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SOLAR ENERGY IN BUILDINGS: IMPLICATIONS FOR CALIFORNIA ENERGY POLICY

JET PROPULSION LABORATORY

CALIFORNIA INSTITUTE OF TECHNOLOGY

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This document presents the results of one phase of research at the Jet Propulsion Laboratory, sponsored by the California Energy Resources Conservation and Development Commission by agreement with the National Aeronautics and Space Administration under contract NAS7-100.

FOREWORD

This is a report on the current status of solar heating and cooling for buildings in California. It was written for the Solar Energy Office of the Alternative Implementations Division on the California Energy Resources Conservation and Development Commission.

The authors wish to extend their appreciation to various colleagues and friends for their help. In particular, Dr. George Hlavka, Mr. Robert French, Ms. Rosalyn Barbieri, Ms. Donna Pivirotto, and Mr. Ira Handleman; each helped us assemble different sections. The authors also wish to extend their appreciation to various people for taking the time to thoughtfully review the report and to provide comments. Ms. Barbara Barkovitch of the California Public Utilities Commission provided useful comments on the possible role for utilities in solar heating and cooling. Mr. Samuel Cunningham, Mr. Robert Filip and others from the Southern California Gas Company provided useful critique of the trade-off between solar energy and new natural gas supply. Mr. G. Braun and others from the Southern California Edison Company pointed out some of the interface difficulties with solar energy and electric utilities. Dr. E. Habitch of the Environmental Defense Fund gave us detailed remarks on Section IV. Dr. Walter Baer and Mr. Frank Cam of the Rand Corporation provided a general review of the report as did Mr. John Geesman of the California Citizens Active Group. Dr. Marshall Alper, Dr. Roger Bourke and Mr. Tom Hamilton of JPL gave us detailed remarks on each of the sections. Others who received the draft report included Dr. Jaques Gross of the Council on Environmental Quality, Mr. Garry deLoss of the Citizens Public Action Group, Mr. Bruce Pasternack of Booz Allen Hamilton and Dr. Paul Goldstone of the University of California, Berkeley. Finally Mr. Alec Jenkins and Mr. Mathew Ginosar of the Energy Commission provided a general review of the entire report.

Comments by each of these reviewers have been considered while rewriting this report. In most cases the comments were very helpful in clarifying specific statements and correcting errors in the report. In other cases, comments reflect fundamental disagreements among the reviewers and areas of concerns which have not been resolved at this time. Given the uncertainty which characterizes the energy crisis, we believe that elimination of all such dissagreements is difficult, if not impossible. The report is being published recognizing these disagreements and concerns. The authors hope that the report can contribute to their speedy resolution.

The opinions, findings, and conclusions in this report are those of the authors and do not necessarily reflect the views of the sponsor, the California Energy Resources Conservation and Development Commission, or the views of any of the reviewers of their organizations.

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EXECUTIVE SUMMARY

They said, "You have a blue guitar
You do not play things as they are."
The man replied, "Things as they are
are changed upon the blue guitar."

Wallace Stevens

A. INTRODUCTION

The prospect for using solar energy has recently aroused widespread public attention. Solar energy is clean, safe, and inexhaustible. Many people view the use of solar energy as a step towards independence. Research and development on solar energy technology is proceeding on a number of paths. But the use of solar energy in buildings is closest to readiness for commercial application. Considering the decline in the natural gas supply, as well as environmental and legal issues raised by some of the proposed new natural gas and electricity supply projects, the use of solar energy for space heating and water heating to supplement conventional fuels in California buildings is quite attractive.

Solar energy systems have been classified into two types: active and passive. A typical active solar energy installation uses a flat plate (or concentrating) collector to gather solar energy. Water (or air) flowing through the collector picks up heat generated by the sun and stores it in a large tank (or rock bed). When heat is needed, for space or water heating or for heat-activated space cooling, the stored energy is taken out of the tank and delivered to the building. Although it is possible to design systems which provide 100% of the required heat from the solar energy system, in practice, this is not economically justified (Ref. 3). Most active solar systems provide 50 to 80% of the energy needed with the remaining percentage being supplied by a conventional natural gas or electric system backup. Figure ES-1 is a picture of the Solar Assisted Gas Energy (SAGE) water heating system on an apartment building in Southern California. Figure ES-2 is a picture of the Löf solar energy house built in 1958 near Denver, Colorado. It is an active air system.

Passive solar energy systems utilize the design of the building envelope to provide climate control with little or no mechanical equipment (passive techniques do not usually provide hot water). In a typical passive system, the flow of heat through the walls of the structure is controlled either using design techniques such as louvered windows to control the flow of sunshine into the structure or using movable insulation panels to allow collection and radiation of heat at appropriate times. Figure ES-3a is a picture of a passive system designed by Harold Hay and built in Atascadero, California. It uses water bags on the roof to store thermal energy which is controlled by movable insulation panels. Figure ES-3b shows the roof structure of this house with the water bags. The system provides 100% of the heating and cooling for the single-family building but the economics of the system are uncertain (Ref. 10).

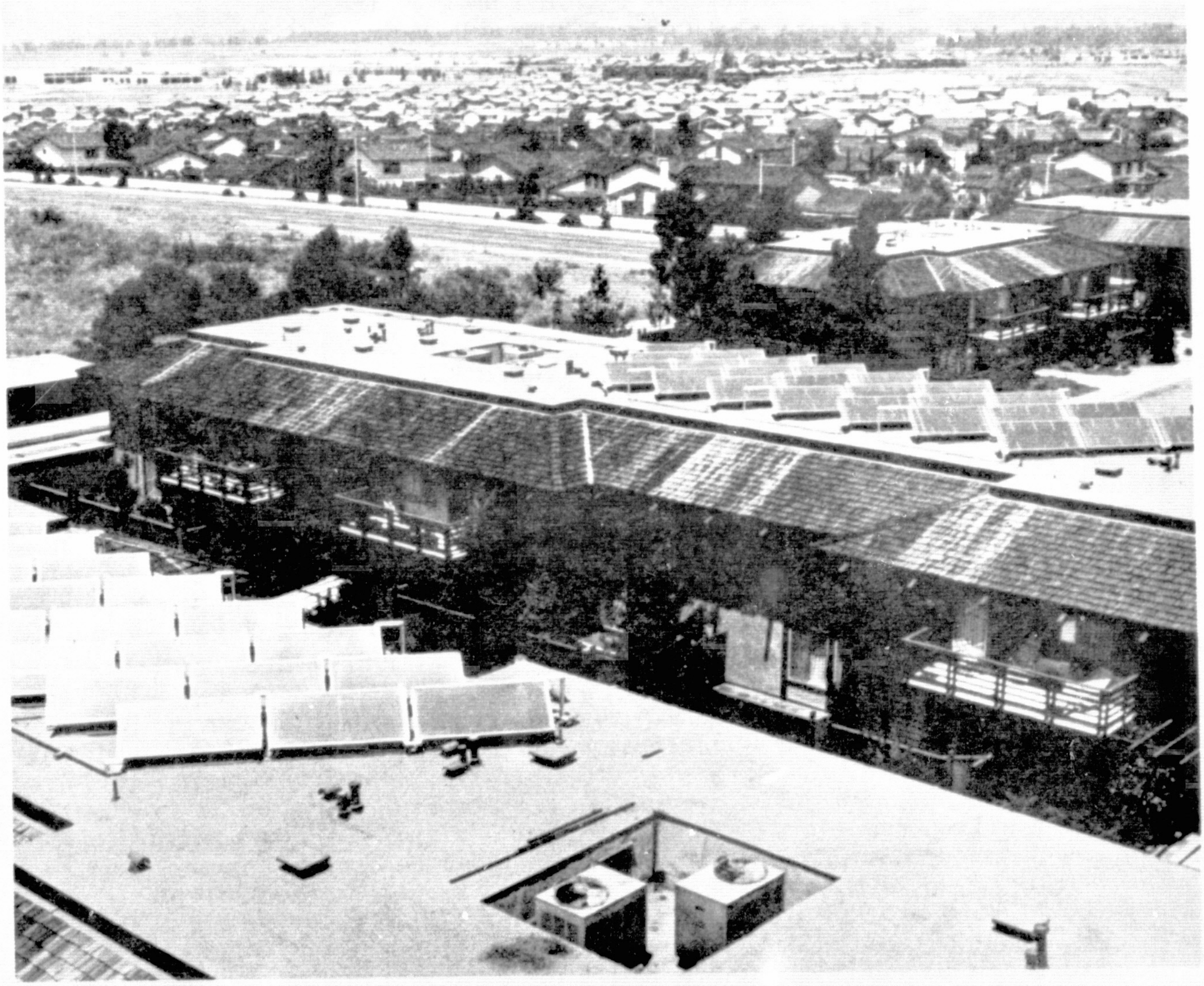
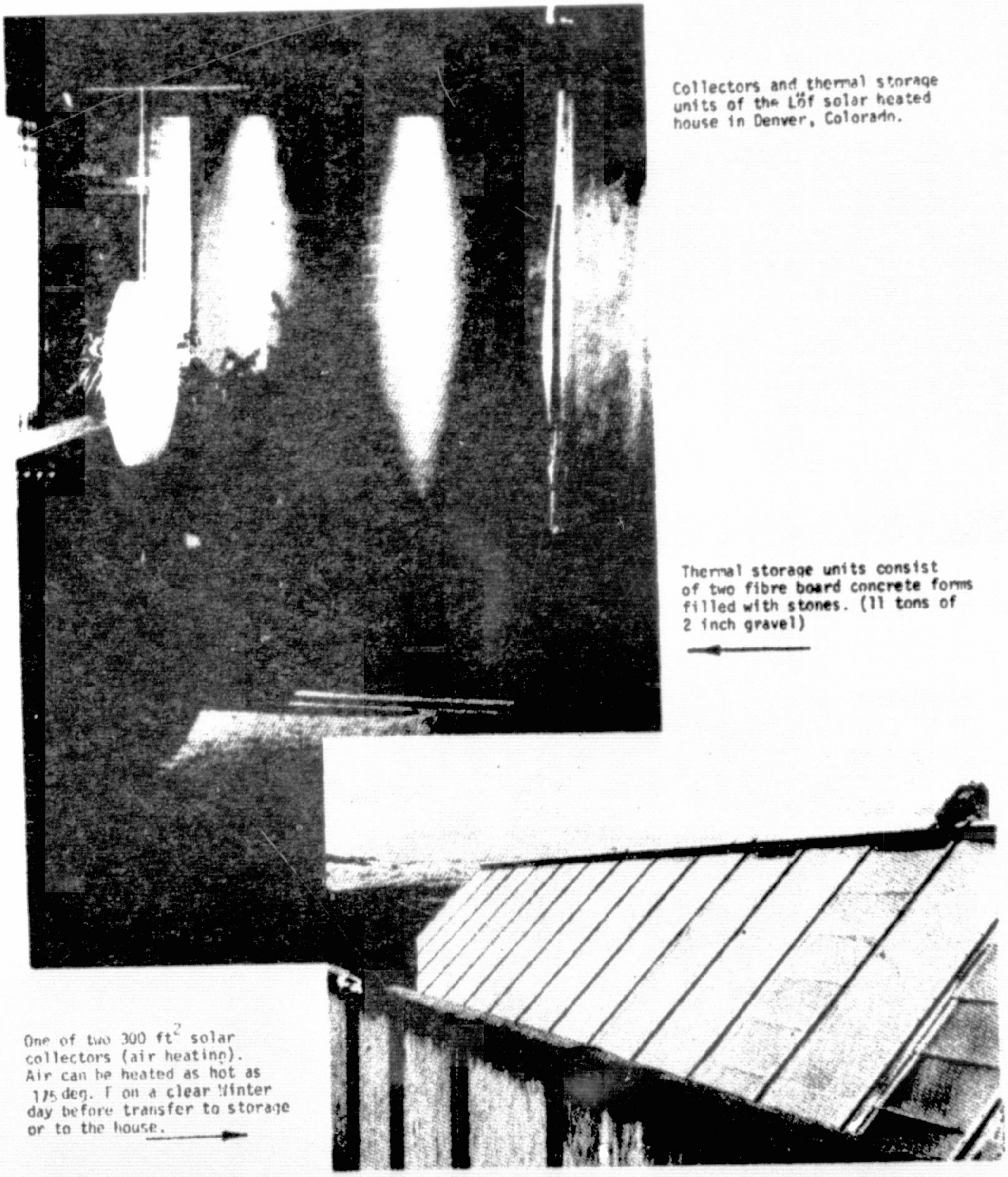


Figure ES-1. SAGE Active Solar Energy System on an Apartment Building in Southern California

Source: New Energy Technologies for Buildings, 1975



Collectors and thermal storage units of the Löf solar heated house in Denver, Colorado.

Thermal storage units consist of two fibre board concrete forms filled with stones. (11 tons of 2 inch gravel)

One of two 300 ft^2 solar collectors (air heating). Air can be heated as hot as 175 deg. F on a clear Winter day before transfer to storage or to the house.

Figure ES-2. The Löf Solar Heated House — Denver, Colorado (1958)

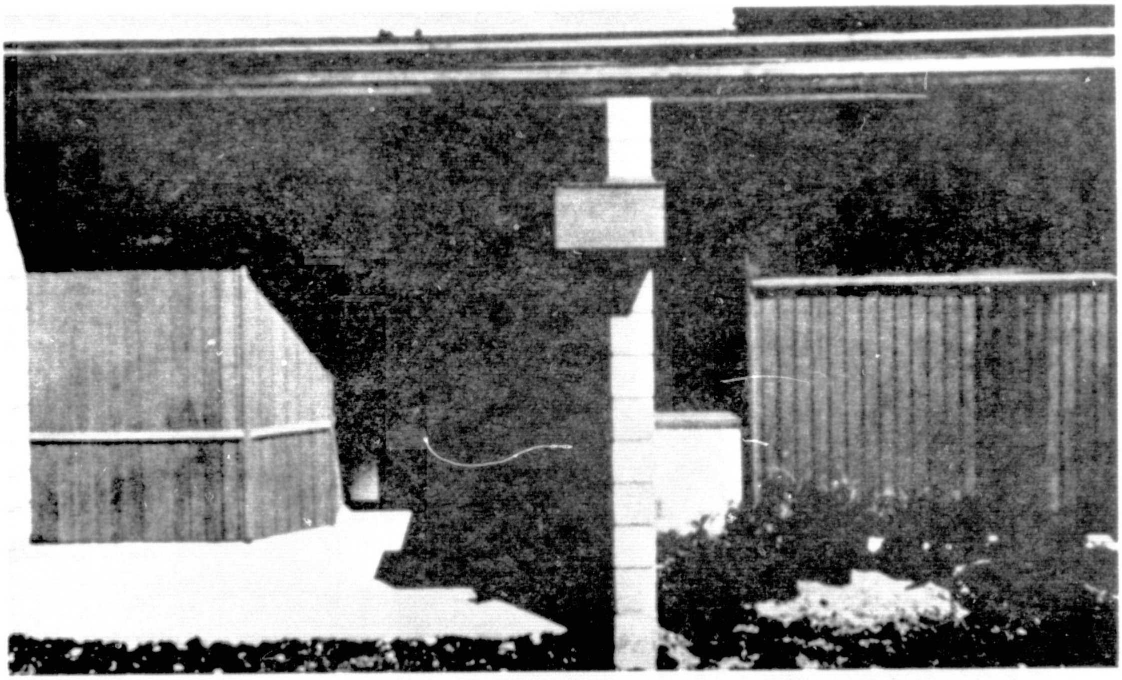


Figure ES-3a. Hay House in Atascadero, California (View One)

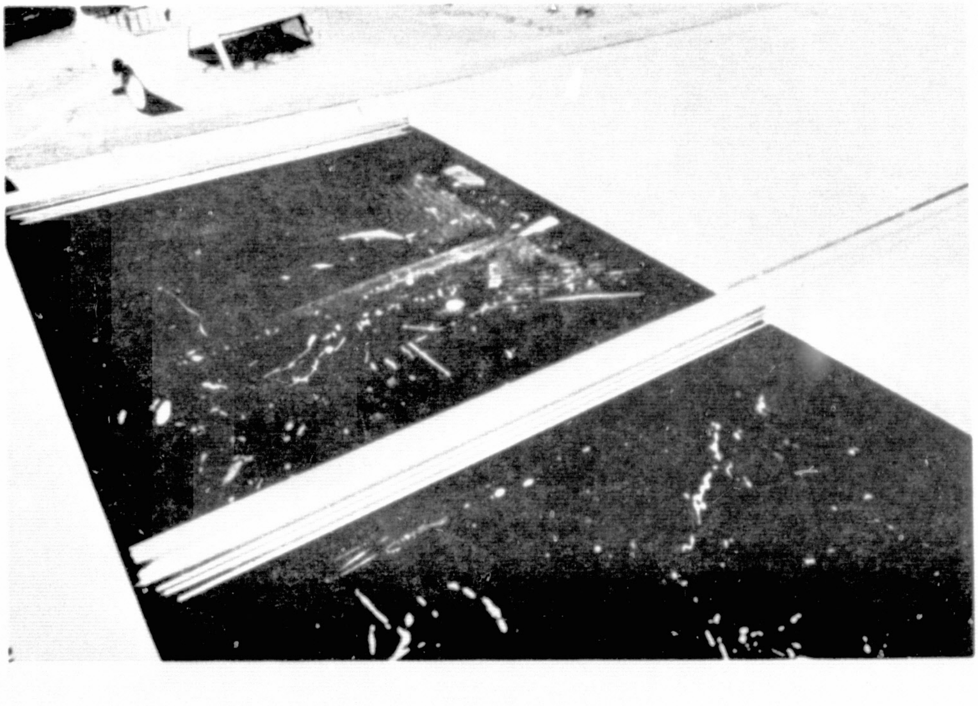


Figure ES-3b. Hay House in Atascadero, California (View Two)

The conclusions of this report are based on a detailed analysis of the technology and applications for active solar energy systems. The analysis has been done in the context of the institutional factors which affect the energy market and affect innovation by the building industry. While passive systems have not been explicitly considered, the general conclusions for active systems are applicable to passive systems and many conservation measures as well. It is important to note that in evaluating specific applications for solar energy, incremental benefits have always been compared to incremental costs. The energy savings from the conservation package adopted for each building was used to justify its adoption. Similarly, only the energy savings attributable to the use of solar energy is compared to the investment in solar energy equipment. In economic terms, solar energy systems were designed in a way that seeks to balance the marginal cost of solar energy with the marginal cost of alternatives. The conclusions presented here attempt to focus on solar energy from the perspective of California as a whole.

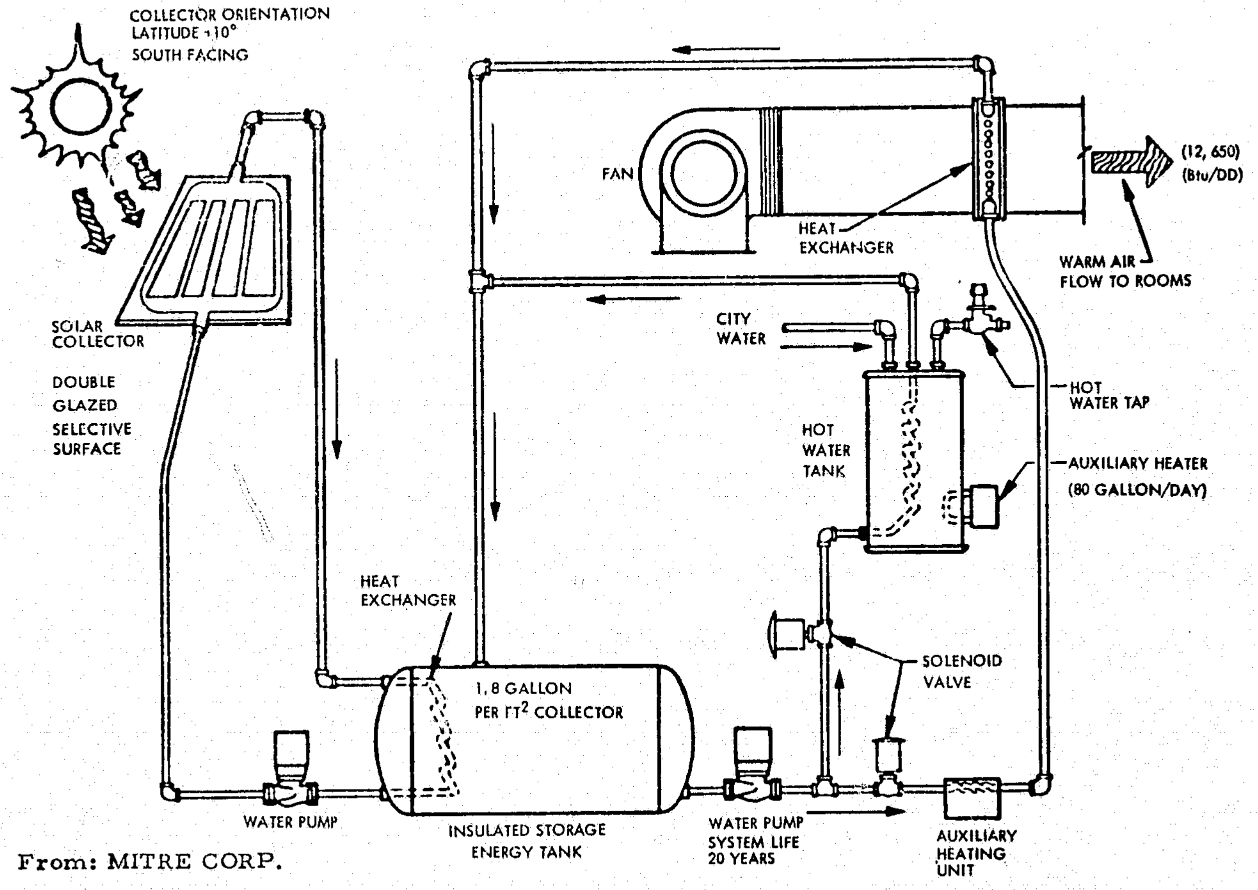
B. TECHNOLOGY

Solar heating and cooling is at present technically feasible. Solar water heating has been successfully applied on a commercial scale in several foreign countries (e.g., Japan, Israel, Australia) where it is already a multimillion-dollar-per-year industry. In addition, hundreds of buildings using solar energy have been built in the United States. The federal government has sponsored the development of systems and components tailored to the unique requirements of the U.S. market. Figure ES-4 illustrates, schematically, a solar space heating and water heating system compatible with U.S. plumbing and heating technology. The technology for water heating and space heating is ready for commercial application. The technology packaged solar cooling, however, is not yet ready for commercial application:

(1) Suppliers exist for all important solar components; many are located in California. Nationally, the capacity of equipment suppliers is many times greater than the current market demand. Therefore, California state action should be focused on means to aggregate demand for solar energy products.

(2) Although packaged solar cooling systems are not ready for commercial application, off-peak-power cooling and passive solar energy technology may be ready. These approaches reduce electric utility peak loads which, because of air conditioning, occur during summers. Therefore, California should monitor and encourage research on packaged solar cooling systems while looking to alternative methods for the near term; e.g., incorporation of passive cooling in new construction, and deployment of off-peak power cooling systems and other load management concepts.

(3) Current commercial flat plate collectors can easily convert 40% of the annual incident solar energy to hot water. With readily available technology, it is likely that this will be improved to 50% by 1980.



From: MITRE CORP.

Figure ES-4. Schematic of a Typical Solar Energy System

Current, solar water heating and space heating systems can be installed for \$23 to \$32 per ft^2 (in 1977 dollars*), depending on the characteristics of the particular application. The potential for future cost reduction can be assessed by separating the total cost into two parts: the installed cost of the collector array, and the installed cost of the remainder of the system. The major potential for cost reduction is limited to the collector arrays. The remaining parts of the system are mostly standard plumbing materials with limited possibilities for cost reductions. The installed cost for these components is in the range of \$8 and \$13 per ft^2 of required collector array. We estimate that, by 1980, an all-glass (or other non-metallic) collector could be produced and installed for approximately \$6.50 per ft^2 using existing technology

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*Costs shown in this executive summary are given in 1977 dollars by projecting the 1974 estimates by inflation rates of 7% in 1974, 12% in 1975 and 6% in 1976. Costs in the main body of this report are given in 1974 dollars.

(cf. Section III). Therefore the projected lower-bound cost for a solar energy system is from \$14.50 to \$19.50 per ft^2. Even without successful development of a non-metallic collector, some cost reductions can be expected as economies of scale are realized in the manufacture of collectors. According to FEA production estimates, in the first half of 1976, collector manufacturers were nowhere near full production and therefore their prices were higher than they can be expected to be when a large-scale competitive market develops.

(1) Solar water heating for loads in excess of 500,000 Btu/day (approximately 600 gal/day) are the most economical applications of solar energy in buildings. Multiple-family residential and institutional domestic hot water systems are in this class. There are also many commercial and industrial processes which have similar requirements. In 1975, 243 bcf of natural gas and 15 billion kWh of electricity were used for residential and commercial water heating. Because of favorable economics and significant potential energy impact, California should put top priority on using solar energy to heat water in large-scale applications.

(2) In the single-family market, combined solar space and water heating appears to have more favorable economics than for solar water heating alone because of the economies of scale associated with the larger solar collector areas required for combined systems.

(3) Solar water heating in single-family applications has the lowest first cost of any of the other solar energy applications. It is an important application because of the relative lack of alternative energy conservation measures.

C. ECONOMICS

Currently available solar energy systems are nearly economically competitive with electricity at residential retail prices (see Table ES-1). Assuming typical home mortage financing terms (i.e., 9% loan for a 25-year term), the least expensive solar applications cost less than the 3.5 cent per kWh average residential price of electricity but more than the \$1.75 per mcf average residential price for natural gas. Furthermore, the cost of some new natural gas supplies are estimated to be two or three times higher than the current average price. The marginal cost of imported LNG is estimated to range between \$2.50 per mcf and \$6 per mcf, while the cost of coal gasification may be even higher (Ref. 52, 53, 54). New baseload electricity projects (either coal or nuclear) are also expected to be more than 3.0 cent per kWh and could be as high as 8.5 cent per kWh (Ref. 2). The cost ranges for new electric and natural gas supplies are compared with the similar ranges for solar in Figure ES-5.

California should formulate policy toward solar energy based on the marginal cost of new energy supplied. This approach would minimize the total cost of energy to Californians.

