solar energy, combined with the use of waste heat from refrigeration equipment, should be able to reduce considerably the use of conventional fuels for water heating. For plants in urban areas there may be some question about the availability of sufficient roof space or other locations for solar collectors.

b. Dairy Products. The dairy products industry includes the production of fluid milk, cheese, condensed and evaporated milk, and ice cream and frozen desserts. Fluid milk production represents over 80 percent of the value of shipments nationwide, and is the only element of the industry considered in this study.

Although milk consumption per capita has been declining, the total production has been increasing at the annual rate of 2.3 percent because of population growth. This increase has been accompanied by a trend to fewer and larger plants; the 5,700 plants in 1954 have been reduced to somewhat over 2,400 plants today nationwide (Ref. 4). In California there are 195 plants, of which slightly less than half employ more than 20 people. The industry employs about 10,000 people, of whom 4,000 are production employees. The value of shipments in 1972 was approximately $1 billion in California (Ref. 5).

Energy use in the fluid milk industry has decreased sharply in the last 20 years, primarily due to the change in the mode of delivery of milk to the processing plants. Milk was formerly received in cans, which had to be stored under refrigeration and washed. Now milk is held in large refrigerated tanks at the farms until a refrigerated tank truck picks it up for delivery to the plant. This change, combined with the elimination of bottling (the bottles required washing and sterilizing), has reduced energy consumption by about two-thirds since 1954 (Ref. 4).

Thermal energy requirements in fluid milk plants are almost entirely for hot water and steam. Natural gas is the dominant boiler fuel in California. The major uses of thermal energy are in truck and tank washing, pasteurization, and clean-up. Pasteurization requires input temperatures of $180^{\circ}F$ to maintain the required milk temperature of $161.5^{\circ}F$. Clean-up water is generally at $180^{\circ}F$, with truck and tank washing using water at 100° to $170^{\circ}F$. Steam is used as the transfer medium.

Fluid milk plants (which may also produce cottage cheese, yogurt, and related products) consume an average of 300 Btu per pound of raw milk equivalent, although there is a considerable variation among plants. The more modern facilities may use less than 150 Btu per pound, while some older plants use over 600 Btu per pound.

Pasteurization today is generally a "flash" process, in which the milk is held at a minimum of 161.5^{o}F for 5 to 7 seconds; the earlier process required holding the milk at 145^{o}F for 30 minutes. Milk leaving the pasteurizer gives up its heat to the incoming milk, recovering in large part of the thermal energy. In some plants, the waste heat from the refrigerating equipment is used to preheat boiler water with a further saving in energy.

Truck and tank washing is an important part of the operation. All equipment with which milk comes in contact must be cleaned and sterilized daily. The amount of hot water required varies considerably between older and newer plants. Older plants may use 14,000 gallons per day for 100,000 gallons of milk throughput, while newer plants may use less than 2,000 gallons per day for the same throughput.

The milk processing industry in general looks for 3 to 5 year payback periods for capital investments, and a return on investment from the prime rate up to 15 percent. Because of the uncertainty of future energy supplies and the possible public relations benefit, milk producers may be willing to consider solar energy systems that did not meet these criteria.

Independent milk producers are well represented by industry organizations, but plants owned by supermarket chains do not belong to these groups for the anti-trust reasons given earlier. This division could inhibit the dissemination of information about solar technology.

The potential for solar energy in fluid milk processing is limited by the fact that steam is used almost exclusively for heat transfer. It would be possible to preheat the boiler water by solar energy, however, and it might also be practical to heat the clean-up water with solar heaters if this supply were separated from that used for pasteurization. It is technically feasible to use solar energy for pasteurization also, although the required temperature of 185^{o}F is somewhat high for flat plate collectors.

One possible drawback is that most milk processing plants are near their markets in urban areas, which may limit the area available for solar collectors. Roof areas are often used for refrigeration equipment, which further restricts the available area.

Milk processing usually takes place over 8 to 16 hours during the day, with clean-up in the evening. This schedule is favorable for solar water heating, since the water could be heated during the day for use in the evening. Pasteurization could use solar energy directly during the day if it were available and the temperature were high enough. It could supplement the boiler, in any case.

c. Canned Fruits and Vegetables. This category of the food processing industry is the second largest energy consumer in California in this sector; it employs 25,000 people full-time and half again as many during the peak harvest season. The value of shipments in 1972 was one and a quarter billion dollars (Ref. 5).

The canning industry is characterized by a large number of firms, with a few of them accounting for a large part of the total volume. Over half of the industry production comes from the top twenty companies. Most major packers distribute their products under their own labels, which makes for a large degree of vertical integration.

Most of the energy used in the canning industry in California comes from natural gas (77 percent of the total energy use), and most of the gas (70 percent) is used to fire steam boilers. Oil can fairly easily be substituted for this application.

Thermal energy requirements are modest for most canned products except for those (tomatoes, juices) which require cooking and/or concentrating. No heat is required in the initial cleaning and preparation stages except for products such as peaches or tomatoes that must be peeled. Peeling is done by immersing the product in a hot lye solution at 195^{o}oF to 210^{o}F. The peeling solution is generally heated by steam coils. In the final stage, vegetables are blanched by exposing them to live steam or immersing them in hot water. The desired temperature is 205^{o}F to 210^{o}F and the time ranges from 2 to 10 minutes. Tomatoes are cooked at 200^{o}F and kept at this temperature for 15 to 18 minutes. Tomato puree or paste requires cooking for as long as an hour.

Another use for thermal energy is can washing and sterilization, which requires water at 180^{o}F to 190^{o}F. This operation was the subject of an ERDA demonstration project (see Ref. 6), which showed that solar energy could be used. Steam is used to create a vacuum in the can prior to sealing, although in some cases the vacuum is created mechanically. Finally, the sealed cans are subjected to temperatures above 210°F to sterilize the product, with the required temperature depending on the acidity of the product. Steam is used in this process because of the requirement to bring the temperature up as rapidly as possible, but there is a low efficiency in the operation (only 16 to 34 percent of the energy is used to heat the cans and contents) (Ref. 7).

One of the difficulties in using solar energy in the canning industry is its seasonality. For example, tomato canning plants operate for approximately three months a year.

d. Frozen Fruits and Vegetables. In 1972, there were 30 establishments for the quick freezing and cold packing of fruits and vegetables in California. Nearly all of the California plants are "commodity packers"; i.e., they freeze the agricultural product itself rather than some secondary product (TV dinners, etc.). All but one of the California plants employ more than 20 people. Total employment is 8,100 and shipments are valued at $275 million (all 1972 figures) (Ref. 5).

Most of the energy used in California frozen fruit and vegetable plants is in the form of electrical energy for refrigeration, lighting, and machinery. The thermal energy consumption is similar to that of canning plants, consisting largely of blanching and cooking. Frozen citrus concentrate requires more thermal energy per unit because of the requirement for concentrating the juice. Waste heat is available in large quantitite from the refrigeration equipment, but is generally not recovered.

Gas is the major fuel in these plants, and is used to feed boilers. Oil can be substituted if necessary, but gas supplies are usually adequate in the summer and curtailments have not been a problem.

The thermal energy requirements are the same as in canning plants, as noted above. In addition, a potential solar application, incidental to the freezing operation but crucial to its success, was discovered inadvertently during the survey. Once frozen, products are stored in warehouses at 0°F. These warehouses have concrete floors, which must be heated to prevent cracking at this temperature. Both hot air and hot water are presently used for this purpose. No estimate of the energy consumed in this application was made because the warehousing facilities are owned independently and not connected physically or financially to the freezing operations.

