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A Review of Selected Solar Market Studies and Techniques

Progress Report

SERI

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NOTICE

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PROGRESS REPORT

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Division of Solar Technology
Under Contract EG-77-C-01-4042

PREFACE

This progress report was prepared by the Economics and Market Analysis Branch of the Solar Energy Research Institute to serve two purposes. First, the report presents the results of Task 5211 on consumer decision criteria which began in the summer of 1978 and ended on September 29, 1978. Second, the report provides a starting point for the solar market studies to be undertaken by SERI in FY79. These solar market studies can be used by those at SERI, the regional solar energy organizations, and potential suppliers concerned with understanding and increasing the market penetration of the various solar technologies. To that end, the report includes a preliminary plan for completing those studies in FY79.

The primary authors of this progress report were Don Berliner, project leader, Cheryl Fellhauer, Dennis Costello, and Susan Christmas. Helpful comments were also received from Peter Ketels, David Posner, and Harit Trivedi.

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ABSTRACT

This report presents the preliminary results of a literature review of solar energy market studies in the industrial process heat, passive, solar thermal electric, photovoltaic, wind, and ocean thermal technologies. Useful elements of market studies in other solar areas are described as well. The market research literature is reviewed in order to investigate techniques or approaches that may have some applicability in the context of solar markets. A preliminary plan is presented for the initiation of selected solar market studies during FY79.

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I. INTRODUCTION

The size and characteristics of the markets for solar technologies are among the most important issues facing the commercial development of solar energy. Current and potential markets for solar technologies are as diverse as the solar technologies that will serve them. The current and potential markets include homes, commercial buildings, multifamily dwellings, industries, agricultural applications, large utilities, remote power systems, foreign countries, and transportation. Many of these markets have been investigated in projects funded by the federal government. This progress report presents a review of selected solar market studies and market analysis techniques that may be useful in future market studies. The report also helps identify: (1) gaps in the existing market literature, (2) topics that need additional analysis, and (3) areas in which conflicting research results have not yet been resolved. Finally, the report outlines a preliminary plan for market studies at SERI in FY79.

The report is organized into four chapters. Following this introduction, the market studies dealing with six solar technologies are reviewed in Chapter II. The introduction to that chapter presents a list of questions that form the framework for the review. While market studies in solar heating and cooling of buildings are not addressed in Chapter II, useful elements of those market studies are reported in the last section of the chapter.

Chapter III summarizes some of the available market research techniques that may be applicable to research on solar markets at SERI. The purpose of investigating these methods is to determine if there are any techniques or approaches that have been used in contexts analogous to those confronting solar markets.

Chapter IV outlines the future direction that SERI intends to follow in the area of solar market studies. In particular, three solar technologies have been identified as initial candidates for study--process heat, passive solar technologies in residences, and solar thermal electricity in utility applications. These three technologies were chosen because of the pressing need for market information to be input to a number of policy studies being undertaken at SERI. The market studies completed in FY79 at SERI will, therefore, serve to increase the general stock of information on those markets, help guide ongoing policy studies at SERI and the regional solar centers, and assist potential suppliers by providing more understanding of the specific marketing issues to be addressed.

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II. LITERATURE REVIEW OF SOLAR ENERGY MARKET STUDIES--PRELIMINARY RESULTS

In this preliminary review of the literature on solar market studies, the primary interest was in the determination of a basis for future work in this area. To this end, the studies were reviewed with the following (neither mutually exclusive nor totally exhaustive) areas of issues/questions in mind:

- What data were collected or used and what methods were applied?
- How were the markets defined or delineated?
- What is the potential size of the total market relative to what time periods? What were the projected market shares?
- What fuels/technologies will compete with each solar technology? At what price will the solar technology compete?
- What investment criteria were mentioned as relevant to the market?

It is hoped that the information gained through the review can be used by the project team to guide (1) in deciding what issues/questions are important to pursue, and (2) in understanding in what areas there appears to be a lack of useful data.

A. Industrial Process Heat Market Studies

Four publicly available market studies have been conducted in the area of agricultural and industrial process heat. Organizations funded to research technology included Battelle/Honeywell, InterTechnology Corporation (ITC), Aerospace Corporation, and Mathtech, Inc. The studies focused primarily on industrial process heat, with Mathtech emphasizing some agricultural applications. The studies are discussed below.

The first industrial process heat study examined was condusted by Battelle Columbus Laboratories, Honeywell, Inc., and Battelle Pacific Northwest Laboratories, and was entitled "Survey of the Applications of Solar Thermal Energy Systems to Industrial Process Heat"[1]. The major objectives of the Battelle/Honeywell study were to:

- identify and characterize industrial process heat requirements,
- identify state-of-the-art applications of solar thermal energy systems (SES),
- analyze the expected performance of conceptual solar thermal energy systems,
- identify needed R&D, and
- perform preliminary assessments of related nontechnical issues.

The study objectives were met by a process heat industry survey/analysis, an analysis of solar energy systems, and a survey of industry to assess nontechnical issues. Data sources for the analyses were obtained via a literature search, Battelle staff experience, and direct contact with the industry. These data sources are provided on an industry-by-industry basis in Volume II of the study.

The nontechnical issues were assessed based on a telephone survey. Telephone contacts were made with approximately 100 individuals in 28 industries or agencies in an effort to identify the responsible official most qualified to respond to the questionnaire. The contacts represented the following industries: aluminum, automobile, cement, coal, food processing, glass, paper, pulp (plywood), and rubber.

The process heat survey focused on six 2-digit Standard Industrial Classification (SIC) groups: food, textile, lumber, paper, chemicals and stone, clay and glass; and nine 4-digit SIC groups: coal mining and cleaning, sulfur mining, petroleum refining, blast furnaces and steel mills, primary copper, primary aluminum, and automobile and truck manufacturing.

Industry descriptors included process heat requirements according to temperature range, forms of process heat (air, hot water, and steam) by temperature range, sources of process heat, and costs. Solar energy systems were identified by performance, cost, and heat form.

The basic technology of solar thermal systems is currently capable of providing process heat at temperatures up to 350°F. In 1974 about 1.5×10^{15} Btu, or 19.4% of the total process heat used, was at $\leq$ 350°F. By 1985, 2.0×10^{15} Btu (of a total 9.73×10^{15} Btu) will be required at temperatures $\leq$ 350°F. Requirements in 2000 will be 3.0×10^{15} Btu (out of a possible 13.2×10^{15} Btu). Extrapolating the data analyzed to all industry requirements below the 350°F level results in a potential of 35% of total Btu requirements in 1974. No solar process heat market share was projected in the study.

The Battelle/Honeywell study assumed solar energy systems would compete with petroleum (including oil shale), natural gas, coal, nuclear, hydro, and geothermal sources. Industrial consumption of energy is presented in Table 1. Price estimates for the fuels are given in Table 2. There were no breakdowns of conventional fuel requirements by industry or location.

Before investing in a new technology, manufacturers examine the costs of the conventional energy systems versus the new process. Battelle/Honeywell concluded solar ponds for hot water heating were competitive today to displace fuel oil [1].

The issues assessment survey identified other investment decision criteria. The basic problem identified was industry's preference for short-term payback. Life-cycle costing will not satisfy industry. One other barrier to a favorable investment decision in a solar system is the fact that the cost of fuel is tax deductible as an operating expense while a solar system is deductible under specified depreciation schedules. Currently, these fuel deductions are greater than capital cost deductions.

ITC concurrently investigated the potential use of solar thermal energy for process heat in industry [2]. Tasks involved in fulfilling this objective were:

- the identification and summarization of the important characteristics, including performance and cost, of various solar thermal

TABLE 1
INDUSTRIAL CONSUMPTION OF ENERGY, 1974-2000
AS PREPARED BY BATTELLE/HONEYWELL IN 1977 [1]
(10^{12} Btu)

	1974	1980	1985	2000
Coal	7381	9455	11738	19907
Fuel use	(4093)	(4600)	(4680)	(5460)
Nonfuel use	(115)	(200)	(250)	(450)
Electric power	(3623)	(4666)	(6531)	(10288)
Synthetic gas[a]	--	--	(277)	(3230)
Synthetic liquids[a]	--	--	--	(479)
Petroleum	7485	9442	11124	12706[b]
Fuel use	(3760)	(4380)	(4950)	(6200)
Nonfuel use	(2284)	(3120)	(3550)	(5400)
Electric power	(1441)	(1942)	(2579)	(2336)
Synthetic gas[a]			(75)	
Natural gas	12520	10762	10124	9497[c]
Fuel use	(9495)	(9240)	(8920)	(10360)
Nonfuel use	(1634)	(760)	(820)	(900)
Electric power	(1321)	(762)	(624)	(497)
Oil Shale				
Synthetic liquids[a]	--	--	185	1281
Nuclear Power				
Electric power	490	1733	4295	22902
Hydro and Geothermal Power				
Electric power industrial	1296	1447	1602	3017
Total Energy Consumption	29600	32900	39700	69300
Electric Power as % of Industrial Total	27.8	32.1	41.0	56.4
& of Total U.S. Energy Consumption	40.5	37.8	38.2	42.4

[a]Gross energy requirements to manufacture synthetic fuels (industrial sector equivalent share).
[b]Includes synthetic liquids--1230 x 10^{12} Btu.
[c]Includes synthetic gas--2260 x 10^{12} Btu.

TABLE 2
ESTIMATED PRICE RANGES FOR SELECTED FUELS, 1974-2000
AS PREPARED BY BATTELLE/HONEYWELL IN 1977 [1]
(Constant 1976 Dollars per Million Btu)

	1976	1980	1985	2000
Petroleum				
Crude oil, composite @ refinery	1.70-1.80	2.25-2.50	2.50-3.50	3.50-4.50
No. 2 distillate fuel @ terminal	2.00-2.30	2.45-2.75	2.70-3.75	3.70-4.75
Residual fuel, low sulfur	1.70-2.20	2.25-2.60	2.50-3.50	3.50-4.50
Natural Gas				
Industrial uses, average	0.85-0.95	1.70-2.25	2.75-3.25	3.50-4.50
Intrastate, new @ well head	1.90-2.00	2.25-2.50	2.50-3.25	3.50-4.50
LNG @ pipeline	1.90-2.00	2.25-2.50	2.50-3.25	3.50-4.00
Coal (Steam)				
Utilities, average	0.80-0.90	1.00-1.50	1.25-1.75	1.50-2.50
East North Central Region	0.80-0.90	1.00-1.50	1.25-1.75	1.50-2.50
Mountain Region	0.30-0.40	0.50-1.00	0.75-1.25	1.00-2.00
Synthetic Gas				
Pipeline quality @ pipeline	3.00-4.00*	3.50-4.50*	3.50-5.00	3.25-4.50
Low Btu, East North Central	3.00-3.50	3.00-3.25	3.00-3.25	3.00-4.25
Synthetic Liquid Fuel				
Oil Shale	N/A	N/A	3.00-3.50	3.00-4.50
Coal	N/A	N/A	3.50-4.00	3.25-4.50

*Produced from naphtha.

energy systems pertinent to their use as providers of industrial process heat;

- the development of an industrial process heat data base with the required amount of detail; and
- the identification and assessment of the relevant nontechnical issues associated with widespread implementation on a national scale.

Information for the tasks was obtained from technical literature, trade associations, industrial consultants and industry contacts. An analysis of solar thermal energy systems for industrial process heat required information on the following factors:

- Types of solar systems, their performance and cost,
- regional insolation data,
- industrial load requirements, and
- conventional fuel costs and mix.

The results of the analysis were the marginal costs of solar process heat by city as a function of temperature requirement and percentage annual load. These costs were compared to present and estimated future costs for conventional fuels to indicate when, where, and under what conditions of system type, temperature, and percentage annual load solar process heat will be cost effective for industrial use.