Table ES-1. Comparisons of Solar Energy Cost With Costs of Fossil Fuels and Electricity

Fuel	Units	Btu Value Per Unit	Average Cost Per Unit	Conversion Efficiency	Net Cost $/MBtu
Solar Energy	Square Foot	560,000 per yr.	$23.00-32.00 $14.50-19.50	40% 40%	10.45-14.50 6.50-8.80
Coal	Ton	24,000,000	$20.00	60%[3]	1.40
Natural Gas	1000 Cubic Feet	1,000,000	$1.75 Avg. $3-6.00 New	60%[3] 60%[3]	2.90 5-10.00
Electricity	Kilowatt-hour	3,413	$0.035 Res. Avg. $0.030 Com. Avg.	95%	10.80 9.25
		3,413	$.03-.07 Nuclear New $.035-.085 Coal New	95%	$ 9.25-21.60 10.80-26.20

1. Prices of fossil fuel and electricity were derived from a number of sources.
2. Solar energy costs (SEC) calculated based on an 9% loan for 25 years.

$$SEC = \frac{(23\ \$/ft^2)\ (.09)\ (1.09)^{25}/[(1.09)^{25} - 1]}{(.56 \times 10^6\ Btu/yr/ft^2)\ (.40)}$$

3. Optimistic estimates for efficiency in space heating and water heating applications.

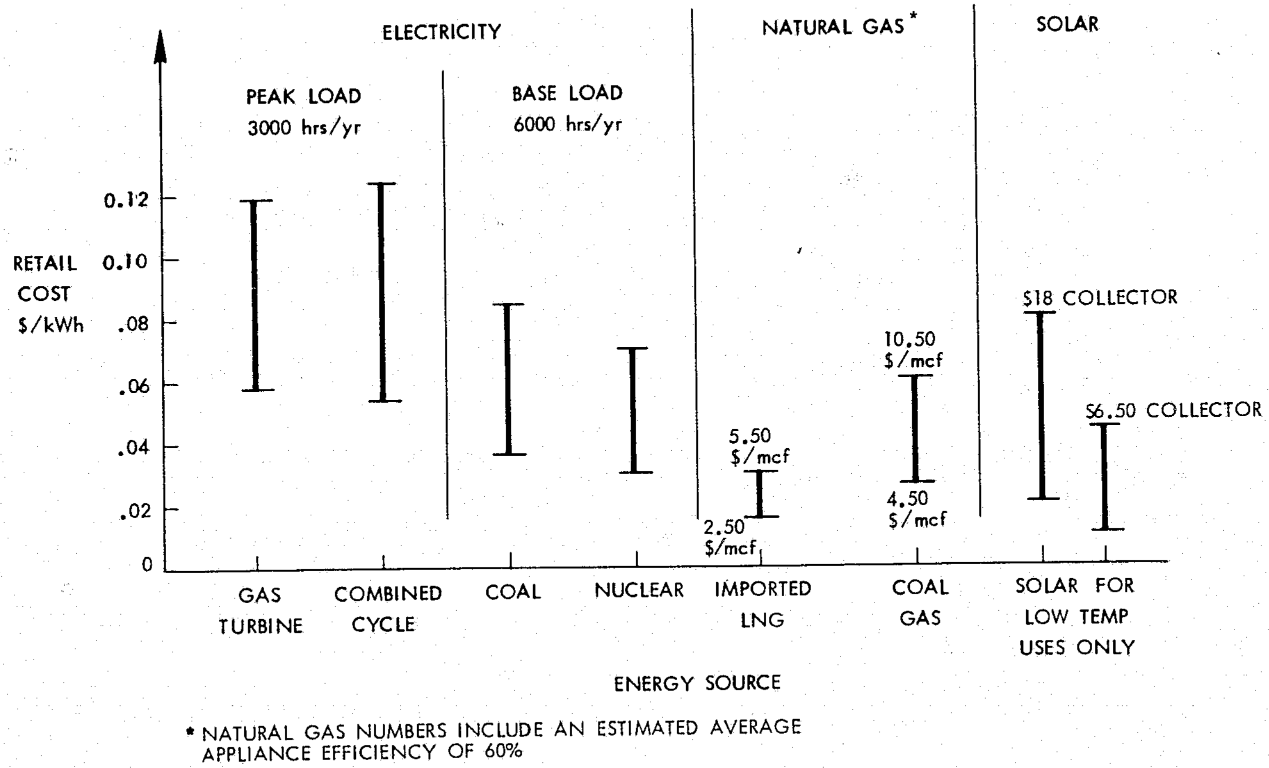

Figure ES-5. Retail Cost Ranges of New Energy Sources

D. THE POTENTIAL CONTRIBUTION OF SOLAR TO THE CALIFORNIA ENERGY BUDGET

The potential market for solar space heating and water heating in California buildings is large: nearly half of the State's annual natural gas consumption of 1680 bcf and about 5% of its electricity usage is used for these purposes. Two-thirds (2/3) of the energy being used for these purposes could potentially be supplied by solar energy. Thus, the use of solar energy for buildings is a major untapped resource with the potential to supply 12% of California's total energy needs by 1995. Not all of this is necessarily economically justifiable. But, many individual markets are both economically attractive and of a scale that is significant to California Energy Policy.

(1) From the point of view of what is most economical for California as a whole, it would be justifiable to encourage consumers to make a 2-billion dollar investment in the least expensive solar energy systems over the next 10 years. Because the best solar applications are in the natural gas water heating markets, most savings would be of natural gas. The investment would contribute 38 to 55 bcf of natural gas annually in 1987; equivalent to about 3% of the current annual natural gas consumption. The larger contribution would be

possible if $6.50 collectors become available as we estimate. The investment would be split 50-50 between single- and multiple-family units. (Table ES-2).

(2) Under adverse conditions for price and availability of alternate fuels, an even larger investment may be justified. A 10-billion dollar investment over the next ten years, in the least expensive systems, would replace between 140 and 220 bcf equivalent of natural gas annually. (Table ES-2). This is 8 to 14% of the State's annual gas energy use and is equivalent to the supply capacity of some of the larger new gas supply projects such as the Arctic Pipeline or Indonesian LNG projects.

(3) To replace 10% of the 1975 natural gas usage of 1680 billion cubic feet, 7.9 million units must be equiped with solar space and water heating systems. Some retrofit of space heating must also be accomplished. If this were to be accomplished in a 10-year period, the cost is estimated to be $14.2 to 22.4 billion (Table ES-3) and $10 to 16 billion if accomplished in a 20-year period (Table ES-4).

(4) If all 2.6 million new residential units over the next 10 years have solar water heating, the result will be an estimated annual displacement of 1.8 billion kWh per year and 21.1 billion cubic feet per year (Table ES-3). The total cost would be $1.3 to 2.3 billion, depending on the speed with which anticipated cost reductions occur (see Section III). The $2.3 billion assumes current installation costs of about $900 per unit without future cost reductions.

(5) The use of solar water heating in all new residential buildings in the next 20 years could save 44 billion cubic feet of natural gas and 4.4 billion kWh of electricity annually (Table ES-4). This represents about 8% of the 1975 residential natural gas consumption (nearly 3% of the total gas consumption) and is about one third the size of new gas supply projects (Indonesia LNG, Arctic pipeline, etc.). The cost of solar water heating in all 5.7 million new units for the next 20 years is estimated to be between $2.8 and 4.7 billion (mostly from the private sector) depending on the speed with which cost reductions occur. About two thirds of these installations will be on multiple-family units.

(6) If all 2.6 million new residential units over the next 10 years are installed with both space and water heating, they will displace 4.9 billion kWh of electricity and 60.7 billion cubic feet of natural gas per year. The cost is estimated to be $4.8 to 8.0 billion. This is an $1800 to $3000 cost per unit. The space heating portion is between $1000 and $2000 because the energy conservation measures decrease collector areas needed for each installation (Table ES-3).

Table ES-2. Energy Displacement Potential From Two Alternative Large-Scale Investments in Solar Water Heating and Space Heating

Strategy	Total Energy Displaced			
	$6.50 Collectors		$19.50 Collectors	
	Billion kWh/yr	Trillion Btu/yr	Billion kWh/yr	Trillion Btu/yr
$2 Billion Investment in "Best Options" Multiple Family $1 Billion Single Family $1 Billion	16.0	54.6	11.0	37.5
$10 Billion Investment in "Best Options" Multiple Family $2 to 3.2 Billion Single Family $8 to 6.8 Billion	64.0	218	41.0	140.0

Table ES-3. Energy Displacement Potential for Various Large-Scale Solar Energy Applications for a 10-Year Time-Frame 1976-86

Strategy	Total No. of Installed Units, Millions	Annual Energy Displaced[a]				Total Installed Cost Range for $6.50 to $19.50[b] Billions of Dollars
		Electric, Billions kWh	Natural Gas, Billions cu. ft/yr	Total		
				Billion kWh/yr	Trillion Btu/yr	
All New Residential Water Heating	2.6	1.8	21.1	8.0	27.[illegible]	1.5 to 2.[illegible]
Retrofit All Residential Water Heating	5.2	1.7	59.1	19.0	64.8	4.6 to 7.[illegible]
All New Residential Water Heating and Space Heating	2.6	4.9	60.7	22.7	77.5	4.8 to 8.0
Replace 10% of 1975 Natural Gas Supply	7.9	-	168	49	168	14.2 to 22.4

[a]All energy displacements were determined after using energy conservation measures (see Section III). The displacements are for solar only and do not include additional, less expensive, displacements from energy conservation measures.

[b]1977 dollars.

Table ES-4. Energy Displacement Potential for Various Large-Scale Solar Energy Applications for a 20-Year Time-Frame 1976-96

Strategy	Total No. of Installed Units, Millions	Annual Energy Displaced[a]				Total Installed Cost Range for $16.50 to 19.50[b] Billions of Dollars
		Electric, Billions kWh	Natural Gas, Billions cu. ft/yr	Total		
				Billions kWh/yr	Trillion Btu/yr	
All New Residential Water Heating	5.7	4.4	45.7	17.2	58.7	2.8 to 4.7
Retrofit All Residential Water Heating	5.2	1.7	62.5	20.0	68.[illegible]	4.5 to 7.4
All New Residential Water Heating and Space Heating	5.7	11.8	120	47.1	161	11.2 to 16.9
Replace 10% of 1975 Natural Gas Supply	7.9	-	168	49	168	16.2 to 16.8

[a]All energy displacements were determined after using energy conservation measures (see Section III). The displacements are for solar only and do not include additional, less expensive, displacements from energy conservation measures.

[b]1977 dollars.

(7) Retrofit of all 5.2 million residential water heaters with solar will displace 1.7 billion kWh of electricity and 59.1 billion cubic feet of natural gas per year. The cost is estimated to be between $4.6 and 7.5 billion (Table ES-3).

E. INSTITUTIONAL FACTORS AFFECTING PRIVATE ECONOMIC DECISIONS TO USE SOLAR ENERGY

Solar energy systems for buildings face serious institutional problems. The most important institutional problem is produced by the current Public Utility Commission (PUC) practice of average cost pricing of natural gas and electricity. The practice insulates the consumer from the true costs of these new supply projects by averaging the cost of the "new" gas (or electricity) with the cost of "older" less expensive gas (or electricity). The practice distorts the energy marketplace and insulates the consumer from the true cost of new fossil fuel and electricity supplies; encouraging him to continue to purchase these conventional fuels and to ignore both energy conservation and solar energy alternatives. Still other problems are produced by the gas priority system, as well as real estate property tax and income tax laws which favor the use of conventional fuels at the expense of solar energy and other conservation techniques. The result is a policy quagmire.

(1) While the policy of basing the retail price of energy on the average wholesale cost minimizes the cost of natural gas and electricity to the consumer in the short run, it temporarily insulates him from the higher costs of new supplies for which he must eventually pay. This produces inefficient economic allocation of resources and produces a major barrier to the use of solar energy and other energy conserving technologies. The State needs to balance the humane policies which keep prices of energy low with policies which produce a more balanced use of energy.

(2) Both Federal and State income tax policies encourage consumers to purchase conventional electric and fossil fuel energy rather than equipment to capture energy from the sun (or equipment for conservation). Similarly, State property tax policies favor conventional fuel usage by consumers. Exemption of solar energy systems from California property taxes should be enacted while ways to mitigate the effects of other tax policies are developed.

(3) Lifeline rates and policies, giving top priority for natural gas to residential users, take natural gas away from high efficiency, industrial uses where solar energy is less economically attractive. The current priority system (while aiding hard pressed consumers) provides inexpensive gas at subsidized rates to low-temperature, low-efficiency applications where solar energy would otherwise be economically attractive. From a technical efficiency viewpoint, application of solar energy to these low-temperature residential and commercial markets would be a

better way to allocate energy use (Ref. 11). Allocation of solar energy to residential and commercial markets would save the high-temperature fuels for industrial markets where good substitutes are difficult to find. This allocation policy would tend to preserve the industrial tax and job base.

(4) Lack of clear regulations and definition of property rights cloud the individual decisions to adopt solar energy. Sun rights and building codes for solar energy are undefined in California. Conditions, covenants, and restrictions (CC&R) have already been used to block the use of solar energy systems in some areas of California. Uncertainty concerning regulation and rights undoubtedly will have an inhibiting effect on the rate of solar energy adoption unless remedial action is taken by the State of California.

F. MARKET FACTORS AFFECTING THE USE OF SOLAR ENERGY

Other institutional problems are produced by the fragmented nature of the building process and the attendant high costs of acquiring reliable information concerning solar energy (and energy conservation). These problems are related to the housing industry organization and attitudes, as well as the emerging characteristics of solar equipment suppliers.

(1) There are thousands of builder/developers in the country. The largest handles less than 1% of the building market.

(2) Builder/developers work in a highly leveraged environment and are generally conservative in what is a risky business. There is a resistance to high first-cost items even if the investment results in a lower life-cycle cost.

(3) The majority of building industry suppliers are highly specialized. One manufacturer supplies the furnace and another supplies the thermostat. Modular and mobile homes are the closest thing the industry has to a package product. Specialized contractors and subcontractors assemble manufactured products into complete living and working environments.

(4) The building industry needs to be assured of the realiability and performance of solar energy systems before they will be willing to take the risk of using them. The cost of entering the solar energy component manufacturing business is very low. Many of the components are high quality, but some are not. Poor choice and use of materials are sometimes made. None of the available special solar energy components have an in-service durability and performance history. There are needs for field testing, life testing, and careful evaluation of results. Consumer protection laws requiring the performance labeling of solar components should be adopted.

(5) Selecting components for complete systems requires specialized skill. There are hundreds of manufacturers of solar energy equipment in the country, but only a very few offer a complete system. A number of consulting firms have entered the market in response to the need for component evaluation, selection, and system design. But high quality, easy to use design information is not widely available. The State Energy Commission should continue to develop specialized design information handbooks and increase its efforts to disseminate this and related information.

G. MARKET DEVELOPMENT SCENARIOS

Forecasting the development of a market for new products is a very inexact science. But simplified models have been used to simulate the future use of solar energy in buildings under a variety of circumstances. These models incorporate JPL's best judgment concerning the impact of the major factors affecting individual decisions to adopt solar energy. The major insights provided by these models are:

(1) Without correcting the energy pricing, taxation, and allocation and other institutional policies that are currently shutting solar energy out of the market, solar energy is unlikely to contribute more than a fraction of a percent of California's energy-needs within a 20-year planning horizon. Solar water and space heating will be unable to compete in the strategically important "New Energy Market" until the early 1990s. At this point the average price of retail natural gas is expected to nearly equal the marginal cost of new gas supply projects.

(2) If these institutional policies are corrected and the State decides to launch a major program to encourage a $2-billion investment by consumers in solar energy, then there is a good chance that solar energy will supply a significant level of energy (greater than 3%) to California within 10 years. If successful, the program would produce annual savings from solar energy which are equivalent to a project 1/3 the size of new gas supply projects (e.g., LNG imports).

H. SOLAR ENERGY AND THE UTILITIES

Utilities are a potentially valuable asset to the State for encouraging rapid use of conservation and solar technologies. They have an existing contact with consumers which could be used to encourage the use of these "new" technologies. Utilities could help through promotion, warrantee, direct subsidy, and field test and demonstration of equipment. Utility purchase and/or ownership of solar energy could overcome the average cost problem and stimulate the rapid use of solar energy, provided that a favorable regulatory and legal climate is established toward their entering the solar energy field. In California, the use of solar energy is compatible with the existing utility system.

(1) Gas utilities can readily supply backup energy to solar energy systems because of their existing capabilities to store very large quantities of natural gas.

(2) Solar energy is also compatible with California's summer peaking electric utility system. By 1985, total California reserve generating capacity in the winter is projected to exceed the reserve capacity in the summer by 5900 MW. (see p. 5-27). 5900 MW of capacity could be used to supply electrical backup to approximately 700,000 solar heated homes or approximately 12,000,000 solar water heaters in single-family and multiple-family dwellings. For levels of solar energy usage above these levels, California would become a winter peaking utility area and additional solar energy penetration would contribute directly to the need for increased electrical generating capacity. Below these levels of solar energy usage, there would be some impact on the need for additional generating capacity to preserve the same reliability of service. This impact has not yet been estimated.

I. STRATEGIES FOR CALIFORNIA ACTION

While solar energy is not a realistic option for solving the energy-environmental dilemma being faced in the next two to five years, now is the time to act if solar energy is to be a realistic option for contributing to the solution of the dilemma to be faced 10 years from now.

Two parallel strategies are recommended for making solar energy a realistic option for the 1987-97 decade. They must be implemented now to be effective. The strategies are to use the private marketplace and to use the regulated marketplace. It is not clear at this time which of these strategies will be successful. Both paths have major obstacles to overcome, but for the most part these obstacles can be overcome by strong State action.

(1) Policy Options to Utilize the Private Marketplace

(a) Establish a marginal cost pricing system for conventional energy and solve the associated equity and administrative problems.

(b) Provide a 2-billion dollar fund for financing the most cost-effective applications of solar energy.

(c) Provide direct financial incentives amounting to 25 to 50% of the first cost of the solar energy equipment - solve the associated equity and administrative problems, decide on the mix between sales tax exemption, property tax exemption, tax credit, and low-interest loans. A 50% tax credit for the $2 billion package of least expensive solar options (cf: page ES-9) could be financed by a $.06/mcf tax on natural gas or a $.007/kWh tax on electricity for a period of 10 years.

(d) Establish State funded centers to disseminate information, evaluate projects, and actively assist building owners to use solar energy. The centers could be called "implementation centers" (Ref. 50). An average of 1-2 million dollars per year may be needed for funding an effective center, (equivalent to a $.001 per mcf tax on all natural gas sales).

(2) Policy Options to Utilize the Regulated Utility Industry

(a) PUC approval of a set of rules allowing utilities to own solar energy equipment and to offer an energy service to the consumer. The consumer would also be free to purchase a system from other than a utility company.

One possible set of rules would provide for:

- Granting certificates of necessity and convenience to a utility to supply solar energy to a given market in its own territory.
- Including the investment in solar energy equipment in the rate base.
- Setting rates for solar energy based on the average cost of solar and other energy.
- Contracting with developers for installation of equipment specified by the utility.
- Maintenance of equipment by the utility.

(b) Establish a regulatory and political climate conducive to utilities taking the initiative. If including the investment for solar energy in the rate base is not an adequate incentive to attract private capital to solar, then other incentives need to be proposed and evaluated; i.e., granting a direct incentive to utilities based on the number of installations achieved in a specific time period. Allow different corporate structures to exist which would provide for higher rates of return on capital invested in solar energy.

J. IN CONCLUSION

Solar energy for heating and cooling of buildings is currently technically feasible. Solar water and space heating is nearly economically competitive with retail electric rates and the marginal costs of several new gas supply projects. The scale at these applications of solar energy is comparable to the scale of new supply projects. However, institutional factors will retard the growth of solar energy and other energy conservation technologies unless strong policies are adopted by California.

SECTION I

INTRODUCTION

> O chestnut tree, great rooted blossomer
> Are you the leaf, the blossom or the bole?
> O body swayed to music, O brightening glance,
> How can we know the dancer from the dance?
>
> William Butler Yeats

The purpose of the report is to summarize an assessment of the potential of active solar energy systems for buildings in California. The potential of other solar energy applications such as agricultural crop drying and industrial process heat are not evaluated in detail in this report, although they appear to offer promise. An assessment of these other applications is being conducted by JPL in another study and results will be available in late 1977.

The report is divided into five major sections. The first four (Sections I, II, III, and IV) provide an introduction to the technical, economic, and institutional questions surrounding solar heating and cooling applications.

Section II discusses the technology used for solar heating, cooling, and water heating in buildings. This section also describes the characteristics of California buildings and the types of heating, cooling, and water heating systems which are currently being used in these buildings. Section II describes the major California weather zones and the solar energy designs. Finally, the sizing of solar energy systems and their performance is discussed.

Section III provides an assessment of the economics of solar heating, cooling, and water heating. The cost of solar energy systems is given both at current prices and at prices consistent with JPL's most optimistic estimate for the cost of collectors. These two prices yield a price range from the lower cost estimate associated with mass production of less expensive collectors to higher cost estimates associated with current solar collector production rates. The price range provides policy sensitive bounding conditions (from low cost to high cost) which will be useful for understanding the cost of a California policy to rapidly use solar energy. Section II also provides a summary of energy use for heating, water heating, and cooling in California, as well as a comparison of the cost of solar energy with the marginal cost of alternative energy supplies such as LNG, coal gasifications, nuclear energy, and coal.

Section IV summarizes the main institutional barriers to the wide spread use of solar energy. Institutional issues concerning the high first cost of solar energy and the problems imposed by average cost pricing of conventional fuels is described. Other institutional problems such as the differential tax advantages given to conventional sources compared to solar are also described.

In Section V the maximum potential for solar energy in buildings is examined. Solar energy applications are compared with estimated costs of other energy supply options such as coal gasification and LNG imports as well as with current fossil fuel and electric supplies and prices. The comparison is made in two ways: (1) at a fixed level of investment, e.g., how much energy a billion dollar investment in solar energy will supply compared to other alternatives and (2) at a percentage of replacement of existing energy sources, e.g., how much investment in solar energy will be required to replace 10% of the natural gas used for heating buildings?

The likely penetration of solar energy into the different heating and cooling submarkets is then examined using a "new product" market simulation model. The market simulation model uses historical rates of product substitution in the building industry and is consistent with the previous solar energy commercial sales experience in Florida (where over 60,000 solar water heaters were installed in the late 1930s prior to the rapid decrease in the retail price of electricity, cf Reference 32). The market penetration analysis indicates the time scale which will probably be required for widespread solar energy use assuming (1) that building owners use the historically conservative 5 to 7 year payback requirement (12 to 18% internal rate of return) before buying solar energy systems and (2) that there is no vigorous government program to encourage its use.

Taken together, the sections of this report will raise and at least partly answer a set of important questions concerning the potential role of solar energy in California buildings:

(1) What are the technical characteristics of active solar energy systems for heating, cooling and water heating? What types of solar collectors are available and how much energy will solar energy systems provide? (Section II)

(2) How do the costs of solar heating and cooling compare to those for fossil fuels in different building applications? (Section III)

(3) What market inequities and other barriers does solar energy face which warrant State action? (Section IV)

(4) What size investment in solar energy for buildings is required in order to replace a sizable fraction of California fossil fuel use and over what period of time can this be accomplished? (Section V)

(5) Using the historical rates of acceptance of new products in the building industry, what will be the likely market penetration of solar energy? What will be the impact of State or Federal financial incentives on penetration rates and how might the rates change under different assumptions concerning the future price and availability of fossil fuels in California? (Section V)

Specific conclusions and recommendations evolving from JPL's prior experience and the analysis described in this report are given. Future reports will perform the same function for industrial, commercial, and agricultural applications of solar energy.

SECTION II

SOLAR TECHNOLOGY AND APPLICATIONS

> O people! My people!
> Something weirdly architectural
> Like a rackety cannibal
> Came to Haarlem last night
> And ate up a canal!
>
> Gregory Corso

Solar energy systems have been classified into two types: active and passive. A typical active solar energy installation uses a flat plate (or concentrating) collector to gather solar energy. Water (or air) flowing through the collector picks up heat generated by the sun and stores it in a large tank (or rock bed). When heat is needed, for space or water heating or heat activated space cooling, the stored energy is taken out of the tank and delivered to the building. Although it is possible to design systems which provide 100% of the required heat from the solar energy system, in practice this is not economically justified (Ref. 3, 27). Most active solar energy systems provide 50-85% of the energy needed with the remaining percentage being supplied by a conventional natural gas or electric backup system.

In contrast, passive solar energy systems utilize the design of the building envelope to provide climate control with little or no mechanical equipment (passive techniques do not provide hot water). In a typical passive system, the flow of heat (or loss of "coolness" in summer) through the envelope of the structure is controlled either using design techniques such as louvered windows to control the flow of sunshine into the structure or using movable insulation panels and high heat capacity material like water to absorb, store, and radiate heat at appropriate times.

Although both types of solar energy systems have important applications, this report evaluates only the potential for active systems, for several reasons. First, active systems have greater promise for retrofitting existing buildings with solar energy. Second, the new California building standards already incorporate several passive techniques as design requirements; therefore, policy issues are somewhat moot although improved standards could help reduce energy use further. Finally, the economics and market potential for specific passive techniques have not yet been evaluated in either a consistent or complete way for California. We do recommend that a thorough evaluation of the potential for passive technique, given the new California building standards, be conducted in a framework which will allow the comparison of passive solar techniques both with each other and with active systems.

In order to develop a coherent assessment of the potential of solar energy for buildings in California, a technical analysis was performed. The analysis relied heavily upon work previously performed at JPL (Refs. 3, 5, 13) and was performed in four parts. In the first part, the California buildings were characterized both in terms of typical physical characteristics and in terms of the different heating, ventilating and air conditioning (HVAC) currently used. In parallel, the major weather zones in California were identified and the building populations were assigned to each zone. Third, solar energy system were designed for each major HVAC in each zone. Fourth, solar energy system performance was analyzed using the appropriate weather data and building characteristics in each weather zone. The result was a set of case studies of solar energy performance for each building type and each weather zone. The computer program was used to determine the optimum collector size for each case study analyzed. The end product was a technical evaluation of over 150 solar energy system variations on four types of buildings.

A. BUILDING POPULATION CHARACTERIZATION AND ANALYSIS

Four building types were studied: two residential buildings, a 2250 ft^2 single family building and a 9-unit 900 ft^2 per unit, multiple family dwelling; and two commercial buildings, a 6-story, 50,000 ft^2, curtain wall, bank and office building and a 3 story, 120,000 ft^2 department store.* The two residential building types were evaluated state wide, while the commercial buildings have only been evaluated for Southern and Central California (cf Ref. 3). However, since the internal heating and cooling loads of commercial buildings are less sensitive to the climate variations of the magnitude experienced in the populated areas of California, the evaluation presented in Reference 3 are applicable to the entire state.

As a first step in characterizing California buildings, the number of single family and multiple family units in each major California population area were determined. The population areas were determined from the 1970 California census (Ref. 40). The census defines 16 major California Standard Metropolitan Statistical Areas (SMSAs). The sixteen SMSAs are:

(1) Anaheim-Santa Ana - Garden Grove

(2) Bakersfield

(3) Fresno

(4) Los Angeles - Long Beach

(5) Modesto

(6) Oxnard-Ventura

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* These four buildings were chosen as "typical" of California existing buildings after reviewing several studies of building types and descriptions (see Ref. 13). Although the average single family building is about 1630 ft^2 the larger 2250 ft^2 building was chosen because JPL had actual heating and cooling performance data available from an instrumented 2250 ft^2 home. This data was used to calibrate a computerized model of the house.

(7) Sacramento

(8) Salinas-Monterey

(9) San Bernardino-Riverside-Ontario

(10) San Diego

(11) San Francisco-Oakland

(12) San Jose

(13) Santa Barbara

(14) Santa Rosa

(15) Stockton

(16) Vallejo-Napa

For each SMSA the number and percentage of residential units were identified as well as the ownership category. Table 2-1 gives this data. The first 9 columns present the data for residential buildings in each SMSA. The first column gives the total number of units. Columns 2 & 3 present the number and percent of residential units with warm air heating. The following three pairs of columns 4 to 9 give the number and percent of units with built-in electric heating, wall or pipeless furnace, or room heaters with a flue. Columns 10-18 present the same data as the first 9 columns for owner occupied units. Columns 19-27 give this data for renter occupied units. In addition, the type of fuel used for house heating and water heating are given for each SMSA (see Table 2-2). Using this data it is possible to obtain estimates of the types of HVAC equipment and fuels used in each of the representative buildings.