Investment criteria are similar to those of the canning industry, and there is a similar willingness to consider solar energy even though it may not meet these criteria, because of concern over future availability of gas and oil.

Because the freezing operations are so simple, there is little reluctance to share information within the industry, so that dissemination of any new technology should be rapid. The major industry organization is the American Frozen Food Institute in Washington, D.C.

The potential for solar energy appears to be in preheating boiler feed water and, although not part of the freezing plant operation, in warming of warehouse floors. Although above the desirable operating range of flat plate collectors, the blanching of vegetables at 205°F is within the range of evacuated tube and concentrating collectors. There is a tremendous amount of waste heat generated by the refrigeration equipment which is not yet being recovered. Although this waste heat could take care of some part of the heating requirements, no studies have been made of the amount of heat involved. There may also be some solar energy potential in the concentration of citrus juice, but this too has not been investigated. Citrus pulp and peel drying appears to require too high temperatures for solar energy using today's technology.

One characteristic of the industry which will inhibit the application of solar energy is the location of many of the plant facilities. The majority of the 14 vegetable plants are along the California coast. Solar insolation as well as the canning season is at its peak during the summer. However, along the coast this is also the period of the heaviest fog. Often the sun shines for only a few hours a day.

e. <u>Grain Mill Processing</u>. This SIC code category (204) includes flour milling, animal feeds, breakfast cereals, rice milling, blended and prepared flour, and wet corn milling. The only one of these subcategories that consumed any significant amount of energy in California (1972) was animal feeds. The following discussion deals with this part of the industry.

Farm animal feed is produced by milling and mixing several ingredients, typically grains, beet and orange pulp, whole cotton seed, walnut shells, antibiotics, vitamins and minerals; molasses and vegetable fat may also be included in the mix. The mix is formulated by a computer program that takes the nutrient requirements of the individual customer and calculates the least-cost feed mix that meets these requirements. The grain is run through metal rollers to flatten it, and at the same time heated to $210^{o}F$-$235^{o}F$ by steam for at least three minutes. Steam is necessary to produce the right feed texture for pelleting and mixing. Pelleting requires a temperature of $180^{o}F$, and is a possible candidate for solar energy. At the present time, the cost of energy is a small fraction of total operating costs. It is not included in the computer program even though some types of mix are more energy-intensive than others.

In the plant visited for the survey, steam is produced by 100=horsepower boilers at $235^{o}F$-$250^{o}F$ that use 80,000 cubic feet of gas per day and operate continuously throughout the week. Although retrofit of existing plants would be difficult and expensive, it appears feasible to include solar preheating of boiler water in new plants. The animal feed industry in California is expanding, indicating that there will probably be such opportunities.

Little roof area is available in animal feed plants because the plant consists primarily of hoppers and storage tanks rather than buildings. However, they are usually located in rural areas, where there is normally open land that could be made available for solar collectors.

Payback periods for new capital equipment may be as long as 10 years. Solar energy is attractive because of its reliability and the present threat of gas curtailment. A change to oil would entail extensive provisions to eliminate contamination of the feed as well as conformity with emission requirements.

There are no proprietary difficulties within the feed industry, which has an active national trade organization as well as statewide group (the California Hay and Grain Association in Sacramento). There are industry-wide efforts to improve feed technology, including periodic short courses that would be good vehicles for information dissemination.

Thermal energy consumption figures for the industry are not available, making it difficult to estimate the potential for displacement of conventional fuels by solar energy.

f. Bread, Cake, and Related Products. This industry has two subcategories: bread, cakes and related products and "dry" products (cookies and crackers). The first accounts for most of the volume and will be the only one considered here.

There are over 300 establishments in this category in California, about 9 percent of the national total, with 42 percent of them having more than 20 employees. There is a trend toward fewer and larger establishments, although total demand has grown slowly but steadily. Bread is the dominant product, accounting for 65 percent of the sales and 82 percent of the product output. Types of establishments, with their respective 1967 shares of the sales volume (Ref. 5) are:

(1) Wholesale bakeries	86.2%
(2) Grocery chain bakeries	9.2%
(3) Home service bakeries	2.0%
(4) Retail multi-outlet bakeries	2.6%

Unit consumption of energy in this category is low, but volume is high and total energy consumption is significant. Energy consumption has remained approximately constant in recent years, even with the increase in volume. Energy per unit has therefore declined, dropping from 12,800 Btu per dollar in 1947 to 9,600 Btu per dollar in 1967; this trend is largely due to the trend toward larger and more efficient units (Ref. 8).

Thermal energy is used for baking, water heating, and "proofing." Baking is the most energy-consuming operation, and natural gas is the dominant fuel for this as well as for the other two operations. Proofing refers to the step in which yeast-leavened products are allowed to rise after the dough is put in the pan prior to baking. Proofing is done in two stages for the sponge-dough process, which involves two steps of mixing rather than one as in the continuous mix process. Final proofing in either process consists of placing the dough pieces, in pans, in a proof box for 50 to 75 minutes. The proof box is basically a steam radiator with a steam fan coil unit; the temperature is maintained at $105^{o}F-115^{o}F$ and the relative humidity at 90 percent. Live steam is injected into the proof box as needed to maintain the required humidity.

Most of the boiler capacity is used to provide steam for the proof box; 20 percent is used for other purposes such as heating water. Hot water is required for clean-up and for washing the bread baskets. The basket washer may be a separate unit with its own auxiliary heater to maintain the water at $165^{o}F$. The water is recycled and therefore must be heated in the washer.

Bakeries run on a different schedule from most other food operations. Production generally begins at midnight and runs one or two shifts, ending at 3 p.m. in the afternoon. Clean-up follows the last shift. Thus, they are desirable customers for electric power plants since much of their energy consumption is during off-peak periods. This could have a negative impact on the potential for solar especially if off-peak pricing of electricity is put into effect.

Bakeries in California have so far not suffered interruptions of their gas service even though they are on P3 or P4 priorities primarily because of their operating schedules. Backup fuels, if necessary, would be oil for the boilers and propane for the ovens. It has been estimated that conservation and other housekeeping measures might reduce energy consumption on the industry by 5 to 10 percent without a loss of production. Anymore than that, however, would have a negative impact on production.

Like the rest of the food industry, the bakery industry is in the position of having its prices under continuous public scrutiny. The expected increases in energy prices will be hard to pass along to consumers, which suggests that solar energy may become an attractive alternative to the extent that it can replace conventional fuels. Today, energy costs are less than 5 percent of total costs and the incentive to reduce them is accordingly low. The baking industry looks for 3 to 5 year payback periods.

The industry is well represented by trade organizations and has major trade journals that can serve as channels for the dissemination of information on new technologies. As in the other segments of the food industry, the grocery chain bakeries have very little interaction wth the rest of the industry.

The potential for solar energy appears to be primarily in the proofing process and in water heating. The proofing operation is at a suitable temperature (105°F-115°F). Humidification would be required, however, which is presently supplied by the steam.