ITC selected those industries on the 4-digit SIC level that consume over 5 x 10^9 kWhr of fuel, excluding electricity, for study. The 78 industries chosen account for 59% of the total amount of process heat currently required in all of the SIC manufacturing categories.

Factors required by industry for the process heat data base included:

- amount of energy required and form of energy used in specific applications in specific processes,
- production data--current and future, and
- temperature ranges.

In 1974 the estimate of total amount of process heat required was 16.6 x 10^{15} Btu. The 78 SIC groups studied consumed 9.81 x 10^{15} Btu or 59.1% of the total use of initial process heat in 1974. The study estimated that industry will require 23.0 x 10^{15} Btu for process heat in 1985 and 36.6 x 10^{15} Btu in 2000.

A quantitative assessment by ITC of the potential of solar thermal energy systems to provide process heat technically, practically, and economically indicates a maximum potential of 0.6 x 10^{15} Btu per year in 1985. In 2000, solar energy could provide 7.3 x 10^{15} Btu per year, or 70% of the 10.4 x 10^{15} Btu needed for applications having a maximum required temperature of 550°F. (Estimates of solar thermal energy systems' share of market potential were limited to heat requirements less than 550°F. ITC considered this the highest practical temperature that could be reached by a concentrating solar collector system having practical potential to provide a significant amount of process heat. The survey data revealed that 28% of process heat is used below 550°F.)

Solar energy also has the potential of providing low temperature preheat requirements which are currently met by high quality fossil fuels, but this potential is hard to quantitatively assess. Of the additional 8.6 x 10^{15} Btu required for preheat below 550°F, solar energy can perhaps provide about 6.0 x 10^{15} Btu, according to ITC. Combining the two estimates, the total potential for solar process heat in industry in the year 2000 is about 13.3 x 10^{15} Btu or about 36% of the total use of process heat in that year. Target industries include food, textiles, chemicals, and primary metals.

ITC compiled regional fuel mix and fuel cost data for coal, oil, and natural gas on a "constant-performance solar region" basis. These totals are shown in Table 3.

TABLE 3
ITC ESTIMATES OF FUEL MIX FOR THE INDUSTRIAL SECTOR[2]

Constant-Performance Solar Region	Percentage of Thermal Needs Supplied by Coal	Oil	Gas
United States	14.5	11.8	73.7
I	22.2	23.4	54.4
II	21.5	18.1	60.4
III	30.9	10.0	59.1
IV	6.1	7.8	86.1
V	1.2	3.3	95.5
VI	0.0	9.4	90.6

Nationally, gas accounts for 73.7% of industrial fuel requirements. Within the solar regions this number varies from half to approximately all of the fuel requirements. The same variation is evident in the percentage of oil used. The fuel mix data are a quantitative measure of the amount of competition solar process heat will face from each competing fossil fuel by solar region.

Investment decision criteria specific to industrial process heat were not discussed. A general review of barriers and incentives to solar energy systems was included in the ITC study.

The investment decision process of any industry will focus on the cost of a solar energy system versus a conventional system. While initial capital investment for solar systems is high, on the basis of simple life-cycle cost analysis, ITC concluded that solar process heat provided by a tracking parabolic trough collector system might be cost-effective now in competition with oil heat in the region of the country with the highest insolation (Arizona and

New Mexico). By 1985, solar process heat should be cost-competitive with oil in all locations in indirect heat applications and some locations in direct heat applications. By 2000, solar process heat should be able to compete with the fuel cost of oil and gas anywhere in any application. Solar process heat would not appear to compete against coal energy in the year 2000 [2].

A third market-oriented study of process heat was completed by the Aerospace Corporation as part of the Solar Total Energy System (STES) Mission Analysis for DOE [3]. Objectives of the analysis were:

- the identification and selection of appropriate STES applications,
- definition of characteristics and operational modes of economically attractive STES configurations,
- assessment of the size and potential penetration rate of available markets, and
- development of recommendations for commercial demonstrations.

To accomplish these objectives for the industrial sector, Aerospace developed two models. The Solar Total Energy Systems Applications Model (SAM) was formulated to develop data on STES development potential by state and industry as a function of time from 1985 through 2015. The Market Penetration Model (MPM) was used to develop forecasts of STES market penetration and national energy displacement by fuel type. The MPM was also used to generate sensitivity factors for incentives and variations in assumptions of cost of STES and competing fuel.

Input data for the models were obtained from:

- 1972 Census of Manufactures,
- 1974 Survey of Manufactures,
- InterTechnology Corporation Report [2], and
- Sherman H. Clark Associates, who developed forecasts of energy use and price for the 1985 through 2015 time period.

The effective market for solar energy process heat was restricted to industries with heat requirements below 500°F. Using ITC data [2] this eliminates 36% of the industries. Aerospace identified 140 industries on a 3-digit SIC level and developed data on a state-by-state basis for seven time periods between 1985 and 2015.

Market characteristics for industrial applications include:

- temperature requirements,
- thermal to electric demand ratios,
- demand phasing characteristics,
- effective mean daily insolation (on an hourly basis) by city,
- total-to-direct insolation conversion,

- cost of fuels for process heat, and
- cost of electricity by state.

Equivalent cost ratios, which give the ratio of annualized STES cost to annualized cost of conventional fuels it displaces, were developed from the SAM model. Fuel displacement figures were also developed from SAM. SAM provides equivalent cost ratios and fuel displacement as functions of industry location and time period. Both were used as input to the market penetration model. Other input requirements for the model were:

- type of fuel displaced,
- new versus retrofit STES installations,
- size of capital investment in STES,
- age of existing capital equipment,
- penetration already achieved by STES,
- government policy relative to fuel use restrictions,
- tax incentives, and
- loan programs.

Aerospace identified the potential market for STES based on the model results. Manufacturing industries will require 16.5 x 10^{15} Btu in 1985 and 26.5 x 10^{15} Btu in 2015. Of these requirements 32% are high temperature demands (>600°F) which could not be replaced by solar process heat. Of the remainder, STES have the potential of displacing approximately half of the fuels used (see Fig. 1). Not all of the industries are economically viable in terms of equity cost ratios $\leq$ 1. In 1985 there are no industries with ECR $\leq$ 1. In 1990 there are two--paint manufacturing and drug manufacturing in California. In 1995 there are 114 economically viable STES applications throughout 15 states that displace 0.8 x 10^{15} Btu annually. The most favorable sites are in California, Texas, Florida, Hawaii, and New Jersey. Industries with potentially large fuel displacements include agricultural chemicals, industrial organic chemicals, plastics, and drugs. Table 4 summarizes these findings.

The market penetration model takes suitability of solar installations into account and limits the availability to new construction. With technical and economic risk factors included for a more realistic forecast of STES adoption, the results show initial penetration by 1990 with rates greatest in Texas, California, Florida, and New Jersey. By the year 2000, Aerospace predicts a 76% penetration rate with 1.8 x 10^{15} Btu of energy saved. By 2015, 6.0 x 10^{15} Btu could be saved, of which 2.2 x 10^{15} Btu would be natural gas and fuel oil. A 30% tax credit incentive would provide some market penetration by 1985 and double penetration of the base case by 1995. A tentative ranking based on the Aerospace model results would suggest the most viable markets to be:

- agricultural chemicals in California,
- plastic materials and synthetics in Texas,

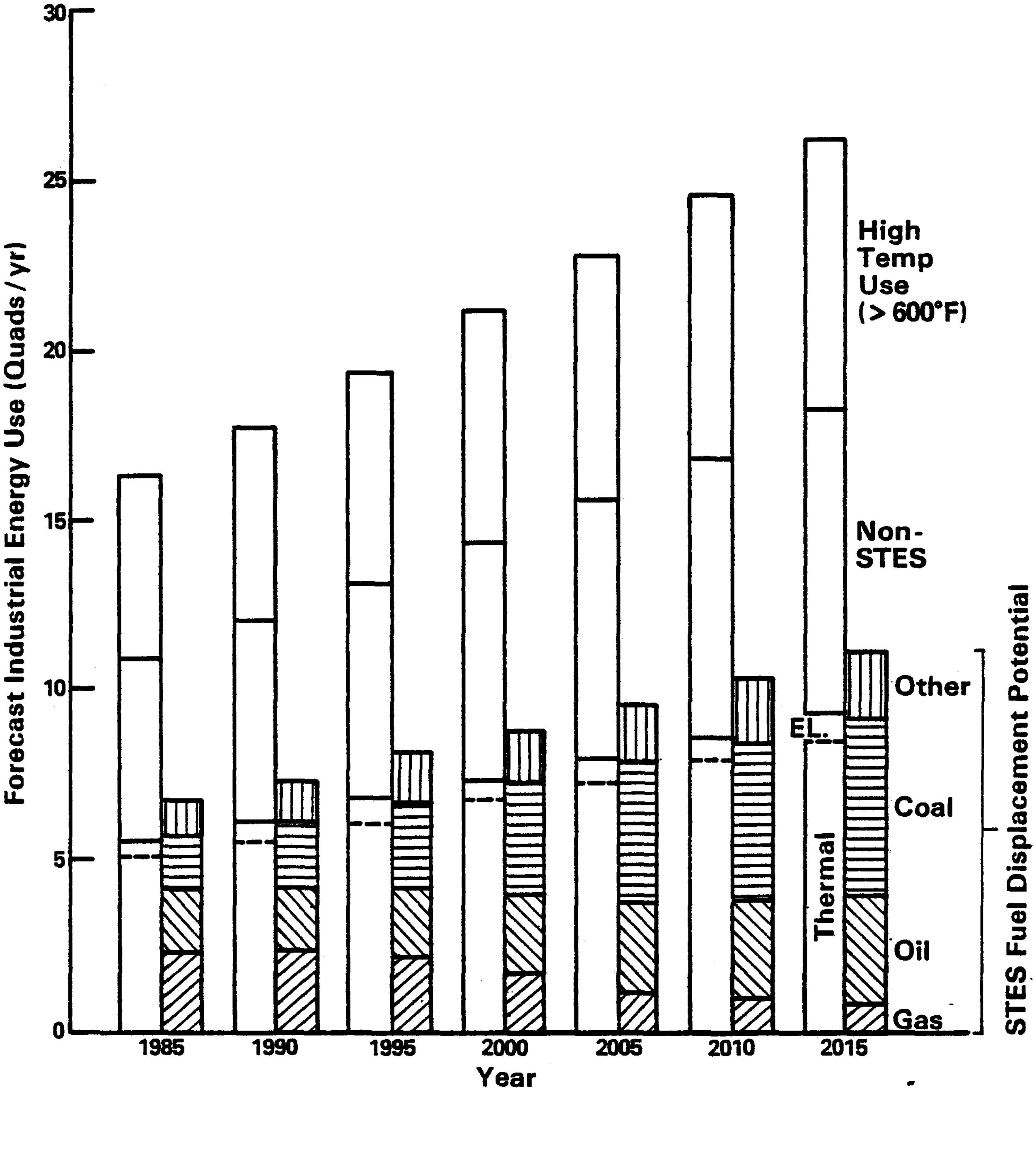

Figure 1. STES Energy Displacement Potential [3]

Table 4. 1995 - Ranking of STES Applications (Possible Demonstration Candidates)
Compiled from Aerospace Results

- RANKING BY STATE:

LOWEST ECR IN STATE		LARGEST ENERGY DISPLACEMENT (QUADS)		No. OF APPLICATIONS WITH ECR ≤ 1	
CALIFORNIA	- 0.66	CALIFORNIA	- 0.29	CALIFORNIA	- 40
HAWAII	- 0.68	TEXAS	- 0.11	NEW JERSEY	- 14
ARIZONA	- 0.79	NEW JERSEY	- 0.09	MASSACHUSETTS	- 9
KANSAS	- 0.80	FLORIDA	- 0.08	NEW YORK	- 8
FLORIDA	- 0.87	NEW YORK	- 0.05	CONNECTICUT	- 7

- RANKING BY INDUSTRY

LOWEST ECR IN INDUSTRY		LARGEST ENERGY DISPLACEMENT (QUADS)		No. OF STATES WITH ECR ≤ 1	
PAINTS	- 0.66	PLASTICS	- 0.14	NON-FERROUS	
DRUGS	- 0.67	AGRIC CHEM	- 0.08	ROLLING & DRAW	- 11
SOAP		IND ORG CHEM	- 0.07	DRUGS }	
IND ORG CHEM }		PAPERBOARD MILLS	- 0.06	MISC CHEM }	- 8
AGRIC CHEM }	0.68			PRODUCTS }	
MISC CHEM }		IND INORG CHEM	- 0.05	PLASTICS }	
SUGAR }				PAINTS }	- 7
				SOAP }	

SOURCE: The Aerospace Corporation, Eenergy and Transportation Division, El Segundo, California "Solar Thermal Dispersed Power Program, Total Energy Systems Project", Volume I Solar Total Energy Systems Market Pentration. Prepared for Division of Solar Technology, Department of Energy Washington, D.C. March 31, 1978 Aerospace No. ATR-78(7692-01)-1 Table IV-4, p. IV-16

- industrial organic chemicals in New York,
- paperboard mills in Florida,
- industrial inorganic chemicals in Kansas,
- drugs in New Jersey.