1. HVAC and Fuel Combinations

A description of the characteristics of the heating, cooling and water heating systems (called HVAC systems) and fuels they use is necessary in order to characterize the various submarket applications for solar energy. The characterization is complex since many combinations exist. Systems may have water and space heating functions only or they may include cooling. Each function (water heating, space heating or air conditioning) uses electricity or natural gas (wood, propane, and fuel oil, although currently used, were disregarded to reduce the complexity of the analysis). In addition, heat pumps may also be used instead of forced air or electric resistance heating. The result is 14 distinct combinations of functions and fuels as shown in the first column of Table 2-3 where the symbols represent the fuel, Electric (E) or Natural Gas (G) used for water heating, space heating and cooling in that order.

In order to fully characterize the submarkets for solar energy, the market saturation of each HVAC combination was estimated. Table 2-3 is an example of the JPL estimates of the HVAC market saturations for the South Inland weather

Table 2-1. Selected Heating Equipment Characteristics for State and SMSAs: 1970 (all numbers x 10^3)

	All Year-Round Units									Occupied Housing Units																			
										Owner Occupied										Renter Occupied									
	Total	Warm Air Furnace	% of Total	Built-In Electric Units	% of Total	Floor, Wall or Pipeless Furnace	% of Total	Room Heaters with Flue	% of Total	Total	Warm Air Furnace	% of Total	Built-In Electric Units	% of Total	Floor, Wall or Pipeless Fur.	% of Total	Room Heater with Flue	% of Total	Total	Warm Air Furnace	% of Total	Built-In Electric Units	% of Total	Floor, Wall or Pipeless Fur.	% of Total	Room Heater with Flue	% of Total
The State	6976	2455	35	469	7	2241	32	1064	15	3612	1799	50	138	4	1115	31	364	10	2960	554	19.	289	10	1013	34	634	21
STANDARD METROPOLITAN STATISTICAL AREAS																											
Anaheim-Santa Ana-Garden Grove	462	258	56	40.5	9	102	22	46.2	10	282	198	70	18.4	7	44.0	16	15.7	6	154	46.7	30	18.1	12	52.1	34	28.0	18
Bakersfield	110	33.7	31	3.00	3	47.1	43	11.6	10	60.5	24.5	40	1.40	2	25.2	42	4.31	7	41.1	7.87	19	1.06	2	18.9	46	5.97	14
Fresno	134	46.1	34	3.64	3	55.9	42	18.0	13	76.2	34.4	45	1.83	2	29.4	39	7.20	9	50.6	10.1	20	1.55	3	23.7	47	9.52	19
Los Angeles-Long Beach	2537	694	27	168	7	989	39	424	17	1179	495	42	30.1	3	481	41	118	10	1251	177	14	128	10	468	37	288	23
Modesto	65.1	20.8	32	2.99	4	27.4	[illegible]	9.93	15	39.5	16.2	41	1.73	4	16.0	40	4.12	10	22.6	3.80	17	1.11	5	10.3	45	5.17	23
Oxnard-Ventura	112	56.5	50	5.18	5	27.1	24	15.5	14	69.9	45.7	65	1.84	3	13.0	19	6.97	10	36.5	8.41	23	2.96	8	12.6	34	7.88	21
Sacramento	270	103	38	14.6	5	93.4	34	43.2	16	158	74.4	47	6.27	4	51.2	32	19.6	12	98.1	24.2	24	7.23	7	37.2	38	21.3	22
Salinas-Monterey	76.0	29.6	39	4.18	5	22.4	29	12.2	16	37.4	18.8	50	1.85	5	10.4	28	4.17	11	33.8	9.21	27	2.15	6	10.9	32	7.18	21
San Bernardino-Riverside-Ontario	418	145	35	21.5	5	146	35	66.8	16	231	105	45	8.43	4	75.4	33	30.2	13	131	27.3	21	8.41	6	56.6	43	27.9	21
San Diego	450	156	35	39.4	9	143	32	74.5	16	239	116	49	11.1	5	70.9	30	28.9	12	184	30.6	17	23.9	13	63.3	34	42.0	23
San Francisco-Oakland	1129	486	43	65.8	6	253	22	144	13	561	350	62	13.3	2	127	23	42.9	8	525	122	23	49.2	9	118	22	94.9	18
San Jose	336	175	52	27.7	8	80.1	24	34.5	10	199	134	67	5.31	3	38.4	19	12.5	6	124	35.2	28	19.2	15	38.7	31	20.7	17
Santa Barbara	88.8	40.0	45	7.55	8	23.2	26	12.6	14	45.1	28.6	63	2.28	5	8.69	19	3.83	8	38.8	9.84	25	4.52	12	13.2	34	8.09	21
Santa Rosa	77.2	26.5	34	5.68	7	23.0	30	13.3	17	43.7	19.8	45	2.74	6	12.2	28	5.75	13	24.2	4.94	20	1.82	7	8.87	37	5.84	24
Stockton	96.6	29.2	30	3.97	4	39.6	41	16.1	17	56.7	22.5	40	1.60	3	23.5	41	6.56	11	36.7	5.71	15	2.15	6	14.5	40	8.57	23
Vallejo-Napa	80.3	30.7	38	3.85	5	29.7	37	11.3	14	46.1	22.8	50	1.79	4	15.3	33	4.55	10	30.1	6.66	22	1.71	6	13.0	43	6.07	20

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Table 2-2. House and Water Heating Fuel Characteristics for State and SMSAs: 1970 (all numbers x 10^3)

	Total Occupied Housing	House Heating Fuel						Water Heating Fuel					
		Houses Using Utility Gas	% of Total	Houses Using Electricity	% of Total	Houses Using Both Tank or LP Gas	% of Total	Houses Using Utility Gas	% of Total	Houses Using Electricity	% of Total	Houses Using Bottled Tank or LP Gas	% of Total
The State	6574	5651	87	566	8.6	204	3.1	5740	87	581	8.8	210	3.2
STANDARD METROPOLITAN STATISTICAL AREAS													
Anaheim-Santa Ana-Garden Grove	436	389	89	42.4	10	2.78	0	392	90	39.2	10	4.03	0
Bakersfield	102	88.3	87	4.93	5	6.93	7	89.4	88	5.52	5	5.94	6
Fresno	127	102.4	81	8.57	7	12.7	10	103	81	10.2	8	12.3	10
Los Angeles-Long Beach	2432	2191	90	187	8	19.1	1	2247	92	142	6	32.3	1
Modesto	62.1	52.2	84	4.63	7	4.13	7	50.3	81	8.72	14	2.47	4
Oxnard-Ventura	107	97.2	91	5.90	5	1.67	1	97.4	91	6.88	6	1.76	2
Sacramento	256	219	86	21.2	8	10.8	4	210	82	34.2	13	9.88	4
Salinas-Monterey	71.2	60.1	84	6.59	9	3.14	4	61.3	86	6.61	9	3.00	4
San Bernardino-Riverside-Ontario	362	314	87	26.8	7	14.4	4	315	87	31.2	9	13.9	4
San Diego	424	355	84	46.4	11	13.8	3	364	86	43.9	10	12.9	3
San Francisco-Oakland	1086	961	88	83.0	8	15.8	1	996	92	58.4	5	23.2	2
San Jose	323	283	88	31.8	10	4.87	2	293	91	21.9	7	6.62	2
Santa Barbara	83.9	72.3	86	7.74	9	2.57	3	72.9	87	8.57	10	2.21	3
Santa Rosa	67.9	54.1	80	6.25	9	5.06	7	53.4	79	9.10	13	4.82	7
Stockton	93.4	78.1	85	6.15	7	6.34	7	78.5	85	7.67	8	5.56	6
Vallejo-Napa	76.2	66.7	88	4.98	7	3.35	4	66.9	88	5.41	7	3.45	4

Table 2-3. Heating, Cooling and Water Heating Market Saturation Statistics for Single Family Buildings in the Inland Zone

HVAC System Mix*	Existing Systems 1975	New Systems	
		1975	2000
Water Heating and Space Heating Only	85%	65%	35%
E-E	(0.07)	(0.15)	(0.55)
E-G	(0.02)	(0.05)	(0.05)
G-E	-	-	-
G-G	(0.91)	(0.80)	(0.45)
Water Heating, Space Heating, and Space Cooling	15%	35%	65%
E-E-E	(0.15)	(0.25)	(0.25)
E-E-G	-	-	-
E-G-E	-	-	-
E-G-G	-	-	-
E-HP-HP	(0.15)	(0.25)	(0.25)
G-E-E	(0.10)	(0.10)	(0.10)
G-E-G	-	-	-
G-G-E	(0.35)	(0.25)	(0.25)
G-G-G	(0.05)	(0.00)	(0.00)
G-HP-HP	(0.20)	(0.15)	(0.15)

*Note: E = electric; G = gas; HP = heat pump. In this table (and subsequent tables as applicable) HVAC systems are identified by combinations of these symbols, used without column headings, and indicating functions in the following order: water heating, space heating, space cooling.

Table 2-4. Equipment Characteristics for Areas: 1970 (all numbers x 10^3)

Standard Metropolitan Statistical Areas	Anaheim-Santa Ana-Garden Grove	Bakersfield	Fresno	Los Angeles-Long Beach	Modesto	Oxnard-Ventura	Sacramento	Salinas-Monterey	San Bernardino-Riverside-Ontario	San Diego	San Francisco-Oakland	San Jose	Santa Barbara	Santa Rosa	Stockton	Vallejo-Napa
	Total	Total	Total	Total	Total	Total	Total	Total	Total	Total	Total	Total	Total	Total	Total	Total
AIR CONDITIONING																
All year-around units	462	109	134	2 536	65.0	111	270	76.0	417	449	1 129	336	88.0	77.0	96.0	80.0
Room unit:																
1	64.0	9.00	19.0	435	20.0	5.00	96.0	0.641	105	34.0	44.0	16.0	1.00	4.00	32.0	10.0
2 or more	6.00	1.00	3.00	70.0	2.00	0.874	15.0	0.070	20.0	4.00	6.00	1.00	0.112	0.459	5.00	0.929
Central system	29.0	26.0	38.0	182	13.0	5.00	62.0	1.00	98.0	16.0	30.0	10.0	1.00	3.00	16.0	6.00
None	369	71.0	72.0	1 847	28.0	99.0	96.0	74.0	193	394	1 048	306	86.0	69.0	42.0	62.0
HEATING EQUIPMENT																
All year-around units	462	109	134	2 536	65.0	111	270	76.0	417	449	1 129	336	88.0	77.0	96.0	80.0
Steam or hot water	2.00	1.00	0.960	53.0	0.364	0.704	2.00	1.00	2.00	6.00	124	9.00	1.00	0.807	2.00	0.968
Warm-air furnace	234	33.0	46.0	693	20.0	56.0	103	29.0	145	155	485	174	39.0	26.0	29.0	30.0
Built-in electric units	40.0	2.00	3.00	167	2.00	5.00	14.0	4.00	21.0	39.0	65.0	27.0	7.00	5.00	3.00	3.00
Floor, wall, or pipeless furnace	103	47.0	56.0	989	27.0	27.0	93.0	22.0	145	143	252	80.0	23.0	22.0	39.0	29.0
Room heaters with flue	46.0	11.0	18.0	424	9.00	15.0	43.0	12.0	66.0	74.0	144	34.0	12.0	13.0	16.0	11.0
Room heaters without flue	6.00	7.00	3.00	99.0	1.00	2.00	5.00	2.00	11.0	11.0	23.0	5.00	1.00	1.00	1.00	1.00
Fireplaces, stoves, or portable heaters	5.00	4.00	4.00	79.0	2.00	3.00	6.00	3.00	19.0	16.0	22.0	3.00	2.00	5.00	2.00	1.00
None	1.00	0.934	1.00	28.0	0.464	1.00	0.656	0.544	5.00	3.00	9.00	0.534	0.711	0.402	0.873	0.155
Owner occupied	282	60.0	76.0	1 179	39.0	69.0	157	37.0	231	238	561	199	45.0	43.0	56.0	46.0
Steam or hot water	1.00	0.544	0.233	8.00	0.128	0.288	0.874	0.426	0.738	1.00	15.0	5.00	0.234	0.364	0.458	0.284
Warm-air furnace	198	24.0	34.0	494	16.0	45.0	74.0	18.0	104	116	349	134	28.0	19.0	22.0	22.0
Built-in electric units	18.0	1.00	1.00	30.0	1.00	1.00	6.00	1.00	8.00	11.0	13.0	5.00	2.00	2.00	1.00	1.00
Floor, wall, or pipeless furnace	44.0	25.0	29.0	481	15.0	13.0	51.0	10.0	75.0	70.0	127	36.0	8.00	12.0	23.0	15.0
Room heaters with flue	15.0	4.00	7.00	118	4.00	6.00	19.0	4.00	30.0	28.0	42.0	12.0	3.00	5.00	6.00	4.00
Room heaters without flue	1.00	2.00	1.00	18.0	0.431	0.876	1.00	0.622	4.00	2.00	4.00	1.00	0.512	0.703	0.786	0.582
Fireplaces, stoves, or portable heaters	2.00	1.00	1.00	25.0	0.914	1.00	3.00	1.00	6.00	7.00	7.00	1.00	0.926	2.00	1.00	0.714
None	0.354	0.133	0.145	3.00	0.059	0.184	0.106	0.090	0.594	0.748	0.597	0.092	0.124	0.035	0.139	0.020
Renter occupied	154	41.0	50.0	1 251	22.0	36.0	96.0	33.0	130	183	524	123	38.0	24.0	35.0	30.0
Steam or hot water	1.00	1.00	0.657	40.0	0.226	0.369	1.00	0.944	1.00	4.00	100	3.00	0.690	0.361	1.00	0.609
Warm-air furnace	46.0	7.00	10.0	177	3.00	8.00	24.0	9.00	27.0	30.0	122	35.0	9.00	4.00	3.00	6.00
Built-in electric units	16.0	1.00	1.00	127	1.00	2.00	7.00	2.00	8.00	23.0	49.0	19.0	4.00	1.00	2.00	1.00
Floor, wall, or pipeless furnace	52.0	18.0	23.0	467	10.0	12.0	37.0	10.0	8.00	65.0	117	38.0	13.0	8.00	14.0	13.0
Room heaters with flue	27.0	5.00	9.00	288	5.00	7.00	21.0	7.00	27.0	42.0	94.0	20.0	8.00	5.00	8.00	6.00
Room heaters without flue	4.00	3.00	2.00	76.0	0.733	1.00	3.00	1.00	5.00	7.00	18.0	3.00	1.00	0.703	0.894	1.00
Fireplaces, stoves, or portable heaters	2.00	1.00	2.00	50.0	0.976	1.00	2.00	1.00	5.00	7.00	15.0	1.00	0.906	1.00	1.00	0.736
None	1.00	0.476	0.804	22.0	0.328	0.914	0.347	0.377	1.00	2.00	7.00	0.390	0.456	0.136	0.620	0.106

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zone (see sub-section B for a definition of weather zones used in this study). The Table is composed of three different estimates. First, estimates of the fraction of existing buildings with each HVAC combination were made using data available from three sources - Southern California Edison, Reference 2 by Berman, and the 1970 California Census. Estimates were made both for buildings with and without air conditioning and for the fuel (gas or electric) used to provide each function. For example in Table 2-3, 7% of the non-air conditioned units use electric water and space heating, 2% use electric water heating and natural gas space heating, negligible numbers use gas water heating and electric space heating, and 91% use gas for both space heating and water heating.

Second, the HVAC combination fractions were estimated for the new buildings in 1975 and third, for the new buildings in 2000. this set of 48 estimates (16 for existing, 16 for new 1975 and 16 for new 2000) formed the core of the JPL estimate for the potential size of each submarket for specific solar energy systems. Each potential solar energy submarket, in theory, requires a separate solar energy design. In practice, several submarkets were combined so that fewer energy designs were needed. Even so, over 51 solar energy systems were designed for the single family analysis. The cost for each of these systems were then estimated. (cf section II for an example.)

The multiple family building market is more complex than the single family market. In addition to the building variations between insulated and non-insulated, and the weather dependent HVAC loads, the types of conventional HVAC systems are much more varied. A multiple family residence may have a central space heating or distributed space heating system, hot air or hot water system, gas or electric energy source, or hydronic heat pumps. By eliminating solar air conditioning from consideration the total market was simplified and represented by 19 building/HVAC types and three weather zones. A total of 114 variations on solar systems were allowed to penetrate into the multiple family. Capacity and cost varied with basic HVAC function, building construction, weather zone and new or retrofit installation. The energy savings was calculated "at the meter" and the differences in end use efficiency of various HVAC equipment types was taken into account.

2. Physical Characteristics of Buildings

The physical characteristics of California residential buildings are extremely diverse. Using data available from the National Association of Home Builders Research Foundation, the American Institute of Architects and others (Refs. 42-48), two building descriptions were developed-one for single family and the other for multiple family buildings.

Although single family units exist in a wide variety of different designs, most units range between 900 ft^2 and 2500 ft^2. Furthermore most have 25 percent of glass area. Most have only minimal insulation in the ceiling and generally none in the walls and use natural gas for heating and water heating. (All electric units are better insulated however). A typical unit averages 1630 ft^2 with stucco and wood frame design. Infiltration is typically 225 cubic feet per minute (one air change per hour). Lighting loads are about 3/4 watt per ft^2 when occupied at night (before midnight). Non-lighting appliance usage is about 16 kWh per week and hot water usage is about 80 gal/day. The representative building chosen for the JPL analysis differed from this "typical" building. It had 2250 ft^2 of flow area with 6 inches of fiberglass insulation in the ceiling.

It was chosen for analysis because it was reasonably close to the "average" and we had performance data available for the representative building. The description of this building is given in Table 2-5.

Multifamily buildings also have a wide variety of designs. Most units range between 600 ft^2 and 1600 ft^2. Most have 25% glass area for windows and six inches of insulation in the ceiling. Most utilize natural gas for space heating and water heating, although electric heating and water heating is used in over 25% of the units in some parts of the State. Infiltration is generally one air change per hour (120 cfm for a 900 ft^2 unit). Lighting and appliance loads are similar to the single family unit. The representative building chosen for the JPL analysis was a two-story, 9-unit apartment building with 900 ft^2 per apartment (see Table 2-6).

3. Conservation Packages

Many California buildings do not have adequate insulation, and yet the addition of this insulation (and a few other conservation techniques) is cost effective. Furthermore, the addition of conservation in buildings alters the solar energy sizing and adversely affects solar economics (it lowers the total cost required but also makes the payback period for the investment in solar energy longer). The JPL team adopted a philosophy of adding conservation where feasible to existing buildings and assuming that all new buildings would utilize even better conservation techniques. Solar energy systems were then added after the conservation.

Energy-conserving packages can take many forms ranging from simple thermostat adjustments to fully insulated buildings with highly efficient HVAC units. Greatest returns are achieved when conservation is integrated into new building construction. In theory, old buildings can be equally well insulated but, in practice, costs become excessive. Therefore, in the insulation packages conceived for this study, existing or old buildings were assumed to have been treated with a minimum package while new buildings were assumed to have more extensive insulation. Energy-conserving savings are therefore mostly applicable to new buildings. Conservation packages were developed for each building type - one package for existing buildings and one for new buildings. Table 2-7 summarizes these conservation packages for single family buildings.

A dramatic demonstration of the effect of an energy-conserving package is shown in Table 2-8. The comparison shows annual heating load for a Single Family Building with and without the conservation package. The conservation package reduces the annual heating load by 50 to 70% depending on the weather zone.*

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* It should be noted here that the results of the JPL model show a greater conservation effect from adding 4 inches of insulation in the walls and reducing infiltration loss modestly than other models show. This is produced because the JPL model includes insolation through windows and walls in the winter. The net effect is to reduce the overall heating requirement in the JPL model compared to other methods which utilize a degree day method and so not include winter solar gains for heating. The net effect is that the JPL conservation package makes a larger percentage impact than that calculated from other methods.

Table 2-5. Typical Single-Family Building

Location: Tarzana
Type: Single family
2250 ft^2 (56 x 39 x 8)

A. Floor Plan: 56 x 39 x 8 ft
B. Orientation: See diagram
C. Roof: White rock (30% slope)
D. Insulation:
  1. Roof: 6 in. fiberglass
  2. Walls: Stucco (5/8 in.) + 1/2 in. lath plaster + no insulation + 1/2 in. stucco
  3. Floor: Wood foundation, 3/4 in. carpet

E. Windows:
  1. Exterior walls: 204/1520 or 20%
  2. Sliding glass doors: 126 ft^2

F. Infiltration: 300 cfm
1400 cfm blower about 10% outside 3 hours/day

G. Internal Load:
  1. People: 4 people, 2 people (10 a.m.-6 p.m.); 4 people (6 p.m. - 10 a.m.)
  2. Lights: 3/4 watts/ft^2, none (10 a.m. - 6p.m.); full (6 p.m. - 12 p.m. and 6 a.m. - 12 p.m. and 6 a.m. - 10 a.m.); none (12 p.m. - 6 a.m.)
  3. Utilities: Gas heater (120,000 Btu), electric air (5 ton)
  57% efficient at 1400 cfm without distribution losses
  Hot water - 80 gal/day

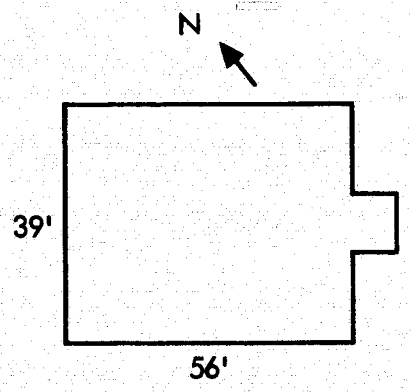

Table 2-6. Typical Multi-Family Building

Location: Inglewood

Type: Rectangular, 9 units/2 stories, stucco, 910 ft^2/unit (28 x 32) (approximately)

A. Floor Plan: 64 x 56 x 8 ft

B. Orientation: Long side north/south

C. Roof: Flat and built up

D. Insulation:

1. Roof: Built up - 6 in. batts + 1/2 in. plywood ceiling + 1/2 in. plaster + 1/4 in. topping
2. Exterior Walls: Stucco (5/8 in.) + 1/2 in. batts + 1/2 in. dry wall
3. Foundation/Floor: Carpeting (pad 3/4 in.) Slab (3.5 in. concrete)

E. Windows:

1. Walls: 25% evenly distributed (for energy conservation: Fully shaded east/west windows by exterior shade)
2. Sliding glass doors: 35 ft^2/unit (drapes will be used about half of the time)

F. Infiltration: 120 cfm (1 air change/hr) per unit

G. Internal Heat Loads:

1. People: 2.1 people/unit, distribution: Half day/full night
2. Lights: 3/4 watts/ft^2, 0.08 watts/ft2 (midnight to 6 a.m.), 0.25 watts/ft^2 (6 a.m. - 5 p.m.), 3/4 watts/ft^2 9 p.m. - 12 p.m.)
3. Utilities: 9.4 kWh/day average all day
   All electric: Radiant cable, no air, range, water heater, refrigerator, disposal; 42 gal/day hot water

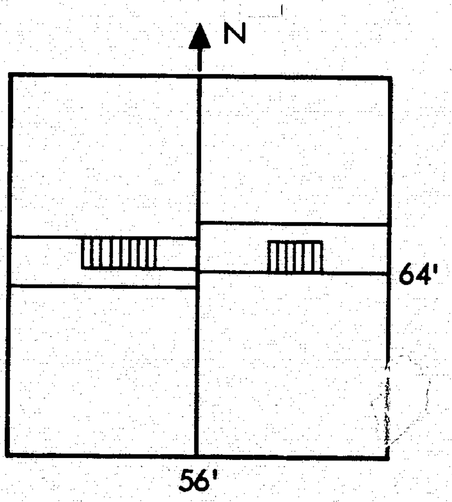

Table 2-7. Energy Conservation Building Summary

Basic Description: Wood frame, 1 story, stucco 2250 ft^2, sloped roof, wood floor, carpeted

Thermal Variable	Thermal Model Value	
	Nonconserving Existing Building	Energy-Conserving Package for New Buildings
Insulation*		
Ceiling	6 in.	6 in.
Walls	----	4 in.
Floor	----	----
Windows	20% single pane	No change
Infiltration	300 cfm	225 cfm + outside air for cooling when $T_{AMB} < 75°F$
Thermostat		
Heating	70°F	70°F
Cooling	75°F	75°F
Internal Loads	0.75 $watts/ft^2$	No change

*Insulation: Rock wool with k = 0.31 Btu/hr ft^2/in.
Note: Please see Note on p. 2-9.

Table 2-8. Annual Heating Load for the Single Family Building

Zone	Annual Heating Load (kWh)		% Reduction
	Without Energy-Conserving Package	With Energy-Conserving Package	
I. North Coastal/ Inland and Central Valley	31,040	14,700	53%
II. South Coastal	18,600	5,422	71%
III. South Inland Valley	18,700	5,747	69%

4. Building Stock Estimates

To estimate the number of residential buildings available for solar energy in 1995, JPL developed a method for estimating growth rates separately for single family and multiple family building units. A brief description of this procedure is given here. The details of the method and the particular assumed numbers are given in Reference 13, 49.

The method consists of the following procedure: first, the 1970 existing single family and multiple family units were estimated for each weather zone in the State. These estimates were obtained from the 1970 California census (Reference 40) data. Second, the rate of construction of new units was estimated for each zone (one estimate for single family and one for multiple family). This was accomplished by using the annual new building figures for 1971, 1972, 1973, 1974 and 1975 published by Security Pacific Bank (Reference 41). The individual annual growth rates were exponentially averaged to obtain a five year annual new construction growth rate for each weather zone - one estimate for single family and one for multiple family units. The results of these estimates are shown in Table 2-9.

Third, the annual rate of demolition or removal (death rate) of existing buildings was estimated.

In summary, three numbers for each zone and each type of building unit were estimated for the JPL model. They are:

(1) The existing number of existing units in 1970.

(2) The annual growth rate of new construction addition to the units.

(3) The annual death rate of existing units demolished.

Although these numbers were estimated individually for each zone, it is possible to determine the average birth and death rate estimates for each type of building unit by weighing the individual estimates in each zone by the fraction of the number of units in each zone. The result is an assumed average annual single family new additions growth rate of 2.1% for single family units and 4.4% for multiple family units. The demolition rate used was 1% for single family and 1% for multiple family. The 1975 number of single family units was 5.2 million and the number of 1975 multiple family units was 2.6 million. These numbers are shown in Table 2-10. The average annual new additions rate for all residential units is 3.14% with a 1% demolition rate.*

B. WEATHER ZONES

The weather zones were defined in two ways. First, seven major weather zones for California were defined. They were:

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* The JPL method of utilizing historical construction patterns was required to adequately estimate the potential of solar energy in California. The difference between the Commission net growth rate figure of 1.6% net (10.7 million units in 1995) and the JPL estimate of 2.14% net (12.1 million units) yields a difference of 1.4 million units in 1995 assuming both procedures began with 7.8 units in 1975.

