SOLAR HEATING AND COOLING
OF BUILDINGS - PHASE I
(NON-RESIDENTIAL)

INTERTECHNOLOGY/SOLAR CORPORATION
COST/BENEFIT ANALYSIS REPORT
AND SUPPORTING OPINION SURVEY
COMMERCIAL BUILDINGS
NATIONAL SOLAR DEMONSTRATION PROGRAM
EXECUTIVE SUMMARY

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PREFACE

The InterTechnology/Solar Corporation (ITC/S) was one of two companies which received awards to conduct studies and analyses for the Energy Research and Development Administration (ERDA) in support of the National Solar Heating and Cooling Demonstration Program. The report, "InterTechnology Incorporated, Cost/Benefit Analysis Report and Supporting Opinion Survey, Commercial Buildings, National Solar Demonstration Program," has been prepared as part of the requirements under contract E(11-1)2688. It is not intended to reflect an ERDA plan or position but may be used by ERDA in the development of their plans for implementing the Solar Heating and Cooling Demonstration Program.

I. INTRODUCTION

The National Solar Heating and Cooling Act of 1974 has provided the basic authority and guidance for creating a national solar heating and cooling demonstration program. The detailed planning necessary to ensure the efficient use of government funds allocated by this act has been left to ERDA and the private contractors involved. The question, long debated and argued by qualified and informed representatives of Congress, ERDA, and private industry, concerning the number of demonstrations required to meet the overall goals of the program is the subject of special report, C00-2688-1 prepared for the Energy Research and Development Administration and summarized herein. The specific task, as defined by ERDA, was to perform a parametric study to provide an estimate of the number of non-residential solar demonstration projects that will be required to start a commercial industry in solar equipment manufacturing, marketing, financing, and installation.

II. SUMMARY

An opinion survey was conducted among several experts in the field of solar energy to provide a preliminary estimate of the number of demonstrations that would be needed to stimulate the industry. The results of the opinion survey are shown in Table 1.

TABLE 1
THE OPINION OF SOLAR EXPERTS

<u>Expert</u>	<u>Field</u>	<u>Number</u>	<u>Reasoning</u>
John I. Yellott	Solar Engineering	84	Number of People
John F. Wagner	Statistics	200-400	One Per Application
J. Edward Taylor	Solar Manufact- uring	50-100	One Per Market Infrastructure
William Graff	Architect	240	One Per Million People
Anthony W. Adler	Solar Investor	120-156	One Per Structure, Climate

A techno-economic computer simulation of the solar industry was constructed to provide a more objective estimate of the number of demonstrations. This simulation predicts the response of the market place to the ERDA program. The simulation included models of the cost to design, produce and install the solar heating and cooling systems; of the market penetration as a function of the potential savings in fuel costs; of the risk-aversion character of the market place; and of the technical performance of the solar systems, including the weather, climate, heating and cooling loads and collector characteristics*. The ERDA program was not defined on the basis of a specified number of demonstration units, since fixing the number requires that, for the program to be optimally effective, ERDA must have intimate foreknowledge of the action of the marketplace. Instead, the ERDA program was hypothesized to be such that ERDA would offer, through its Program Opportunity Notice (PON), to pay a certain percentage of the solar system cost. Respondents to the PON would be required to demonstrate that their particular project was cost-effective in terms of the fuel savings as compared to their share of the solar system cost.

The computer model showed that, for the demonstration program to act as a significant stimulant to the solar industry, ERDA should offer to pay 75% of the initial cost of the system plus 90% of the maintenance and insurance costs over the next 20 years. This combination of payments amounts to ERDA's paying approximately 150% of the initial cost of the system.

The predicted response of the market place to the ERDA offer of 75%/90% is that 667 demonstration units would be built in all regions of the country, except the region around Seattle, Washington*. The ERDA stimulus is predicted to be effective in establishing a commercial solar industry in all regions of the country except Miami, Omaha, Nashville and Seattle. Other programs, such as the Housing and Urban Development (HUD) program on

*See Figure 1 for definition of solar/climatic regions.

residential solar heating and cooling, could stimulate the markets in these four regions; however, the combination of low insolation, low energy costs and high heat-pump effectiveness indicates that none of these four regions would ever become cost-effective for solar energy.