Figure 1, presented earlier, shows STES displacement of natural gas, light fuel oil, heavy fuel oil, coal, and electricity. The Aerospace study suggests that in 1985 the displacement will be largely oil and gas; by the year 2015, coal will begin to replace some of the other fuels. The net effect is to achieve an almost constant maximum potential displacement of approximately 4.1 x 10^{15} Btu of oil and gas throughout the 1985-2015 period.

Investment decision criteria were not discussed in the study. However, the Aerospace model can predict breakeven cost of collectors by site. Table 5 shows these costs by selected location.

A fourth major study of the market for solar industrial process heat was completed by Mathtech Inc. [4]. The Mathtech study focused on the development and analysis of alternative commercialization options for solar thermal energy in industrial and agricultural applications. Figure 2 summarizes the approach used. The economic evaluation and market penetration model evaluates the economics of solar thermal energy for process heating and then calculates the optimum fraction of the process heat requirements that can be provided economically by solar energy.

Target industries for analysis were selected using data from ITC [2], Battelle [1], and the Mathematica/Drexel/UTC Industrial Applications Studies Data Base [5]. Process heat demands by type of fuel were obtained from ITC [2], Mathematica/Drexel/UTC [5], 1972 Census of Manufactures and 1974 Survey of Manufactures. The 1976 National Energy Outlook, Federal Energy Administration [6], provided regional demand by fuel type. Other fuel price data were obtained from Energy Price Projections, Federal Register, April 15, 1977. Investment preference functions were derived by industry on a 3-digit SIC level from Value Line Investment Survey [7] and News Front Directory of 30,000 Leading U.S. Corporations.

Twenty industries from ITC's 78 were chosen for analysis based on a ranking among the following criteria:

- process heat temperature demands of < 212°F,
- weighted process heat temperature demands of ≤ 550°F, without adjustment for waste heat utilization,
- weighted process heat temperature demands of ≤ 550°F adjusted for waste heat utilization, and
- average weighted process heat temperature demands under latter two criteria.

Market descriptors for each of the 20 industries (shown in Table 6) include process heat requirements by solar regions (from ITC for 1976, 1985, and 2000); application temperature (< 212°F, 212-350°F, 350-550°F, and > 550°F);

Table 5. Aerospace Corporation's Evaluation of Idealized STES Application for Different Geographic Locations

Location	Equivalent Cost Ratio	Fuel Displacement	Base-Case Costs & Economics Charges For Break-Even Operation		
			Collector Cost $/Ft^2	Fixed Charge Rate	Competing Energy Cost
Inyokern, CA	.80	78%	18.3	18.7%	-20%
Albuquerque, NM	.85	73	17.0	17.6	-15
El Paso, TX	.85	73	17.0	17.6	-15
Yuma, AZ	.86	73	16.8	17.4	-14
Edwards AFB, CA	.87	71	16.6	17.2	-13
Tucson, AZ	.89	70	16.2	16.9	-11
Ely, NV	.91	70	15.7	16.4	- 9
Phoenix, AZ	.91	69	15.7	16.5	- 9
Riverside, CA	.92	67	15.5	16.3	-
Santa Maria, CA	.96	66	14.8	15.7	- 4
Salt Lake City, UT	.98	65	14.4	15.3	- 2
Grand Junction, CO	.98	63	14.4	15.4	- 2
Midland, TX	1.00	62	13.9	14.9	0
L.A.C.C., CA	1.02	59	13.7	14.7	- 2
Fresno, CA	1.04	60	13.3	14.4	+ 4
Dodge City, KS	1.04	60	13.3	14.4	+ 4
L.A.X., CA	1.04	60	13.3	14.4	+ 4
San Diego, CA	1.05	59	13.1	14.3	+ 5
Fort Worth, TX	1.10	56	12.4	13.6	+10
Boise, ID	1.11	56	12.3	13.6	+11
Miami, FL	1.12	56	12.1	13.4	+12
Great Falls, MT	1.22	64	10.9	12.3	+22
Charleston, SC	1.15	54	11.8	13.1	+15

SOURCE: The Aerospace Corporation, Energy and Transportation Division, El Segundo, California "Solar Thermal Dispersed Power Program, Total Energy Systems Project", Volume I, Table V-4, p. V-13 Solar Total Energy Systems Market Penetration. Prepared for Division of Solar Technology, DOE Washington, D.C. March 31, 1978 Aerospace No. ATR-78(7692-01)-1

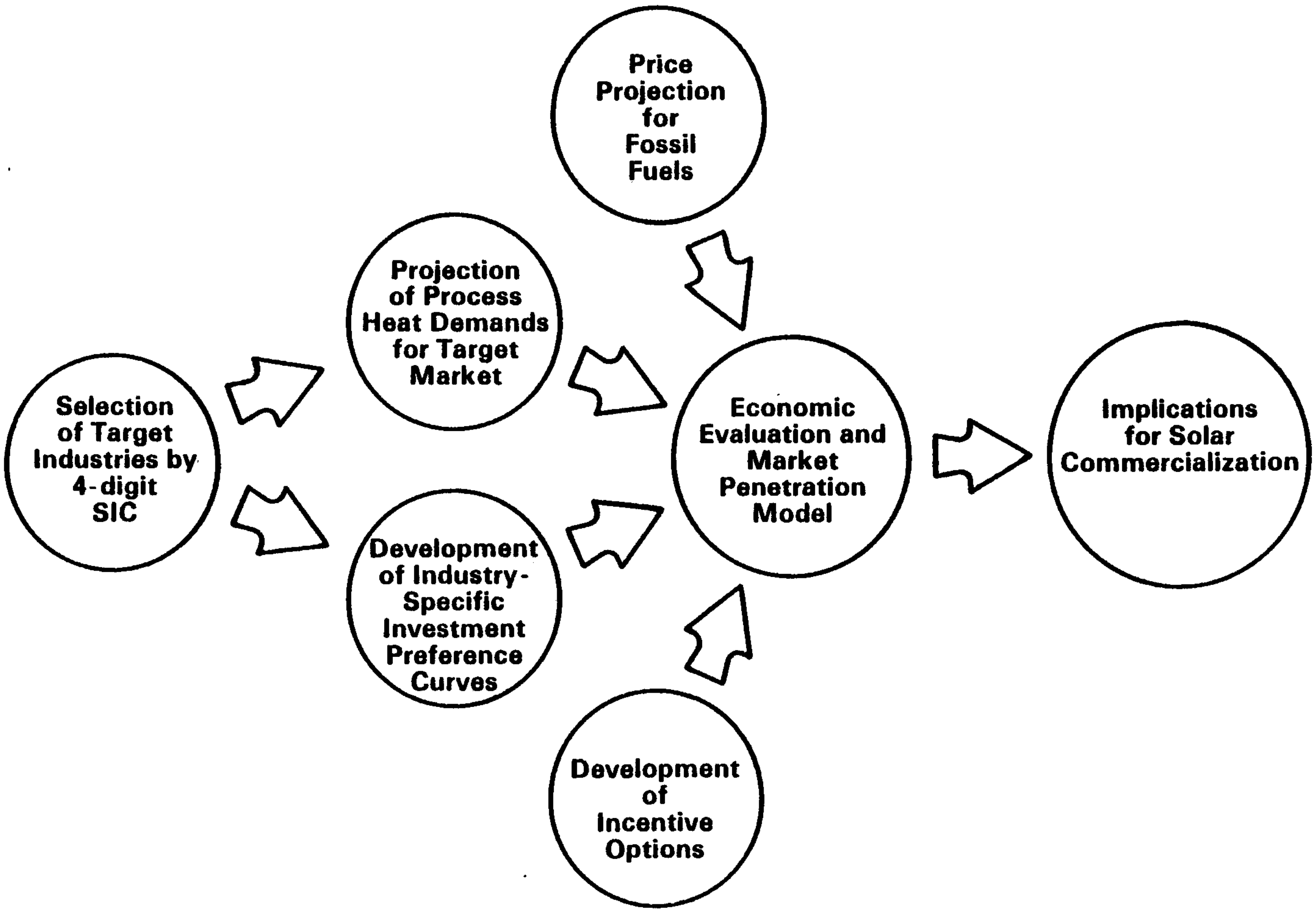

Figure 2. Method of Approach [4]

Table 6. Process Heat Characteristics of Industries Selected by Mathtech for Evaluation

SIC	Industry	1974 Process Heat Requirement --- 10^{12} BTU				
			Application Temperature			
		Total	$\leq$ 212°	212-350°	350-550°	> 550°
2611, 2621, 2631, 2662	Paper and pulp	1011.0	175.0	547.0	253.0	36.0
3321, 3322 3323	Iron foundries	430.7	151.0		117.7	162.0
2819	Alumina	148.5		113.2		35.3
2951	Paving mixtures	93.0		93.0		
2824	Non-Cellulose fibers	75.4	75.4			
2823	Cellulosic man-made fibers	118.0		23.5	94.5	
2262	Finishing plants, synthetic	74.3	51.1	23.2		
2812	Alkalies and chlorine	82.1		82.1		
2911	Petroleum refining	2537.0	59.0	60.0		2418.0
2436	Veneer	57.8	57.8			
2421	Sawmills and planing mills	63.4		63.4		
2063	Beet sugar	64.8	14.5	47.3		3.0
2013	Sausages and prepared meats	46.4	45.4		1.0	
2435	Plywood	50.6		50.6		
2261	Finishing plants, cotton	42.1	19.9	22.2		
ALL	Top Twenty	4895.1	649.1	1125.5	466.2	2654.3

Orignial Source: "Analysis of the Economic Potential of Solar Thermal Energy to Provide Industrial Process Heat," Intertechnology Corporation, 1977.

Industrial Application Study Data Base, Drexel University/MATHTECH, Inc./United Technologies, 1977.

SOURCE: Mathtech, Inc., Princeton, NJ "Commercialization Plan for the Implementation of Solar Industrial Process Heating" Draft Final Report, Volume II, Table A-10, p. A-17 - Technical Supplement. Prepared for U.S. Department of Energy. March 1978 fuel mix (percentage gas, percentage oil, and percentage coal); plant size (small, medium, and large); and target years (1980, 1985, 1990, 1995, and 2000).