Table 2-9. Residential Units (all numbers x 10^3)

	1970							1975										
										Single Family Dwelling Units			Multiple Family Dwelling Units					
	Total Dwelling Units	Single Family Dwelling Units	% of Total	Multiple Family Dwelling Units	% of Total	Mobile Homes or Trailers	% of Total	Total Dwelling Units	Five Year Average Annual Growth Rate	S.F. Units	% of Total	Five Year Aver. Annual Growth Rate	M.F. Units	% of Total	Five Year Aver. Annual Growth Rate	Mobile Homes or Trailers	% of Total
South Coastal	3650	2320	63	1250	34	85	2	4050	2.1	2510	62	1.6	1540	38	4.1		
North Coastal	1280	781	61	486	38	16	1	1430	2.2	861	60	2.0	566	40	3.1		
North Inland	416	293	70	111	27	14	3	485	3.1	343	71	3.2	142	29	5.0		
North Central Valley	432	331	77	88	20	14	3	511	3.4	381	75	2.9	130	25	8.1		
South Central Valley	244	204	84	33	13	8	3	276	2.5	225	81	2.0	51	18	9.1		
High Desert	418	331	79	62	15	26	6	465	2.1	378	81	2.7	87	19	7.0		
Outside SMSA's	535	486	91	63	11	21	3	673	4.7	500	74	0.57	91	14	7.6		
State Total	6980	4700	67	2100	30	184	3	7800	2.2	5200	67	2.1	2600	33	4.4		

Table 2-10. JPL Estimates of Residential Building Units

Table 2-10. JPL Estimates of Residential Building Units

Type of Unit	Millions of Units		Average Annual New Additions	Average Annual Demolitions	Millions of Units 1995	Average Net Annual Growth Rate
	1970	1975				
Single[1] family	4.70	5.2	2. %	1.0%	6.4	1.04%
Multiple family	2.10	2.6	4.4%	1.0%	5.1	3.4%
All Residential[2] Actual	6.80[2]	7.8	3.0%	1.0%	11.50	2.0%

[1] Population weighted average of single family and multiple family

[2] Excludes mobile homes which numbered 184,000 units in 1970.

(1) North Coastal,

(2) North Island,

(3) North Central Valley,

(4) South Central Valley,

(5) High Desert,

(6) South Coastal,

(7) South Inland.

Each of the sixteen SMSAs was included in one of the seven weather zones. Weather stations were defined for each of the zones. The cooling degree days, heating degree days and insolation for each station were determined as well as relevant weather data for January and August. This data is shown in Table 2-11.

By comparing the weather data for these stations, a characteristic weather station was defined for each zone. Annual heating degree days for many locations in California are shown in Figure 2-1. The locations are also grouped according to the SMSA regions. The North Coast and San Joaquin Valley areas group around 3000 heating degree days per year and can be represented well by Edwards (high desert) winter weather data. Summer loads for these areas are not like Edwards and air conditioning systems then will not be similar. However, from other studies (Ref. 5) we know that current designs of solar air conditioning systems are not economically attractive. An economically viable solar air cooling system does not now exist. Therefore, if solar cooling options are excluded from the buildings in the central valley and North coastal regions, a large building population can be studied using Edwards weather data and system designs.

Using the 1970 census data, the building population data including the HVAC mixes was combined with the weather zone information (see Table 2-12). Finally using the analysis, the seven original zones were collapsed into three major zones. Table 2-13 summarizes the data for these three final weather zones. The table includes a description of the characteristic weather station used for each zone, the number of single or multiple family units in each zone, and the type of fuel used in single family ~~heating~~ systems for each zone.

C. SOLAR ENERGY SYSTEM DESIGN

1. Design Specifications and Cost Estimates

The solar energy system costs were estimated in three steps. First, the system was designed and a detailed system specification was prepared. Figure 2-2 shows one schematic diagram for a heating and cooling system. Second, since much of the solar energy system costs are for conventional components (e.g., pipe, insulation, tanks), the costs of the conventional equipment was estimated using the 1974 Dodge manual and the 1974 National Construction Estimator (Ref. 29 and 30). Third, the costs of the solar energy collectors were estimated. The details of the cost estimating procedures are described in Section III. Because of the importance of the solar collector technology assumptions to the solar heating and cooling systems, a brief summary of the key collector related assumptions and findings will be discussed in this section.

Table 2-11. Seven Weather Zones and Characteristic Weather Station Data

						January			August		
Weather Regions	SMSA Areas Included	Weather Stations	Total Average Cooling Deg. Days (1)	Total Average Heating Deg. Days (2)	Total Yearly Average Insolation (4)	Heating Degree Days (1)	Amb. Temp	Inso-lation (4)	Cooling Degree Days (3)	Amb. Temp	Inso-lation (4)
A. North Coastal	San Francisco-Oakland Santa Rosa Salinas Monterey	San Francisco	108	3042	NA	518	48.3	741	22	63.0	1980
		Oakland	128	2909	1445	508	48.6		28	63.5	
		Santa Rosa	315	3065	NA	586	46.1		18	67.0	
		Salinas	74	2959	NA	465	50.0		16	62.5	
B. North Inland	San Jose	San Jose	444	2416	1519	481	49.5	723	111	68.1	2044
	Vallejo-Napa	Napa	374	2769	NA	546	47.4		85	67.2	
C. North Valley Central	Modesto Sacramento Stockton	Sacramento	1159	2843	1611	617	45.1	472	286	74.1	2253
		Stockton	1259	2806	1707	632	44.6		323	76.7	
D. South Central Valley	Fresno	Fresno	1671	2680	1615	611	45.3	724	412	78.3	2183
	Bakersfield	Bakersfield	2179	2185	1569	543	47.5	706	515	81.6	2164
E. High Desert	San Bernardino	San Bernardino	1557	2254	1519	403	52.0	839	409	78.2	2014
	Riverside	Edwards	565	3344	1652	722	41.7	169	169	79.9	2141
F. South Coastal	San Diego Los Angeles-Long Beach Santa Barbara	San Diego	722	1507	1540	314	552	892	201	71.4	1908
		Los Angeles	615	1819	1404	331	54.5	844	154	69.5	1940
		Santa Barbara	386	2110	1534	371	53.2	856	99	67.5	1944
		Santa Maria	84	3033	1748	450	505	973	18	62.3	2249
G. South Inland	Oxnard-Ventura Los Angeles-Long Beach	Burbank	1179	1701	1582	356	53.7		301	74.6	

NOTES: (1) 65°F Base; (2) 65°F Base; (3) 75°F Base; (4) Btu/ft^2/day on a horizontal surface

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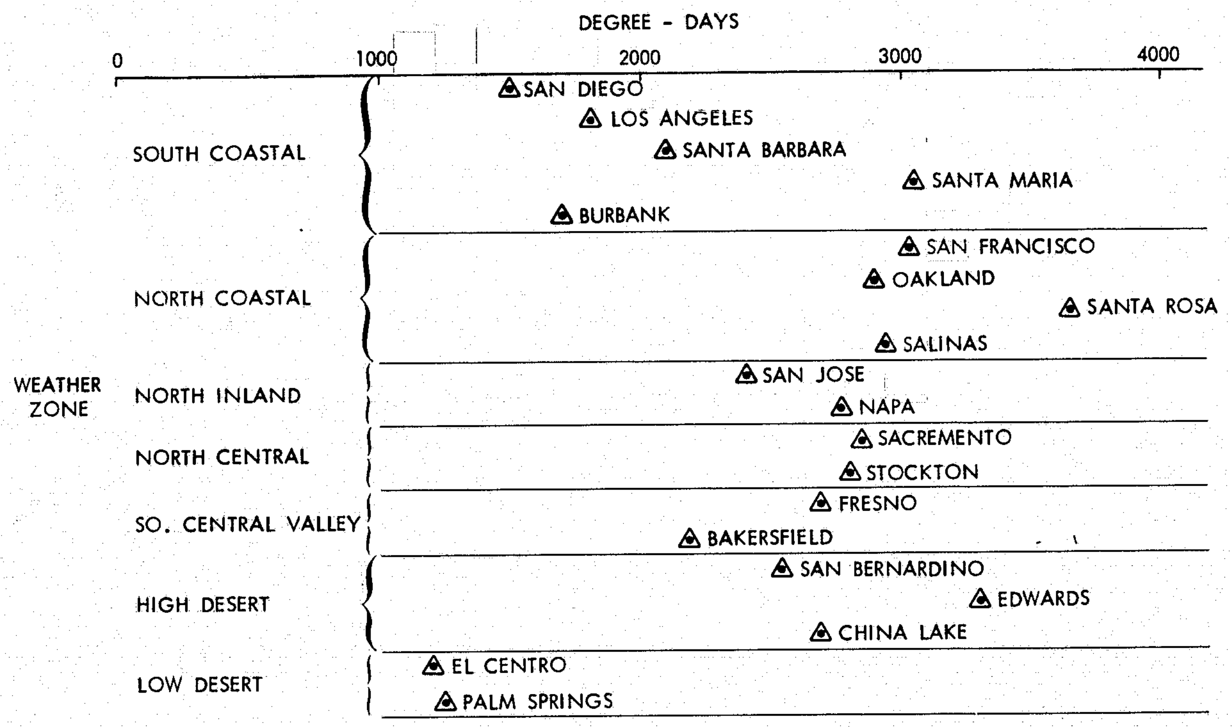

Figure 2-1. Comparison of Heating Degree Days

Table 2-12. Weather Zone and Building Data

Weather Zone	SMSA Areas Included	Characteristic Heating	Weather Station Cooling	No. of Buildings 1975				All Units			Single Family			Multi Family		
				Single Family		Multi-Family										
				No. x 10^3	Growth Rate %	No. Units	Growth Rate %	Central Air %	Gas SH & WH %	Elec. SH & WH %	Warm Air %	Gas SH & WH %	Elec. SH & WH %	Warm Air %	Gas SH & WH %	Elec. SH & WH %
North Coastal	San Francisco - Oakland Santa Rosa Salinas - Monterey	Edwards	No Cooling	816	2.0	566	3.1	3	88	8	60		3	24		9
North Inland	San Jose Vallejo-Napa	Edwards	No Cooling	343	3.2	142	5.0	4	88	9	64		3	27		14
North Central Valley	Modesto Sacramento Stocton	Edwards	Edwards	381	2.9	130	6.1	26	85	8	44		4	22		6
South Central Valley	Fresno Bakersfield	Edwards	Edwards	225	2.0	51	9.1	30	84	6	43		2	20		3
High Desert	San Bernardino - Riverside	Burbank	Burbank	378	2.7	87	7.0	26	87	7	45		3	21		7
South Coastal	Anaheim - Santa Ana Los Angeles - Long Beach	37% Los Angeles	37% Los Angeles	930	5.7	569	7.6	11	89	8	49		4	16		11
South Inland	Oxnard Ventura San Diego Santa Barbara	63% Burbank	63% Burbank	1560	1.6	968	4.1	"	"	"	"		"	"		"
MTS & Misc.	Outside SMSA	-	-	500	0.6	91	7.6	20	60	15	33		10	9		6
State Total	Total Units =	7800 x 10^3	2.2% growth rate	5200	2.1	2600	4.4	13	86	9	50	96	4	18	91	9

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Table 2-13. Final Weather Zone Data Summary

	Characteristic Weather Station		Units No. of Buildings, 1975				All Units	% Gas WH & SH	% Elec.
			Single Family		Multiple Family				
Zone	Heating	Cooling	No. x10^3	Growth Rate %	No. x10^3	Growth Rate %	x10^3		
1a. North Coastal/ Inland	Edwards	None	1160	2.3	708	4.2	1870	88	8
1b. Central Valley	Edwards	Edwards	606	2.5	185	8.3	791	85	7
2. South Coastal	Los Angeles	Los Angeles	930	1.6	569	4.3	1500	89	8
3. South Inland Valley	Burbank	Burbank	1960	1.9	1060	4.5	3010	88	8
Mountains & Miscellaneous	-	-	500	.6	91	7.6	591	60	15
Total Calif.			5200	2.1	2600	4.4	7800	86	9

NOTE: Because zone 1a and 1b utilize the same characteristic weather station, they were combined into one zone for convenience.

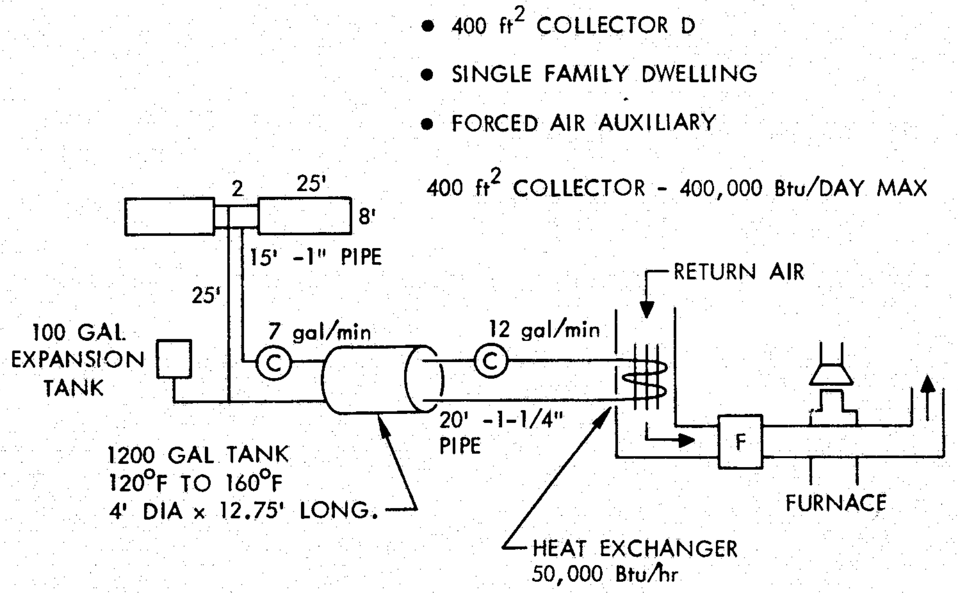

Figure 2-2. Schematic Diagram of a Solar Hydronic Heating System

2. Collector Types and Costs

Most flat plate collectors may be categorized generally into the following four classes:

Class A: Flat black absorber with glazing envelope.

Class B: Selective coating absorber with evacuated glazing envelope.

Class C: The swimming pool type which has no glazing envelope.

Class D: Selective coating absorber with air filled glazing envelope.

These four basic types are illustrated in Figure 2-3 as collectors A through D.

To illustrate the four classes of flat plate collectors and to provide baseline references, four collector designs are considered in this study. Each collector is considered to be representative for the characteristic performance of its own class. Collector A is equipped with a flat absorber and double glazing. The baseline design is described in Reference 36. Collector B has a selective black absorber in an evacuated single-pane glass envelope. It represents the upper limit for the performance of non-tracking flat plate collectors. The performance characteristics are described in Reference 37. Collector C is a collector with flat black absorber and no glazing envelope (Reference 38). Collector D has a selective black absorber and a double-pane glass cover. The design details and performance tests are described in Reference 39.

Collector A represents the state-of-the-art of 1974 technology and is suitable for space and water heating applications (around 140°F outlet temperature). Collector B is one of the advanced concepts for a high performance collector for high temperature applications, i.e., cooling. Collector C is simple and inexpensive. Because of its outlet temperature limitation, this type of collector is used mainly to supply swimming pool heating and could be used for solar augmented heat pumps. Collector D is considered to be practical for solar heating and cooling applications (140° to 210°F) in the near-term future. The practicality of each class of collector depends solely on the cost-performance tradeoff for specific applications. The performance of each of these collectors is shown in Figure 2-4.

D. SYSTEM SIZING AND PERFORMANCE ANALYSIS

To size the collector area for each of the specified and costed solar energy designs, a computer program was developed. This program simulated both the solar energy available and the space heating, cooling and water heating demands for each building based on a 10 year sample of actual weather data. The demand requirements were established using ASHRAE thermal information and the HVAC combinations described in Section II.A.

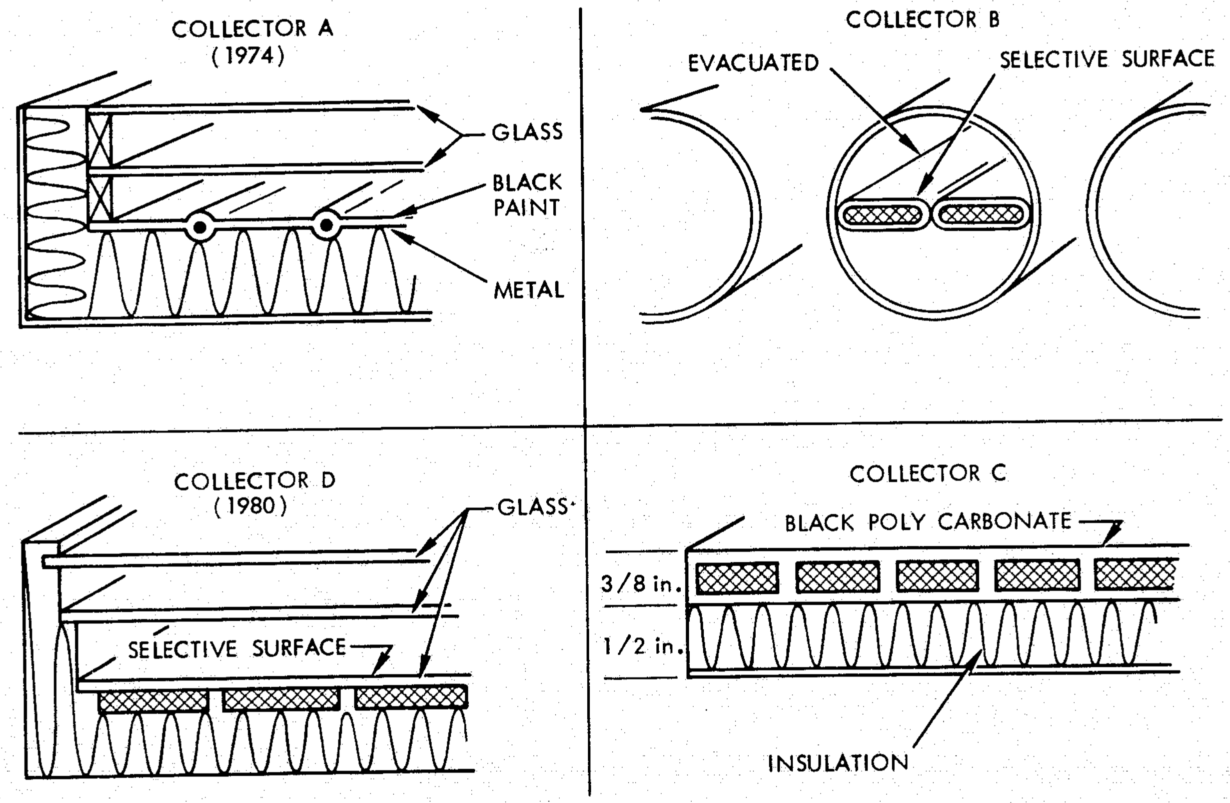

Figure 2-3. Conceptual Design of Baseline Collectors

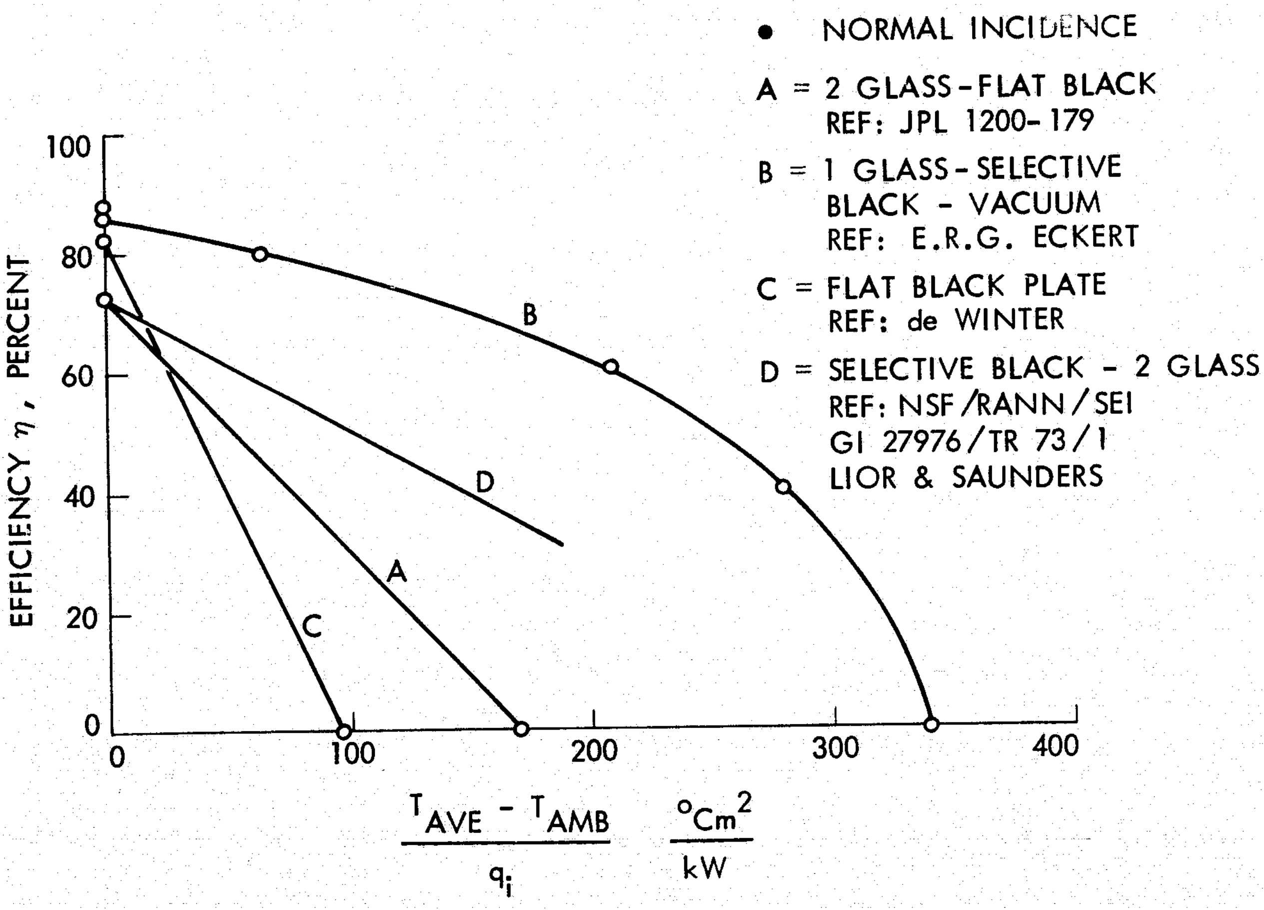

Figure 2-4. Efficiency of Baseline Collectors

Performance of the solar energy systems was calculated using a generalized multinodal thermal analyzer program (SINDA).* Building heat capacities and solar radiation affects have been considered in calculating both heating and cooling demands on an hourly basis.** The computer models have been calibrated against available heating and cooling load data. For the single family dwelling, hourly data were used to calibrate the computer model. For the other buildings, monthly and yearly data were used. The model for calculating the solar energy available from any of the collectors included both the effect of direct and diffuse solar radiation. A simplified model of the solar energy storage subsystem has been used to calculate the performance of the system. The storage subsystem is assumed to be lossless except that energy not used on the day collected is not carried over to the next day. The details of this program are discussed in Reference 3.

The "theory of the firm" from economics was applied to the problem of system sizing. This is an economic theory that applies to the case of a small firm whose individual decision does not affect the market price of its product. The theory shows that for maximum profit this firm should increase its production to the point where its marginal cost (cost per an additional unit of output) equals the market price. Of course, if the average cost is not less than the market price the firm will not produce.

The conditions are met for the "theory of the firm" to apply in the situation of sizing solar energy systems at the individual load center. The load center is an energy producer and should produce an amount of energy such that the marginal cost of the energy equals the price of the equivalent energy in the market, i.e., the price of delivered auxiliary energy. This will minimize the cost of supplying the energy service to the individual load center.

The forms of the curves chosen for presenting the solar energy available to meet the load (e.g., Figure 2-5) is designed to allow computation of the properly sized system. The baseline building in the South Inland zone (using Burbank weather data) is chosen as an example to demonstrate this method. Using first the performance vs. size data and then the cost estimate vs. size data for water heating and space heating, the marginal cost of solar energy can be calculated

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* J. P. Smith, "SINDA User's Manual," TRW Systems, 14690-H001-R)-0.0, April, 1971.

** Standard ASHRAE procedures normally ignores solar heat gains in estimating the heating requirements of a building.

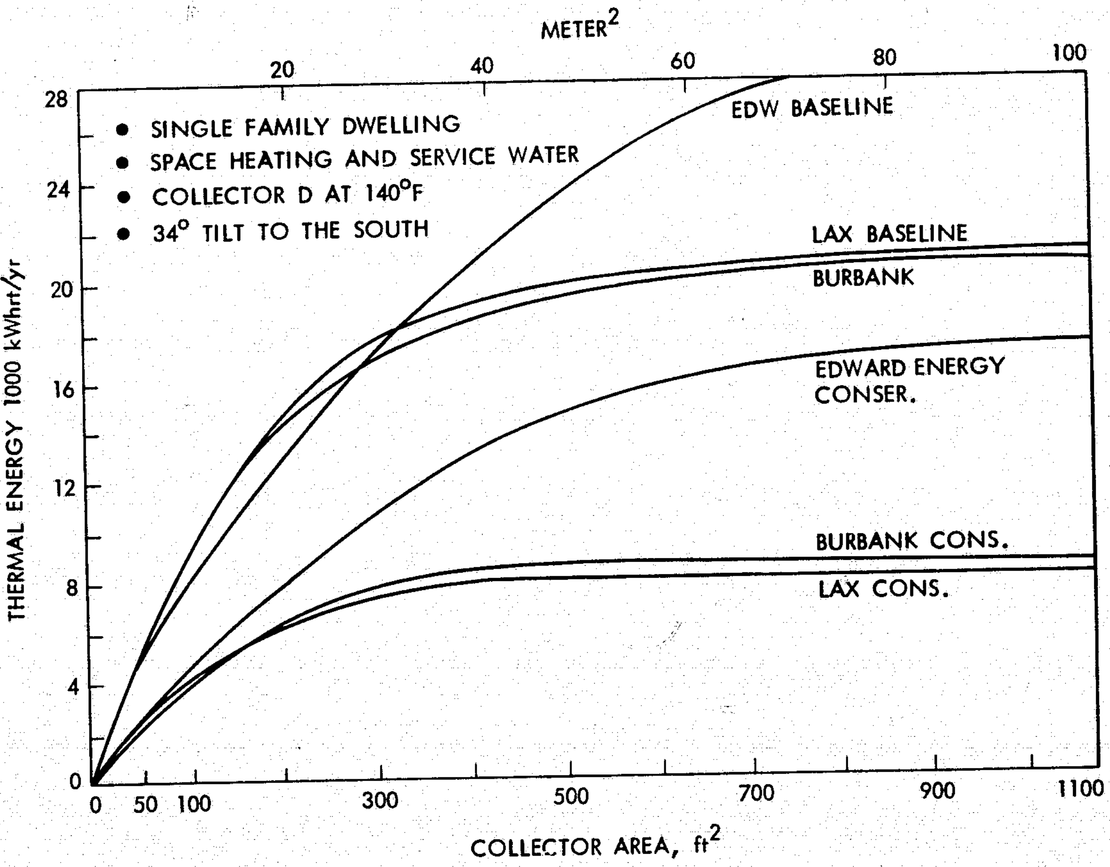

Figure 2-5. Share of Solar Energy for Space Heating

as a function of size. The results of this analysis are plotted in Figure 2-6. Two scales are supplied for capital recovery factors (crf) of 0.2 and 0.1.* Using the crf = 0.1 scale** the individual load center should not produce solar energy unless the price of the auxiliary fuel is 0.023 $/kWh. If the price of auxiliary fuel is 0.023 $/kWh, the marginal cost analysis would require a collector area of 215 ft^2. Figure 2-5 implies that the proper share of energy to be supplied by on site solar energy is 66%.

The use of marginal cost analysis for sizing is important if capital is efficiently deployed. The use of average cost for sizing would suggest a broad range where the size of the system makes little difference economically. The marginal cost approach shows the economic inefficiency of oversizing of solar energy systems.