The fact that bakeries operate primarily at night and during the early morning, makes storage a necessary ingredient in any solar energy system. Except for clean-up which occurs in early evening, solar energy used in any other process would have to be stored the previous day. Thus, although the temperature requirements and duty cycles are appropriate for solar energy systems, the operating times and the high degree of humid heat required in the process reduces the attractiveness of this solar energy application.

g. Fats and Oils (SIC 207). This industry produces two types of products: animal and marine fats and oils, and vegetable fats and oils. The vegetable oil plants are the largest and account for most of the production; they will be the only type discussed in this section. There are 15 major plants of this type in California, with most of them concentrated in the San Francisco and Los Angeles areas.

Thermal energy in this industry is primarily in the form of steam generated by gas-fired boilers. Steam is used both for heat and as an agent in some of the processing steps. Thermal energy consumption is roughly estimatd at 1200 to 1500 Btu per pound of finished product.

Some plants begin with the oil-containing seeds, which are crushed to produce raw oil. Others import the raw oil from seed-crushing operations elsewhere. Both do the oil processing for final distribution. In the seed-crushing operation, the seed is first conditioned by steam at about 180°F and then "cold-pressed" to extract most of the oil. After filtering, this oil may be sold as is, or further refined. The residue from the cold-pressing operation is heated and treated with a solvent (hexane) to remove more oil. After removal of the hexane, this "crude" oil is cooled and is then ready for processing.

Besides the seed oils, California plants also process coconut, palm, palm kernel and other imported oils. These are imported in ships and are stored in large, uninsulated tanks at ambient temperature. A few days before processing a type of oil, the tanks are heated to 110°F to 120°F with steam coils at the bottom of the tanks. This is necessary to make the oils pumpable.

Processing consists of four steps: removal of fatty acids, bleaching, deodorizing and hydrogenation. In the first step, lye is mixed with the oil (180°F to 190°F for most oils). Excess lye is neutralized with acid and the resultant salts and soaps are removed with water. The next step, bleaching, is accomplished by pressing the oil through a bed of diatomaceous earth. Deodorization is done by vacuum distillation at temperatures up to 600°F. Eighty percent of the heat is reclaimed by a heat exchanger, transferring heat from the outgoing oil to the incoming oil. Hydrogenation is the last step and is used when it is desired to increase the melting point of the oil. This is a batch process in which the oil is mixed with a catalyst and hydrogen gas under pressure at 380°F. All processed oils are stored at 110°F to 120°F in insulated tanks so that they may be readily transferred to tank trucks.

This industry generally expects payback periods of two to three years, but might consider longer periods for energy-related investments.

There is a national organization (the American Oil Chemists Society) that has links to most of the industry and publishes a widely-read journal. There does not appear to be any barriers to the dissemination of information through the industry.

The potential for solar energy at the present time appears to be in heating the storage tanks. This is a low-cost, attractive application for solar energy, especially since the storage tanks themselves are a medium of thermal storage. Solar-heated water could maintain the required temperature of 120°F, supplemented when necesary by steam. No major modifications would be required other than the installation of solar collectors. This application was one of those selected for the design/cost studies.

h. Malt Beverages (SIC 2084). The brewing of beer began before the dawn of recorded history and has always been an important craft or industry. The details of the process are closely guarded by each brewery, but the process itself is well known. A large part of the beer consumed in Californiais imported from other states and countries, but over 10 million barrels (of 31 gallons each) were produced in the state in 1976 by eight companies employing about 9000 people (this does not include those employed in the distribution of beer). Taxes paid by the industry amount to about 220 million dollars per year.

The production of beer is estimated to require 0.14×10^6 Btu of energy per barrel. This figure multiplied by the annual production yields 1.4×10^{12} Btu thermal energy consumption. As an example of the wide discrepancies in determining energy use, another estimate gives a total thermal energy consumption in California of 2.31×10^{12} Btu. The major boiler fuel is gas, with oil as a backup.

The first major step in the brewing process is adding milled, malted grain to heated, filtered water in a large mash tub. Other ingredients are added and the temperature is raised. Heat is supplied by low-pressure steam. The liquid is removed and boiled with hops for a specified time. The hops are then strained out and the liquid (called "wort") is cooled. It is placed in fermentation tanks where yeast is added. After fermentation, the brew is aged at low temperature (32-34°F) for three to five weeks. After a final filtering and carbonation, the beer is ready to be packaged for distribution.

Draft beer requires no further processing, but bottled (or canned) beer must be pasteurized. About 12 percent of the total production is draft beer. Of the packaged beer, 60 percent is canned, 24 pecent is in one-way bottles, and 15 percent is in returnable bottles. Both one-way and returnable bottles are washed before being filled.

The pasteurization and bottle washing operations appear to have the most promise for solar energy application.* The other steps use high-temperature steam. Bottle washing uses water at 140 to 160^{o}F. The can pasteurizer begins by spraying the cans with 90^{o}F water, which includes recycled heat for a cooling stage at the end of the line. After this preheat, the water temperature is raised to 145^{o}F and the cans are maintained within a half a degree of this temperature for at least 7 minutes. The beer is then cooled in stages to 70^{o}F and leaves the pasteurizer.

The can pasteurizer consumes large amounts of energy--at one brewery it uses a quarter of the total thermal energy. At another, it uses about 0.10×10^{6} Btu per minute of operation and operates two or three shifts per day, depending on the season.

The breweries interviewed indicatd that a 2-5 year payback period is expected, with a 15 percent return on investment after taxes on capital investments. These requirements might be relaxed for energy-conserving investments, because of the possibility of sharply higher energy costs. Gas priorities are low (P4 in one case), and oil costs about 2.5 times as much as gas. Modern breweries already use waste heat reclamation and other conservation practices, which may make solar energy a more attractive near-term application.

The industry is represented by the Master Brewers Association, which publishes a quarterly journal. Other more general journals such as Chemical Engineering can reach an industry-wide audience. As noted, information on the brewing process itself is proprietary. However, innovations in can pasteurization or bottle washing would not be viewed in this light.

It is estimated that about 25 percent of thermal energy is used for pasteurization and 10 percent for bottle washing. The pasteurization process was selected for one of the design/cost studies.

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*Solar energy systems are being designed and installed for such an application by Miller Brewing Co. in Florida.

i. Other Applications. Interviews were conducted with plants producing carbonated beverages, and drying and dehydration of onions. They have not been discussed here because work is similar to that done by others in these or related areas (Refs. 6-9). The amount of potential energy displacement by solar has

been included in our calculations, however. Also, although sugar beets are the largest energy consumer in the food processing area, due to extensive research in this area (Refs. 10 and 11) it is not included in this discussion.

2. Paper and Allied Products (SIC 26)

This SIC category is subdivided into six subcategories:

(1) Pulp mills.
(2) Paper mills.
(3) Paperboard mills.
(4) Converted paper and paperboard products other than containers and boxes.
(5) Paperboard containers and boxes.
(6) Building paper and building board mills.

Fairly intensive studies of the industry have been made (Refs. 12 and 13) from the energy and environmental points of view. Details of process and energy usage can be found in the references.

In California, the value of shipments in this industry amounted to 2.7 percent of the total of state industries, making it a significant contributor to the state's economy. This results, in part, from the availability of lumber resources combined with the large demand for containers required by California's agricultural products. Of the 506 estalishments in this category in California, 34 are in the first three subcategories listed above. These 34 plants, however, contribute 20 percent of the value of shipments and employ 15 percent of the people in this industry. It should be noted here that some mills are integrated and manufacture both pulp and paper.