Data from 1976 show 28% of the total industrial process heat required was at temperatures < 550°F. In 1976 the twenty target industries accounted for 55% of the demand in that range. This percentage is expected to rise to 64.5% of the < 550°F requirement by 2000. Seven cases for market penetration were evaluated and are summarized in Table 7. The cases were:

1. Reference case: a complete absence of government intervention in the marketplace;
2. Increased investment tax credit from 10% to 45%;
3. Tax deductibility of full cost;
4. Accelerated depreciation: total writeoff of all solar investment cost in first year;
5. Solar energy tax credit bonus: an equivalent bonus of $1.00/MBtu given for the equivalent savings in fossil fuels displaced by solar energy;
6. Fuel surtax: a surtax of $2.00/MBtu imposed on industrial consumption of oil and gas; and
7. Accelerated depreciation plus investment tax credit increase: the total writeoff of solar system first costs combined with the 20% investment tax credit.

The summary Table 7 and Tables 8, 9, 10, and 11 show that in the absence of government intervention, the market penetration prospect for solar energy in industrial process applications is 1.8% by 2000. Targets of 20% penetration levels were set and met given incentives discussed in cases 2, 3, 5, 6, and 7.

Mathtech provided data for process heat energy demand being met by gas, oil, and coal for the target industries. These requirements by fuel mix are given in Table 12. Fuel displacement by solar process heat was shown in Table 10.

The Mathtech study asserted that investment options by an industry are based on the concept of internal rate of return on investment (ROI). The required rate of return is influenced by the lending institutions and their perception of the inherent riskiness of an industry's activity. Mathtech derived investment preference curves for input into the economic evaluation model. An average value of the equilibrium share for solar energy was calculated over the full range of discount rates and by industry. The curves show that, as the discount rate increases, the fraction of process heat that can be provided by solar energy declines. This is explained by the fact that at higher discount rates the present value of the future savings of conventional fuels displaced by solar energy declines. On the other hand, as the rate of return for solar investment increases, a larger fraction of the industry is willing to invest in solar process heat.

Table 7. Summary of Case Studies Analyzed by Mathtech

Case \ Parameters	Tax Rate (%)	Investment Tax Credit %	Deductibility of Fuel Costs	Depreciation	Solar Energy Fuel Savings Tax Credit	Fuel Surtax	Target Solar Net Penetration by 2000 (%)	Achieved Penetration By 2000 (%)
1. Reference	48	10	Full allowance	Sum-of-the Digits (20 years)	NO	NO	None	1.8
2. Increased Investment Tax Credit	48	45	Full allowance	Ditto	NO	NO	20	22.5
3. Deductibility of Fuel Costs	48	10	Only 20% of Fuel Costs Deductible	Ditto	NO	NO	20	22.1
4. Accelerated Depreciation	48	10	Full allowance	Instant write-off	NO	NO	20	9.0
5. Solar Energy Fuel Savings Tax Credit	48	10	Full allowance	Sum-of-the Digits (20 years)	$1.00 per MMBTU	NO	20	18.6
6. Fuel Surtax	48	10	Full allowance	Ditto	NO	$2.00 per MMBTU	20	19.5
7. Accelerated Depreciation Combined with Investment Tax Credit	48	20	Full allowance	Instant write-off	NO	NO	20	19.1

SOURCE: Mathtech, Inc., Princeton, NJ "Commercialization Plan for the Implementation of Solar Industrial Process Heating" Draft Final Report, Volume I, Table 5-1, p. 5-4 - Technical Supplement. Prepared for U.S. Department of Energy. March 1978

Table 8. Industry-Specific Implications of Incentive Options Analyzed by Mathtech

SIC	Industry Name	Proc. Heat* Requirement In Year 2000 (Trill. BTU)	Solar Market Share in Year 2000 (%)						
			Cases**						
			1, Ref.	2	3	4	5	6	7
2611, 2621, 2631, 2662	Paper, pulp, paper-board mills, building paper	3353.87	0.58	21.57	20.93	8.15	17.58	18.48	18.17
3321, 3322, 3323	Gray and malleable iron foundries, steel foundries	341.92	2.82	23.65	22.91	10.70	21.90	22.94	19.10
2819	Alumina	302.37	0.88	24.79	24.06	6.20	18.12	21.66	19.10
2951	Paving mixtures	124.11	2.38	28.54	27.65	12.15	22.98	23.91	24.06
2824	Non-cellulose fibers	251.71	0.44	13.07	14.27	2.75	8.16	10.19	10.54
2823	Cellulosic man-made fibers	418.22	1.90	11.86	11.84	4.70	11.58	12.51	9.86
2262	Finishing plants, synthetic	155.30	1.36	27.60	26.75	12.15	24.24	25.19	24.06
2812	Alkalies and chlorine	237.28	0.44	15.41	15.68	2.85	12.12	13.18	12.83
2911	Petroleum refining	491.33	2.97	32.23	31.23	16.20	27.54	28.61	28.21
2436	Veneer	102.01	0.29	19.16	20.54	4.95	15.42	16.23	16.43
2421	Sawmill and planing	114.91	1.02	23.05	22.66	8.10	16.86	18.30	19.53
2063	Beet sugar	110.02	16.88	43.28	41.79	25.80	38.64	39.65	37.82
2013	Sausage and prepared meats	59.71	0.97	31.83	31.04	12.95	27.18	27.94	28.21
2261	Finishing plants, cotton	85.90	0.78	25.19	24.45	9.65	20.64	21.47	21.64
2435	Plywood	88.51	0.34	18.16	18.05	4.35	13.56	14.09	14.38
All 20 Industries		6237.16	1.36	22.24	21.70	8.65	18.30	19.40	18.66

* Less than 550°F ** See Table 7

SOURCE: Mathtech, Inc. Princeton, NJ "Commercialization Plan for the Implementation of Solar Industrial Process Heating" Draft Final Report, Volume I, Table 5-2, p. 5-6 - Technical Supplement. Prepared for the U.S. Department of Energy. March 1978

Table 9. Region-Specific Implications of Incentive Options Analyzed by Mathtech

Solar Region	Proc. Heat* Requirement in Year 2000 (Trill. BTU)	Solar Market Share in Year 2000 (%)						
		Cases **						
		1, Ref.	2	3	4	5	6	7
I	1124.88	+	1.7	1.6	0.1	0.8	0.8	0.7
II	2886.98	0.4	17.5	17.0	4.6	12.9	12.1	13.7
III	1883.95	1.4	16.8	16.8	7.1	15.8	14.9	14.5
IV	1900.56	0.7	21.8	21.3	6.7	18.9	17.6	17.6
V	1914.54	1.9	37.9	37.0	15.3	34.2	32.6	33.3
VI	368.24	25.3	77.0	76.7	58.2	74.5	73.5	74.8
All	10079.14	1.8	22.5	22.1	9.0	19.5	18.5	19.1

+ Less than .1%

* Less than 550°F

** See Table 7

SOURCE: Mathtech, Inc., Princeton, NJ "Commercialization Plan for the Implementation of Solar Industrial Process Heating" Draft Final Report, Volume I, Table 5-3, p. 5-7 - Technical Supplement. Prepared for the U.S. Department of Energy, March 1978.

Table 10. Fossil Fuel Savings Implications of Incentive Options Analyzed by Mathtech

Fuel Type	Proc. Heat* Requirement In Year 2000 (Trill. BTU)	Solar Market Share in Year 2000 (%)						
		Cases **						
		1, Ref.	2	3	4	5	6	7
Oil	2257.07	1.89	27.05	26.76	11.55	18.14	24.65	23.67
Gas	6026.89	2.28	27.28	26.70	10.65	23.45	19.19	22.96
Coal	1797.18	0.002	0.55	0.53	0.06	2.51	2.84	0.29
All Fuels	10079.14	1.80	22.50	22.10	9.00	18.50	19.50	19.10

* Less than 550°F

** See Table 7

SOURCE: Mathtech, Inc., Princeton, NJ "Commercialization Plan for the Implementation of Solar Industrial Process Heating" Draft Final Report, Volume I, Table 5-4, p. 5-7 - Technical Supplement. Prepared for the U.S. Department of Energy, March 1978.

Table 11. Temperature-Specific Implications of Incentive Options Analyzed by Mathtech

Temperature Range	Proc. Heat* Requirement In Year 2000 (Trill. BTU)	Solar Market Share in Year 2000 (%)						
		Cases **						
		1, Ref.	2	3	4	5	6	7
Low, <212°F	2713.49	1.7	24.9	24.7	9.8	20.4	21.5	21.3
Medium, 212-350°F	5152.82	2.3	24.1	23.7	10.1	20.0	21.0	20.6
High, 350-550°F	2203.32	0.8	15.7	15.0	5.2	12.8	13.8	12.8
All Temperatures	10079.14	1.8	22.5	22.1	9.0	18.5	19.5	19.1

*Less than 550°F

**See Table 7

SOURCE: Mathtech, Inc., Princeton, NJ "Commercialization Plan for the Implementation of Solar Industrial Process Heating" Draft Final Report, Volume I, Table 5-5, p. 5-7 - Technical Supplement. Prepared for the U.S. Department of Energy, March 1978.

Table 12. Mathtech's Assessment of Process Heat Energy Demand of the Top Twenty Industries for Application Temperatures Less Than 550°F

FUEL TYPE / YEAR	GAS		OIL		COAL		TOTAL	
	10^{15} Btu	% Industrial Sector	10^{15} Btu	% Industrial Sector	10^{15} Btu	% Industrial Sector	10^{15} Btu	% Industrial Sector
1976	2.01	74.6	0.74	44.6	0.34	26.6	3.09	55.0
1980	2.30	77.6	0.85	45.2	0.40	28.2	3.55	56.7
1985	2.72	81.6	1.02	45.9	0.51	30.2	4.25	58.8
1990	3.22	85.5	1.22	46.4	0.63	31.7	5.07	60.4
1995	3.81	89.8	1.46	47.1	0.80	33.2	6.07	62.2
2000	4.55	95.3	1.76	48.5	1.02	34.6	7.33	64.5

SOURCE: Mathtech, Inc., Princeton, NJ "Commercialization Plan for the Implementation of Solar Industrial Process Heating" Draft Final Report, Volume II, Table A-11, p. A-21 - Technical Supplement. Prepared for the U.S. Department of Energy, March 1978.

The four market studies of industrial and agricultural process heat concur that the target industry applications are those which require temperatures below 600°F. The conclusions were reached by secondary data collection, industry contact, and penetration models. The studies further identified regions of the country most conducive to solar energy processes and conventional fuels most feasible for displacement. The analyses were limited to six geographic solar regions. Also, while the studies discussed energy requirements, none of the analyses addressed the qualities of energy required by process on a geographic basis. These are areas that need to be analyzed to assist DOE in their penetration projections and assist manufacturers in developing systems for industrial use.

B. Solar Passive Market Studies

In the review of literature pertaining to market studies for passive systems, it was discovered that very little has been done to date. The most comprehensive study is the Commercialization Readiness Assessment, to be discussed below. A paper by J. D. Balcomb discusses a potential market; however, no analytical market techniques appear to have been used. Finally, Booz-Allen has recently conducted a market study for passive systems, but the report is not yet available.

The market and economic readiness results reported in "Commercialization Readiness Assessment for Passive Solar Heating" [8], are based upon a state-by-state feasibility analysis methodology previously developed by Los Alamos Scientific Laboratory in conjunction with the Resource Economics Group at the University of New Mexico. Lawrence Berkeley Laboratories and members of the commercial assessment team provided additional input.

The markets can be segmented according to the following criteria:

- Space conditioning function; i.e., heating, cooling, hot water. (At present, heating and hot water are more economical than cooling.)
- Geographic location. (The market is nationwide, with regions experiencing higher heating fuel costs providing greater competitive opportunity for passive solar heating.)
- Building type and use; i.e., new, retrofit, single-family residential, multifamily residential, commercial, low-temperature agricultural applications such as greenhouse operations, livestock shelters, and direct gain drying. (The residential and commercial segments are expected to be the largest markets available.)