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*The capital recovery factor is a multipler which gives the annualized cost of a mortgage. It is computed from the interest rate (r) and length of the loan (n) as follows:

$$CRF = r \frac{(1+r)^n}{(1+r)^n-1}$$

**8% loan for 20 years or 9% loan for 25 years.

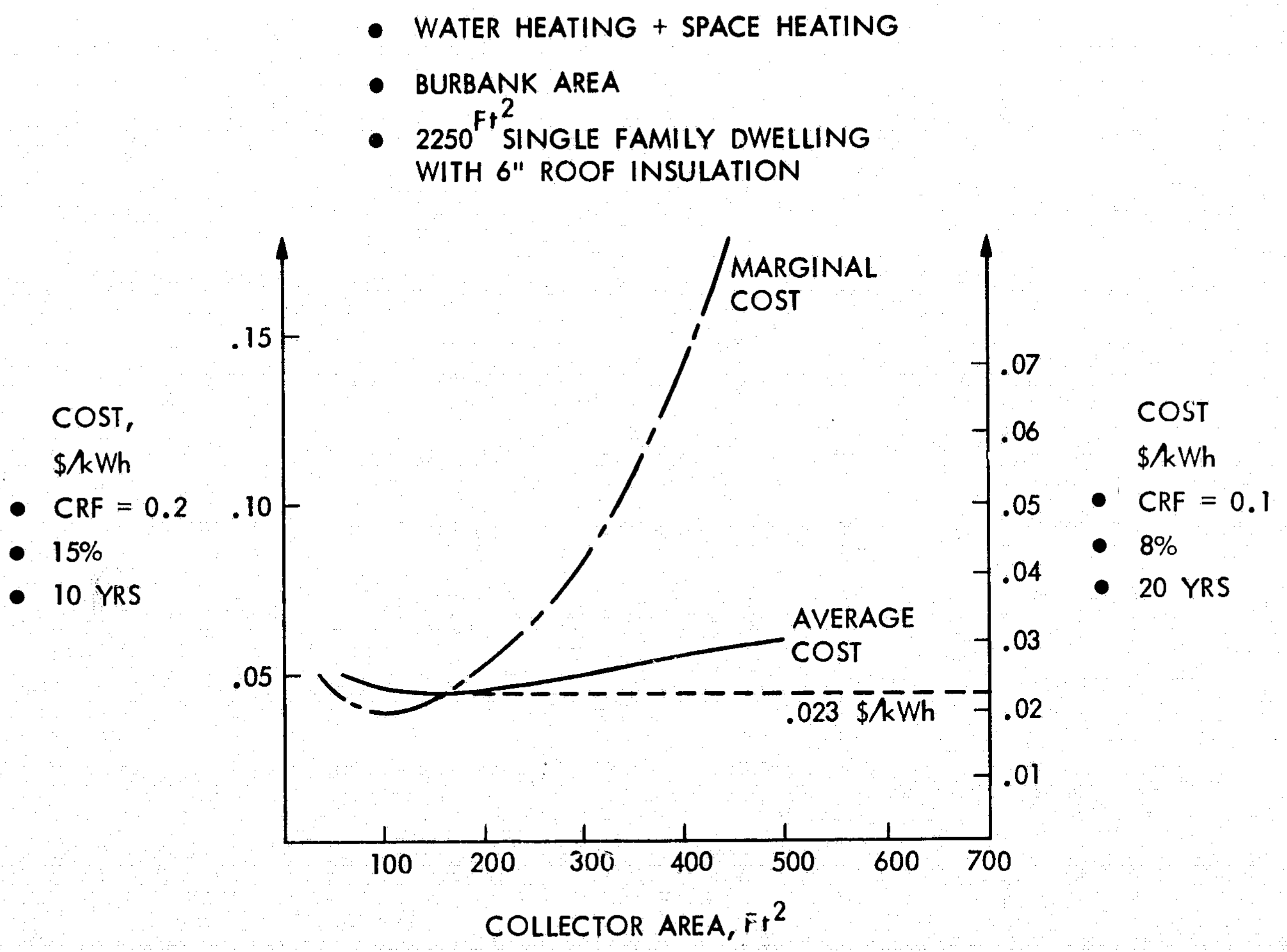

Figure 2-6. Cost of Solar Energy

SECTION III

ECONOMIC ANALYSIS

> If I have any taste
> It is only because I have interested myself
> In what was slain in the sun
> I pose you your question
> 'Shall you uncover honey where maggots are?
> I hunt among stones.'
>
> Charles Olsen

The costs of solar energy systems must be compared in a consistent manner with the costs of other energy supply options. Therefore projections, both of solar energy system costs and of alternative energy costs, must be made. These costs must then be compared on a life cycle basis. The following discussion provides an overview of solar energy system costs estimates, then considers energy supply alternatives for space heating and water heating, and finally evaluates the comparison of costs in terms of the economic attractiveness of solar energy.

A. SOLAR ENERGY SYSTEM COSTS

It is convenient to divide the cost of solar energy systems into two components: 1) the collector cost installed and 2) the cost of the remaining parts of the solar energy system. This division is useful because there is considerable variation in the cost of currently available collectors and considerable uncertainty in the cost of future collectors. The costs of the remaining parts of the system are pretty much standard plumbing materials with limited possibilities for cost reductions except for changes in system design (e.g., reducing the amount of piping in the system).

Much of the variation in the current cost of collectors is related to differences in durability and performance. Although cost per square foot of collector is certainly an important factor, the most important factor is the long-term cost of the energy delivered by the collector including amortization, maintenance, and periodic repair or replacement. To simplify the multi-dimensional issues of detailed collector design, a collector with the performance of prototype double glazed, flat plate collectors with a selective coating, and the durability to last 20 years, has been adopted as baseline for further discussion of collector cost.

The cost of collectors depends on the method of construction, the materials used and the pressure requirements for the particular application. Projected costs as low as \$2.75 per square foot (in 1974 dollars) may be possible for mass-produced, non-metallic collectors with a selective coating. However, the 1974 equivalent f.o.b. prices for the collectors are in the range of 6 to 9.25 \$/ft^2. Examples of the cost for collectors of various designs are listed in Table 3-1. Today an all-copper absorber plate would be required to assure a 20-year life.

Table 3-1. Example Collector Costs

Type of Collector	Construction	F.O.B. Price* 1974 $/ft^2	Availability
A	Metal Box (150 psi)**		1974
	Al Absorber	6.20	1974
	Cu Absorber	8.50	1974
	Steel Absorber	6.70	1974
	Composite Al-Cu	8.00	1974
A	Integral Absorber & Structure-Foam		
	Steel/selective coating (10 psi)**	3.00	1978
A	Non Metallic (10 psi)**	2.00	1980
B	Evacuated Glass cylinder	10.00	1978
C	Plastic (10 psi)**	1.60	1976
Baseline Collector	Metal Box with a selective absorber (150 psi)		
	Al absorber	7.00	1976
	Cu absorber	9.25	1976
	Steel abosrber	7.50	1976
	Non metallic with a selective absorber (10 psi)	2.75	1980

*F.O.B. cost is list price minus 30%

**refers to working pressure limit in the absorber plate.

Using the current and projected f.o.b. prices for solar collectors, it is possible to establish high and low limits for the installed cost of collectors. Transportation, overhead, profit and expense for mounting collectors on the roof must be added to the f.o.b. price to determine the installed cost. Including these factors (see Table 3-2), the current installed cost of collector arrays is estimated to be $15 per ft^2 (1974 dollars). By 1980 it might be possible for collector arrays to be installed for as little as $5.00 given the development of currently available technology into commercially produced products. Certainly, $5.00 per square foot is at the lower bound of anybody's current estimate for the installed cost of a collector. Therefore $5 and $15 per ft^2 of collector provide reasonable bounds for conducting a parametric analysis of the potential for solar energy in California.

Table 3-2. Limiting Estimates for the Installed Cost of Collector Arrays

Parameters	High	Low
	Collectors Available In 1975	Collectors Available In 1980
Collector Cost F.O.B. the Factory	$ 9.25/ft^2	$2.75/ft^{2*}
Installer Overheat and Profit at 30%	2.75	.85
Installation Labor at $17/hr. 3 hrs/100 ft^2	.50	.85
Mounting Hardware and Plumbing of Collector Arrays Only	2.50	.90
Total Installed Cost per ft^2 of Collector in 1974 dollars	$15.00/ft^2	$5.00/ft^2

*This number is often hotly contested as being unreasonably low. It should be remembered that it is an estimate for an all glass collector f.o.b. factory in 1974 dollars. It would be $3.55 in 1976 dollars. The number represents our estimate of the possible lower bound of the materials cost for an all glass collector with selective coating in a large volume mature industrial process.

The total cost of solar energy systems has been estimated for well over one hundred different applications defined by the type of building, location, and type of coventional heating equipment used in the building. Each cost estimate involved a number of identifiable steps. First, loads were estimated and a system of appropriate size chosen. Next, the system was designed and detailed system specification was prepared. Figure 3-1 shows one typical schematic diagram for a heating and cooling system. Then, since much of the solar energy system costs are for conventional components (e.g., pipe, insulation, tanks), the costs of the conventional equipment was estimated using the 1974 Dodge Manual and the 1974 National Construction Estimator (Ref. 29 and 30). Finally the cost of the collector array is added in. Table 3-3 is an example of the cost estimate for the system shown in Figure 3-1. Table 3-4 shows the estimated cost for adding water heating to the space heating system.

In addition, the cost of connecting (or interfacing) the solar energy system with the convientional equipment used for backup varies with the type of conventional equipment being used in a building. Such differences in the details of each application give rise to a range of possible costs for solar energy systems even for the same building type. This additional complication has been considered in the market analysis included in Chapter V of this report.

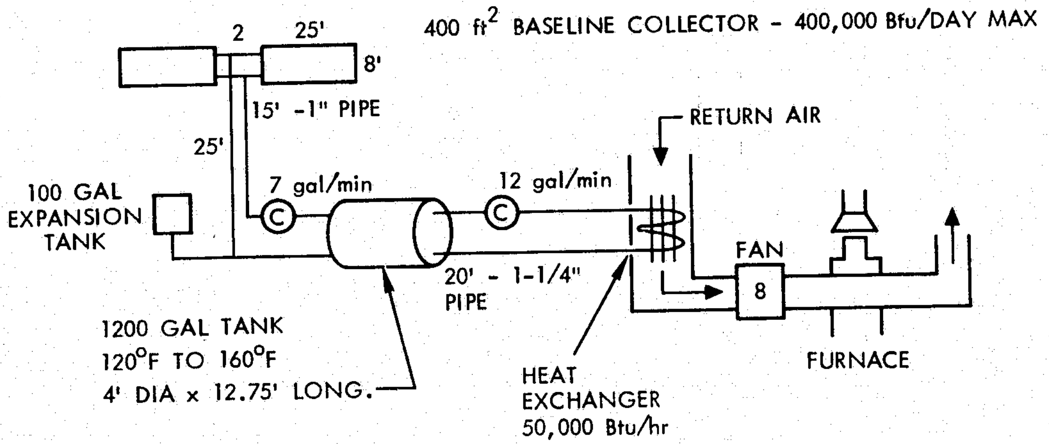

Figure 3-1. Schematic Diagram of a Solar Hydronic Heating System With a Forced Air Auxiliary

Table 3-3. Solar Hydronic Space Heating Cost Estimate (400 ft^2 collector)

Item	Material	Labor	Total
1. 400 ft^2 Baseline Collector	$5.00	Installed	$2000
3. 44'-1" pipe 10'-1-1/4" insulated	2.77 $/ft instal. 1.90 $/ft instal.	3.06 $/ft instal. 2.23 $/ft instal.	310*
4. 100 gal. exp. tank	$164	$89	253*
5. 1200 gal. tank		Installed	540*
6. Tank insulated	3 $/$ft^2$	Installed	640
7. 2 pumps 1"	$80 ea.	Installed	160*
8. Heat exchanger 2.5 ft^2	$350	Installed	350
9. 2 Controllers	$50 ea.	3 hrs.	151
		Total (1974 dollars)	$4404

*National Construction Estimator - 1974

Table 3-4. Incremental Cost for Adding Water Heating to a Solar Hydronic Heating System

Item	Material	Labor	Total
1. 1 tank 100 gal.			$250
2. 1 thermostatic mixing valve	$ 40	Installed	40
3. 10 feet 3/4" cu	$2.63	Installed	26/30
		Total (1974 dollars)	$316.30

Some differences in the cost of applications of solar energy are simply related to size. Because of the smaller required area of collectors for solar water heaters, they typically have higher costs per installed area although a lower cost per delivered Btu. Retrofit installations will, in general, cost more than new installations. Our analysis indicates a 25-35% cost premium for retrofit systems compared to new systems. The cost ranges are also influenced by the collector costs. Two estimates have been prepared, one for 1976 collectors, available today and installed for \$15 per ft^2, and a second estimate for 1980 collectors, assuming the development of existing technology and economies of scale consistent with a large collector manufacturing industry. The 1980 collectors are estimated to be installed for no less than \$5 per ft^2. Table 3-5 summarizes the cost ranges for solar energy systems per ft^2 of collector for single-family homes in California

Larger scale installations on multiple family, commercial and institutional buildings have lower system costs per square foot of collector. The costs for these applications are potentially as low as \$10 per square foot.

B. ENERGY USE IN CALIFORNIA FOR SPACE HEATING, WATER HEATING AND AIR CONDITIONING

In 1975 California consumed nearly 1.6 trillion kWh (5.5 quadrillion Btu) of energy. By 1995 California energy consumption is expected to rise to 1.9 trillion kWh (6.5 quadrillion Btu). To establish the breakdown of total energy consumption for heating, water heating, and air conditioning of buildings, reports were reviewed (Ref. 1, 2, and 51-58) and personal contacts were made with key people in the State Energy Commission and Public Utilities Commission as well as major fuel suppliers in the state. The future energy supply and demand estimates for California vary widely between authors, reflecting considerable uncertainty for the period 1975-1985. Between 1985 and 1995 the variations are not as great. In general, there is more agreement on the percentage of total energy consumption for each sector in the period between 1974 and 1995 with residential consuming about 16%, commercial about 8%, and the industrial sector about 18%. The remaining 58% is primarily consumed by transportation, with other miscellaneous uses contributing a small fraction. The split of energy use in each of these sectors by energy source is tabulated in Table 3-6.

Space heating or cooling and water heating in buildings are important applications for solar energy. Tables 3-7, 3-8, and 3-9 break down energy use for residential, commercial and industrial space heating, water heating and air conditioning. Approximately 19% of the energy that California uses is consumed to provide space conditioning and water heating. About 88% of the energy for these applications is currently supplied by natural gas. Six percent is supplied by electricity, with miscellaneous sources supplying the remaining 4%. About 50 billion kWh were consumed in each of the major end use areas: residential, commercial, industrial. Nearly 18% (8.2 billion kWh) of residential electric use was consumed for space heating and water heating with an additional 6% (2.8 billion kWh) used for residential central air conditioning.

During the same period, California consumed roughly 1680 billion cubic feet (bcf) (509 kWh x 10^9) of natural gas. Of this total 38% (645 bcf) was consumed in residential uses. Fifty-five percent of residential natural gas was consumed for space heating and 35% for water heating; that is, 90% of residential natural

Table 3-5. Total System Cost (Installed) for Single-Family Solar Energy Systems (South Inland Zone)

System	Combination Solar Space Heating and Solar Water Heating, $				Solar Water Heating Only,[a] $			
	New		Retrofit		New		Retrofit	
	Total	$\$/\text{ft}^2$	Total	$\$/\text{ft}^2$	Total	$\$/\text{ft}^2$	Total	$\$/\text{ft}^2$
1976 Collectors ($\$15/\text{ft}^2$)	3070	30	3060[c] to 7500[b]	30-35	1010	28	1260	35
1980 Collectors (Result of 1976 Technology with Large-Scale Manufacturing and Economics of Scale)[d]	2000	20	4060[b] to 2500[c]	20-25	900	25	1080	30

Notes:

a. System uses 36 ft^2 of baseline collector with a 150 psi working pressure.
b. For 215 ft^2 of collector for existing gas buildings.
c. For 107 ft^2 of collector for existing all electric buildings.
d. For space heating and water heating, assumes a collector with a 10 psi working pressure costing $5 installed. For water heating only, assumes a collector with 150 psi working pressure costing $12 installed.

Table 3-6. Estimated California Energy Consumption - 1975

Parameters	Energy Source				Total	Sector as % of Total
	Electricity	Gas		Other		
	10^9 kWh/yr	10^9 kWh/yr	bcf/yr	10^9 kWh/yr	10^9 kWh/yr	
Residential	46	195	645	9	250	16
Commercial	47	68	225	2	117	8
Industrial	45	168	556	77	290	18
Other	12	77	254	824	913	58
Total	150	508	1680	912	1570	100
Energy Source as % of Total	10	32	----	58	100	

Source:

(1) A. D. Little, Inc., Energy Shortage Contingency Plan: Technical Appendix, A Report to the California Energy Resources Conservation and Development Commission, October 31, 1975, p. I-2.

(2) Fuller, R., et al., Evaluation of Possible Actions to Alleviate the Natural Gas Shortage in California, A report to the California Energy Resources Conservation and Development Commission, January, 1976.

Table 3-7. Estimated Residential Energy Consumption in California - 1975

Parameters	Energy Source				Total	End-Use as % of Total
	Electricity	Gas		Other		
	10^9 kWh/yr	10^9 kWh/yr	Bcf/yr	10^9 kWh/yr	10^9 kWh/yr	
Space Heating	4.0	107	354	7	118	47
Water Heating	4.2	68.8	228	2	75.2	30
Air Conditioning	2.8	0	0	0	2.8	1
Other	35	19.2	63	0	55	22
Total	46	195	645	9	250	100
Energy Source as % of Total	18	78	---	4	100	
% of Dwelling Units (DU) w/ space heating by fuel type	10	86	---	4	100	
% DU w/water heating by fuel type	10	87	---	3	100	

Source:

(1) A. D. Little, Inc., Energy Shortage Contingency Plan: Technical Appendix, A Report to the California Energy Resources Conservation and Development Commission, October 31, 1975, p. I-2.

(2) Fuller, R., et. al., Evaluation of Possible Actions to Alleviate the Natural Gas Shortage In California, A report to California Energy Resources Conservation and Development Commission, January 1976.

Table 3-8. Estimated Commercial Energy Consumption in California

Parameters	Energy Source				Total	End-Use as % of Total
	Electricity	Gas		Other		
	10^9 kWh/yr	10^9 kWh/yr	bcf/yr	10^9 kWh/yr	10^9 kWh/yr	
Space Heating	1.3	54.4	180	1.7	57.4	49
Water Heating	10.7*	4.4	15	0.3	15.4	13
Air Conditioning	3.3	8.3	27	0	11.6	10
Other	31.7	0.9	3	0	32.6	28
Total	47.0	68.0	225	2	117	100
Energy Source as % of Total	40	58	---	2	100	

Source:

A. D. Little, Inc., Energy Shortage Contingency Plan: Technical Appendix, A Report to the California Energy Resources Conservation and Development Commission, October 31, 1975, p. I-2.

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*The validity of this figure is questioned by the authors.

Table 3-9. Estimated Industrial Energy Consumption in California - 1975

Parameters	Energy Source				Total	End-Use as % of Total
	Electricity	Gas		Other		
	10^9 kWh/yr	10^9 kWh/yr	bcf/yr	10^9 kWh/yr	10^9 1Wh/yr	
Space Heating	0	6.8	22	2.5	9.3	3.2
Water Heating	0	0	0	0	0	0
Air Conditioning	2.3	0	0	0	2.3	0.8
Other	42.7	161.2	534	74.5	278.4	96
Total	45	168	556	77	290	100
Energy Source as % of Total	16	58	---	26	100	

Source:

A. D. Little, Inc., Energy Shortage Contingency Plan: Technical Appendix A Report to the California Energy Resources Conservation and Development Commission, October 31, 1975, p. I-2.

gas was used for space heating or water heating purposes. The commercial market consumed about 13% (225 bcf) of natural gas of which 87% was used for space heating, and water heating purposes. The consumption of electricity and natural gas for the various end-uses is summarized on Table 3-10.

To aid in the evaluation of market potential for solar energy applications, data from Tables 3-6 through 3-9 were used in Table 3-11 to rank various items in terms of total energy consumed. Two-hundred-ninety billion kWh (990 trillion Btu) were consumed in 1975 for space conditioning and water heating or roughly 20% of total California energy consumption. This was 80% of total residential consumption and only 4.0 of total industrial consumption. Ninety-six (96%) percent of the consumption (277 billion kWh) was for space heating and water heating with air conditioning comprising a minor 4%.

This ranking shows that 80% of the space conditioning and water heating consumption (230 billion kWh) was for 3 items: Residential and commercial gas space heating, and residential gas water heating. Residential gas space heating alone consumed over one-third (109 billion kWh) of the energy. The fourth ranking item, "Commercial Electric Water Heating," is somewhat of a surprise. This figure needs further substantiation.* Figure 3-2 presents the data from Table 3-11 in histogram form.

C. THE COST OF ALTERNATIVES TO SOLAR ENERGY

Natural gas is the least expensive and most widely used competitor to solar energy.

The current retail price of natural gas is about $1.75 per thousand cubic feet (mcf). Assuming generously a 60% conversion efficiency, natural gas costs $2.90 per million Btu to use in space and water heating applications. Although natural gas is currently the best energy bargain, there is particular concern for the cost of new natural gas supplies. Discussions with PUC staff and others reveal that both the prices and supply time schedules are uncertain. Table 3-12 summarizes the current status of new natural gas supply. The current projected costs of new natural gas supplies range from a low of about $2.50 per mcf for Indonesian LNG to $6 per mcf for coal gasification. These costs include a delivery charge. Given recent cost escalations associated with these estimates, these projections could well be low.

Of the total electricity being used in the sectors of interest, over 70% (20.2 x 10^9 kWh/yr) goes to space heating and water heating application while the remaining 8.4 x 10^9 kWh/yr is used for air conditioning. Commercial electric water heating is the largest single user of electrical energy. This sector alone is estimated to consume 10.7 x 10^9 kWh/yr* of electrical energy. Increasingly, electricity is being used for apartment buildings; in some areas of the State nearly one-quarter of the space heating systems now use electricity. The current retail price of electricity in California ranges from 1.0 to 5.0 cents per kWh.

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* Better substantiation is needed for this figure than is given in Ref: ADL Oct. 31, 1975. Unfortunately repeated attempts at clarifying the validity of this number have failed so that we have used the source material as written.

Table 3-10. Estimated California Energy Consumption by End-Use - 1975

Parameters	Energy Source				Total	End-Use as % of Total
	Electricity	Gas		Other		
	10^9 kWh/yr	10^9 kWh/yr	bcf/yr	10^9 kWh/yr	10^9 kWh/yr	
Space Heating	5.3	168	556	11.2	185	12
Water Heating	14.9	73.2	242	2.3	90.4	6
Air Conditioning	8.4	8.3	27	0	16.7	1
Other	121.4	258.5	856	898.5	1278	81
Total	150	508	1680	912	1570	100

Source:

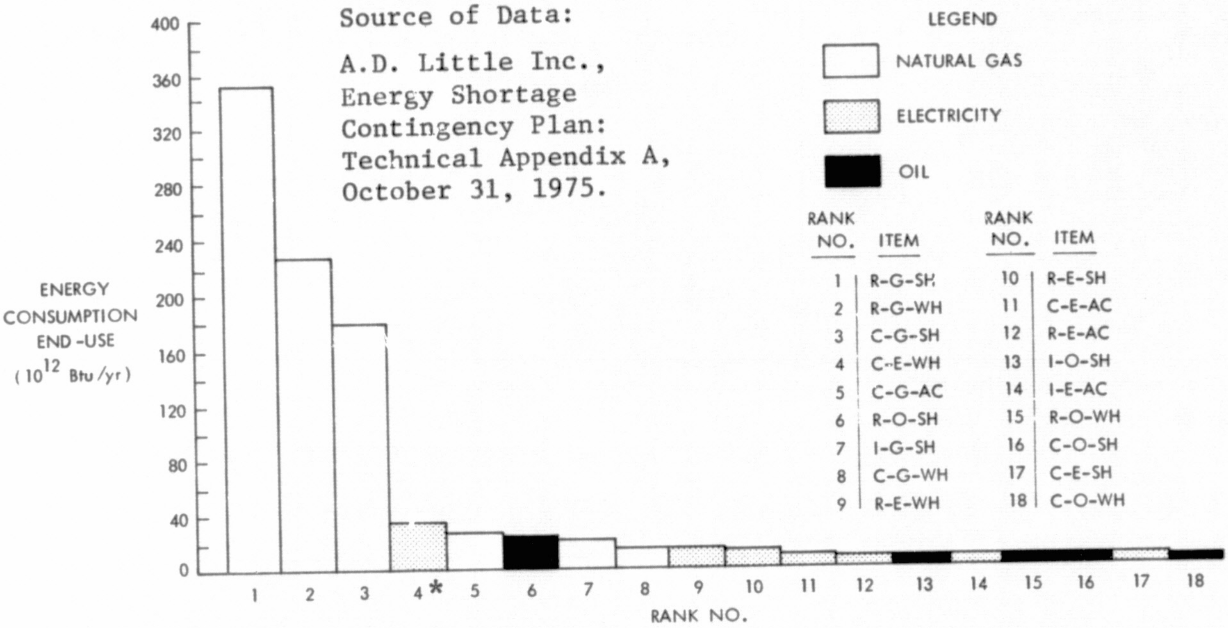
Tables 3-6 through 3-9.

Table 3-11. Energy End-Use Ranking by Consumption - 1975

Rank	Item	Energy Consumption			Item as percentage of consumption in sector			
		Bcf/yr	10^9 kWh/yr	10^{12} BTU/yr	Residential	Commercial	Industrial	State
1	R-G-SH	354	107.0	354	43	----	---	6.8
2	R-G-WH	228	68.8	228	28	----	---	4.4
3	C-G-SH	180	54.4	180	----	46	---	3.5
4	C-E-WH	-----	10.7	35.4	----	9.1	---	0.68
5	C-G-AC	27.5	8.3	27.5	----	7.1	---	0.53
6	R-O-SH	-----	7.0	23.2	2.8	----	---	0.45
7	I-G-SH	22.5	6.8	22.5	----	----	2.3	0.43
8	C-G-WH	14.6	4.4	14.6	----	3.8	---	0.25
9	R-E-WH	-----	4.2	13.9	1.7	----	---	0.27
10	R-E-SH	-----	4.0	13.2	1.6	----	---	0.28
11	C-E-AC	-----	3.3	10.9	----	2.8	---	0.21
12	R-E-AC	-----	2.8	9.27	1.1	----	---	0.18
13	I-O-SH	-----	2.5	8.28	----	----	0.9	0.16
14	I-E-AC	-----	2.3	7.61	----	----	0.8	0.15
15	R-O-WH	-----	2.0	6.62	0.8	----	---	0.13
16	C-O-SH	-----	1.7	5.63	----	1.5	---	0.11
17	C-E-SH	-----	1.3	4.30	----	1.1	---	0.08
18	C-O-WH	-----	0.3	0.99	----	0.3	---	0.02
Total energy used for WH, SH, AC / % Energy used for SH, WH, AC in sector		827	292	967	79	72	4	18.6

Source: Tables 3-6 through 3-10.

Note: X-Y-ZZ has the following meaning: X indicates the end-use submarket—Residential (R), Commercial (C), or Industrial (I); Y indicates the fuel used Natural Gas (G), Electricity (E), or Oil (E); ZZ indicates the type of end-use—Space Heating (SH), Water Heating (WH) or Air Conditioning (AC). Thus the No. 1 ranked item (R-G-SH) is residential natural gas for space heating which is the largest single energy consuming end use.