The paper industry is a large consumer of energy, although it generates a part of its own fuels in the form of bark and "black liquor" (an intermediate in the pulp manufacturing process). The sequence of steps in the complete production process, with the energy consumed in each step, is as follows:

(1)	Acquisition of pulpwood	1%
(2)	Debarking	1%
(3)	Chipping	1%
(4)	Pulping	46%
(5)	Pulp bleaching	4%
(6)	Paper/paperboard production	43%
(7)	Converting	5%

As might be expected, the two steps that consume the bulk of the energy (pulping and paper production) are those using thermal energy. Thermal energy is provided by steam. The steam boilers are primarily gas-fired in California, except for the internally-generated fuels mentioned above. Many plants generate part of their own electric power through burning these wastes, and then use the exhaust from the turbines for process steam. This increases the efficiency of fuel use considerably. In general, larger plants are more likely to have their own generating plants because the economics are more favorable than for small plants.

Energy consumption per unit of output has been calculatd as approximately 10×10^6 Btu. A third to a half of the fuel requirements may be met by burning plant wastes in an integrated mill.

In the manufacture of pulp, the digester is the largest energy consumer. In the digester, the wood chips are cooked with appropriate chemicals to break down the wood fiber sufficiently for paper making. Pressure, temperature, and chemical makeup are carefully controlled. The heat is supplied by steam at 120 to 160 psig ($300^{\circ}F$-$350^{\circ}F$); this temperature, combined with the large amounts of heat required, makes low temperature solar energy systems unsuitable for this operation.

In an integrated mill, the pulp is fed to a paper machine at 60 percent moisture content, and the paper is dried after fabrication to a moisture content of 4 to 5 percent. The drying takes place as the paper passes over steam-heated rollers. Drying temperatures range from 150 to $800^{\circ}F$. The exhaust steam may be used to preheat the boiler feed water, further conserving energy. In general, integrated mills do no appear to offer a suitable application for solar energy. Excessive amounts of low temperature heat appears to be readily available.

In paper mills that use purchased pulp as a starting material, the initial step is the "slusher" or pulper, where the pulp is added to water at $140^{\circ}F$ to $180^{\circ}F$ and mixed to give it the right consistency for paper making. This mixture is then fed to the paper machine, which is the same as that in the integrated plant. In the plant visited, the pulping is done in batches of about about 10,000 gallons and 12 to 16 batches per day are "slushed." The water from each batch is recycled to the pulper after it is removed mechanically from the web going into the paper machine. The temperature of the new batch is raised by injecting steam directly into the water until it reaches the required temperature for the addition of the pulp. This operation appears to be suitable for solar energy, particularly since these separate paper mills have no available waste fuel and must purchase all their energy. In addition, the "slusher" appears to be easily separated from the rest of the process, making integration of a solar energy system easier and causing less disruption.*

The paper industry is capital-intensive and requires a rapid payback period on the order of two to three years. For energy investments they might, like other industries, accept longer payback periods. Energy costs are in the range of 3 to 5 percent of operating costs, but increasing.

The paper industry is well represented by industry organizations and has two major journals. Processes are generally not proprietary and there should be little impediment to communication of new technology. The industry is conscious of its high energy consumption, and some steps have already been taken to improve conservation measures. The FEA (now part of the Department of Energy) is monitoring these conservation measures through the American Paper Institute.

As noted above, the availability of low-grade heat within integrated paper mills allows little scope for solar energy even where process temperatures are acceptable for solar. The best potential seems to be in the

*The slusher in one plant consumed roughly one-third of all thermal energy used in the plant, thus solar could significantly contribute to the reduction of energy requirements.

independent paper mill operating with purchased pulp, where the "slusher" offers a good opportunity. Paper mills operate continuously, 24 hours a day and 7 days a week, but it would be possible to devise a system in which all available solar energy would enter the process directly with no provision for storage. Fossil fuel requirements would be reduced by the amount of solar energy available, and no large capital investment would be needed for storage. In one plant visited, there was some storage already available.

One problem may be that of finding enough space for the solar collectors. Most paper mills are located in and around urban areas, where space for collectors is limited. A rough calculation shows that a medium-size plant making 150 tons of paper a day would require twelve acres of collectors to provide one-third of its thermal energy requirements. This application is the subject of a design-cost study, however, and such detailed analysis of other plants may indicate that the situation is more favorable than appears from this initial look.

3. Chemicals and Allied Products (SIC 28)

Soap and Detergent Manufacturing (SIC 2841)

Soap manufacturing has a very long tradition, and the basic process (reacting alkali with fats) is relatively simple. Detergent manufacturing is more complex and involves fairly intricate chemical reactions. The processes of making the final product (granules, flakes, bars) are common to both.

There were 93 soap and detergent manufcturing plants in California in 1972, 30 of which employed more than 30 people. Total thermal energy use is estimated at 4.77×10^{12} Btu for 1974.

Soap making has traditionally been by the kettle process, which is still in wide use. The trend, however, is toward continuous processes. In the kettle process the raw materials (fatty acids and caustic soda) are piped into large kettles and heated by steam for several days. When the mixture has been made clear and homogeneous by the addition of more caustic soda, the heat is turned off and salt is added to cause the soap curd to rise to the top. The process may be repeated to recover additional glycerine, which is a major by-product of the process. The soap is then mixed with other ingredients before being processed into its final form.

Cold-process soaps are not boiled, but are made by mixing the ingredients at a low temperature, slightly over $100^{\circ}F$.

Continuous processes include the hydrolyzer process, the Sharpes process, and the Mazzoni process. The Mazzoni process is of special interest for its solar energy potential. In this process, the fatty acids and caustic soda are preheated to 130°F and fed through metering pumps to a mixing tank. In the mixing tank, which is maintained at 130°F by an electrically heated water jacket, an exothermic reaction occurs and the soap is formed. It is then sent to a holding tank, also maintained at 130°F with a water jacket. The "neat" soap is then pumped to a dryer where the moisture content is reduced from 35 percent to 12 or 13 percent, making it a solid. The drying process uses steam to obtain the maximum rate of heat penetration. This process is used only for bar soap, for which it is much more efficient than the kettle process.

Detergents are manufactured in a mixer, where both direct steam injection and a steam jacket heat the slurry to 180°F. The detergent is then sent to a spray-drying tower. It is sprayed through nozzles at the top and dried in particles as it falls to the bottom through a rising current of air at 500°F to 1,000°F. The exhaust from the dryer is about 250°F and is used to preheat water to the mixer. The waste heat available, plus the exothermic reaction in the process, make detergent manufacturing more attactive for waste heat utilization than for solar energy.

The process described above for granulating detergent in a vertical dryer is also used for soap granules. Bar soap is made by allowing the liquid soap to harden in a frame, after which it is cut into bars and packaged; there is also a continuous process which extrudes the soap as a continuous bar which is sliced to make individual bars. Soap flakes are made by a milling process that uses no thermal energy.

Gas is the principal fuel used in soap manufacture in California. Oil could be used to fire the steam boilers, but would be unsuitable for the drying towers in their present form because soot would blacken the soap granules.

Energy costs, including electricity, are currently less than 10 percent of total costs, but are expected to increase. The industry expects a 2 to 5 year payback period for new investments, with about a 10 percent return on investment after taxes.

Soap and detergent manufacturing is represented by a strong industry organization and has three widely-read trade journals. Companies vary in the extent to which they protect proprietary processes. The equipment for detergent manufacturing is mainly general in nature (boilers, vats, conveyor belts, etc.), while soap manufacturing equipment is much more specialized. Equipment manufacturers play an important part in the development of new technology, and should probably be included in any experiments or demonstrations in this industry.