The market penetration projections were determined in the study under two scenarios--with and without the National Energy Act. This is based on a new market of two million units per year for single-family and multifamily housing and average new commercial building space of 1.0×10^9 ft^2/year (see Table 13).

The incremental capital costs for passive design vary significantly according to generic design, sizing, and degree of finishing. The following are the ranges in current dollars--

TABLE 13
PASSIVE MARKET PENETRATION ESTIMATES OF
COMMERCIAL READINESS ASSESSMENT [8]
Without NEA

	1982	1985	1990	2000
New energy market (quads)	0.134	0.134	0.134	0.134
Energy penetration (quads in that year)	0.0004	0.0017	0.0057	0.0071
Percent of new energy market penetrated	0.3%	1.3%	4.3%	5.3%
Percent penetration of new units	0.8%	3.0%	8.9%	16.3%
Total retrofit energy market (quads)	9.12	9.52	9.94	10.5
Energy penetration (quads in that year)	0.0011	0.0042	0.0120	0.0196
Percent of penetration number of retrofit units of total stock	0.01%	0.04%	0.12%	0.19%
Cumulative energy displaced (quads)	0.003	0.016	*	0.35

Market Penetration With NEA

	1982	1985	1990	2000
New energy market (quads)	0.134	0.134	0.134	0.134
Energy penetration (quads in that year)	0.0035	0.008	0.012	0.014
Percent of new energy market penetrated	2.6%	6.0%	8.9%	10.4%
Percent penetration of new units	5.3%	11.5%	17.0%	19.4%
Total retrofit energy market (quads)	9.12	9.52	9.94	10.5
Energy penetration (quads in that year)	0.0052	0.0272	0.116	0.347
Percent penetration number of retrofit units of total stock	0.13%	0.41%	0.88%	0.62%
Cumulative energy displaced (quads)	0.012	0.054	0.192	0.56

*Misprint in original report.

- thermal storage wall: \$8 to \$18/ft^2
- direct gain: \$0 to \$11/ft^2
- attached sun space: \$5 to \$15/ft^2
- thermal storage roof: \$10 to \$25/ft^2
- convective loop: \$5 to \$8/ft^2.

The assessment concluded that major reductions in these costs are not expected.

The potential competing technologies are considered to be any alternatives which can be used for space conditioning. This includes oil, natural gas, fossil/nuclear electricity, heat pumps, insulation, active solar systems, and wind.

The initial cost for passive systems represents the major investment criterion discussed in the assessment. (Operating and maintenance costs are considered negligible.) With most systems custom-designed for private clients today, the cost is substantial. Other factors mentioned deal with the perceived risk on the part of consumer and lender, negative image, as well as a lack of credible information on performance and economic benefits.

The next document [9] surveyed does not report on a comprehensive market study, but is included because it does discuss a potential market for passive systems, that of manufactured housing. (Active systems were also considered in the study, but will not be addressed here.) The report deals primarily with the definition of this potential market for solar systems, discussing the advantages of this market, and sketching possible prototype designs. No first-order market research techniques are discussed in the article.

The market addressed is the manufactured housing market; i.e., a house that has been assembled in major modules or as a whole unit in a factory, transported over the highways to the desired location, and then put into final form on the site. This includes mobile homes, modular homes, prefabricated homes, paneled construction, etc. This market represents possible cost reductions over site-built solar systems through centralized buying, assembly-line construction, and lower wage cost for factory wages.

The size of the total new sales market in 1976 averaged about 250,000 units (seasonally adjusted). The study did not attempt to project the potential solar share of this market.

For competing technologies, the study considered conventional systems as well as other solar systems. While a passive system will probably not be competitive with natural gas until gas prices go up by a factor of three or four, it is exprected to be competitive now with electric or propane heating. Other solar systems—active water and air systems—were also discussed.

Although initial cost was the major criterion considered, the investment decision was expected to be made based on life-cycle costing. Other factors considered actually reflected the expected characteristics of the buyers.

Prospective buyers were described as looking for a longer term investment, able to pay a larger price, planning to live in the house longer, and concerned about future fuel costs.

In summary, very little research has been done for passive system markets. Work is needed to define the different markets, determine the current and future potential markets, and, from the potential markets, project the market penetration for passive systems.

C. Solar Thermal Electricity Market Studies

The market studies available for solar thermal electric power are of two different types, those analyzing the potential for solar thermal central power stations, and those examining repowering applications only. Two studies, both by Aerospace Corporation, represent the first study type, while the MITRE Corporation and the Public Service Company of New Mexico discussed the repowering market. The following discussion reviews these four studies, with emphasis on the issues previously mentioned.

This solar thermal electric power study by Aerospace Corporation [10] examined the potential for large central power stations in Southern California. Existing maps and surveys, combined with an exclusion process (discussed below), determined the area definitions and siting analysis. For the demand analysis, Aerospace contacted the Southern California power utilities and federal and state agencies for basic data, background material, technical reports, and insight into the demand forecast problem.

While utility applications represented the only market considered, this analysis delineated the study boundaries and estimated the useful land. Demographic, physiographic, geomorphic, and climatologic issues, as well as institutional characteristics and locations and boundaries of utility service districts, were all considered in determining the study area boundaries. The final study area selected covered that portion of California south of the northwest boundary of the Southern California Edison Company.

The exclusion process used to identify unsuitable locations started with a set of predetermined criteria. For this study, the criteria covered both technical and institutional considerations. The technical criteria were: relief or grade, soil type and condition, meteorological factors (e.g., snow line elevation), surface vegetation (e.g., crops, trees, bushes), and seismic activity--ground shaking.

The institutional considerations were: national and state parks and monuments, national forests and wilderness areas, military reservations and Indian reservations, urban areas, farming and other high-value lands, and public domain.

Each criterion, when applied to a map of the study area, determined unsuitable land based on measurable variables. For example, the meteorological factor excluded land above 5,000 feet. Upon combining the results of all these factors, the composite showed total potentially useful land.

Based on all the above criteria except seismic activity and public domain land, this exclusion process resulted in 15,000 square miles of suitable land out of a potential 67,000 square miles. Upon incorporating seismic design criterion, suitable land became 11,500 square miles for 0.42G plant shaking associated with an M8 earthquake and 5,000 square miles for 0.2G plant shaking associated with an M7 earthquake. However, because of the uncertainty associated with the ability to purchase some of this land (i.e., that which is in the public domain or in railroad land grant ownership status), the actual land available could be much less.

Another potentially important criterion that was not examined is that of water availability. Should water be required for cooling, the amount of suitable land would be severely reduced. This problem may require the use of dry cooling towers.

The potential market size over time appears in Table 14.

TABLE 14
POTENTIAL MARKET ESTIMATES OF
AEROSPACE SOLAR THERMAL MISSION ANALYSIS [10]

Year	Peak Electric Demand Trends (MW)	Electric Energy Consumption (kWhr)
1970 (Historical)	14,000	52×10^9
1980	28,000	116×10^9
1990	53,000	260×10^9
2000	90,000	530×10^9

No estimates were made for the projected market share for solar thermal electric plants.

An economic analysis compared, on a life-cycle basis, the relative costs of solar thermal electric power for baseload, intermediate, and peak capacity against plants using coal, nuclear, and a combined cycle. The results, in year 1990, are shown in Table 15.

TABLE 15
LIFE CYCLE COSTS OF SOLAR THERMAL PLANTS
ESTIMATED BY AEROSPACE [10]

	Baseload (mills/kWhr)	Intermediate (mills/kWhr)	Peaking (mills/kWhr)
Solar Thermal Plant			
Collector Cost $25/m^2	38	50	112
Collector Cost $15/m^2	29	39	84
Conventional Plant (Nuclear, Fossil, or Combined Cycle)	18-26	40-44	85-115

The primary investment criterion considered by Aerospace was life-cycle cost. As a secondary factor, the environmental aspects were mentioned. These could result in the need for costly additions to conventional systems, making solar thermal plants more competitive, or even eliminating conventional systems altogether as an alternative.

Aerospace continued work in the same area with a study [11] that applied a similar methodology to a larger region. Two study boundaries were selected, both very similar, again determined by map and literature surveys. The first set of boundaries coincided with state lines and natural, geological, and climatological divisions. The second set of boundaries, used to summarize the statistical attributes of this region, was based on the boundaries of the Federal Power Commission, power supply areas, individual utility service areas, state boundaries, and geological and climatological boundaries. The region contained the states of Arizona, California, Colorado, Nevada, New Mexico, Oklahoma, Texas, and Utah.

The approach taken to determine suitable land area was the exclusion method as previously discussed. The same technical and institutional issues were examined, with the addition of the issue of mineral resources. Using both least-stringent and most-stringent conditions for each criterion the potentially suitable land area ranged from 21,500 square miles for the most stringent conditions to 161,000 square miles for the least stringent conditions, out of a total land area of 1,031,000 square miles. Again, water resources and ability to purchase land were not considered. 21,500 square miles is equivalent to about 2,150,000 MW_e of intermediate load capacity. If the cooling water constraint was considered, this capacity would be reduced to only about 60,000 MW_e of generating capacity. The potential market over time appears in Table 16.

TABLE 16
POTENTIAL MARKET FOR SOLAR THERMAL ELECTRICITY IN THE SOUTHWEST [11]

Year	Peak Electric Demand Trends (MW)	Electric Energy Consumption (kWhr)
1980	79,600	467.7×10^9
1990	170,500	$1,024.9 \times 10^9$
2000	334,200	$2,023.0 \times 10^9$

The information in Table 17 shows the market projections for this region in the southwestern United States. The market penetration figures were based on the assumption of a 100 MW_e commercial demonstration plant by 1985, a 50% growth rate in construction until the year 2000, and a maximum growth rate of 7.8% per year after the year 2000.

TABLE 17
AEROSPACE MARKET PROJECTIONS OF
SOLAR THERMAL PLANTS IN THE SOUTHWEST [11]

Year	Market Penetration (MW)	Initial Capacity Displaced (%)	Barrels of Oil Displaced (millions/yr)	Land (sq mi)
1985	100	0.17	0.8	1
1990	700	0.85	5.6	7
1995	5,400	4.32	43.2	54
2000	40,000	21.83	320.0	400
2005	145,000	50.00	1160.0	1450

Numerous economic analyses were performed with different collector designs and various combinations of collector and storage sizes to meet different loads (i.e., baseload, intermediate, and peak). Based on this analysis, the primary preferred system was an intermediate central receiver power plant, modular (about 50 MW_e/module), 1 km^2 collector area per six-hour storage per 100 MW_e, and a 260-m tower. The cost objectives of $30/$m^2$ for heliostats and $15/$kW_e$hr for storage yielded a competitive busbar energy cost of 40 to 50 mills/kWhr (in 1991 dollars). The competing technologies considered in this study included nuclear, fossil, combined cycle, and gas turbine plants.

In addition to economics, these factors were listed as contributing to the potential market:

- projected growth in installed generation capacity,
- allocation of load by operational mode (base, intermediate, or peaking),
- manufacturing rate capabilities,
- construction lead times,
- siting constraints,
- environmental factors, and
- conventional fuel availability.

The second group of solar thermal electric studies deals specifically with the repowering market in the southwestern United States. The MITRE study [12] obtained information through a survey of the potential market. The study area encompassed Arizona, California, Colorado, Kansas, Nevada, New Mexico, Texas, Utah, and Wyoming.