A schedule of the demonstration units that would be built under the 75%/90% ERDA offer is shown on Table 2. Notice that the four "unattractive" regions are indicated as having demonstration units. The demonstration units will, indeed, be cost-effective; however, those solar units that might be built under totally commercial sponsorship would not be cost-effective. The apparent waste involved in building units in the four unattractive regions is the price one pays for a program geared to the market response. It is a small price to pay in comparison to the losses that might be experienced if demonstration units were forced into undesirable applications just to fill a quota.

The techno-economic model indicates that, at the same time when the commercial market commences, the prices of solar heating and cooling systems will be from \$10 to \$12 per square foot of collector, depending upon the climatic region. These prices should be the target of the ERDA research and development program in solar heating and cooling systems.

III. DISCUSSION

A. Introduction

The Solar Heating and Cooling Demonstration Act calls for the construction of a sufficient number of demonstration buildings to make the solar industry an economically viable part of the energy industry. The question to be answered is: What number is sufficient? The purpose of the study summarized herein was to answer the basic question, as well as to supply more detailed information on location, timing and types of buildings.

The approach taken in the study involved the development of an analytical, techno-economical model of the solar industry, including sub-models of the supply, demand, government and economical-environment sectors. The model was exercised with various demonstration strategies and the most effective was selected as the recommended program. Details of the response of the commercial sector of private industry to the selected strategy was predicted by the model for the next 20 years. The results of the prediction for the nominal case provide information of considerable use in implementing the demonstration program. In addition, the sensitivity of the predicted response was tested for many variations in the model and its parameters. The results of the predictions for the variations indicate potential problem areas and suggest suitable remedies.

B. Description of the Model

The analytical model of the solar industry was divided into submodels for (1) supply; (2) demand; (3) government; and (4) economical environment. The interaction of the submodels will be described below by following the logic of the model.

The present production capacity is assumed to be 5,000 square feet per year and cumulative production experience to date is assumed to be 50,000 square feet of collector. The current price of an installed system is assumed to be \$32.40 per square foot. Each possible user is assumed to consider applying solar heating and cooling to his building at this price. Only those with electrical resistance or heat-pump heating (17% of all buildings) would find that the possibility is worth considering. At a price of \$32.40, none of the consumers would find solar attractive, so an ERDA cost-share is necessary. But even with the ERDA offer of 75% of the initial cost and 90% of the insurance and maintenance cost, not all consumers would find solar systems advantageous. Those owners who find solar advantageous would apply for an ERDA subsidy, but ERDA would select only the most advantageous for each building type

TABLE 2
 PREDICTED SCHEDULE OF DEMONSTRATION UNITS
 WHEN ERDA PAYS 75% OF INITIAL PRICE PLUS 90% OF MAINTENANCE AND INSURANCE FOR 20 YEARS

REGION	1	2	YEAR 3	4	5	Totals	ERDA Expend- itures (millions)	Average Collector Size for all Units Built in First 5 Years (ft ²)	Total Number of Units Built Commer- cially by 1995
Phoenix	24	24	7	4	3	62	10.5	1,921	20,000
Boston	11	24	24	6	-	65	16.5	3,812	216,000
Los Angeles	23	24	24	14	-	85	12.1	2,163	106,000
Washington, D. C.	8	20	24	24	2	78	16.0	3,417	96,000
Madison	5	20	24	20	2	71	17.8	4,067	70,000
Charleston	2	9	23	24	23	81	10.9	2,706	47,000
Fort Worth	2	6	19	24	24	75	11.6	3,456	34,000
Bismarck	-	-	-	6	24	30	9.4	4,860	24,000
Miami	13	17	18	18	20	86	2.1	386	0
Omaha	-	-	-	2	24	26	6.4	3,802	0
Nashville	-	-	-	-	8	8	0.8	1,386	0
Seattle	-	-	-	-	-	0	-	-	0
Totals	88	144	163	142	130	667			
ERDA Expenditures (Millions)	7.5	19.5	28.5	30.8	27.3	114.0			
Average Collector Size for all Units (ft ²)	1568	2965	2348	2695	3446				

TABLE 3
DEFINITION OF BUILDING TYPES AND REGIONS

<u>Building Types</u>	<u>New</u>	<u>Existing</u>
Restaurants:	1	2
Stores, Service stations:	3	4
Supermarkets:	5	6
Churches:	7	8
Offices:	9	10
Schools:	11	12
Hospitals:	13	14
Shopping Centers:	15	16
Motels:	17	18
Warehouses:	19	20
Libraries, Museums:	21	22
Hotels:	23	24