The most promising application of solar energy in the industry was found to be the Mazzoni process, which was selected for a design-cost study. However, it was determined by design-cost engineers that the 1890 unreinforced brick structures at the selected site were totally unsuitable for retrofitting a solar energy system. Thus, no further studies were done for this application. This exemplifies a general problem which needs to be much more thoroughly analyzed. For retrofit situations, the capability of existing buildings to support solar energy systems is marginal. The implications for solar system designs and potential additional costs are not known.

4. Fabricated Metals (SIC 34)

Metal Plating (SIC 347)

The metal plating industry in California consists of about 500 relatively small plants, employing on the average 10 or 15 people each. Total volume of business is estimated at 250 million dollars. The industry serves the automotive, electric, building, and aerospace sectors, with about half of the business serving electronics and aerospace applications. Thermal energy use is estimated at roughly 2×10^{12} Btu annually. There appear to be additional industries which employ this same type of operation as one part of their production processes, and these industries may not show up through a survey process such as we used. Just as with hot water used for clean-up, plating may be an application for solar with wide-spread potential. Although energy displacement may be small for a particular industry, at an aggregated level, it may be quite significant.

The plating industry uses thermal energy to heat the numerous plating tanks. A typical "line" (i.e., a series of tanks through which objects being plated must pass for cleaning, pickling, rinsing, plating, etc.) may have 15 tanks, of which half are heated to temperatures of 130°F to 180°F, although some processes require temperatures as high as 215°F. Plating is frequently done on a 3-shift, 24-hour per day basis, so that the energy demand is constant.

At present, the most common method of heating the tanks is by electric immersion heaters. About a quarter of the total requirement is met by heat-exchanger coils in the bottom of the tank, heated by hot water or steam. In this case the thermal energy source is natural gas.

Energy costs (not all of which are for thermal energy) are in the range of 3 to 5 percent of total costs. New investments are expected to payback in 3 to 5 years.

There are both national and state industry associations, and a publication that could serve as a medium for disseminating new technology. Since most shops are small, they are not likely to undertake experimental projects with solar energy without some form of subsidy.

There is no technical reason why solar heating could not be used in the plating industry, although the 24-hour operation implies the need for large amounts of storage if the solar system is to make a significant contribution to the total energy requirements. The temperatures are well within the range of solar collectors operating with reasonable efficiency. Indications are that at least some plants would be interested in solar systems if they promised to reduce energy costs appreciably.

C. OTHER INDUSTRIES WITH HIGH-TEMPERATURE REQUIREMENTS

Two additional SIC categories were briefly investigated to determine whether there might be some potential for solar energy. These are chemicals and allied products (SIC 28) and petroleum products (SIC 29). Both are characterized by very high energy consumption.

1. Chemicals and Allied Products (SIC 28) (Other than SIC 2841)

This category is the second largest user of thermal energy in California, and for this reason was briefly investigated to identify any possibilties for solar energy.

a. Inorganic Chemicals. It was found that all processes studied were either exothermic, made use of available waste heat, or required higher temperatures than are practical for solar energy at this time. Specific processes examined were for the manufacture of the following chemicals:

- Ammonia
- Phosphorous
- Sulfuric acid
- Nitric acid
- Hydrochloric acid
- Aluminum compounds
- Potash, sodium carbonate, and sodium sulfate
- Chlorine, sodium, and sodium hydroxide
- Carbon black
- Organic chemicals

b. Plastics. A brief inquiry made to several plastics manufacturing companies indicated that there may be a few potential applications for solar energy, but that the industry is highly competitive and averse to risky investments (which would include solar energy). There may be some potential in the future for new plants, if reliability and economics appear favorable.

2. Petroleum Products (SIC 29)

Petroleum refining was found to be unsuitable for solar energy. Although there are some low-temperature process steps, there is adequate thermal energy available from the high-temperature parts of the processes.

SECTION IV

AGRICULTURAL PROCESS HEAT SURVEY

A. INTRODUCTION AND GENERAL FINDINGS

1. General Sector Characteristics

The agricultural sector includes all farm and ranch related activities. A distinction is maintained between agriculture and industry by excluding all processing that takes place "beyond the farm gate" from the agricultural sector. An exception is made in the case of crop drying, which is done both on the farm and in central facilities and is covered in this report. On the other hand, residential heating and cooling on the farm is not considered because it is considered under heating and cooling of buildings.

2. Energy Utilization and Requirements

The production and processing of agricultural products in California consumes 5 percent of the total energy used in the state, or 297×10^{12} Btu annually (Ref. 1). On-farm applications represent 37 percent of this total or 111×10^{12} Btu. This energy consumption does not include greenhouses, which use an additional 8×10^{12} Btu annually (Ref. 1).

Thermal energy uses on the farm are low-temperature applications requiring temperatures of $50^{o}F$ to $180^{o}F$ that are within the range of near-term solar energy systems. Table 4-1 shows the amounts of thermal energy used for the three thermal energy uses on the farm -- crop drying, space heating for animal shelters (including brooders) and greenhouses, and dairy water heating.

3. Technical Characteristics

It is important to note here that there are many different agricultural energy users with potential for solar energy, including the specific applications to be discussed (Ref. 2). These applications have been and are the subjects of several investigations, experiments, and demonstrations carried out under the auspices of the Department of Energy, the Department of Agriculture, and other public agencies. These projects in total will yield a large amount of technical information that should be valuable in encouraging the wider use of solar energy in agriculture.

Table 4-1. Annual Thermal Energy Use in California Agriculture (Btu x 10^{12})

Application	Thermal Energy Consumption
Crop Drying	3.5
Space Heating	
Livestock shelters	0.1
Brooders	1.9
Greenhouses	0.8
Dairy Water Heating	1.8
Subtotal	15.3
Other*	9.7
Total	25.0

Sources:

1. Cervinka, V. et al, Energy Requirements for Agriculture in California, California Dept. of Agriculture and University of California, Davis, California.

2. Federal Energy Administration, U.S. Department of Agriculture, Energy and U.S. Agriculture: 1974 Data Base, (Washington, D.C.: Volume I, September 1976.

3. A. D. Little, Inc., Energy Shortage Contingency Plan: Technical Appendix: A Report to the California Energy Resources Conservation and Development Commission, October 1975.

*NOTE: Primarily LP gas which is accounted for as thermal energy but is used as back-up fuel for internal combustion engines in equipment such as field machinery and irrigation pumps.

The principal technical characteristic of thermal energy processes in agriculture has already been mentioned; namely, the low temperatures required. One important implication of low temperature is that solar collectors are most efficient at low temperatures and therefore able to compete better with fossil fuels for such applications. On the other hand, agricultural production is very seasonal, reducing the number of days the solar system will be in operation.

A number of the specific applications to be discussed require heat 24 hours a day or mainly at night. Solar energy systems for such applications will require a large amount of storage, which tends to raise the capital costs. On the other hand, space is not usually at such a premium on farms as in urban areas, and storage may not be as difficult to provide. The cheapest form of storage, the solar pond, may often be practical; there may be ponds already available.

Because of the low temperatures required, collector design is not as critical as in other applications and a variety of relatively low cost collectors can be used.