Results of the survey showed there to be a capacity of over 76,000 MW_e of oil and gas-fired steam plants, and 197 sites with 624 boilers and turbogenerators, owned by 65 utilities. From this basis it was determined that sufficient land was available either on or near these sites to repower approximately 18,000 MW_e of capacity (11,000 MW_e was a lower bound and 25,000 MW_e an upper bound based on a 95% confidence level) and to displace 0.5 quad/year of conventional fuels. The criteria for this selection included a maximum of 15,000 feet of pipe run, reheat turbines, a minimum fossil plant size of 25 MW, and no lower limit on percentage of repowering when more than 150 acres (~25 MW_e of repowering capacity) are available. Anticipated expansion through 1985 is expected to substantially increase this potential market.

Market penetration was estimated under three scenarios:

1. A 20% investment tax credit for all solar technologies, a $3 billion demonstration program by 1985 for first generation plants, the earliest possible introduction date for each technology into the commercial marketplace (1981 for repowering);
2. A 30% investment tax credit, parallel demonstrations, and streamlined permit/license/EIS approval procedures for all solar technologies;
3. A program similar to the guidelines of the National Energy Plan (NEP) with a 20% investment tax credit and the planned demonstration program.

The MITRE/Metrek System for Projecting Utilization of Renewable Resources (SPURR) model was used to estimate the size of the solar thermal electric market for repowering. The results for the three scenarios they used are shown in Table 18.

TABLE 18
MARKET PENETRATION OF REPOWERING IN THE SOUTHWEST [12]

Year	Cumulative Capacity* (MW) Scenario 1	Scenario 2	Scenario 3
1985	1,850	2,000	0
1990	2,900	4,600	0
1995	4,400	9,600	0
2000	7,250	16,700	0
2005	19,250	19,250	0
2010	19,250	19,250	0
2015	19,250	19,250	0
2020	19,250	19,250	0

*Separate estimates for combined cycle, fuel saver, solar thermal electric (STE) with three-hour storage, and STE with six-hour storage, while included in the study, are omitted in this summary report.

In the SPURR model, the penetration of repowering plants is based on cost comparisons with a number of solar technologies (wood-burning steam plants, wind energy conversion systems, photovoltaics, and other solar thermal electric configurations) and conventional technologies (coal steam with flue-gas desulfurization plants and oil combined-cycle plants).

The cost estimates ranged from $1500/kw (early costs) to $900/kw (after about 10GW$_e$ of cumulative capacity have been built) for capital costs, and about $10/kw/yr of operation and maintenance costs for a mature system acquisition.

Other factors affecting the investment in repowering discussed in the MITRE report dealt mainly with the availability and potential problems of conventional fuels. Most of the potential market surveyed was gas-fired. However, if the National Energy Act passes, these facilities would need to convert to a fuel other than natural gas over the next ten years or be retired. The MITRE report also states that the current oil glut is expected to diminish. Coal-fired facilities (for baseload applications) would require substantial construction time and costs and have environmental problems as well. The study indicates that solar-repowered facilities could be a reasonable alternative--less construction time and comparable costs to coal--and existing facilities could continue to operate.

The second repowering study [13], done by the Public Service Company of New Mexico (PNM), looked at a region in the southwestern United States slightly different from that of the MITRE study. PNM surveyed southwestern utilities to identify potential candidate plants and/or units. A Westinghouse market information survey and the Federal Power Commission (now Federal Energy

Regulatory Commission) "Form 12" data augmented the study. The states considered were Arizona, California, Colorado, Louisiana, Nevada, New Mexico, Oklahoma, Texas, and Utah. The survey was directed toward potential repowering of oil or gas fired plants less than 200 MW_e in size. Of the 78 utilities surveyed, 60 responded, reporting on a total of 379 units. (The literature search revealed a total of 755 units in the area.) A general conclusion made from this survey was that most utilities in the southwest are very interested in solar power and, in particular, in solar hybrid repowering as a means to conserve dwindling fossil fuels. Based on the survey results, this study also included a description of the typical candidate repowering unit.

The potential market, based on the current status of the utilities, is shown in Table 19, for different criteria.

TABLE 19
POTENTIAL REPOWERING MARKET IDENTIFIED BY
PUBLIC SERVICE COMPANY OF NEW MEXICO [13]

Category	Number Units	Total MW_e
Potential market size (rated MW_e) based on literature survey	755	40,954
Solar repowering potential (effective MW_e)	263	19,273
-- based on land availability	263	10,699
-- and < 2,500 ft from plant	197	6,879
-- and > 50% repowering	72	4,799
-- and utility interest	72	4,799

These 263 potential candidate units represented about 35% of all units in the data base established by the literature survey. Their total capacity of 19,273 MW_e represented about 47% of the total rated generating capacity in the literature survey.

No market penetration figures were developed in the study.

A cost/benefit analysis is currently underway but not yet complete. Four utilities were selected for analysis: PNM, the EPRI Synthetic Utility System E (Texas, Louisiana, Oklahoma), the Arizona Public Service Company (APS), and the Nevada Power Company. The results to date are encouraging, with repowering especially attractive in cases where it displaces high cost fossil fuels (as in the Texas utility). Assuming DOE cost goals ($65/$m^2$ in 1977 dollars), the repowering cost/benefit ratio ranged from 1.37 to 1.50 for PNM, 1.21 or less for APS, and 1.02 or less for EPRI Synthetic Utility E. (The range depends upon method of startup. Limited analysis for the EPRI utility model assuming different insolation data also affected the results.) In comparing these results with stand-alone solar thermal plants, the repowering alternative is more cost effective. The competing technologies considered are coal and nuclear. The study contained no discussion on investment criteria relevant to the market other than costs.

As seen in the above discussion, all the solar thermal electric studies addressed the utility grid-connected market in some region of the southwestern United States. The two studies for the solar thermal electric central power stations used an exclusion principle to determine available land, while the two repowering studies employed a survey of existing utility plants to determine repowering potential. Market penetration methods ranged from no method (that is, no penetration estimates were made), to a fixed percentage annual penetration, to a simulation based on cost comparisons (i.e., SPURR).

The summary points made in the previous paragraph indicate possible future directions for new market studies. The market for nonutility applications has not yet been examined. (MITRE is currently investigating repowering applications in the petrochemical industry.) In comparing the estimates for repowering potential, a substantial difference is seen (MITRE estimates 18,000 MW_e of capacity while PNM estimates under 11,000 MW_e). The potential capacity must be well established before penetration estimates can be made. Finally, penetration models could be developed which incorporate other important investment criteria, as well as cost.

D. Photovoltaic Market Studies

A large number of markets have been identified which may be served by photovoltaic technologies. One of the main reasons for the widespread applicability is that the photovoltaic cell can produce electricity without moving parts or intermediate thermal processes. The markets for photovoltaics are usually divided into three general categories: current markets, intermediate markets, and grid markets. Current markets are those in which photovoltaics are used today and could be used more extensively in the future. Intermediate markets are defined as new applications that may use photovoltaics as the price of the arrays decrease through the range of \$10 to \$2 per peak watt of output (W_p). Grid markets are those currently connected to the utility network. These markets will probably not be penetrated by photovoltaics until array prices decrease to the range of \$0.50 to \$0.20/W_p.

There have been three major studies completed on current and intermediate markets for photovoltaics. The first of these is "Photovoltaic Power Systems Market Identification," by BDM Corporation [14]. The BDM study is the most comprehensive photovoltaic market study that is publicly available. It investigated the United States and world market potential of photovoltaics for approximately 167 different applications. These applications ranged across all types of energy use areas, and the data used in the analysis came from a wide variety of sources.

Data on market size and growth rates were obtained from U.S. government statistics (e.g., Bureau of Census data), trade association data, and survey estimates from manufacturers and users. Information about competing energy system costs in each market were obtained from user data, manufacturers' interviews, and government statistics. The energy demand of a typical application in each market was assembled from interviewing users and manufacturers.

The method for estimating sales in each market in the BDM analysis began by estimating the size of the photovoltaic array. The price at which the photovoltaic system would compete with the conventional power source in each market was then calculated. This price (termed the breakeven price) was calculated using the costing approach that is typical of users in that market (e.g., first cost, life-cycle costing, payback, etc.). Sales of photovoltaics per year in each market is then calculated by estimating the date at which the photovoltaic systems would begin to penetrate the market and then estimating the rate of takeover in that market. The formulation is similar to the Fisher-Pry model of technological substitution.*

One of the major tasks of the BDM study was to identify potential markets for photovoltaics. This was done by brainstorming sessions, discussions with experts, and reviews of energy literature. Over 1,000 applications were identified. These were then reduced to 227 nonredundant categories. The size of these markets and the breakeven price for photovoltaics were estimated and used to rank these applications. The ranking resulted in the selection of 30 applications for detailed investigation. These 30 applications included many types of marking and warning devices, corrosion protection equipment, monitoring and sensing devices, communication equipment, consumer applications, and general power systems.

Another study of the current and intermediate photovoltaic market was "Photovoltaic Energy Technology Market Analysis," by Intertechnology/Solar Corporation [15]. The ITC study was designed to be parallel to the work of BDM and cover the same market sectors. ITC employed brainstorming sessions to generate an extensive list of potential new applications. These were than distilled down to a list of 100 applications most likely to produce substantial markets as array prices drop to $\$0.50/W_p$. The total U.S. potential market was estimated for each of the 100 applications by developing scenarios for typical target markets from statistical sources. Each scenario specified the number of units likely to be installed in 1985 and the power requirements of each unit. Market penetration percentages for photovoltaics were then estimated by ITC to yield sales forecasts.

World markets for these same 100 applications were estimated by ITC under the assumption that all countries consume energy at the same rate as the United States and that the product mix for the rest of the world is the same as in the United States. A calculation to determine the size of the world market for these applications was made by generalizing U.S. sales forecasts to the rest of the world, using a crude approximation technique. Similar to the world estimates for current markets, this approach is highly speculative.

The third major study of current and intermediate markets was the "Mission Analysis of Photovoltaic Solar Energy Conversion, Volume II, Survey of Near-Term (1962-1985) Civilian Applications in the United States," prepared by

*Fisher, J.C. and R.H. Pry, "A Simple Substitution Model of Technological Change," Technological Forecasting and Social Change, 3, p. 75, 1971.

Aerospace Corporation [16]. The Aerospace market study focused on U.S. markets only. In particular, the study contained forecasts of current and new U.S. commercial sales and U.S. government sales for nonmilitary uses. The Aerospace study was completed before the BDM or ITC study and used data available in 1976.

The photovoltaic markets delineated by Aerospace were similar to those delineated by BDM and ITC. Many of the markets identified in the three studies were identical. However, often the three studies defined markets to different levels of detail. For example, the market defined as "environmental" by Aerospace was divided into three markets by BDM (i.e., precipitation gages, remote weather stations, and weather monitoring). The ITC study did not identify any markets in this area.

After the markets were delineated, the Aerospace study predicted sales in each market. However, they did not use a substitution model as in the BDM study. Their forecasts were derived from interviews with users of remote powered equipment who might use photovoltaics in the future.

The Aerospace Corporation also published a review and comparison of the three studies mentioned above and studies of grid markets by Westinghouse and General Electric. The comparison was entitled "Overview of Photovoltaic Market Studies" [17]. The study compared market delineations, methods, and sales forecasts. The study was not designed to generate any new market information.

The most recent investigation of near-term photovoltaic markets was completed as part of the "Photovoltaic Venture Analysis," by D. Costello, D. Posner, D. Schiffel, J. Doane, C. Bishop, Solar Energy Research Institute [18]. The analysis of photovoltaic markets in this study began with a comparison of the BDM, Aerospace, and ITC studies. The information from these studies was first arranged in a common format and then reviewed by experts in those markets during a photovoltaic demand workshop.