Regions

1. Bismarck
2. Madison
3. Omaha
4. Boston
5. Seattle
6. Washington, D.C.
7. Nashville
8. Los Angeles
9. Fort Worth
10. Phoenix
11. Charleston
12. Miami

in each climatic region. (See Table 3 for a definition of building types and regions.) Since there are 24 building types and 12 regions, there is a possibility of 288 demonstration projects in any one year; however, the economics limits the number of demonstrations to 163 in any one year. In the second year, the production rate and production experience would have increased because of the demonstration projects. Consequently, the price of installed systems would decrease. The mathematical model describing the relationship between production rate, production experience and price is as follows:

$$\text{TOTAL PRICE} = \text{Product Price (PC)} + \text{Installation Price (IC)} + \text{Design Price (DC)} + \text{Differential Price for Retrofit (RC)}$$

where:

$$PC = \frac{PC1}{\overline{DA}} + [7.5 + 2.5 \left(\frac{5000}{\overline{DA}} \right)^{1/4}] * [1 - f] * \left[1 + \frac{0.8}{1 + (A/50000)} \right] * AC \quad (1)$$

fixed
costs

effect of optimal
automation

effect
of the
introduction
of lower-cost
materials

effect of
learning
curve

variable costs

$$+ [360. + 360. * \text{EXP} (-T/3)] * PCL * SNS + 500. * [1 + \text{EXP} (-4000/AC)]$$

installed price for
absorption system
= CABS

installed price of controls,
set up of installation equipment
= CNTROL

where DA = present production rate, ft²/yr

$\overline{DA}$ = average production rate, ft²/yr, equal to A/T

A = accumulative collector area produced, ft²

AC = collector area, ft²
 PCL = peak cooling load, tons
 SNS = fraction of cooling load carried by solar
 PC1 = 24000 - 22000 * EXP(-DA/2500), \$/yr

and

$$f = 1/3 [1 - \exp(-(T/3)^2)]$$

where T = time in years. PC has the units of \$.

The installation price was modeled as follows:

$$IC = \left(\frac{IC1}{DA} + [1.50 + 1.61 \left(\frac{5000}{DA} \right)^{1/4}] * \left[1 + \frac{2.5}{1 + (A/50000)} \right] \right) * AC \quad (2)$$

fixed cost effect of optimal automation effect of learning curve

where IC is in \$ and

$$IC1 = 15000 - 14000 * \exp(-DA/2500), \text{ in } \$/\text{yr}.$$

The fee to be paid to the designer was modeled as follows:

$$DC = \left(\frac{DC1}{DA} + 0.25 * [1 + 58.5/(1 + A/50000)] \right) * AC \quad (3)$$

fixed costs effect of learning curve

where DC is in \$ and

$$DC1 = 200 + 4000/(1 + A/50000), \text{ in } \$/\text{yr}.$$

Finally, the differential between new construction and existing construction was taken as:

$$RC = 3 * AC, \$ \quad (4)$$

Note that we have assumed that retrofit installations will cost more than new units. There is a possibility that the opposite will be the case, since the infrastructure is different for new and retrofit installations and the markups associated with retrofit could be less. All of the prices given by these model equations are in late 1975 dollars. The prices were allowed to escalate at the general inflation rate.

The factor f in this equation represents an additional cost-reducing feature of the model that simulates technological advances that are expected to bring the cost down to two-thirds of what it would be without continuing research and development in the solar field.

In the second year, the owners again look at the price of the solar system, now below the original \$32.40 and once again decide whether it is cost-beneficial for them to install a solar system on their building. For each building/region combination for which solar is cost-effective, no request is made for an ERDA subsidy and some of the owners of this type of building in this region are assumed to install solar systems on their buildings. If the second-year price does not make the solar system cost beneficial, the owners are again assumed to apply to ERDA for government support. Again, if there are several applications for grants from the same building type in the same region, ERDA funds only that which is most cost-effective and in no case supports a system that is not cost-effective to the owner (who pays only 25 percent of the first cost and 10 percent of the annual costs).