4. Economic Characteristics

Most agricultural thermal processes in California use either natural gas or LP gas, and for some applications oil is not a practical substitute. Both price and availability of these fuels is therefore a concern. Price is especially important where energy costs are a significant fraction of overall costs, as in greenhouses. Availability is important in nearly all cases because of the risk of losing large amounts of valuable product (milk, grain, chickens) by spoilage in case of energy supply interruption. This situation means that farmers may be interested in solar energy if they are convinced that its use will improve reliability over fossil fuels.

An economic factor of importance is that agricultural operations frequently have a large capital investment in facilities. Consequently, even a cost-effective and technically sound solar energy system is likely to arouse little interest if it requires abandoning or replacing existing facilities.

One economic consideration that was encountered repeatedly in the course of the survey is that of property taxes, which was also a major concern in many industrial applications. Solar energy systems generally require a large initial investment, and if the entire cost of this investment is added to the property assessment, the possible cost savings of solar energy may vanish.

Farmers are used to making substantial capital investments by borrowing money against future crops or livestock, and this factor alone should not inhibit the acquisition of solar energy systems.

A final economic consideration that may be important in many cases is that of labor for the installation of solar energy systems. Farms frequently have full-time employees (or owners) who are used to installing, maintaining, and repairing equipment and whose work load is intermittent. Therefore, if a solar energy system is well designed and there are adequate installation instructions, it will be possible in many cases for the farm staff to do the installation and not incur costs that would be required for contracted installations.

5. Institutional Characteristics

There are no proprietary barriers to the dissemination of information in the agricultural sector. On the contrary, the Cooperative Extension Service (CES) provides an excellent mechanism for the dissemination of information on new technology. The CES as well as the farming community is generally unfamiliar with solar energy technology. There has been little effort within California to disseminate information on solar to CES and the farmers, and they are looking for a central place to provide them with that information. This situation provides an excellent opportunity for the State to have a significant effect on the rate of adoption of solar technology at relatively little cost. In other areas of the country, it can be shown that where the CES is behind solar - it goes; where they aren't - it doesn't (Ref. 3).

The primary need is for multiple demonstrations of those solar technologies that have been developed to the point where their technical effectiveness is established. Demonstrations are the most persuasive form of information, and can allay many of the doubts and fears about solar technology.

The point regarding property taxes was mentioned as an economic consideration, but since taxation is a governmental function, it becomes an institutional question as well. Some State action will be required if this very important barrier is to be removed. One suggestion that was made was that solar equipment should be assessed at the value of conventional equipment that uses an equivalent amount of fossil fuel. This would eliminate the penalty now associated with the acquisition of a solar energy system.

6. Potential for Solar Energy

The agricultural thermal energy uses listed in Table 4-1. were all investigated in the course of the study and will be discussed in the following section.* These are large users of energy, and have temperature requirements suitable for solar energy. These applications have also been identified by other researchers in the field, and are the subject of current studies and demonstrations by DOE and USDA. (Ref. 4).

The total energy use by these four applications, is 15.3 x 10^{12} Btu, which is the upper limit of fossil fuel displacement by solar energy in this sector. Practically speaking, not all of this energy can be provided by solar systems. The amount that can be displaced can be determined only when a significant number of systems have been installed and their performance has been measured. The specific applications to be discussed below are:

(1) Crop drying.
(2) Water heating for dairies.
(3) Brooding house heating.
(4) Greenhouse heating.

B. SPECIFIC APPLICATIONS

1. Crop Drying

Rice, corn, and milo (grain sorghum) are the three primary grains grown in California that require drying. The grains are dried to reduce the moisture content to the point at which they can be stored without spoiling. Drying is done either on the farm or at large central dryers. Approximately 70 percent of all grain, and 90 percent of all rice, is dried at central facilities.

The four methods of drying grain are:

(1) A batch process using ambient air, with no additional heat. The air flow carries off the moisture.
(2) A continuous process using high speed air flow and high temperature (120^{o}F to 275^{o}F).

*Because of the mild climate, only heating for poultry brooding houses was examined. Other livestock shelters are generally not heated in California.

(3) A low-temperature (ambient plus 5°F to 10°F) batch process.

(4) A two-stage process that eliminates half the moisture in a high-temperature continuous process and the other half in a low-temperature batch process.

Low-temperature drying is used in the on-farm operations, with the grain stored and dried in the same bin. A bin holds from 6 to 10 thousand bushels, at a depth of 6 to 30 feet depending on the grain. The bin has a perforated floor and a fan forces air up through the grain. Ambient air may be used, but some addition of heat speeds the drying and minimizes the possibility of spoilage. The temperature and humidity of the ambient air determine the drying time and the need for added heat.

Most commercial dryers use either high-temperature (single or multiple pass) systems or a two-stage, high-low temperature process. In the multi-pass systems, air heated to about 110°F for rice and 275°F for milo, is passed through a continuously moving column of grain to remove part of the moisture; the grain is then stored for about 24 hours to allow the moisture to equilibrate in the individual kernels. This procedure is repeated as needed to bring the moisture to the desired level.

Drying is generally done in column or tower dryers 40 or 50 feet high. The grain takes about 5 hours to flow down the dryer column, and it is continuously removed from the bottom.

The rice harvest season runs from the end of August to the middle of November; the principal rice-growing counties are Butte, Colusa, Gleen, and Sutter.

The amount of heat required for drying rice depends on the initial moisture content of the rice and on the temperature and humidity of the ambient air. Most on-farm drying is done with LP gas, but 80 percent of all rice is dried off of the farm with natural gas.

Corn and sorghum are planted and harvested about the same time as rice and go through the same drying process. Half the corn and milo are dried at central commercial facilities, with about two-thirds of the total using natural gas.

The cost of drying grain is about $.75 per ton with natural gas, and approximately twice as much with LP gas. LP gas is used as a backup source, for natural gas, but gas availability has not been a problem for the commercial dryers using natural gas. The drying season comes at a time when winter heating demands are relatively low, and the average consumption over the year is low enough so that dryers have high gas priorities.

Considerable work has been done on collectors and solar systems for agricultural drying, and some types are readily available. The least expensive type consists of large plastic tubes that are kept inflated by the pressure of air from an input fan. The air is heated as it passes through the plastic tube and then enters the bin plenum and is forced up through the grain. A similar type consists of plastic chambers attached to the wall of the storage bin or of some adjacent structure, with the air piped to the bin. The plastic tubes are cheap (about $.50 per square foot), but have a life expectancy of only a year. The wall-mounted type cost from $1 to $3.00 per square foot and have expected lifetimes of 5 to 15 years.

Availabilty of energy for drying is more critical than the price of the energy. All the grains considered here must have drying started within 24 hours of harvest to avoid spoilage. Reliability of energy supply is thus very important. If fossil fuel supplies become more uncertain, this factor may operate in favor of solar systems.

There appear to be few if any institutional barriers to the use of solar energy for crop drying. The industry is geographically concentrated and there are no proprietary processes. The Cooperative Extension Service provides an excellent channel for dissemination of information on solar technology. Demonstration projects are probably needed to motivate adoption of solar technology by commercial dryers.

The most attractive application for solar crop drying appear to be rice drying, which required temperatures of $110^{o}F$ or less, while corn and milo require much higher temperatures. A rough estimate of the total energy used for rice drying in California is 33.5×10^{9} Btu annually (1972).