The workshop included representatives of communications, cathodic protection, agriculture, and grid markets. Attendees were asked to review the market size estimates, breakeven costs, competing power source designs and costs, and possible rates of photovoltaic penetration. The communication and cathodic protection groups derived new quantitative estimates for those variables. The results of the agricultural and grid market workshops were much more qualitative, addressing general issues rather than numerical estimates of market sizes.

A few other near-term and intermediate market studies are also publicly available. These are more limited than the previously mentioned studies, dealing with only one or two markets. For example, BDM Corporation completed a study of possible U.S. Department of Defense markets for photovoltaics ("DOD Photovoltaic Energy Conversion Systems, Market Inventory and Analysis" [19]. In this study BDM attempted to identify mobile and stationary military applications for photovoltaics. These applications were characterized by potential market size and breakeven costs.

Other studies dealing with only a limited number of markets include:

- "The Economics of Adopting Solar Photovoltaic Energy Systems in Irrigation," Massachusetts Institute of Technology/Lincoln Laboratory Report #COO/4094-2 for Energy Research and Development Administration, July 1977.
- "Analysis of Photovoltaic Total Energy Systems for Single Family Residential Applications," by V. Chobotov and B. Siegel, Aerospace Corporation, prepared for U.S. Department of Energy, August 1978.
- "Conceptual Design and Systems Analysis of Photovoltaic Systems," by General Electric Corporation, prepared for Energy Research and Development Administration, March 1977.
- "Conceptual Design and Systems Analysis of Photovoltaic Systems," by Westinghouse Electric Corporation, prepared for Energy Research and Development Administration, April 1977.
- "Long Term Demand Estimation," by MIT Energy Laboratory, subcontract to Solar Energy Research Institute, contained in the "Photovoltaic Venture Analysis," Appendix I, July 1978 [18].

The last four studies cited deal with grid connected markets. The size of markets for utility electricity are quite well known and the grid-related studies focus on the cost necessary for photovoltaics to compete in the grid market and how many units will be sold. The grid market in these studies is usually divided into three categories--residential, commercial/industrial, and central power stations.

In summary, there have been a number of market studies completed in photovoltaics. These studies vary significantly in treatment of markets and in their predictions of breakeven prices and yearly sales. The methods used in the studies involve either substitution models or estimates from experts. Very few quantitative market analysis techniques have been used in the studies. A limited number of user surveys have been conducted. However, none of these have been done in sufficient depth to adequately deal with the uncertainties of these markets. It can be concluded that the present knowledge about photovoltaic markets indicates that there are a large number of potential applications of the technology. However, there is uncertainty concerning how large those markets will be and what price they must achieve in order to penetrate those markets.

E. Market Studies in Wind Energy Systems

Primary emphasis to date in the wind systems area has been on system design and technology. One market study has been performed identifying the potential of wind energy conversion systems in remote applications. The study, "A Market Analysis of the Potential for Wind Systems Use in Remote and Isolated Area Applications," by Energy Resources Company, Inc., is in review at DOE and the information provided was from a telephone conversation with the contractor.*

The objective of the Energy Resources Study was to define, study, and estimate the size of markets for small and large wind systems in remote and isolated areas of the United States and Canada, their contiguous islands, and the West Indies. In addition, the project was to provide private industry with a collection of facts to serve as a basis for determining the market potential for commercial wind systems in these areas and provide strategies for developing these markets.

Most of the data for the study was obtained from industry representatives and users. Agencies providing data include: Department of Agriculture, Farm Extension Service, Federal Energy Administration, Department of Defense, Rural Electric Coops, and telecommunications agencies. Energy Resources also conducted a small survey (approximately 50 questions) of potential agriculture and residential users to determine investment decision-making criteria other than breakeven cost. The sample involved approximately 20 potential agricultural users in the northern-midwest United States and approximately 18 potential residential users in northern New England. The results were not representative of the whole market.

The primary markets for large systems were identified as nonconnected utilities, offshore gas production, and telecommunications. The primary market characteristics defining each application were location and energy requirements. Through conversations with industry and users, Energy Resources expanded their original number of markets and grouped them into 15 sectors (see Table 20). A summary matrix for the 15 sectors by energy requirement revealed approximately 250 potential sites. This information was translated into number of wind units of a particular size required by sector. (These tables were not available at the time of writing of this review.)

Wind systems in remote applications will be competing with gasoline generators, diesel generators, and gas turbine generators. Three scenarios were developed based on fuel costs delivered by tanker truck, tanker ship, and air. These costs were compared with wind systems' dollars/kWhr costs to determine a breakeven point.

Investment decision-making criteria from results of the attitude survey were also not available at the time of this writing. Besides the breakeven cost analysis Energy Resources did run sensitivity analyses using interest rates for the public and private sectors.

The limited market research in wind systems was conducted using industry contacts, nonrepresentative survey data, and sensitivity analysis. The market analysis did identify a potential market in remote areas to displace expensive fuel oils.

*Ron Beck, Energy Resources Company Inc., Personal Communication to C. A. Fellhauer, Solar Energy Research Institute, 18 September, 1978.

TABLE 20
APPLICATIONS FOR WIND ENERGY CONVERSION SYSTEMS

Private consumer: primary dwelling, secondary dwelling
Commercial Consumer
Farm: crops, livestock
Fish farm
Fertilizer/chemical plant
Offshore oil and gas production/distribution
Telecommunications
Railroad
Parks/campgrounds
Outdoor advertising
Monitoring (NOAA, EPA)
Logging
Mining
Utilities
Institutions: military, police, parks, etc.

F. Market Studies in Ocean Thermal Energy Conversion Systems (OTEC)

There has only been one major study that identifies potential markets for OTEC and investment decision criteria of the markets [20]. A University of Southern California (USC) study team focused on the identification of legal, jurisdictional, environmental, institutional, and other nontechnological barriers to the development of solar energy technologies in general, and OTEC in particular. Strategies designed to diminish these barriers were recommended. Of particular interest for this review was the first portion of the report, which provided the background for development of incentives for accelerated innovation of OTEC. Included in this first portion were the energy technology selection decision-making criteria of the industrial organizations most likely to use OTEC, and the relative economic competitiveness of OTEC versus coal and nuclear technologies. Information on decision-making criteria came from an analysis of existing literature, reviews of current industrial plans, and a survey of 55 of the public and private utilities in the United States.

A comparison of OTEC costs to coal and nuclear energy was accomplished via the ERDA/EPRI Power Plant Economic Model. OTEC cost inputs to the model were supplied by Lockheed Missile and Space Corporation, Ocean Systems Division. California Energy Resources Conservation and Development Commission and Southern California Edison Company supplied coal and nuclear plant cost data.

The potential markets identified in the study were public utilities in the southeast United States and Hawaii, ammonia and aluminum industries in the United States, and thermal gradient belt countries, defined as lying $\pm 15°$ of the equator. Utilities were defined by the nature and type of technological innovation undertaken by generating capacity by location. The potential size of the utility market included all baseload generating capacity for the southeast United States and Hawaii. The potential market for ammonia production at sea focused on consumption of ammonia for use by the nitrogenous fertilizer industry. Currently the nitrogenous fertilizer industry consumes 4% of U.S. demand for natural gas. The aluminum industry consumes 4% of total U.S. electrical demand. There are about 40 countries that lie in the thermal gradient belt, with the most promising OTEC candidates being Puerto Rico, Singapore, and Brazil; next most promising are Mexico, India, Philippines, Indonesia, Australia, and Malaysia.

Competing fuels/technologies considered for electrical generation by utilities were coal and nuclear energy. The competing fuel for ammonia in the nitrogenous fertilizer industry was natural gas. Power generation for aluminum production is currently supplied in the low cost hydropower regions of the northwest and southeast United States.

Using a straight levelized busbar cost technique, and assuming maximum annual fuel costs, the study found that OTEC will become competitive with new coal units in 1987 and new nuclear units in 1988. However, the utilities market has its own decision-making criteria regarding capital investment and energy supply and demand. The following criteria, ranked in decreasing order of importance, were developed from the survey:

- capital costs of new capacity (investment),
- long-term availability of fuel,
- operating costs estimates,
- cost of capital (interest rates),
- environmental assessment/impact,
- reserve and reliability criteria,
- capacity forecast,
- construction and licensing time,
- site costs,
- transmission cost estimates,
- candidate site selection.

The following factors were identified by USC as representative of the nitrogenous fertilizer industry's key decision-making criteria regarding OTEC produced ammonia:

- the availability and price of the natural gas supply (or alternative feedstock, such as the air and water used for electrolytic production);
- the supply/demand forecast of nitrogenous fertilizers within the United States and abroad;

- the degree of stabilization of fertilizer prices at a level conducive to providing a positive food-to-fertilizer price ratio for high application rates;
- the location and storage facilities of developing markets;
- new developments in fertilizer products (e.g., complex compounds for temperate zones);
- plant capacity factor averages; and
- the development of substitutes for fertilizers.

The aluminum industry's decision-making criteria center mainly on the issues of resource and commodity supply and demand. The following were identified as the industry's primary decision-making criteria:

- a guaranteed access to the foreign source of bauxite at a cost related to the price of aluminum ingots, or some other relevant commodity;
- the availability of abundant and inexpensive electrical power;
- the ability to raise sufficient capital, although the industry characteristically has a high debt-to-equity ratio;
- supply and demand of aluminum, and particularly plant capacity factors, supply stockpile, and aluminum price relief; and
- the location of the markets to be served.

As for the last potential market, the aspect of the foreign owner/operator in thermal gradient countries poses a host of complex decision-making criteria. The first involves the geopolitical evaluation of a host government and the economic relationship a U.S. corporation has with the foreign operation. The second stage of decision-making analysis considers the general state of the international energy market. Two prime factors are the current energy posture of the candidate countries and the size and status of their national power grid. The third and final stage of analysis of decision-making criteria involves a preliminary selection of the countries "most likely" to use OTEC.

On the basis of a single OTEC study three markets were identified for the alternate energy technology. The analysis was based on industry contacts and a utility survey. The research concluded that OTEC could become competitive with coal and nuclear energy if initial capital investment for the OTEC plants could be reduced.

G. Useful Elements of Other Studies

In addition to the market studies of the six solar technologies described above, other solar market studies of interest have been completed. The three studies discussed below are of interest because of the techniques used. As stated in the introduction, a comprehensive review of the solar heating and cooling (SHAC) market studies is not included in this report because SHAC will not be the subject of a SERI market study in FY79.

not in intro

The work by Jerome Scott [21, 22] provides some very relevant contributions to the area of market studies. Although his work deals mainly with the residential heating and cooling market, there could be applications to other solar markets. His work could be described as a combination of controlled experiment, in-depth sample survey, and further quantitative analysis. In it he relies upon two analytical approaches: (1) demand curve estimation--a regression technique used to build up a more complete demand curve (describing probability of solar purchase versus certain key demand factors); and (2) conjoint analysis--to aid in the quantification of trade-offs between demand variables (e.g., fuel savings versus first cost of system). A more detailed description of these and other techniques is described in Section III.

Scott also injects an element of controlled experiment into the study by, among other things, providing educational materials to sample subjects several days before they are interviewed. This was part of an attempt to simulate the conditions of a real marketplace in which prospective buyers would presumably investigate aspects of such a purchase before coming to a final decision. Scott's market research design will be studied further to ascertain what elements should be applied to other market studies.

Also relevant (again having been applied only to the SHACOB residential market) is the Real Estate Research Corporation study [23] done for the Department of Housing and Urban Development (HUD). In connection with the HUD residential solar demonstration program, sets of in-depth interviews were conducted with each different category of actor (stakeholder) and institution in the housing industry potentially involved with the market acceptance for solar units--builder, purchaser, construction lender, permanent lender, utility, assessor, and planning/zoning/building officials. In addition, field visits were undertaken to gather detailed data on the solar houses, their subdivisions, and their competitors. Although the voluminous information gathered is presented in straightforward tabulation, the specific questions addressed as well as the impacts investigated should be of help in framing the dimensions of a future study.