Source of Data:

A.D. Little Inc., Energy Shortage Contingency Plan: Technical Appendix A, October 31, 1975.

RANK NO.	ITEM	RANK NO.	ITEM
1	R-G-SH	10	R-E-SH
2	R-G-WH	11	C-E-AC
3	C-G-SH	12	R-E-AC
4	C-E-WH	13	I-O-SH
5	C-G-AC	14	I-E-AC
6	R-O-SH	15	R-O-WH
7	I-G-SH	16	C-O-SH
8	C-G-WH	17	C-E-SH
9	R-E-WH	18	C-O-WH

*Validity of source data not confirmed.

Figure 3-2. 1975 Thermal Energy in California by End-Use Categories (see note Table 3-11)

Table 3-12. New Natural Gas Supply for California

Table 3-12. New Natural Gas Supply for California

Supply Project	Annual Supply Potential	% of 1975 Usage*	Date 1st Delivered to Calif.	Costs/mcf		
				Cost Into Pipeline $/mcf	Distr Costs $/mcf	Total Cost $/mcf
Indonesian LNG bcf/yr mmcf/day	200 (550)	12%	1981	3.36-3.75	Generally $.50-1.00 per mcf distribution cost, however, not directly applicable to all new gas.	4.40-4.75
Artic Pipeline (So. Alaska) bcf/yr mmcf/day	150 (400)	8.7%	1981	2.50 $1.40=transportation		3.50
Coal Gasification (WESCO) bcf/yr mmcf/day	90 (250)	5.4%	4 years from Approval	$3.50-4.50		4.40-5.50
Prudhoe LNG (No. Alaska) bcf/yr mmcf/day	150 (400)	8.7%	1983+	No contracts $1.40 trans+ well-head price		---
El Paso-Algerian LNG bcf/yr mmcf/day	150 (400)	8.7%	1984+	No well-head price set - $1.90 transp		---

*1975 Usage equaled 1680 bcf

Source:

(1) Personal Conversation 11/25/75 w/Donald L. King, Senior Utilities Engineer, Public Utilities Commission.

(2) California Public Utilities Commission, 10-year Forecast of Gas Utilities Requirements and Supplies, 1976-1985: Staff Report, San Francisco, January, 1976.

The retail price of electricity also depends on the type of customer. For most of California the cost of electricity is greater than:

- $ .02/kWh for industrial customers
- $ .03/kWh for commercial customers
- $ .035 kWh for residential customers

Averaged over all customers, the price of electricity varies between utility companies because of differences in generating mix. In 1976, the average prices for California's investor owned utilities was:

PG&E	$ .024/kWh
SCE	$ .033/kWh
SDG&E	$ .034/kWh

Estimating the cost of new electric supply capacity is a complex problem. The cost of new capacity depends on: (1) How well the utilities are able to predict their future load and get the proper plant mix installed, (2) The cost of various plant options, (3) The future cost of fuel, and (4) New plant reliability. These factors have been considered in a recent ERCDC report (Ref. 56). High and low estimates for new electrical energy are presented in Table 3-13. Estimates for the cost of power from nuclear and coal average $.050 $.060/kWh. Power for peak loads is somewhat more expensive, but averaged over all customers, new electrical energy can be expected to be produced for approximately double the current cost.

D. COST COMPARISON WITH SOLAR ENERGY

Solar energy and various alternatives can be put on a common basis for comparison by including the end use efficiency of various fuel options. For electrical space heating and water heating, a 100% conversion efficiency to heat is possible. For natural gas and other fuels, appliances are less efficient. A very generous estimate for appliance efficiency would be 60%. Many furnaces and water heaters operate at much lower efficiencies because of over-sizing and degraded performance of heat exchange surfaces.

Using these assumptions for efficiency, Table 3-14 summarizes the cost comparisons of solar energy and conventional fuels. Figure 3-3 shows the cost ranges of electric, natural gas and solar energy sources in graphic form.

Although more expensive than natural gas, some solar space and water heating applications are currently competitive in cost with electric space and water heating. Furthermore, solar space and water heating are less expensive than several of the new natural gas and electric supply projects currently being examined.

In this context, i.e., both compared with the costs of new conventional fuel supply projects and compared with the costs of electric heating and water heating, solar energy appears to be within the economically competitive range and warrants a careful examination of implementation options by the State. In particular, given that solar energy is nearly economically competitive, the fundamental question becomes: can it be developed and applied on a large enough

Table 3-13. Estimated Cost for New Sources of Electricity

Option	Utilization Hours per Year	(1) Busbar Revenue Requirement, $/kWh	(2) Other Revenue Requirement, $/kWh	Retail $/kWh
Highest Cost Assumption				
Gas Turbine	3000(3)	.113	.005	.118
Combined Cycle	3000	.117	.005	.122
Coal	6000	.074	.010	.084
Nuclear	6000	.065	.005	.070
Lowest Cost Assumption				
Gas Turbine	3000(3)	.053	.005	.058
Combined Cycle	3000	.048	.005	.053
Coal	6000	.027	.010	.037
Nuclear	6000	.025	.005	.030

Notes:

(1) Source from which costs were derived: CERCDC "Staff-proposed Electricity Forecasting and Planning Report," p. IV-9, October, 1976. (Ref. 3-1)

(2) Other costs (transmission, distribution, insurance, user-taxes, etc.) are application-specific, but typical values of 5 mills/kWh for in-state plant location and 10 mills/kWh for out-of-state plant location are assumed here.

(3) Lower utilization than assume here would result in an even higher busbar revenue requirement.

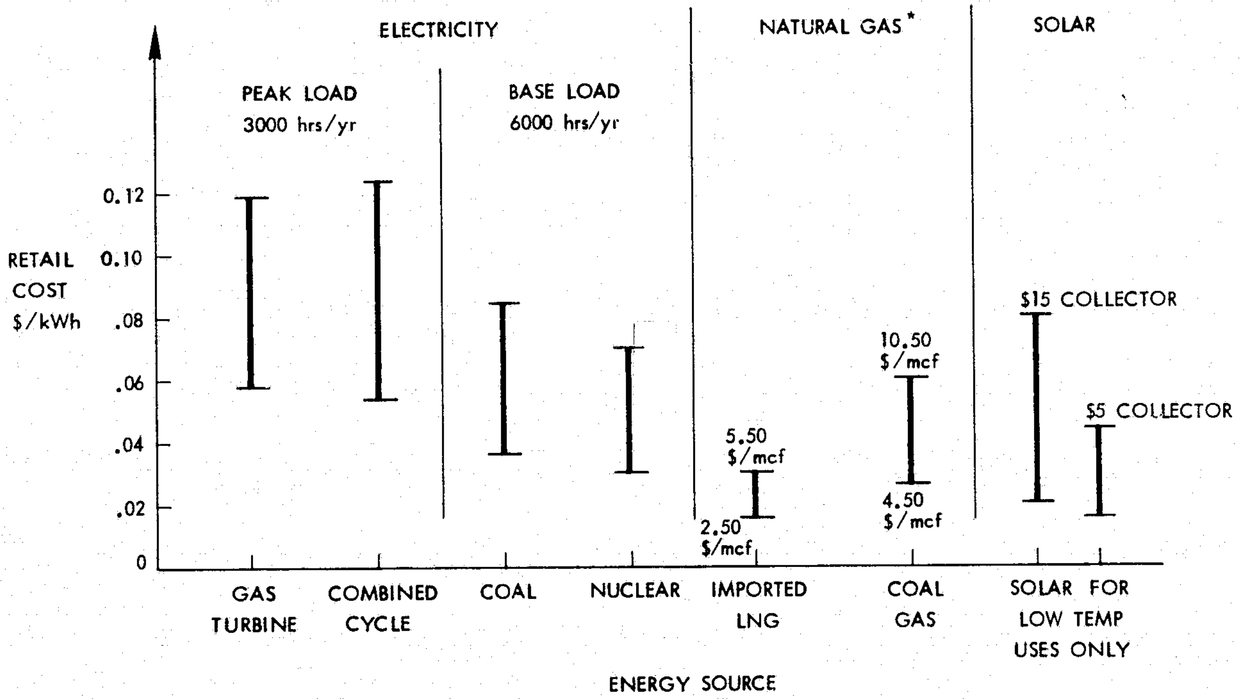
Table 3-14. Comparisons of Solar Energy Cost With Costs of Fossil Fuels and Electricity[1]

Fuel	Units	Btu Value Per Unit	Average Cost Per Unit	Conversion Efficiency	Net Cost $/MBTU
Solar Energy [2]	Square Foot	560,000 per yr.	25.00 10.00	40% 40%	11.40 4.55
Coal	Ton	24,000,000	$20.00	60%[3]	1.40
Natural Gas	1000 Cubic Feet	1,000,000	$1.75 Avg. $3-5.00 New	60%[3] 60%[3]	2.90 5 - 10.00
Fuel Oil	Gallon	138,000	$0.48	60%	5.75
Electricity	Kilowatt-hour	3,413	$0.035 Res. $0.030 Com.	95%	10.80 9.25
New Electricity	Kilowatt-hour	3,413	.03 - .07 Nuclear .06 - .12 Gas Turbine	95%	9.25 - 21.60 18.50 - 37.00

1. Prices of fossil fuel and electricity were derived from a number of sources.
2. Solar energy costs (SEC) calculated based on an 8% loan for 20 years.

$$\text{SEC} = \frac{(10\ \$/\text{ft}^2)(.08)\ (1.08)^{20}\ \left[(1.08)^{20} - 1\right]}{(.56 \times 10^6\ \text{Btu/Yr/ft}^2)\ (.40)}$$

3. Optimistic estimates for efficiency in space heating and water heating applications.
4. 40% is the average throughput efficiency of a well designed solar energy system. It is the percentage of insolation falling on the collectors which actually is delivered to the thermal load and thereby used.



* NATURAL GAS NUMBERS INCLUDE AN ESTIMATED AVERAGE APPLIANCE EFFICIENCY OF 60%.

Figure 3-3. Retail Cost Ranges of New Energy Sources scale, soon enough, to be a viable energy supply option for California before the turn of the century?

To answer this question, the institutional environment in which solar energy will be applied must be examined. This environment can either deter or encourage the use of solar energy. For example, differential treatment of energy supplied by oil and the sun can discourage oil users from switching to solar. Once the environment is understood, the market potential can be analyzed to define the sizes of the best solar applications. The next chapter discusses institutional issues while Chapter V discusses the penetration potential.

SECTION IV

INSTITUTIONAL CONSIDERATIONS

> And what might have been,
> And what might be, fall equally
> Away with what is, and leave
> Only these ideograms
> Printed on the immortal
> Hydrocarbons of flesh and stone.
>
> Kenneth Rexroth

Even solar energy technologies which are technically feasible and cost-effective face a number of institutional barriers which will deter their market acceptance. These barriers may be classified as: (a) factors affecting private economic decision, (b) factors affecting the time scale for adoption of solar energy technologies, and (c) cultural and organizational factors. Many of the institutional barriers and possible means of alleviating them have been discussed and analyzed in References 8, 14, 15, 16, 42, 43. These include the conservatism of potential buyers of solar energy technologies, legal and environmental constraints, financing and insurance considerations and the nature of the existing and needed energy industry. The following discussion will focus primarily on those institutional factors which are most important in abating or hampering the market penetration of solar energy technologies, and on those to which State action could be applied.

A. INSTITUTIONAL FACTORS AFFECTING PRIVATE ECONOMIC DECISIONS TO USE SOLAR ENERGY

Should solar energy be given special treatment? Some type of direct or indirect subsidy may be justified to correct for market inequities which solar energy systems face: (1) The Public Utilities Commission policy of basing the retail price of energy on the average cost ("rolled-in pricing"), (2) differences in the treatment of solar energy equipment versus conventional equipment for real estate taxes, (3) differences in treatment of solar energy and conventional energy by the Internal Revenue Service and the Franchise Tax Board for income tax purposes, and (4) the problems of getting people to use products with lower life cycle costs.

1. First Cost vs. Life Cycle Cost

In the United States, people often make purchase decisions on the basis of first cost rather than life cycle cost. In single family home buying decisions, the cost of solar energy equipment adds to the first cost of a home, raising the difficulty of borrowing money and the required down payment. To derive the life cycle cost benefits, the payback times for energy conserving technologies must be short for the homeowner who pays the higher first cost. This homeowner resistance to high first costs makes builders reluctant to raise the initial cost of a dwelling by adding solar energy and they, of course, derive no benefits from a life cycle cost effective system. In apartment buildings, if renters pay utility bills, apartment owners have no direct incentive to save operating costs and solar energy systems are not attractive. If building owners pay utility bills, they have a life cycle cost incentive but renters then have no incentive to conserve energy.

Financial institutions are reluctant to lend money on new systems whose resale value is uncertain. Buildings with solar energy systems are new and uncertain territory. Insurance companies set rates on the basis of large risk pools or on large amounts of statistical data, neither of which exist for solar energy systems. Consequently, acquiring loans and/or insurance for buildings with solar energy systems, or for retrofit installations, is not straightforward. An additional difficulty with making solar energy systems economically attractive even on a life cycle cost basis is the "average cost pricing barrier".

2. Average Cost Pricing

The current PUC utility pricing policy insulates the consumer from the true costs of new natural gas supplies by averaging or "rolling-in" the price of a new supply with the price of existing supply contracts. Consequently, the price which the consumer sees does not adequately reflect the marginal costs of new natural gas. The consumer faces a choice between solar energy (which can be considered a new supply of energy) and natural gas at the average retail price. The wholesale cost of new gas typically exceeds the retail price of gas and can be greater than the cost of solar energy. Furthermore the upside price risk of solar (as apposed to SNG and LNG) is small. In the case where solar is cheaper than new gas supplies, the result is economic waste because of the false signals given the consumer by the averaged cost pricing problem. An example, using natural gas supplies (the largest heating and water heating fuel), should help clarify this point.

Some new natural gas supplies such as coal gasification are estimated to cost \$5 per mcf.* Assuming \$1 per thousand cubic foot distribution charges and 60% efficient usage, the final cost of useful energy delivered to the consumer would be about \$10 per million Btu. The cost of solar water heating delivered to the consumer is about \$8 million Btu assuming an 8% loan and 20 year term on the solar equipment. If the consumer could directly choose between this gasified coal and solar energy he would choose to purchase the solar energy system since it would save him about \$2 per million Btu. However, under current regulatory practice the consumer does not face this choice because the cost of the new gas supply will be "rolled-in" with the existing supply, which currently costs from \$0.50 to \$1.50 per million Btu. Assuming that the new gas supplies about 5% of the total (not an unreasonable amount for a coal gasification plant), the result of "rolled-in"

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*Other projects are also projected to have similar prices, e.g., Algerian LNG via the Tenneco Atlantic pipeline has a delivered price of \$4.30 per mcf.

pricing will be that the gas will cost about $1.70 mcf, or $2.85 per million Btu delivered, assuming 60% efficiency. (If one assumes 100 million mcf at $1.50 and 5 million mcf at $5, the result is 105 million mcf at a total value of $175 million or about $1.70 per mcf.)

The rational consumer will find the $2.85 per million Btu "rolled in" natural gas a bargain, even though the cost of the new gas alone exceeds the cost of the solar energy space conditioning. Thus, the "rolled in" pricing method essentially insulates the consumer from the true cost of new fuel supplies. This pricing method is the source of a substantial inequity that solar energy faces upon entering the market. The inequity is the same for residential, commercial, and industrial consumers.

The rolled in pricing method is economically irrational, particularly in a period when margin costs of new supplies are several times higher than the average price. The utility buys supplies at a cost exceeding the near-term price charged the rate payers at the margin of consumptions. When the average price exceeds the cost of alternative sources, such as solar, large, flexible, customers will switch to these alternatives. This will raise the revenue requirements needed from the retail market which will force gas rates higher thereby encouraging more rate payers to switch. As E. Hanich of the Environmental Defense Fund points out, this process could force the gas market to the wall.

a. Potential Alternatives to Average Cost Pricing. Two general types of remedies to the average cost pricing barrier are available. One consists of new policies that leave gas prices alone, but work to offset the effects of prices that are too low. These include (1) direct subsidies to the consumers and others in the marketing chain, (2) specific bans on certain uses for natural gas, and (3) prescribing the use of solar energy in specific applications. All of these measures have either been adopted by some state or country or are under serious consideration for adoption, although in no case is the measure being considered for adoption specifically designed to solve this average cost pricing barrier. Instead, these measures are simply being promoted to encourage adoption of solar energy on the basis that "solar energy is good." All of these measures have well known efficiency equity, and administrative difficulties. They do a very poor job of giving the economy the proper price signals for efficient use of energy resources and related allocation of capital.

The second type of policy change is to change the price structure for gas. Economists have advocated multipart tariffs for all utilities, with the price on the last unit of consumption set equal to the "long-run marginal cost." (Ref. 60) The long-run marginal cost is based on the wholesale cost of the most expensive "new gas" being purchased by the utility. The rest of the price structure would be calculated so that the utility just covers its revenue requirements.

This remedy would eliminate the average cost pricing barrier to solar energy. It would provide the correct signal for the consumer to use in allocating his capital. It would treat everybody equally.

The problem with establishing multipart tariffs is that utility commissions find themselves in a classical double bind in contemplating the adoption of the policy. The unilateral adoption of such a policy is not only politically unpopular but also can have negative secondary economic impact on the state taking the action. For example, suppose California adopts a policy of marginal cost pricing of natural gas but other states do not. Industries which use natural gas would find that capacity expansion would be unattractive in California. This would tend to erode the California industrial base and its economy relative to other states. Therefore it is unlikely that pricing based on long-run marginal cost will be adopted unilaterally by any state.

b. Purchase of Solar Energy and Conservation Equipment by Utility Companies for Consumers. Utilities which distribute natural gas must pay the marginal cost for the last increment of gas which they purchase to meet the demand. Even though the consumer is insulated from the price of marginal gas, the utility company is not. Thus the utility company is in a position to properly allocate its investment capital between supplies of "new gas" and solar energy equipment (and other conserving technologies). This is clearly a compromise solution to the average cost pricing dilemma. On one hand, the ultimate consumer continues to demand and use more energy than he would if he had to pay the true cost of the energy he uses. On the other hand, the formidable inequities which solar energy faces due to average cost pricing will be eliminated, and under the proper regulatory set of rules for ownership, solar energy and other conserving technologies could be given a tremendous market boost.

Although the idea of utilities purchasing solar energy equipment for use by the consumer is applicable to both public and privately owned utility companies, the regulatory issues apply only to privately owned utilities since publicly owned utilities are not regulated by the PUC. Municipal utility leasing of solar equipment is a concept which is currently being tested by the City of Santa Clara.

B. REGULATORY IMPLICATIONS OF UTILITY OWNERSHIP OF SOLAR EQUIPMENT

Ownership of solar energy equipment would directly affect both the earnings and the rate base of a private utility company. The Public Utilities Commission would therefore certainly establish regulations governing the solar energy aspect of the utilities operations.

The type of regulations under which utilities would own the equipment is very important to development and commercialization of solar energy equipment. In establishing these regulations, a number of issues must be considered: (1) stimulation of innovation, (2) production and marketing efficiency, (3) generation of working capital, (4) fair and efficient pricing for the solar energy, (5) unfair competition, and (6) consumer protection. The regulations themselves must deal with: (1) approvals for certificates of necessity and convenience, (2) franchising territory or markets, (3) treatment of solar energy equipment in the rate base account, (4) setting rates for solar energy, and (5) the corporate and operational relationship between the utility company and other parties of interest (manufacturer, specifier, developer, building owner).

Although there are undoubtedly many sets of rules under which a company could commercialize solar energy equipment, one such set is presented here to serve as a model for debating the issues. This model set of rules is intended to indicate that a satisfactory set of rules can be designed which addresses the critical issues in a socially desirable way.

A set of model rules for regulating utility ownership whould be:

Rule 1. Certificates of convenience and necessity would be granted for the utility to provide a specified annual supply of energy from solar to a specific type of application (e.g., domestic water heating in multiple family dwellings, hot water for laundries, etc.).

Rule 2. The utility would be authorized to conduct this business in its own service territory.

Rule 3. The depreciated value of the investment in solar energy equipment would be included in the rate base account of the utility company.

Rule 4. A fixed billing rate for solar energy would be established for the solar energy equipment. The billing rate would be established to make the solar energy competitive with the average cost of gas being marketed by the utility. The cost of new supplies of solar energy would be "rolled-in" with gas to determine the price. As an optional incentive, this rate could be guaranteed to the consumer for a period of time, say — for example — 10 years.

Rule 5. The utility company would contract with the building developer or a plumbing contractor for installation of equipment specified by the utility company. The utility company would take title to the equipment and the contract would be used for establishing the initial value for inclusion in the rate base. The utility would be responsible for maintenance of the solar equipment.

Nothing in this set of rules would prevent a consumer from purchasing solar energy on his own. Utility specifications would be available for anyone to use for buying quality equipment. In fact, a consumer purchasing his own equipment to utility specifications may want to sell the equipment to the utility company. Such transactions could certainly be allowed.

Rule No. 4 effectively provides the same subsidy for solar energy as that now being provided for "new gas" through the policy of average cost pricing. The cross-subsidy takes place within the community of energy users thereby providing an even-handed method of pricing the solar energy which is easy to administer. For the near term, Rule No. 4 gives the utility company a competitive advantage over firms engaged in the direct sale of solar energy systems to home builders. As long as the utility companies can get any gas at old prices, solar energy systems would only look economically attractive to the utility company. This could potentially be viewed as unfair competition; however, the policy of average cost pricing for natural gas is at the root of this unfairness. Although utility ownership makes it difficult for the independent middleman to compete in the retail market, there will not be a substantial retail market until the average cost of gas catches up to the marginal cost of new supplies. With utility ownership, the potential for a large market exists for solar energy equipment manufacturers and installers.

Rule No. 1 makes use of existing powers of Public Utilities Commissions. This mechanism can be used to establish the economic benefits from specific solar energy applications. The utility company would be required to show the economic desirability of solar energy in an application prior to making large investments. This rule protects consumers from making unwise capital expenditures.

Rule No. 2 insures that the benefits form the effective subsidy provided by Rule No. 4 are returned to the providers of the subsidy, i.e., the customers of the utility deploying solar energy systems.

Rule No. 3 gives the utility company the same financial stake in solar energy as it has in investments to supply gas. It would be allowed the same maximum potential rate of return as it would in other natural gas energy investments. In fact, since solar energy involves a higher ratio of capital to other costs than does natural gas, for reasons enunciated first by Averch and Johnson, this rule could make solar energy somewhat more attractive than investments to expand gas supplies.*

Rule No. 3 could also be used to give utilities a higher rate of return. The higher rate could be justified on several grounds: 1) the uncaptured external social benefits from wide-scale use of solar, compared to other new supplies; 2) higher local employment rates; 3) smaller risk of price escalation than LNG or SNG projects; etc.

Rule No. 5 provides a mechanism for establishing the level of investment in the solar energy equipment. In new construction, the installation cost of solar energy equipment will probably be minimized if the job is combined with the overall plumbing contract. This creates a problem in establishing the cost of the hardware to be owned by the utility company. The proposed contracting method would appear to solve this problem. In retrofitting existing buildings, the contract would probably be with a plumber and the level of investment would be easily established. Role No. 5 provides for protection of consumers by controlling the specification of hardware to be installed. Also, since the utility takes title to the hardware, the utility would be responsible for maintenance and servicing.

It may be desirable to extend rule No. 5 to prohibit utility companies from specifying equipment only manufactured by an affiliated company. This would prevent vertical integration of the solar energy business, thereby preventing utilities from passing monopoly profits backwards to the manufacturing affiliate (Dayan 1974, Ref. 19). This extension of rule No. 5 could be important to stimulating innovation and cost reduction of solar energy technology. Utility companies have a reputation for not being the primary source of technological innovations. Major technological innovations have typically been made by manufacturers who supply the utility industry. Utility companies have readily adopted new technology that has been developed.

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*Averch and Johnson have shown that a profit-maximizing firm subject to rate-of return regulation has a tendency to prefer capital-intensive technologies (Ref. 18).

C. UTILITY OWNERSHIP ADVANTAGES

Utility ownership puts the capital allocation decisions for solar and for "new gas" on an equal basis. These technologies would be evaluated on the same economic basis by the gas utility. Investment decisions about solar energy would at least be fairly compared to gas at the wholesale level. Issues related to the qualitative differences between new sources of gas and solar energy could be resolved by utility management.

With utility ownership, solar energy competes with conventional fuels at the margin. Solar energy need not be competitive with the least expensive natural gas to be economically justified. Solar energy only needs to be competitive with the most expensive sources of natural gas which the utility would have to purchase if solar energy was not an available alternative. Utility ownership provides the institutional mechanism for insuring that solar energy is allowed to compete with the most expensive sources of natural gas.

If the retail price of solar energy is based on the average cost of energy to the utility company, a cross-subsidy from nonadopters to adopters of solar energy systems will result. Unfortunately, as long as utilities charge average costs for all new supplies, internal subsidies are unavoidable. Utility ownership at least avoids the administrative costs of a direct federal subsidy program that would be required if solar energy is to be adopted in the absence of utility ownership.

Taking the decision of investment out of the retail market and putting it in the wholesale market should advance the starting point for implementation of solar energy by at least 10 to 15 years. It will take this long or longer before enough old gas is replaced by new gas to make retail gas prices high enough to induce customers to invest in solar systems in the markets where they are attractive.

Besides overcoming this basic institutional situation, the utility ownership approach has advantages for rapid implementation. This approach overcomes the first cost barrier of the building industry, aggregates a market for solar energy equipment manufacturers, and provides single-point responsibility for service and installation.

In addition, with utility ownership, the financing terms for solar energy equipment should be more favorable than those available for ownership by building owners. Without utility ownership, financing terms are likely to be based on the risk associated with building development or home improvements.

Several schemes for commercializing solar energy have been proposed which do not recognize the average cost barrier. The city of Santa Clara is investigating the use of a municipally owned solar energy utility. Their legal studies show that municipalities do have the power to establish a solar energy utility in competition with private electric and natural gas utilities (Jones et al., Ref. 17). Very large subsidies by the municipality would be required for a solar energy utility to overcome the average cost pricing advantage already held by the private utilities in most markets. Similar difficulties are faced by schemes involving separate private solar energy utilities or publicly owned solar energy corporations.

When competitive retail submarkets for solar energy develop, these approaches could succeed without the need for subsidies. But the average cost problem forestalls them now. Meanwhile, there does not seem to be any reason why private utility companies cannot own solar energy equipment. On the contrary, private utility companies should be encouraged to take the initiative to commercialize solar energy if it makes economic sense to do so. Such an approach provides a compromise between a system of true marginal cost pricing and a 15-20 year delay in implementing solar energy. Utility ownership appears to be a sound approach for implementing solar energy.

1. Real Estate Tax Treatment

Solar energy equipment and equipment for conventional energy are treated differently for real estate tax purposes. Investment in property is typically taxed at an annual rate of 2.5 to 3% of the market value. The value of real property is usually raised periodically by the tax assessor from a base established by the initial cost. For residential and commercial buildings the added initial cost of the solar energy system would also be subjected to these escalations. For distributors of conventional fuel, equipment would be taxed at 2.5 to 3% of its book value (i.e., initial cost less accumulated depreciation). Consequently, while real estate taxes have a tendency to go up for solar energy equipment, they go down for equipment to deliver conventional fuels. A property tax exemption for solar energy equipment would rectify this inequity. At least eight states have adopted such legislation.