Two technical problems unique to this application must be considered in designing any particular installation. One is that if collectors are to be mounted on the roofs of sheds or bins, there must be zero risk of leakage through the roofs. A water leak would destroy a whole bin of rice or other grain. The other problem is the large amount of dust generated by handling the grain; the dust could rapidly reduce the effectiveness of a solar collector to near zero in a very short time. In a recent DOE experiment, automatic sprinklers were installed in the collector system to keep the collectors free from the dust generated from the drying process (Ref. 5).

There are also other crop drying applications for solar energy in California. Fruits and nuts such as prunes, raisins, walnuts, and onions are dried in substantial quantities. All thermal requirements are within the temperature range of solar energy. Many of the fruits and nuts are presently dried naturally by the sun. A DOE experiment in Califoria, however, is the application of solar energy to the drying of raisins and prunes (Ref. 6). This can also be applied to other fruits and nuts.

The drying can be done in either a batch or continuous process. Solar preheated air is supplied to the driers, supplementing the natural gas or LPG normally used in the process.

A more complicated drying operation is the drying and dehydration of onions and garlic. Running six months a year, this operation is a continuous process and is also the object of a DOE/USDA sponsored solar energy experiment (Ref. 4). Solar is used to preheat the air to 180°F. Indicative of one of the problems faced by solar when dealing with large energy consumers, the drying operation in the plant visited requires 10×10^6 Btu per hour, 24-hours per day. If only one quarter of the energy were supplied by solar, 60,000 square feet of collector would be required. With energy costs running 5 to 10% of total operating costs, there is little incentive to adopt a capital intensive system such as solar.

However, energy is a vital ingredient in drying processes and reliability is crucial. Therefore, especially for those operations looking to build new facilities, there is a strong emphasis and growing demand to look at solar energy systems as a viable energy supply supplement.

2. Water Heating for Dairies

Dairying is the largest single sector of California agriculture, representing 11 percent of the total value of $9 billion. There were 800,000 milk cows in 1975, producing almost 11 billion pounds of milk. Dairying is carried on in most parts of the State. The largest segments are in the Central Valley with 40 percent of the production and in San Bernardino County with 18 percent.

Dairy herds in Caliornia are larger than the national average, and efficiency is greater. The average dairy herd is 235, compared with the national average of less than 100 and some are as large as 4,000.

Total energy consumption in 1972 was 7.2×10^{12} Btu, of which 1.8×10^{12} Btu was used for water heating. The hot water is used primarily to clean and sanitize the milking equipment, piping, and holding tanks. The water temperature for this purpose ranges from 140°F to 160°F, with some dairies using water at 110°F to rinse the cows' udders before milking.

Milking periods of 5 to 10 hours each occur twice a day, beginning at noon and midnight or slightly earlier. Semi-automatic washing and sanitizing of the equipment takes place following each milking period. The milk holding tank is usually washed once a day after being emptied. Total hot water usage runs from 200 to 400 gallons per day per farm.

The fuel used for heating water is natural gas in those locations near a natural gas supply system, but only 15 percent of the total is supplied from this source. About half is heated by LP gas and the remainder by electricity. LP gas is a backup source for the other two sources.

From a technical point of view, solar energy could provide a large part of the hot water needs of dairies. The economics are not as clear, however, especially as the timing of the demand requires substantial storage. Recent studies (Ref. 7) indicate that the waste heat from the refrigeration equipment on a dairy farm could supply 80 percent of the hot water energy demand. If the true figure is in this range, it would be very difficult to justify an investment in a solar water heating system.

The dairy industry has no institutional barriers to the dissemination of information on new technology, and the Cooperative Extension Service is available as a channel of communication.* There is at present a lack of easily available information, and of demonstration projects that show economic viability.

Dairy farmers, like many other potential users of solar energy systems, have expressed concern about the property tax assessment of any new solar equipment. This continuing added cost could eliminate any modest savings resulting from reduced use of other energy sources.

* CES has been the primary instigator of research into solar energy applications in California agriculture. Desire has been expressed by them also for a more coordinated effort to introduce solar to the agricultural community.

3. Poultry Brooding House Heating

The poultry industry in California produced $594 million dollars worth of chickens, eggs, and turkeys in 1975 (Ref. 9). An essential step in this production process is the hatching and brooding of chicks; brooding is the maintenance of a proper environment for chicks from the time they hatch to about 10 weeks of age, primarily the proper temperature.

Poultry production is concentrated in Santa Cruz, Riverside, and San Bernardino counties and in the Central Valley, especially around Merced. Turkey production is concentrated in the Central Valley, especially around Fresno. Approximately 139 million chicks are brooded annually for chicken production and 18 million for turkeys.

Energy consumption for brooding was 1.9×10^{12} Btu in 1974, with 74 percent supplied by natural gas, 14 percent BY LP gas, and 12 percent by oil. Feed is the major cost element. Fuel costs amount to about 2 percent of the market value of chickens and eggs. However, they are a more significant portion of the brooding costs and there is a direct relationship between the temperature of the brooder, the time of chicks maturity, and the amount of feed consumed.

Survival and rapid growth of newly-hatched poultry depends on maintenance of the proper thermal environment. Body temperature of the birds at hatching is 100°F, and the brooding house should provide a minimum temperature of 95°F(90°F in summer) for the first week after hatching. Temperatures are then normally reduced 5°F per week to 65°F, where they are maintained for the balance of the 10-week "grow-out" stage. This pattern maintains the brooding temperature a few degrees below the body temperature of the chicks.

Part of the heat input to the brooding house comes from the birds themselves, especially as they grow larger and generate larger quantities of heat. In the summer, by the age of three weeks they can supply a large part of their own heating requirements.

Brooding is done in either open or closed shelters, with the trend toward closed "total environment" brooding houses. In the open shelters the heat is provided by "hovers"--heating units suspended from the ceiling, allowing the chicks to move about under them; these units are fired by LP gas or natural gas. In the closed shelters, the heat is provided by a forced-circulation hot air system or by radiators through which hot water is circulated.

Brooding is carried on throughout the year. Supplemental heat is required for the first six weeks in winter, down to one or two weeks in summer.

Brooding temperatures are well within the range for efficient operation of solar collectors, and numerous studies and demonstrations have been funded by the Departments of Energy and Agriculture. Since the heat for brooding is required 24 hours per day, some storage must be provided in connection with a solar energy system.

Fuel costs are a major element in overall brooding costs and solar energy systems should be attractive to this industry. The capital costs are higher than capital costs of a conventionally-heated brooder. Operating costs, however, are significantly lower. Poultry farmers generally look for a 5-year payback, but concern over fuel availability and reliability may increase the incentive to adopt solar heating.

There are few, if any, institutional barriers to the adoption of solar energy for brooding other than a general lack of information and of demonstration projects in California. One demonstration is being carried on at present as part of the State Buildings element of the CERDC solar program. This demonstration is at Modesto Community College, near one of the centers of poultry production in the state, and any favorable results should disseminate rapidly through the industry. As usual, the Cooperative Extension Service can be an excellent channel for information, and it has in fact already begun to inform poultry farmers of the potential for solar energy in brooding.

The potential for solar energy appears excellent in poultry brooding, with few technical problems apparent. When the technology has been adequately demonstrated, it should see wide adoption.

4. Greenhouse Heating

In 1974, California had 38 percent of all the greenhouse acreage in the U.S., or 2370 acres. Most of the acreage (87 percent) is in flowers. The greenhouse industry is about evenly divided between Northern and Southern California, with Santa Clara, Alameda, and San Diego counties having the largest single concentrations (Ref. 1).