III. REVIEW OF AVAILABLE MARKET RESEARCH TECHNIQUES

One of the primary long-term objectives of the market studies is to develop an understanding for the key variables that are considered by prospective consumers in making the decision to invest in a particular solar technology. Along with determining what these variables are (in addition to the obvious one, cost), it is important to understand their relative impact and perhaps be able to quantify the tradeoffs among the variables.

In connection with this last aspect, a significant variable--cost (be it front-end purchase price or investment, operating costs, life-cycle costs or some combination of these costs)--may in some cases so overwhelm the other factors as to make further analysis (of tradeoffs, etc.) seem unnecessary. However, even when cost is the dominant decision variable, it may be very useful to understand the key tradeoffs between, for example, cost and some risk measure.

How can the data necessary for understanding investment criteria and their relative importance be gathered? A first step is to review the literature of existing studies; the preliminary results of this review were presented in the preceding section. From that starting point, first-hand data should be gathered for purposes of analysis. There are several ways and combinations of ways in which this can be accomplished but the approaches to be taken have not as yet been determined. Data may be gathered via survey, controlled experiment, workshop or group discussion, or consensus of suppliers/sellers or potential users/consumers. Each one of these approaches can take on many forms. (To efficiently accomplish some of this data collection, experienced market research subcontracting firms will assist.) One of the initial steps will be to contact the potential suppliers of each technology being investigated in order to help define some of the further dimensions of the study.

The study plan must specifically define what questions are to be answered, what data are required, and what approaches will be used. An analysis of the relevant data should provide insight into the investment decision. With that in mind, this section reviews the market research literature in order to unearth techniques/approaches/methodologies that would appear to be of some help in analyzing data in the present context. This review provides a flavor for what could be accomplished; however, the caveat must be given to avoid the trap of adapting the problem to a solution technique. It would surely be premature (as well as difficult) to decide upon techniques or approaches before knowing exactly what kind of data will be available. A review of the literature can provide a good sample of what researchers have done under similar conditions in the past.

The kind of problem addressed here is often referred to as the multiattribute decision--a choice among alternatives, each varying in degree across more than one attribute or dimension relevant to the decision. Most of the quantitative methods used to analyze data collected to investigate such problems come under the umbrella of multivariate analysis. Also, most of these techniques have been available for a long time but have only more recently been applied in a marketing context. (According to Green and Wind, conjoint analysis, one of the techniques to be discussed, was not placed in a marketing context until

1971 [24].) In any case, multivariate analysis is being used "as a way (a) to measure more accurately consumer perceptions and performance, and (b) to reduce the risks associated with new product development" [25]. Furthermore,

> "equally important are the tradeoffs consumers . . . make in typical multichoice sitations . . . . Most of the decisions we, as consumers . . ., make are multidimensional and MVA's (multivariate analysis) recent refinements enable us to analyze these tough-to-quantify tradeoffs. It is because MVA can sort through the objective as well as subjective aspects of the consumer selection process that its applicability is especially appealing. . . ." [25]

A number of techniques/approaches appear to have some relevance to market related problems in solar energy. The approaches can be roughly broken down into two categories of use--prediction and description (although some of the "prediction" techniques certainly include elements of an explanatory or descriptive nature as well). The "prediction" methods include: multiple regression, conjoint analysis, discriminant analysis, automatic interaction detection, and canonical analysis. The "description" techniques to be described are factor analysis, cluster analysis, and multidimensional scaling (sometimes referred to as perceptual mapping).

Multiple regression: This is probably the most popular and well-known multivariate technique. With this technique, it is hypothesized that a variable of interest--sales, for example--can be explained by the variations of one or more explanatory variables--such as level of sales promotion, level of purchaser income, reliability of product, etc. An analyst chooses potential explanatory variables and a candidate functional form for the mathematical relationship. Regression is used to estimate the parameters of the functional relationship in a way that maximizes the explanation of the variations of the variable of interest. In other words, it is the fitting of a trend line (or trend surface for more than two explanatory variables) to the historic data in order to describe each variable's contribution to variations in the variable to be explained.

Some of the work by Jerome Scott [22] made use of multiple regression in attempting to derive a statistical relationship that could predict the probability of purchase of a solar hot water heater based on the underlying variables of first cost, fuel savings, method of financing, and the existence of a tax credit. The data were gathered by surveying prospective purchasers as to their intention to buy. Four hypothesized forms for the functional relationship were considered: linear, linear with interaction, mixed inverse, and mixed inverse with interaction. The last three forms were investigated "because non-linearities and interactions with initial cost were anticipated" [22].

Conjoint analysis: ". . . starts with the consumer's overall or global judgments about a set of complex alternatives. It then performs the . . . job of decomposing (the) original evaluation into separate or compatible utility scales by which the original global judgments (or others involving new combinations of attributes) can be reconstituted" [24]. Since the resultant utility scales are separate but compatible, one strong result of the conjoint analysis is some basis for explanation of the underlying tradeoffs that exist between decision variables.

Jerome Scott also made use of conjoint analysis in his work on market acceptance of solar hot water heating. He wished to estimate the utility for each level of each decision variable--first cost, fuel savings, financing method, and existence of tax credit--as it related to the decision to buy. To this end, subjects in the study were presented with 32 different possible solar water heaters (made up from the combination of four levels of first cost, and two levels each for fuel savings, financing method, and existence of tax credits) and asked to rank them in order of preference (i.e., global judgments of utility). A computerized algorithm was then used to break down this ranking into its component parts; i.e., separate and compatible utility scales for each decision variable. The algorithm used the ranking and the decision variable tradeoffs implicit within it to derive the individual utility scales which then provided an explicit basis for explaining the tradeoffs. Scott used the information to investigate how much impact fuel savings or a tax credit has on reducing first cost resistance, for example.

As usual, the assumptions underlying an approach must be considered carefully. Scott used an additive model which assumes that a consumers's "total utility for a multicomponent alternative is represented by the sum of the alternative's component utilities" [26]. Some situations may not be well represented by this simple additive model. While more complex (polynomial) models can be used, the complexity requires many more calculations. In addition, some products or services may just not lend themselves to even a complex decomposition approach.

Discriminant analysis involves the development of a functional relationship--an equation--that can discriminate between persons or objects so as to classify them into one of two or more categories. The common example given is that of the bank that wishes to classify an individual as either a good or bad credit risk based on his income, occupation, home ownership, education, and so on. In our marketing scenario, we might want to classify prospective solar purchasers as early triers, late triers, or nontriers. "The challenge is to find discriminating variables that could be combined in a predictive equation and help produce better than chance assignment of the entities to the groups" [27]. Here the variable of interest is one of classification. Although there is an analogy between multiple regression and discriminant analysis, the latter is used to try to predict a qualitative variable based on quantitative inputs.

Automatic interaction detection and canonical analysis are additional techniques that are classified under the umbrella of "prediction" methods. The SERI project team is still investigating these two areas to better judge if they can be of some use to the upcoming solar market studies.

Factor analysis refers to a set of techniques that are used "to discover a few basic factors that may underlie and explain the intercorrelations among a larger number of variables. The technique assumes that the intercorrelations occur because a few basic factors are shared in common by the different variables in different degrees" [27]. The variables to be investigated are not divided into the two groups--explanatory variables (independent) and variable to be explained (dependent). Rather, all the variables are examined together in order to derive any interrelationships that might exist. The main results of a factor analysis are a new set of derived independent variables (called factors) that describe much of the underlying structure of the original set of variables. One particular version of factor analysis, principal components analysis, derives a set of factors (now called components) that are linear combinations of the original variables.

Thus, if we had a group of subjects rate a set of products by preference or utility, we might very well be interested in determining what were the key factors (like first cost, fuel savings, reliability, etc.) underlying these ratings. Actually, the initial output of a factor analysis is a set of factor loadings which relate each of the original variables to each derived factor by a statistic resembling a correlation coefficient. Then, on the basis of this statistical output and knowledge of the original problem, the analyst must venture some creative guesses (hypotheses) as to what these factors actually are. There is also a geometric interpretation of principal components analysis that depicts the derived components as dimensions of a geometric space. In this way, one can get a visual idea of the relationship of each original variable to the principal components.

Cluster analysis, like factor analysis, is concerned with relationships among variables as a group (without segregating them into dependent and independent classes). "The usual objective of cluster analysis is to separate objects into groups such that each object is more like other objects in its group than it is to objects outside the group" [28]. It is a classification technique that seeks similarities between objects. It often has a geometric interpretation which can be an additional aid for insight.

Multidimensional scaling continues and expands upon the aspect briefly mentioned in factor analysis and cluster analysis above; i.e., the geometric representation of perceptions and preferences. It is sometimes referred to as perceptual mapping, the mapping being onto a multidimensional space in which distances or vectors represent the variables of interest. The nature of the dimensions or axes identified, as in factor analysis, is one of the outputs of prime interest. Yet, it is not always obvious what the dimension represents; it is still up to the skilled analyst to infer possible interpretations. With this in mind, multidimensional scaling can possibly aid in determining the key dimensions of product comparison used by consumers.

IV. PRELIMINARY PLAN FOR MARKET STUDIES FOR FY79

A. Overview

By undertaking an organized study of the underlying markets for selected solar technologies, we intend to:

- define the need for such studies from both a society and solar industry point of view;
- segment and define the various markets for each selected technology;
- construct a generally accepted methodology or approach to solar market studies that can be utilized as a plan for such studies undertaken in the future;
- coordinate ongoing market studies by other organizations to assure cross-fertilization of efforts; and
- determine the parameters (cost being just one candidate) that define and drive the demand for solar products in each market.

B. Approach

First, the project will determine the need for such studies and the potential impact they could have on government policymaking and the solar supply industry. To aid in this determination, representatives from the appropriate industries and relevant levels in government will be contacted to elicit their views on this need.

As previously mentioned, a review of the literature is also being undertaken (1) to explore the breadth and depth of existing market studies of solar technologies, and (2) to investigate the range of quantitative techniques/approaches/methodologies from the marketing/market research field that could be of use in any future analysis of data. Much of the review is documented herein.

? by whom

The range of markets to be investigated will then have to be defined. In other words, for each solar technology under consideration, what is a preliminary definition of the market to be studied? These market definitions and the relative importance of demand factors ascribed to each market would be expected to be different across technologies. There are several such dimensions that need to be defined. Some of these include:

- Initial areas of solar technology to be explored, most of which are partially related to market research plans contained in proposed tasks of other branches--industrial process heat, passive technologies, and solar thermal electricity. In some cases, other branches have made provisions for funds to be applied to marketing oriented studies. The work in this task will be used to augment those efforts.
- Demographics and other characteristics of each market. In the case of industrial applications, such characteristics could include measurements of industry size, margins, years of operation, product

mix, energy consumption characteristics, and competitive power systems for that application.

- Demand factors--variables that potentially explain the demand in each market and may vary from market to market. Potentially explanatory variables (not all of which are relevant to all technologies) include: initial cost, operating costs, life-cycle costs, maintenance, system performance, efficiency, reliability, energy savings, resale value, availability of financing, warranty availability and extent of coverage, aesthetics, and environmental/conservation concerns. Ideally, these demand factors should be prioritized for each demand sector in order to indicate the measure of importance of each variable relative to each other. This would be important, for example, for analyzing trade-offs involved. Analytical techniques such as conjoint analysis might aid in investigating these trade-offs.

There will be a need to gather the information relating to all these dimensions. Market research organizations may be utilized to assist in gathering much of the information via surveys, workshops, etc., involving samples of the relevant markets. The Economics and Market Analysis Branch of SERI will work closely with subcontractors to ensure that the market research design is appropriate to the objectives and scope of the study.

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