The price of solar systems in the third year is affected again by the increase in production capacity and production experience resulting from the two years of experience under the demonstration program and its commercial consequences. As a consequence, the price of solar systems would be reduced in the third year according to the modeling equation given above, and each owner would once again examine the benefits of installing a solar system on his building. This process is repeated for the five years of the demonstration program. If, after the five years, unsubsidized solar systems are still not attractive to the owner, the market would disappear after completion of the demonstration program. Such is the case in the four regions of Seattle, Omaha, Nashville and Miami.

Several factors influence the extent to which the solar systems penetrate the market once the systems prove cost-effective without ERDA subsidization. The first factor is the risk-aversion factor. A primary reason why solar systems would not be used today, even if they were cost-effective, is that users fear the unknown; they are reluctant to invest heavily in systems that may prove troublesome. Risk was incorporated into the model in terms of an equivalent cost, equal to the cost of removing the solar system and restoring the building with a conventional heating and cooling system. The equivalent cost of risk was reduced as the number of unit-years of experience increased, the effective unit-years for a given building in a given region being the sum of the number of years' experience on all solar systems on buildings of the same type in the same region, plus a reduced experience factor for other types of buildings and for buildings of the same type in other regions. Hence, the "risk cost" decreases as the public experience with solar systems increases.

The second factor of importance in predicting the performance of the unsubsidized solar market is the rate of market penetration. Although all buildings of a certain type in a certain region might prove cost-beneficial for solar systems, not all would be equipped at the same time. The

availability of capital and the availability of solar equipment and its installers would impose the limits on penetration rate, but the variability of the attitudes of people in purchasing new systems would be the most influential factor. The market penetration rate was estimated according to the equation

$$\begin{aligned}\text{Market penetration rate} &= 15\% \times (1 - e^{-c/0.3}) \text{ (Retrofit)} \\ &= 70\% \times (1 - e^{-c/0.3}) \text{ (New)}\end{aligned}$$

where "c" is the ratio of the life-cycle cost savings possible with solar in comparison with the life-cycle of a conventional system. Hence if the owners were to save 50% of their normal heating bills, 39% ($=1 - e^{-0.5/0.3}$) of the asymptotic market penetration rate would be realized, corresponding to 6% (39% of 15%) per year penetration for retrofit cases and 28% for new construction. These penetration rates are comparable to those of major appliances with proven cost-effectiveness.

The economy was included in the analysis and predictions on the basis of an 8% inflation rate and a 10.3% fuel-price escalation rate. The required return on investment was assumed to be 8%. The predictions would be altered little for other inflation rates as long as the fuel-price escalation rate is 2.3% greater than inflation.

The government aspect of the analysis consisted of the ERDA offer to pay 75% of the initial cost and 90% of the insurance and maintenance, although variations of this plan were also evaluated.

C. Predictions of the Model

One of the most important predictions of the model is illustrated on Figure 2. This graph shows the importance of the fraction of the initial cost borne by ERDA. The recommended program of 75 percent of the initial cost plus 90% of the maintenance cost corresponds to ERDA's paying, over the 20-year life-cycle of the system, 150% of the initial cost. It is evident from Figure 2 that at this subsidy level, the national energy saving is 75% of what would be saved if ERDA paid the entire life-cycle cost.

FIGURE 2: EFFECT OF COST SHARE BORNE BY ERDA ON CUMULATIVE ENERGY SAVINGS

Figure 2 also shows the importance of other programs on the required ERDA cost-share. At a background production rate of 20,000 square feet of collector per year per region (approximately 480 homes per year nationally), the required ERDA cost-share for the same energy savings in 20-years is reduced from 150% to 85%. Hence, to avoid unnecessary governmental expenditure, it is imperative that all government projects be coordinated. As discussed below in connection with Table 4, a regional production rate of 120,000 square feet of collector per year by the third year should be the goal of the combined programs.

Table 2 illustrates the predicted response of the commercial sector to the ERDA offer. The table shows the regional ERDA expenditures for each year (\$7.5 million to \$30.8 million) as well as the average size of the demonstration units (collector areas range from 386 to 4860 square feet per unit, depending on the region). More experience is gained from many small demonstrations than from a few large systems for a given total collector area. The average cost to ERDA per project is \$86,000 first cost, plus \$86,000 for insurance and maintenance. Note that each of the regions has its demonstration program reasonably well concentrated into a three-year period. This suggests that regionally managed programs with staggered starting dates would be effective. Such programs would also permit optimal use of ERDA program managers. Table 2 indicates that Miami, Omaha, Nashville, and Seattle will not develop viable solar markets; consequently, any proposers for these regions should be required not only to propose an application that is cost-effective as subsidized but also to demonstrate that a viable market would develop (in contrast to what the model predicts).