2. Income Tax Treatment

The treatment of solar energy and conventional energy for income tax purposes is more complex than the treatment for real estate tax purposes. For the individual, the only tax factor favoring the solar option is the deduction allowed for interest. For the producer/distributor of the competing fuels, tax savings are available for both depreciation and interest. Since the level of the tax savings is proportional to the tax rate and producer/distributors of conventional fuels typically have higher tax rates than individuals, the individuals's investment choice is biased in favor of the conventional fuel alternative by tax considerations that apply to the producer/distributor.

For the commercial decision makers (including apartment owners, farmers, and manufacturers), the bias is more complex and less clear cut. Like the energy producer/distributor, the commercial firm can deduct both interest and depreciation related to solar energy; however, differences in financial structure and regulatory effects make it impossible to state unequivocally that there is not a biasing effect one way or the other.

D. FACTORS AFFECTING THE TIME SCALE FOR ADOPTION

Every change has costs associated with it. The policy issue is how to find a way to reduce the costs in a way which is beneficial and in the "public interest". Yet, many people believe that once technical and economic conditions are met, the innovation will be accepted and diffused rapidly (Ref. 21). Unfortunately, the "Better Mousetrap" belief - if you build a better and cheaper gadget, the world will beat a path to your door - is largely a myth. Demonstrating technical and economic feasibility is important, but it is seldom sufficient to insure rapid acceptance and diffusion of a technological innovation, particularly when that innovation does not involve a new service but rather must compete with existing services. Experience indicates that significant resistance often remains after an innovation satisfies requisite technical and economic conditions. Organizational and cultural factors, under some circumstances, impede the acceptance of even feasible, demonstrably cost-saving devices.

Although produced for sale in 1874 and offering large economic advantages (in terms of cost per word), the typewriter was not widely used for over thirty years because of questions about the status of women typists in society and social etiquette (Ref. 22, p. 49). It took over 350 years and thirteen kings to eliminate expensive and inflammable straw from Danish towns. (Ref. 22, p. 58) The telephone was resisted not because of technical and economic factors but because it was commonly thought to be "The Work of the Devil". More recently, the Urban Institute has concluded that the inability of cities to utilize cost-saving aerospace technologies can be traced in part to "the traditions of doing things the same old way with the old familiar equipment." (Ref. 23).

In addition to the factors which adversely affect private economic decisions concerning the adoption of solar energy, there are several factors which affect the time scale of adoption. These include the individual differences of potential adoption of solar energy as well as land use laws, sun rights and other issues. Organizational and cultural characteristics of the building industry will also affect the adoption of solar energy. These characteristics will be discussed in another part of this section.

Studies by Griliches, Mansfield, Hagerstrand and others (Refs. 61-65) have yielded analytic models of the adoption process. Some of these studies have developed methods for estimating the quantitative time lag and diffusion time between invention and innovation (The first application of an invention); however, the uncertainty in these models is large with the time lags and diffusion rates varying to a great extent. Mansfield (Ref. 65), for example, identifies four principal factors which seem to govern how rapidly the innovation (occurs): (1) The economic advantage of the innovation over older methods of producing products, (2) the extent of the uncertainty associated with using the innovation when it first appears, (3) the extent of commitment required to try out the innovation, and (4) the rate of reduction of the initial uncertainty regarding the innovation's performance" (Ref. 65, p. 88). The empirical constant in his formula has wide variations from industry to industry (Ref. 65, p. 90) and relies exclusively on economic measures even though he recognizes that other non-economic factors (such as (2) and (3) above) are important to the buyer's decision. The two economic variables used by Mansfield are payback period and size of the required investment in the innovation.

1. Individual Differences of Potential Adoptors

People differ in their willingness to try a new product or service. Rogers and Schoemaker (Ref. 20), have developed a classification scheme based upon "innovativeness" of consumers. They developed this schedule as an ideal type "to guide research efforts and serve as a framework for the synthesis of (diffusion) research findings" (Ref. 20, p. 183). Adopters are divided into five (5) categories — innovators (the first 2.5% of people who adopt a new product), early adopters (the next 13.5%), early majority (the next 34%), the late majority (the next 34%) and finally the laggards (the last 16%). This classification scheme is shown in Figure 4-1.

To be quantitatively precise about the process of penetration of a new product is difficult, but dividing the total feasible adopters into these categories and developing payout requirements for each category will be a useful way of examining the problem of market penetration.

In general, customers require relatively stringent payback criteria before buying a new product. Payback periods between 3 and 7 years are commonly required with a few people willing to buy a product. This will shield them from escalating prices of the conventional products. A 10 year payback requirement seems reasonable for an early adopter with a 5-7 year payback required before the early majority will adopt the product and 3 year payback before the late majority will adopt. The innovator (the first 2.5% of adoptors) and the laggards are probably not classifiable using a payback criterion since their decision is based on more complicated personal variables. In Section V of this report, this notion of payback period will be used as a means for quantifying the buyer's decision process.

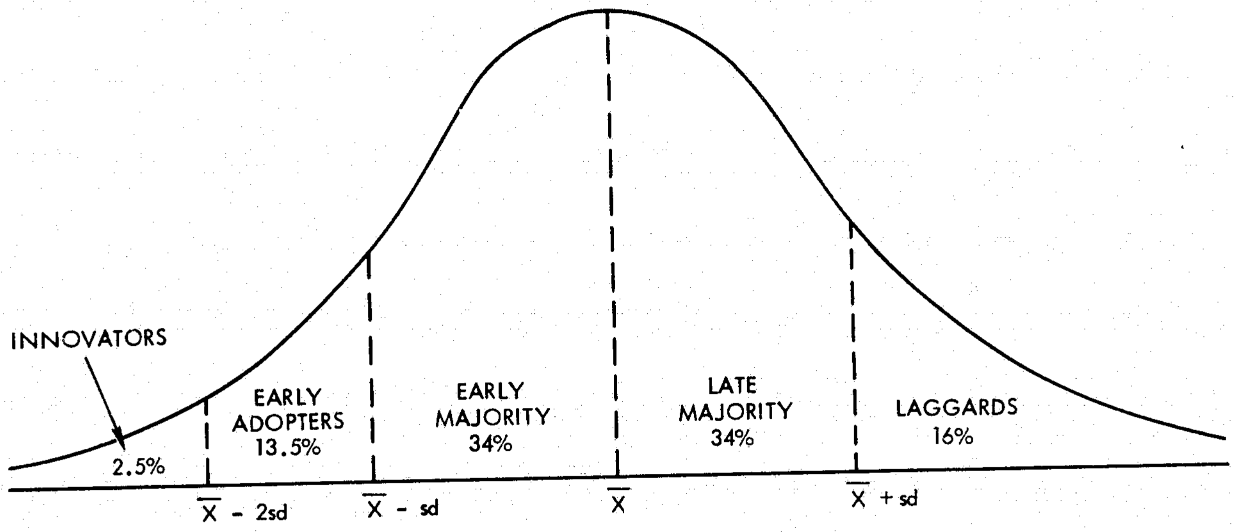
2. Land Use Issues

a. Laws Governing Property Rights. Covenants, conditions, and restrictions may deter the use of solar energy in residences. In recent years developers of new single family and multiple unit housing have increasingly turned to the use of Covenants, Conditions and Restrictions (CC&Rs) applied to deeds to insure the maintenance and enhancement of the "style of life" they seek to create. When CC&Rs began to be more common, the first developments to use them were projects aimed at the more affluent members of society. However, as experience was gained, more and more developments implemented them. Today, although precise figures are not available, it is suspected that a majority of new developments use CC&Rs.

The existence of CC&Rs has two main implications for the use of solar energy conversion systems. First, in retrofit applications, a vote could be taken by the homeowner's association to prohibit the installation because the exterior aesthetics would be altered. Thus, solar units could be excluded from large residential developments. Second, CC&Rs might selectively cut off solar energy conversion systems from one of the most probable initial markets — the relatively affluent residential user. This comes about because CC&Rs are historically associated with expensive housing, appealing to the affluent who would otherwise be most likely to purchase solar units, especially in the retrofit mode.

Thus, we must ask what legislative action can be taken to eliminate or mitigate this constraint on the use of solar energy. At present there are no clear-cut answers. It is an area which requires legislative and legal research.

The right of property owners to have access to sunlight is not guaranteed under existing laws and precedents. T. Thomas of the American Bar Foundation has said that continued uncertainty regarding sun rights could eventually pose serious difficulties for use of solar energy. Although it is not the primary impediment to use of solar energy. It is an impediment which could be sufficient to limit the market for solar energy systems.



The innovativeness dimension, as measured by the time at which an individual adopts an innovation or innovations, is continuous. However, this variable may be partitioned into five adopter categories by laying off standard deviations from the average time of adoption.

From: Rogers and Schoemaker (Ref. 20)

Figure 4-1. Adopter Categorization on the Basis of Innovativeness

A number of options for dealing with the problem have been proposed and two pieces of legislation have been adopted by other states. Oregon has adopted legislation (HB 2036, May 1975) requiring that consideration of access to solar energy be considered in any comprehensive land use plans. The law requires county commissions to recommend height and setback requirements which protect access to solar energy.

Colorado has adopted legislation giving solar easements legal standing in the state. Notice of the easement must be filed. The notice is required to define the vertical and horizontal angles which define the extent of the easement.

William Harris of the RAND Corporation has proposed the use of a transferable solar right, R. Schoen and A. S. Hirshberg have proposed the use of three-dimensional zoning as a means for controlling access to sunlight. Their proposal would (1) require creation of high-rise districts, (2) use height setback formulas to protect incident sunlight, and (3) provide for the right of eminent domain with compensation.

A better definition of individual rights to have access to sunlight is needed in California. However, strong reasons for preferring any one option over the others have not emerged.

b. Building Codes. The existing building codes appear to adequately protect the health and safety of consumers adopting solar energy systems. However they do not protect the consumer from inferior products or improperly engineered installations.

Minimum standards for quality of materials are needed. The closest document to a standard which exists is the "Interim Performance Criteria for Solar Heating and Combined Heating and Cooling Systems and Dwellings," published by HUD on January 1, 1975. This document has been scheduled to be made "operational" in 1977 for commercial buildings and a year later for residential buildings. A number of other efforts are under way which are national in scope and which assure the availability of sound standards within one or two years.

In the meantime, California will need to rely on the engineering profession to specify quality equipment. Once standards are adopted, there may be value in requiring solar energy equipment to be labeled with critical technical characteristics.

Retrofitting existing structures with solar energy equipment is expensive. A limited amount of remodeling cannot be avoided. Constraints on the location and orientation of collectors increase cost. There is no obvious way to reduce this extra cost for buildings which are already built. However, in new construction certain provisions could be made to reduce the cost of a future retrofit:

(1) Dedication of a small amount of vent-free roof space for solar collectors. For example, less than 300 ft^2 of collector is recommended for space heating and water heating for 2000 ft^2 home in most areas of California. Any slope between 20° and 50°, and any orientation within 20° of south, will meet the need.

(2) Development of a preliminary plan for locating thermal storage tanks and connecting the solar energy system to the conventional system before constructing a new building could reduce the cost of future retrofitting.

Procedures for sizing solar energy systems are needed. The engineering profession has not yet developed and adopted standardized procedures for sizing solar equipment. ERDA currently is sponsoring research to establish procedures; these should be available within a year. Once standard sizing procedures are developed and adopted, they should be considered for inclusion in local building codes.

c. Subdivision Laws. The subdivision laws of California do not contain any provisions to facilitate the utilization of solar energy in buildings. Although the basic theory of planning cities to give buildings the proper exposure to the sun goes far back in history, these principles have not been implemented in urban and suburban planning in California. The subdivision laws should be reviewed to assess the impact of constraining the alignment of streets and buildings to allow better access to solar energy.

E. CULTURAL AND ORGANIZATIONAL FACTORS

Experience with the housing industry leads to the definition of the third category of institutional impediments to solar energy adoption — cultural and organizational factors. Although this third category of factors are not as quantifiable as the preceding factors, they are as important for the adoption of solar energy technologies. These factors have deterred and slowed the use of many innovations in building industry. Ewald has estimated that it requires 17 years, on the average, from the invention to the first use of even the most successful innovations in the housing/construction industry (Ref. 24). Even innovations promising significant cost-savings have either not been accepted or have required extended time to diffuse. For example, it took 28 years for the industry to widely use forced air heating combined with air conditioning, even though there were major cost-savings to be realized from the combination. According to Ewald, "Changes proceeded piecemeal, in small segments of the industry. There has been no radical change of great technical and economic significance; no single invention or family of inventions" (Ref. 24, p. 213).

Donald Schön, referring to these institutional factors as "self-reinforcing resistances to change," has demonstrated that the housing industry possesses "fundamentally conservative formal and informal social systems which are aimed at perpetuating things as they are rather than at initiating major changes within the industry." (Ref. 25, p. 164) Unfortunately, but understandably, the evidence supports this view.

This third category of institutional factors is composed of at least two principal subfactors: industry organization and industry culture. By organizational factors, we mean the way the industry is set up and operates, including the roles and interrelationships of the various industry members. By cultural factors, we mean attitudes and behaviors that are widely shared among industry members. Of course, these two factors are themself highly interactive; cultural factors in part arise from the way the industry is organized, and the industry maintains a stable organization because of these cultural factors.

1. Organizational Structure

Besides the building code and financing constraints imposed upon the building industry, the organizational structure of the industry itself produces institutional resistances to new technologies like solar energy. First, because of the variability of weather, building sites and codes, and the differences in individual tastes and life style throughout the country, the industry is regional. Regional difference require that flexibility of the design of solar devices should be "engineered-in" from the beginning. Second, the industry is highly fragmented. Of the 300,000 builders in the United States, 90 percent produce less than 100 units per year. The largest builder produces less than 1 percent of the annual total. Furthermore, the industry is horizontally stratified: that is, it is comprised of many elements performing separate functions. No single person or organization is normally responsible for integrating all of the functions and controlling the residential construction process from beginning to end. Industry fragmentation and horizontal stratification combine to create broadly disaggregated markets and these, in turn, tend to slow the acceptance and diffusion of technological innovation.

In an environment exhibiting these organizational characteristics, those interested in the introduction and diffusion of solar energy devices are faced with difficult marketing, sales, and service problems. At a minimum, solar energy devices will have to achieve "product-fit" within the industry: new products must fit the existing industry distribution, sales, and service systems or, alternatively, be capable of establishing a parallel, equally effective system.

2. Cultural Factors

Two distinctly cultural aspects or institutional characteristics also shape the industry and must be accounted for in efforts to introduce changes. The industry is craft-based and operates through a series of individual craft unions that contribute separate skills and functions to the construction process. These unions have a great deal of control over acceptance of individual technological innovations. For this reason and because there is a relative absence of "performance specification," there tends instead to be a heavy reliance on previous "ways of doing things, and a general resistance to change." The result is a conservative social system which is also generally resistant to change (Ref. 14, 25).

Factors such as the above-building codes, financing arrangements, and the organizational structure of the industry-all pose constraints that tend to slow the pace of technological innovation in the building industry. New technologies, even those which seem to have economic advantages over existing technologies, will not be adopted automatically nor necessarily swiftly without policies and/or incentives to speed their use. General policies, which will foster the acceptance and use of solar energy in the building industry, must take into consideration not only the economic feasibility of solar technologies but also institutional factors such as the ones described here.

SECTION V

SOLAR ENERGY POTENTIAL AND MARKET PENETRATION

> I would build that dome in air,
> That sunny dome! Those caves of ice!
> And all who heard should see them there,
> And all should cry, beware! Beware!
> His flashing eyes, his floating hair!
> Weave a circle round him thrice,
> And close your eyes in holy dread
> For he on honeydew hath fed,
> And drunk the milk of paradise.
>
> Samuel Taylor Coleridge

In this section, two key questions will be answered: (1) What is the potential of those residential solar heating and cooling applications capable of near term economic success, compared to new natural gas and electric energy supplies? and (2) What is the likely market penetration of residential solar heating and cooling applications, given the workings of the energy market place? The answers to these two questions will compare what can happen, given maximal State and Federal actions to encourage residential solar energy applications, with what is likely to happen given the institutionalized pricing practices of conventional fuels and the "normal" buying habits of consumers.

A. SOLAR ENERGY POTENTIAL FOR RESIDENTIAL BUILDINGS

From a State energy policy perspective, the role of solar energy can be defined, in part, by answering three related questions: (1) What is the potential energy displacement of conventional fuels by solar energy? (2) What will it cost to achieve a given level of displacement using solar energy? and (3) How long will it take to achieve? The answer to these questions are uncertain. (In fact, one of the dominant features of the State and National energy dilemma is uncertainty.) The answers will vary according to the following items: (1) The cost of current solar technology both with and without price reductions from economies of scale in manufacturing, (2) The applications for which solar energy appears attractive, (3) The potential cost of new improved solar technology, (4) The future prices of conventional fuels, (5) The likely buying behavior of consumers, (6) Federal incentives, and (7) The resolution of the institutional issues described in Section IV.

In this part of Section V, the solar energy potential for residential buildings will be discussed using the results discussed in Sections II and III which define the first three items. In part B of Section V, the market penetration will be discussed using JPL estimates of items 4 through 7 in addition to items 1 through 3.

1. Potential Energy Displacement of Residential Solar Energy

The potential energy displacement by residential solar energy applications was determined by extending the analysis described in Sections II and III. The potential was determined by using the JPL sizing program and cost estimates to determine the cost and energy savings for each of thirty-two residential applications examined. The program was used for buildings in each weather zone. The potential energy savings were determined by multiplying the energy savings for each application type in each zone by the number of similar applications on buildings in that zone. Because JPL added conservation techniques (where cost effective) to each building, the energy displacement by solar space heating is lower (by up to 50%) compared to estimates without conservation. This is not true for displacement estimates which are less influenced by conservation (e.g., water heating).

The feasibility of applying solar energy (at reasonable cost) varies with the particular application. Estimates of feasibility vary. For example, General Electric estimates that only about 65% of existing residential units could be retrofitted with solar space and/or water heating systems. The 35% difference between feasible and maximum potential is the result of problems caused by the shading of the roof area used for solar collectors as well as the poor orientation of the slope of many single family units. Other estimates are higher, and some applications such as water heating for multiple family units in appear to have feasible potential of over 95% because of typically flat roofs and building setbacks.

The reader can add a feasibility factor by multiplying the potential energy displacement numbers given in this subsection by the fraction of buildings which are judged to be feasible in a given application. The JPL estimate is 75% for single family and 95% for multiple family units.

2. Cost of the Energy Displacement

The costs of achieving the level of energy displacement were also calculated. These are the costs paid by consumers for solar energy, assuming no financial incentives. Upper and lower bound costs were determined by using \$15 per ft^2 and \$5 per ft^2 collectors, respectively. The \$15 collector is the price of a typical flat plate collector in 1974 dollars. This price is expected to fall as production rates increase. The \$5 collector represents the JPL estimate of the least expensive collector using 1980 technology. (This 1980 technology collector is all glass and is feasible without new technical breakthroughs. Although it is expected to be commercially available by 1980, the \$5 per ft^2 collector should be assumed to be an optimistic lower bound for the price of collectors in the near future).

3. Time Frame Over Which Solar Energy Displacement Occurs

The length of time required to achieve a given level of energy displacement depends upon the strength of State (and Federal) efforts to promote solar energy. Two time frames were considered for this report: a ten year time frame, 1976-1986 and a twenty year time frame, 1976-1996. The potential energy displacements were determined for each time frame.

The residential units existing in 1976 have been reduced by 1% per year to account for normal demolition rates. Only units existing in 1996 are assuming to be available for solar energy retrofit for either time frame, since those buildings demolished between 1986 and 1996 are poor candidates for solar energy. The number of new units available for solar energy were determined from the historical California growth rate estimates (see Section II). Growth rates of 2.1% for single family units and 4.4% for multiple family units were used.

4. Summary of Solar Energy Potential

Separate estimates of displacement potential were developed for single and multiple family buildings. Because the JPL cost analysis results indicate that only solar space and/or water heating are likely to be economically competitive with new fossil fuel and electric supplies over the next 5 years, potential energy displacement was defined only for those applications. Tables 5-1 - 5-4 summarize the potential both for the 20-year and for the 10-year time frames. Column one gives the number of units fit with solar energy systems. Column 2 gives the potential energy displaced by solar energy. Columns 3 and 4 give the total cost assuming either a $5 or $15 collector. The marginal cost of each application are also given in the last two columns. The marginal cost is the annualized cost of solar energy assuming an 8% loan over a twenty-year period divided by the annual energy displaced in kWh per year.

To identify possible State policy thrusts to encourage solar energy, eight strategies were developed from Table 5-1 to 5-4. These eight strategies are:

(1) Use of solar for water heating on all new units.

(2) Use of solar for water heating on all existing units.

(3) Use of solar for water heating on both new and existing units.

(4) Use of solar for space and water heating on all new units.

(5) Use of solar for space and water heating on all existing units.

(6) Use of solar for space and water heating on both new and existing units.

(7) Use of solar for space and water heating on all new units and for water heating only on all existing units.

(8) Use of solar to replace 10% of the 1975 total state natural gas useage.

The resulting energy displacement potential for each of these eight interrelated strategies is summarized in Table 5-5. The results of each of these strategies is given both for a 10-year time frame and for a twenty-year time frame. The first column for each time frame gives the number of units on which solar energy is installed. The second, third and fourth columns give the electric, natural gas and total energy displacements respectively. The fifth column gives the cost range of achieving the total energy displacement. The lower cost number is assuming that a $5 collector be used in all installations; the higher number assumes the use of the $15 collector. The last column on the table gives the

Table 5-1. Solar Energy Potential for Solar Water Heating on Single Family Buildings

Submarket	10-Year Scenario						20-Year Scenario						Marginal Cost	
	No. of Units	Potential Energy Displaced			Total Cost		No. of Units	Potential Energy Displaced			Total Cost			
		Gas	Elec	Total	$5 Collector	$15 Collector		Gas	Elec	Total	$5 Collector	$15 Collector	$5 Collector	$15 Collector
	x 10^6	Bcf	x 10^9 kWh/yr	x 10^9 kWh/yr	$ x 10^9	$ x 10^9	x 10^6	Bcf	x 10^9 kWh/yr	x 10^9 kWh/yr	$ x 10^9	$ x 10^9	$/kWh/yr	$/kWh/yr
Gas New	0.747	10.6	0	3.31	0.648	1.08	1.37	19.5	0	6.09	1.19	1.98	0.0196	0.0326
Gas Retrofit	3.13	44.7	0	13.8	3.39	5.65	3.13	44.2	0	13.8	3.39	5.65	0.0245	0.0408
Gas Combined	3.88	54.7	0	17.1	4.04	6.73	4.5	63.7	0	19.9	4.58	7.63		
Electric New	0.356	0	0.899	0.899	0.309	0.514	0.851	0	2.15	2.15	0.739	1.23	0.0344	0.0572
Electric Retrofit	0.434	0	1.10	1.10	0.471	0.784	0.434	0	1.10	1.10	0.471	0.784	0.0430	0.0715
Electric Combined	0.790	0	1.99	1.99	0.780	1.29	1.28	0	3.25	3.25	1.21	2.01		
Gas and Electric New	1.10	10.6	0.899	4.21	0.957	1.59	2.22	19.5	2.15	8.24	1.93	3.12		
Gas and Electric Retrofit	3.56	44.7	1.10	14.9	3.86	6.43	3.56	44.2	1.10	14.9	3.86	6.43		
Total Market	4.66	54.7	1.99	19.1	4.82	8.02	5.78	63.7	3.25	23.2	5.79	9.64		

Table 5-2. Solar Energy Potential for Solar Water Heating and Space Heating on Single Family Buildings

Submarket	10-Year Scenario						20-Year Scenario						Marginal Cost	
	No. of Units	Potential Energy Displaced			Total Cost		No. of Units	Potential Energy Displaced			Total Cost			
		Gas	Elec	Total	$5 Collector	$15 Collector		Gas	Elec	Total	$5 Collector	$15 Collector	$5 Collector	$15 Collector
	x 10^6	Bcf	x 10^9 kWh/yr	x 10^9 kWh/yr	$ x 10^9	$ x 10^9	x 10^6	Bcf	x 10^9 kWh/yr	x 10^9 kWh/yr	$ x 10^9	$ x 10^9	$/kWh/yr	$/kWh/yr
Gas New	0.748	38.4	0	12.0	1.98	3.68	1.37	70.7	0	22.1	3.64	6.78	0.012-0.017	0.021-0.031
Gas Retrofit	3.13	307	0	95.9	15.6	29.3	3.13	307	0	95.9	15.6	29.3	0.016-0.022	0.026-0.039
Gas Combined	3.88	346	0	108	17.6	33.0	4.5	378	0	118	19.2	36.1		
Electric New	0.356	0	2.79	2.79	0.815	1.47	0.853	0	6.88	6.88	2.00	3.63	0.021-0.031	0.021-0.055
Electric Retrofit	0.434	0	3.31	3.31	1.21	2.19	0.434	0	3.31	3.31	1.21	2.19	0.026-0.038	0.027-0.069
Electric Combined	0.790	0	6.1	6.1	2.02	3.66	1.29	0	10.2	10.2	3.20	5.82		
Gas and Electric New	1.10	38.4	2.79	14.8	2.79	5.15	1.87	70.7	6.88	29.0	5.64	10.4		
Gas and Electric Retrofit	3.56	307	3.31	99.2	16.8	31.5	3.56	307	3.31	99.2	16.8	31.5		
Total Market	4.66	346	6.10	114	19.6	36.7	5.43	378	10.2	128	22.4	41.9		

Table 5-3. Solar Energy Potential for Solar Water Heating and Space Heating on Multiple Family Buildings

Submarket	10-Year Scenario						20-Year Scenario						Marginal Cost	
	No. of Units	Potential Energy Displaced			Total Cost		No. of Units	Potential Energy Displaced			Total Cost			
		Gas	Elec	Total	$5 Collector	$15 Collector		Gas	Elec	Total	$5 Collector	$15 Collector	$5 Collector	$15 Collector
	$\times 10^6$	Bcf	$\times 10^9$ kWh/yr	$\times 10^9$ kWh/yr	$\$ \times 10^9$	$\$ \times 10^9$	$\times 10^6$	Bcf	$\times 10^9$ kWh/yr	$\times 10^9$ kWh/yr	$\$ \times 10^9$	$\$ \times 10^9$	$/kWh/yr	$/kWh/yr
Gas New	0.0769	14.8	0	4.63	0.855	1.24	0.175	33.6	0	10.5	1.95	2.82	0.016- 0.045	0.025- 0.054
Gas Retrofit	0.147	44.2	0	13.8	3.41	5.10	0.147	44.2	0	13.8	3.41	5.10	0.019- 0.057	0.031- 0.067
Gas Combined	0.224	58.9	0	18.4	4.26	6.34	0.322	77.8	0	24.3	5.36	7.93	0.016- 0.057	0.025- 0.067
Electric New	0.0441	0	1.35	1.35	0.623	0.841	0.104	0	3.16	3.16	1.46	1.98	0.053- 0.160	0.073- 0.196
Electric Retrofit	0.175	0	0.539	0.539	0.309	0.418	0.0175	0	0.539	0.539	0.309	0.418	0.066- 0.201	0.091- 0.245
Electric Combined	0.0616	0	1.89	1.89	0.932	1.26	0.121	0	3.70	3.70	1.77	2.40	0.053- 0.201	0.073- 0.245
Mixed New	0.0442	3.81	0.776	1.79	0.525	0.747	0.101	8.90	1.77	4.55	1.18	1.69	0.009- 0.170	0.014- 0.208
Mixed Retrofit	0.0291	4.47	0.490	1.87	0.575	0.848	0.0291	4.47	0.490	1.87	0.575	0.848	0.012- 0.217	0.017- 0.260
Gas or Electric New	0.165	18.6	2.13	7.95	2.00	2.83	0.380	42.6	4.93	18.2	4.59	6.49	0.016- 0.170	0.025- 0.208
Gas or Electric Retrofit	0.174	48.3	1.03	16.1	4.29	6.36	0.194	48.3	1.03	16.1	4.29	6.36	0.019- 0.210	0.031- 0.260
Total Market	0.339	66.9	3.16	24.1	6.29	9.19	0.547	90.9	5.42	33.8	8.88	12.80	0.016- 0.201	0.025- 0.260