Greenhouses range in area from one to 40 acres and in design from metal-framed glass to metal hoops covered with plastic. There has been a trend to more use of plastic as costs have increased.

Greenhouses are unusual among the industrial and agricultural operations studied in the survey in that energy costs are a major part of overall operating costs. Total energy use from Table 4-1 is 8.0×10^{12} Btu annually, but consumption varies sharply in accordance with local climate. Northern California greenhouses require two to three times the thermal energy required in San Diego county. There is also a variation in energy consumption with different types of construction; a double-poly design, for example, requires only about 60 percent of the energy per acre required by an all-glass design. As a result of these variations, energy costs per acre can range from $8,800 to over $14,000 per acre.

Natural gas is the predominant fuel for greenhouses and is much cheaper than the most suitable backup or replacement fuels, LP gas or electricity. Fuels from oil burners are assumed to be toxic to the plants.

With increasing energy costs there has been a growing interest in energy conservation in greenhouses. Conservation generally takes the form of preventing the radiation of heat at night, since greenhouses normally collect large amounts of thermal energy during daylight hours. Various insulation techniques have been estimated to save from 20 to 85 percent of the energy now required for heating (Ref. 10). No comparisons have been made in this survey of the relative costs of insulating and using solar energy for heating.

Typical greenhouse heating systems use hot water or steam circulating through pipes on walls or floors, or overhead units through which air is circulated by a fan; the heat may be provided by hot water or by a gas-fired burner. In plastic greenhouses, perforated polyethylene tubes carrying heated air are often used. They may be laid on the floor under the bedding benches or hung from the ceiling.

Temperature requirements in greenhouses range from 50 to 80°F, depending on the plant. Most plants require a minimum temperature of 60°F to 65°F. Heating is normally required only between 4 p.m. and 10 a.m. in the winter, and in the early morning hours in Spring and Fall. Little if any heating is required in the summer. Cooling is the major energy requirement, especially in the summer. This demand pattern is not favorable to the use of solar energy for supplemental heating. It should be remembered that a greenhouse is basically a solar collector, but at present there is no associated storage for any excess heat collected during the day.

The cost of energy in a greenhouse operation is second only to the cost of labor, and can amount to 15 to 30 percent of the market value of the products. This is about the same proportion required for fixed costs (depreciation, taxes, insurance), indicating that a greenhouse is a capital-intensive operation. Studies done to date have indicated that solar system costs would have to be in the range of $2 per square foot to be economically acceptable under today's conditions. Some studies indicate that this price is attainable, but demonstrations will be required to show that there is a positive cost benefit (Ref. 10).

The greenhouse industry is scattered and relatively small, with the result that communication within the industry is not well established. Probably the best channel of communication is the Cooperative Extension Service. CES is not as enthusiastic about solar application to greenhouses as other CES areas, i.e. dairies, which will retard solar's growth somewhat. Another excellent channel is provided by the manufacturers of greenhouses, most of which are prefabricated rather than custom-built. They would be appropriate participants in a study to determine how best to integrate solar system design into greenhouse design, and to promote the resulting designs incorporating solar heating.

The potential for solar energy in the greenhouse industry in California is not clear at the present time. It will depend in particular on the effectiveness of any energy conservation techniques that are developed. In general, this is a good application for solar energy because the required temperatures are well within the range of efficient solar collectors. The cost of the required storage may be a drawback.

The economic attractiveness of solar heating for greenhouses will probably vary with location, since some areas such as San Diego county need relatively little supplemental heating and may not find the investment worth while.

It is technically feasible to replace all the conventional greenhouse heating in California with solar energy systems, but economic factors will probably make the actual displacement much smaller. Energy conservation measures must be taken first and will reduce the potential energy reduction available for solar energy to displace. However, the greenhouse industry is growing rapidly and the integration of solar systems into new structures could reduce the rate of energy demand and growth in the industry.

SECTION V

COMMERCIAL PROCESS HEAT SURVEY

A. INTRODUCTION AND GENERAL FUNDING

1. General Sector Characteristics

The commercial sector consists of offices, retail stores, schools, and services such as hospitals, hotels, restaurants, and laundries. The businesses in this sector are represented primarily in SIC major groups 50 through 89 (wholesale trade, retail trade, finance, insurance and real estate, and services).

2. Energy Utilization and Requirements

Little process energy is used in this sector, where most of the energy is required for lighting, space conditioning, and domestic hot water. Process heat is used primarily for cooking, dishwashing, general sanitation, laundry, and film processing. Process heat in this sector amounted to only 2.82×10^{12} Btu in California in 1972.

3. Technical, Economic, and Institutional Characteristics

Most process heat in the commercial sector is in the form of steam (laundries and large restaurants), but hot water for dishwashing, general sanitation and film processing is the most promising application for the near term for solar systems.

Payback periods (3 to 5 years) expected in the commercial sector are in the same range as those expected for other capital investments. There appear to be no institutional barriers to the dissemination of technology other than lack of information on the specific designs, costs, and performance of commercial scale solar systems.*

Demonstrations will be required for wide-spread adoption of solar energy systems. This effort is presently underway. In addition, private installations of solar are becoming more prevalent. The near-term potential adoption of solar process heat in the commercial sector is higher than in the

* Industry organizations are not as strong as in the industrial sector since these are primarily service industries. Therefore, there is less efficient technical information transfer.

industrial or agricultural sector. The reason is that, in most instances, the process heat can be included with the solar heating and cooling systems where hot air or hot water is required. The only industrial type application for process hot water is for laundries and DOE experiments are already in operation (Ref. 1).

B. SPECIFIC APPLICATIONS

1. Eating Places

Energy costs as a percentage of sales are relatively low in this industry, ranging from 2 to 4 percent, and process hot water is a small fraction of this amount. Nevertheless, many restaurant operators are interested in the potential of solar energy for reducing these costs. Restaurant chains are especially interested because of their typically detailed cost accounting and general cost awareness.

One chain has been operating for four years a restaurant designed from the beginning for energy efficiency. Waste heat is used wherever possible, and a solar collector supplements the water heating system (which is also used for space heating). No results were made available as to the cost effectiveness of the solar element, but the same chain plans additional energy saving units that will include solar collectors. It appears that a fully commercialized design could be attractive to many restaurant operators.

2. Commercial Laundries

Commercial laundries are defined as those engaging primarily in the laundering of industrially soiled items such as work uniforms, gloves, towels, wiping cloths, etc. They use large quantities of hot water at about $180^{\circ}F$, and water heating is a significant cost element. There is a national industry association, and apparently no proprietary barriers to the spread of new technology.

DOE has sponsored a demonstration of solar energy for process hot water at one commercial laundry in Fresno, California. Final results have not been published, but interim figures suggest that the solar heating system contributed significantly to the reduction in fossil fuel use for heating water. The project included a heat reclamation subsystem as well as a solar water heater, and as usual, the conservation effort was a larger factor in reducing energy requirements than was the solar system. Nevertheless, of the total energy reduction of 56 percent, the solar heater contributed 12 percent; this was equivalent to over 2600×10^6 Btu of gas per year.

Another experiment is for water heating for a film processing laboratory in Northern California (Ref. 1).

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APPENDIX

SURVEY CONTACTS

APPENDIX

SURVEY CONTACTS

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