Table 4 contains data on the market when solar first becomes economically attractive without ERDA support--when the market reaches 10% of the 1995 market. As was indicated on Table 2, the commercial market is realized as early as Year 2 (Phoenix), although Bismarck does not take hold until Year 8. Notice that production rates range from 90,000 to 270,000 ft²/yr in the last year that ERDA support is requested (an average of 120,000 ft²/yr

TABLE 4
CONDITIONS WHEN MARKET REACHES 10% OF 1995 MARKET

Region	Year	Production Rates (10 ⁶ ft ² /yr)		Price on New Buildings In Yr. Shown (1975 \$/ft ²)	Production Rate in 20 Yrs. (Units/Yrs.)
		In Last Year of Major ERDA Support	In Year Shown		
Bismarck	8	0.13	1.99	9.85	3216
Madison	4	0.27	8.51	10.68	6005
Omaha	-	0.09	-	-	-
Boston	3	0.18	6.36	12.31	17651
Seattle	-	-	-	-	-
Washington, D.C.	4	0.18	8.82	11.59	8137
Nashville	-	0.01	-	-	-
Los Angeles	4	0.10	6.74	10.11	9107
Fort Worth	5	0.13	1.39	12.33	3438
Phoenix	2	0.09	0.50	15.72	1506
Charleston	5	0.11	2.10	12.38	4847
Miami	-	0.01	-	-	-

- NOTES: 1. Year shown is the beginning of the year in which production exceeds 10 percent of production rate 19 years from today.
2. A "-" indicates that a market did not develop.

for all regions). When the market reaches the 10% point, production rates range from 500,000 ft²/yr (Phoenix) to 8,820,000 ft²/yr (Washington, D.C.).

The unit prices of solar at the 10% point range from \$9.85/ft² of collector to \$15.72. These prices can be used as targets for the ERDA Research and Development Program. Figure 3 illustrates the price histories associated with the forecast for the nominal case. If these price predictions occur, the success of the demonstration program, illustrated on Figure 2, will be realized; hence, Figure 3 can be used as the price goal for the Commercial Demonstration Program.

Not shown on Table 4 is the fact that the payback period* at the 10% market point is between 10 and 12 years.

D. Results of the Sensitivity Study

Variations in the 37 parameters used in the model were examined for their impact on the predicted response of the market to the ERDA offer. The important sensitivities were found to be:

1. Number of buildings to which solar might be applicable:
The nominal case used 17%, corresponding to the fraction of today's buildings that are electrically heated. The energy savings is nearly proportional to this percentage; so if 57% is suitable, as would occur if gas is withdrawn, the energy savings for heating alone would jump from 1.27 to 3.92 quadrillion Btu in 20 years.
2. Fuel-price escalation rate:
The nominal case used 2.3% above the inflation rate. The energy savings would increase from 1.27 quads to 2.65 if a 5% rate is anticipated by potential users. If potential users expect the fuel prices to increase at the inflation rate, only 0.02 quads would be saved -- all in the Phoenix region. The anticipated, not actual, fuel-price escalation rate is critical to the success of solar.

*Payback is the ratio of solar-system cost to fuel cost savings with prices evaluated in the year of installation.

FIGURE 3: PRICE GOALS FOR VARIOUS REGIONS

3. Heat pumps as competition:

The nominal case uses resistance heating as competition for the first five years and heat pumps thereafter. If heat pumps form the competition from the start, less than 0.01 quads would be saved. The public acceptance of heat pump systems will not be immediate, due to poor past experience with such systems. Whether five years is realistic will depend on the experience obtained with systems being installed at present.

E. Implications Deduced From Model

1. Implications for ERDA

The implications of the foregoing analyses for the ERDA program can be divided conveniently into four categories: (1) the cost-share program; (2) the proposal evaluation procedures; (3) program management; and (4) advice to Congress.

a. The Cost-Share Program

ERDA should offer to pay 75% of the first cost of the difference between equipping the commercial buildings with solar heating and cooling and equipping the buildings with a conventional system. ERDA should also offer to pay 90% of the maintenance costs for the first 20 years of operation. ERDA's payment for maintenance could be in the form of a direct grant or in the form of a maintenance contract. The maintenance support should be tied to the data acquisition program by requiring that all data be made public if maintenance support is given. The data presented in this report is the predicted response to these offerings by ERDA. It is predicted that the solar industry will become self-sustaining in Phoenix in two years and somewhat later in other regions.

ERDA should, with few exceptions, limit its support to systems requiring less than 5000 square feet of collector or to the first 5000 square feet of larger

installations since the experience gained with larger systems is of no greater value. It is anticipated that, in the first year, systems involving 5000 square feet will cost approximately \$160,000, with ERDA paying 75%, or \$120,000.

ERDA should guarantee a five-year market of at least 120,000 square feet per year in each region where success is predicted for the solar industry so mass-production methods will be developed. ERDA should sponsor a study of the optimal expansion rate for the manufacturer(s) in each region.

b. Proposal Evaluation

ERDA should fund only those proposals that show the solar system to be cost-effective as cost-shared by ERDA. Maintenance costs must be included in this evaluation; they should be assumed as 4% of the initial cost, unless data is available to the contrary. Only those systems that promise to be reliable, durable and low-cost in the long run should be funded. The proposer should show these merits in his system. It is important to the low-cost feature that the system be mass-producible. Systems with good potential should be funded, even though these systems may be higher in cost under present conditions. In keeping with this concept, manufacturers using mass-production methods should be favored.

To limit the present high costs of system design, ERDA should support only a few, reputable design organizations at first. Design data and specifications developed in these organizations should then be disseminated by ERDA to other design organizations.

The largest part of the market lies with existing buildings, so proposals involving such buildings should be favored by allowing the proposer to receive a higher payment per unit-collector-area from ERDA. A differential of \$3 per square foot appears to be a reasonable differential.

The regions of Phoenix, Boston and Los Angeles should be favored in the first year, since these are the most promising areas. Washington, D. C., and Madison should be added to the list of favored regions in the second year, and Charleston and Fort Worth in the third year. Miami, Omaha, Nashville and Seattle appear to be so unfavorable that the proposer from these regions should prove that the long-term market really exists within that region.

No favoritism should be offered to competing systems, such as air-cooled versus water-cooled collectors, concentrating collectors versus non-concentrating, or heating only versus heating and cooling. The cost-effectiveness criterion should be used in evaluating these competing systems.

c. Program Management

The single most important aspect of the program management will be the integration of the ERDA commercial program with other government-sponsored solar programs, such as the ERDA/HUD residential program and the ERDA industrial program. The goal of the combined programs is to bring the production level up to the point where significant economies of scale can be realized. A production rate of 120,000 square feet per year in each of the twelve regions should be adequate under the combined programs. Because of program interaction and because of the uncertainties of the model used herein, the three programs should be reviewed at least annually. The model can be updated and recalibrated so more accurate projections can be made. Although a five-year program should be planned at present, budget permitting, a four-year program might be adequate. The possibility of decreasing the ERDA share in equal steps each year should also be evaluated periodically.

The criterion by which the ERDA program can be evaluated is quite simple: the reduction in the cost of solar-energy systems in the regions where demonstration programs are installed. It is possible, by use of the results shown on Figure 3, to estimate whether the price decreases with time will lead to a

viable, self-sustaining industry. If so, the ERDA program is successful; if not, failure is indicated. It will be important to use costs as proposed to ERDA to avoid estimates that are dreams rather than realities.

The results obtained with the model indicate that regions become economically attractive for the demonstration program sequentially rather than simultaneously. Three-year programs starting in the first year in Boston, Phoenix, and Los Angeles only would provide pilot programs for the rest of the nation.

Finally, the program management should be such that funding of companion research and development projects will lead to the development of durable, reliable, low-cost systems, including most importantly the collector and its installation, but also the storage, refrigeration and control sub-systems.

d. Advice to Congress

The price of alternate energy sources has a strong impact on the economical viability of solar-energy systems. ERDA should sponsor a study of the full impact of the de-regulation of natural gas and the institution of oil price supports, so the solar industry can compete in a free market but not a market subject to the whims of foreign powers.

2. Implications for the Manufacturer, Designer and Installer

The importance of the development of the solar industry to the manufacturer, designer and installer can be considered in three categories: (1) price goals; (2) market; and (3) competition.

a. Price Goals

The long-range price goal for the manufacturer is \$5.00 per square foot of collector for all of the components in the system, excluding air conditioner and controls. The installer should add no more than \$1.50 per square foot

to this cost. The designer can add no more than \$0.25 per square foot. For a typical 4,000-square-foot installation, the manufacturer would receive \$20,000; the installer, \$6,000; and the designer, \$1,000. These are the long-range goals that would require mass-production techniques and much experience with solar systems. Mass-production to the designer will mean design charts for various regions, standard specifications and the use of packaged components. The market will begin to grow once the price has been brought to the level of \$10 to \$15 per-square-foot total, although the market will remain small at this price level.

b. Market

If the installed price is brought down to the \$10 to \$15 range, the market will be as shown on Figure 4 for each of the regions. It is evident that Phoenix and Boston are the places to start, but most of the other areas are quick to follow. Nashville, Miami, Omaha, and Seattle may never be able to use solar profitably, so producers in these areas should proceed with caution.

Caution is also urged with regard to expansion rate. Figure 4 should be studied for each of the regions and the optimal expansion rate established therefrom. Plant sizes should be based on mass-production techniques, with capabilities between one and ten million square feet per year recommended. Specialized vehicles for installation will probably be required to reduce the price to an acceptable level. Vertically integrated companies will have a decided advantage in keeping prices low.

c. Competition

Many of the assumptions made with regard to the model are unfavorable to the expansion of the solar industry. A number of developments could cause a considerably greater demand for solar-energy systems; the producer should become aware of these. If heat pumps are found unacceptable, due, for example, to high maintenance costs, solar systems will compete with electric resistance heaters rather than heat pumps. The long-term market could increase by 50 percent if this were to happen. If the price of natural

NOTES:

1. DOT (•) INDICATES YEAR MARKET REACHES 10% OF 20-YEAR MARKET

FIGURE 5 : REGIONAL HISTORY OF PRODUCTION RATE REQUIRED TO MEET MARKET

gas approaches that of electricity, the market will triple. If oil becomes scarce, the market will also triple, since approximately 40% of all commercial buildings are oil-heated. If local energy costs are significantly higher, in a subsection of a region, the solar market could be greatly expanded on a local basis. The Long Island section has this characteristic. Finally, if fuel costs increase at a rate exceeding 2.3% more than the inflation rate, the solar market will increase a like amount, being proportional to the difference in these escalation rates.

At present, solar energy systems are not competitive because initial costs are too high, but the ERDA program will probably bring about a decrease in system costs. The decrease should be sufficient for solar to become competitive with electrical resistance heating.

3. Implications for Potential Users

The discussions of the implications for the manufacturers, designers and installers also provide much of the information needed by the potential user.

The payback period for the user when solar energy systems first become economically attractive is approximately 10 to 12 years, so this rule-of-thumb can aid the user in his evaluation.

No a priori judgments can be made of the systems competing at present. Air heating is just as attractive as water heating, so no guidelines can be offered in this regard. The payback period in 1975 dollars is the best criterion, although reliance must be placed on the truthfulness of the claims of the manufacturer with regard to heat delivery. NASA tests and tests by independent agencies are the only safeguard, unless guarantees by the manufacturer would suffice if honored.

F. Limitations of the Techno-Economic Model

The primary weakness of the analysis stems from the lack of data to substantiate the parameters used. The sensitivity analysis lessens the effect of the uncertainties in the parameters, but the problem still remains. Since the intuitively selected values are more credible than would be similar, intuitive selections of the final results of the study, this report should represent an improvement over gross guesses as to what constitutes an effective demonstration program.

The omission of the energy demands of water heating could have an important effect in underestimating the solar market. A similar effect is probably present because average energy rates were used, rather than marginal rates, such as would be used if the demand for electrical energy were to increase. Of course, the model lacks the detail of accounting for each potential customer, dealing instead with average building sizes, customers lumped into classes, etc. It also does not consider interaction with other government-sponsored demonstration programs, which could assist substantially in reducing production costs for similar systems.

The model does have the distinct strength of including the psychological effect of risk aversion, models of the price structure which contain considerable detail, and many of the interactions of the techno-economic world that are important to its behavior. The model also has the advantage that it is easily adjustable so that what is learned in the first year or so of demonstrations can be used to improve and update the predictions.