Table 5-4. Solar Energy Potential for Solar Water Heating on Multiple Family Buildings

Submarket	10-Year Scenario						20-Year Scenario						Marginal Cost	
	No. of Units	Potential Energy Displaced			Total Cost		No. of Units	Potential Energy Displaced			Total Cost			
		Gas	Elec	Total	$5 Collector	$16 Collector		Gas	Elec	Total	$5 Collector	$15 Collector	$5 Collector	$15 Collector
	x 10^6	Bcf	x 10^9 kWh/yr	x 10^9 kWh/yr	$ x 10^9	$ x 10^9	x 10^6	Bcf	x 10^9 kWh/yr	x 10^9 kWh/yr	$ x 10^9	$ x 10^9	$/kWh/yr	$/kWh/yr
Gas New	0.107	9.34	0	2.92	0.234	0.407	0.244	21.3	0	6.67	0.533	0.927	0.0077- 0.0087	0.013- 0.016
Gas Retrofit	0.159	14.5	0	4.52	0.487	0.809	0.159	14.5	0	4.52	0.487	0.809	0.0096- 0.0109	0.016- 0.020
Gas Combined	0.266	23.8	0	7.44	0.721	1.22	0.403	35.8	0	11.2	1.02	1.74		
Electric New	0.0586	0	0.922	0.922	0.149	0.244	0.137	0	2.15	2.15	0.348	0.569	0.016- 0.017	0.026- 0.028
Electric Retrofit	0.0349	0	0.549	0.549	0.111	0.182	0.0349	0	0.549	0.549	0.111	0.182	0.020- 0.022	0.032- 0.036
Electric Combined	0.0935	0	1.47	1.47	0.260	0.426	0.172	0	2.70	2.70	0.459	0.751		
Gas and Electric New	0.166	9.34	0.922	3.84	0.383	0.651	0.381	21.3	2.15	8.82	0.881	1.50		
Gas and Electric Retrofit	0.194	14.5	0.549	5.07	0.598	0.991	0.194	14.5	0.549	5.07	0.598	0.991		
Total Market	0.360	23.8	1.47	8.91	0.981	1.64	0.575	35.8	2.7	13.9	1.48	2.49		

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Table 5-5. Solar Energy Displacement Potential for Residential Space and Water Heating Applications After First Using Conservation Where Appropriate

Strategy	10-Year Time Frame 1976-86					20-Year Time Frame 1976-96					Marginal Cost Range Dollars per kWh
	Number of Installed Units x 10^6	Energy Displaced			Cost Range x 10^9 dollars	Number of Installed Units x 10^6	Energy Displaced			Cost Range x 10^9 dollars	
		Electric x 10^9 kWh	Gas x 10^9 cf	Total x 10^9 kWh			Electric x 10^9 kWh	Gas x 10^9 cf	Total x 10^9 kWh		
1. New water heating only	2.6	1.8	21.1	0.5/3.2(1) 8.0	1.3 - 2.3	5.7	4.4	43.7	1.1/6.9 17.2	2.8 - 4.7	0.008 - 0.033
2. Retrofit water heating	5.2	1.7	59.1	1.2/7.6 19.0	4.6 - 7.5	5.2	1.7	62.5	1.3/8.0 20.0	4.5 - 7.4	0.025 - 0.072
3. New and retrofit water heating	7.9	3.5	80.2	1.7/10.8 27.0	5.9 - 9.7	10.9	6.1	106	2.4/14.9 37.2	7.3 - 12.2	0.008 - 0.072
4. New water heating and space heating	2.6	4.9	60.7	1.5/9.1 22.7	4.8 - 8.0	5.3	11.8	120	3.0/18.8 47.1	11.2 - 16.9	0.012 - 0.20
5. Retrofit water heating and space heating	5.3	4.3	379	7.3/46 115	21.1 - 37.8	5.3	4.3	379	7.3/46.0 115	21.1 - 37.8	0.016 - 0.25
6. New and retrofit water and space heating	7.9	9.2	440	8.8/55.0 138	26 - 46	10.6	16.2	499	10.3/64.8 162	32 - 54	0.012 - 0.25
7. Retrofit water heating plus new space and water heating	7.9	6.6	124	2.7/17.2 43	9.3 - 15.4	10.6	13.5	184	4.3/26.8 67	15 - 24	0.012 - 0.25
8. Replace 10% of natural gas supply Multiple family 25%-$2 to 3.26 Single family 75%-$6 to 9.76	7.9	-	168	49	10.2 - 16.8	10.4	-	168	0/168 49	10.2 - 16.8	

1975 California Energy Use: Gas = 1680 Bcf (508 x 10^9 kWh), Elec. = 150 x 10^9 kWh, Total NG + E = 658 x 10^9 kWh natural gas and elec.,
Total Overall = 1570 x 10^9 kWh

Residential Energy Use: Gas = 645 Bcf (195 x 10^9 kWh), E = 46 x 10^9 kWh, Total = 250 x 10^9 kWh

(1) x/y; x = % Calif. Total all 4 = % residential

marginal cost range of adopting each strategy. In each case, the highest marginal costs occur in the electric markets (see marginal costs in Tables 5-1 - 5-4).

By comparing the potential energy displaced by solar energy with energy use in California, the impact of a massive solar energy installation program can be assessed. Table 5-6 summarizes energy use in California in 1975 for all energy uses, for residential energy uses and for residential space and water heating uses.

Total California energy use in 1975 was 1570 x 10^9 kWh. Natural gas supplied about 1/3 of this use or 1680 billion cubic feet (508 x 10^9 kWh). Residential energy use was 250 x 10^9 kWh or 16% of total California energy use. Natural gas provided 78% of the residential total or 645 billion cubic feet. Finally, residential space and water heating combined was 193 billion kWh which is 77% of total residential energy use of 12.3% of total California energy use.

Over a 20-year time frame, the applications of solar energy to water heating in all new residential units can replace about 7% of 1975 annual residential energy use (1.1% of total 1975 California energy use). This would cost between 2.8 and 4.4 billion dollars over the 20-year period. Installation of solar water heating in all new and all existing units in that time period would replace 15% of the residential energy use and cost between 7.3 and 12.2 billion dollars. Using solar energy to provide water and space heating for all new units will replace 19% of residential energy at a cost of between 11.2 and 16.9 billion dollars over the twenty-year time frame. A massive program to provide retrofit water heating and space plus water heating in all new residential units has a potential saving of 27% of the State's residential energy use by 1996, at a cost of 15 to 24 billion dollars.

Over a ten-year time frame, large energy displacements are also possible. Retrofitting half of existing residential units with solar water heating and installing water heating on all new units will displace about 7% of the residential energy use. Since most of this savings will be in natural gas, the savings of natural gas will be 51 billion cubic feet per year or about 8% of the 1975 residential natural gas useage at a cost of between 3.6 and 6 billion dollars. A program to retrofit all existing units with solar water heating and install solar water plus space heating on all new units over the ten year time frame has an energy displacement potential of 17% of residential energy use (3.7% of total California energy use). This strategy would supply 124 billion cubic feet per year at a total cost of 9.3 to 15.4 billion dollars. The size of this displacement is about the same size as either the arctic pipeline or the prudhoe LNC projects and is 40% larger than the WESCO Coal gassification project (cf Table 3-12).

Because of the past and projected future decline in California natural gas supplies and the environmental plus cost problems of new natural gas and electric supply projects, the use of solar energy as a replacement for natural gas is important. Strategy 8 on Table 5-5 gives the costs of a strategy to replace 10% of total 1975 natural gas supply of 1680 billion cubic feet per year. The cost would be between 8 and 13 billion dollars with 75% of the money being used for single family installations.

Table 5-6. Summary of Energy Use in California: 1975

All Energy Use

Fuel	Bcf/yr	x 10^9 kWh/yr	Percent of Total California Energy Use
Electricity		150	10%
Natural Gas	1680	508	32%
Other Sources (petroleum, etc.)		912	58%
Total California	1680	1570	100%

Residential Energy Use Only - 250 x 10^9 kWh/yr or 16% of California Total

Fuel	Bcf/yr	x 10^9 kWh/yr	Percent of Residential Use
Electricity	-	46	18
Natural Gas	645	195	78
Other (propane, etc.)	-	9	4
Total Residential	645	250	100%

Residential Space Heating and Water Heating - 193 x 10^9 kWh/yr or 77% of Residential Energy Use

Fuel	Space Heating Only		Water Heating Only		Combined		Combined Percent of Total
	Bcf/yr	kWh/yr x 10^9	Bcf/yr	kWh/yr x 10^9	Bcf/yr	kWh/yr x 10^9	
Electricity	-	4.0		4.2		8.2	4.2
Natural Gas	354	107.0	228	58.8	582	175.8	91.1
Other Sources	-	7.0		2.0		9.0	4.7
Total	354	118	228	75.0	582	193	100%

For Source: Cf Tables 3-6, 3-7, and 3-8 in this report (Ref 1 and 2)

5. Solar Energy Ranking Curves ("Marginal Cost" Curves)

As mentioned in Sections II and III, a computer analysis was performed to determine the optimum collector size for each given applications. The program used simulated hourly demand for space heating, cooling and water heating, and ten year insolation data to optimize the solar energy system design.

Over 45 applications were examined, ranging from water heating in single family buildings to space cooling in office buildings. The applications were ranked from the least costly to the most expensive in the single family and multiple family markets. When the ranking of each market is plotted on a vertical scale with its energy potential plotted on a horizontal scale, the result is a "marginal cost" curve which ranks each solar energy submarket and provides an easy way to determine the least expensive way to replace a given quantity of conventional energy with solar energy. Each "step" in the curve represents a different solar application submarket. These submarkets include water heating only, space heating only, and water plus space heating. Two different markets (retrofit or new) are defined for each of the three major weather regions, which for the purposes of this analysis comprise 80% of the building population in California.*

In all, over 125 submarkets were examined for each of the single and multiple family cost curves reflecting the number of combinations of submarkets (45 applications, three weather zones, retrofit, or new markets).

Separate marginal cost curves for the single family and multiple family markets are presented in Figures 5-1 and 5-2, respectively. Separate curves for solar water heating in single family units is given in Figure 5-3. These curves show cost comparisons for various solar energy applications. The height of each step is the cost (in $ per kWh per year) of providing solar energy and the width of each "step" indicates the amount of energy displaceable by solar energy (in billions of kWh per year) in the particular solar application submarket. To simplify cost curves, submarkets were combined so that the rough cost and size of important single and multiple family energy markets could be easily identified. The marginal cost curves are, therefore, approximations which graphically illustrate the ranking and size of markets but should not be used for detailed analysis. For detailed analysis use the tabular data presented in the Appendix.

Two curves are shown in each figure. The upper curve indicates the cost of solar energy if the collector arrays cost \$15 per ft^2 in 1974 dollars (the approximate cost today). The lower curve indicates the cost of these applications

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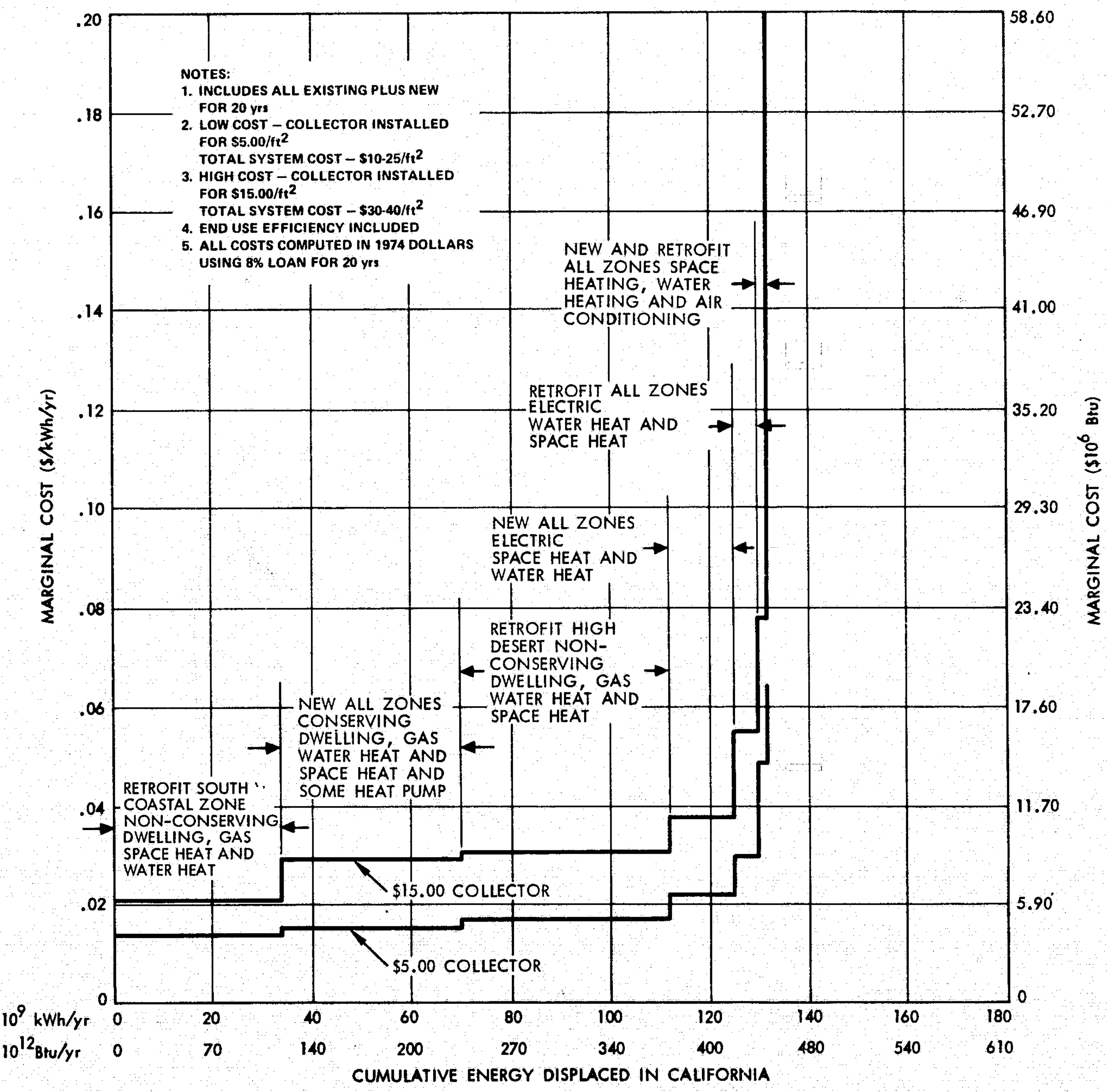
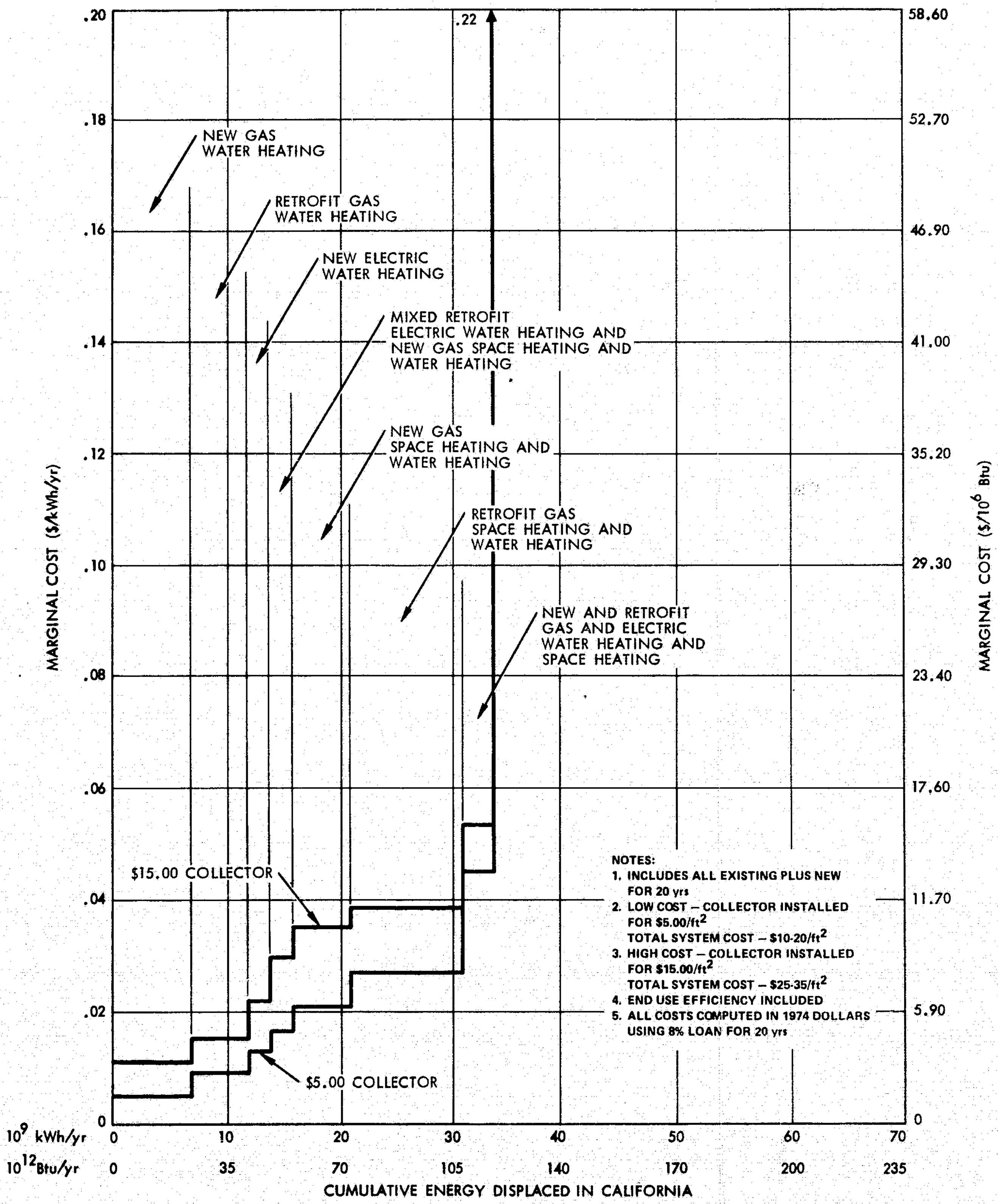
*The weather parameters of each of the major California population areas were examined and the respective building populations allocated to the most appropriate of the three weather zones on the basis of winter temperature, heating degree-days, summer cooling degree-days, and average available sunshine. The weather zones encompass (1) the South Coastal area, (2) the Central Valley, and (3) the North Inland region of California. For a detailed analysis of the impact of weather zones on solar energy applications, see Ref. 5.



NOTES:
1. INCLUDES ALL EXISTING PLUS NEW FOR 20 yrs
2. LOW COST – COLLECTOR INSTALLED FOR \$5.00/ft^2 TOTAL SYSTEM COST – \$10-25/ft^2
3. HIGH COST – COLLECTOR INSTALLED FOR \$15.00/ft^2 TOTAL SYSTEM COST – \$30-40/ft^2
4. END USE EFFICIENCY INCLUDED
5. ALL COSTS COMPUTED IN 1974 DOLLARS USING 8% LOAN FOR 20 yrs

Figure 5-1. Marginal Cost of Displacing Conventional Energy in the Single Family, Water Heating and Space Heating, Market



NOTES:
1. INCLUDES ALL EXISTING PLUS NEW FOR 20 yrs
2. LOW COST – COLLECTOR INSTALLED FOR $5.00/ft^2 TOTAL SYSTEM COST – $10-20/ft^2
3. HIGH COST – COLLECTOR INSTALLED FOR $15.00/ft^2 TOTAL SYSTEM COST – $25-35/ft^2
4. END USE EFFICIENCY INCLUDED
5. ALL COSTS COMPUTED IN 1974 DOLLARS USING 8% LOAN FOR 20 yrs

Figure 5-2. Marginal Cost of Displacing Conventional Energy in the Multiple Family Market

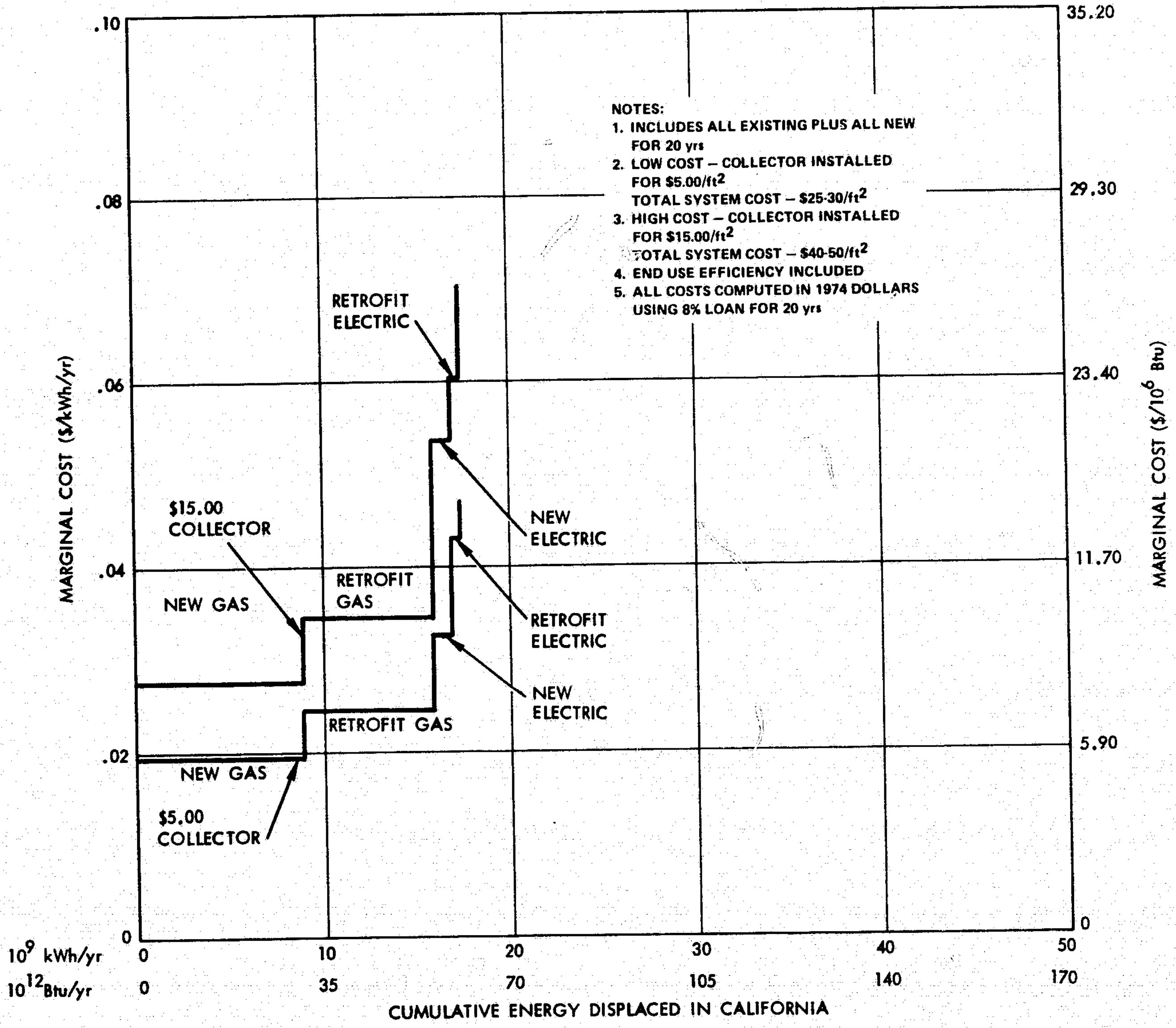


Figure 5-3. Marginal Cost of Displacing Conventional Energy in the Single Family, Water Heating Only, Market

if the collector array cost is reduced to about \$5.00 per ft^2 (1974 dollars), which is our estimate of potential 1980 prices without major technical breakthrough.*

An example should help clarify the usefulness of these ranking curves. Suppose the following question was asked: "What is the approximate size of the competitive solar energy market if all alternatives cost \$0.035 per kWh (\$10 per million Btu)?" The question is easily answered by looking at the solar markets which fall below this cost in Figures 5-1 and 5-2. Assuming a \$5.00 per ft^2 collector cost (installed) and 8% interest for a 20-year loan, multiple family water heating markets cost less than \$0.035 per kWh and have a total of energy use of 15 x 10^9 kWh/yr. For single family buildings, the water plus space heating markets all cost less than \$0.035 per kWh with a total energy replacement of 135 x 10^9 kWh per year of fossil fuel. The total investment required to make this replacement, using solar energy, is the area under each curve between the y-axis and the appropriate total energy displaced divided by the capital recovery factor for an 8% loan for a 20-year period which is 0.1. In this example, the cost of displacing 150 x 10^9 kWh per year of fossil fuel. The total investment required to make this replacement, using solar energy, is the area under each curve between the y-axis and the appropriate total energy displaced. In this example, the cost of displacing 150 x 10^9 kWh annually is a one-time cost of \$24 billion (2.0 billion in the multi-family market and 22 billion in the single family market). Over the 20-year life of the equipment, the \$24 billion investment plus about \$4.8 billion in maintenance will yield 3,000 x 10^9 kWh displacement.

Using these marginal cost curves, one can identify the best applications of solar energy for residential buildings and ascertain the annual savings which will be obtained from a reasonable level of investment in solar equipment. Figures 5-1 and 5-2 indicate that solar water heating in apartments is the most economically advantageous application of solar energy, the cost being less than \$0.02 per kWh (\$5 per million Btu) if a \$5.00 per ft^2 collector is assumed (1974 dollars). Combined solar space and water heating systems for single family units are the next most attractive application, with a cost of about \$0.025 per kWh for the \$5.00 per ft^2 collector.

6. Cumulative Cost Curves

If the integral of marginal cost curves are plotted (after dividing by the capital recovery factor of 0.1), the result is a cumulative cost curve which shows the cumulative cost of replacing a particular level of energy. Because the marginal cost curves were developed for a ranking from the least expensive to the most expensive solar applications, each point on the cumulative cost curves gives the minimum investment required to achieve a given level of energy saving. In other words, the curves show the cost and energy displacement of beginning with the least expensive solar applications and sequentially installing the next best (i.e., next least expensive) solar application.

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*The price per ft^2 includes only the cost of the solar collector and its installation. The cost of storage tanks, piping, etc. adds \$5 per ft^2 or more, depending on the details of the application, and is included in the total cost of the system.

The cumulative costs of sequentially implementing the "next-best" solar energy applications are shown in Figures 5-4, 5-5, and 5-6. Figure 5-5 shows the total investment required to replace a given amount of energy in the single family market. Total costs are indicated both for the current solar technology $15 per ft^2 of installed collector (1974 dollars) and for our estimate of the 1980 price assuming large-scale production of solar collectors and without any major technical breakthroughs (i.e., $5.00 per ft^2 of installed collector in 1974 dollars). These curves provide a means of estimating the largest energy displacement possible for a given level of expenditure and provides a way of identifying several large-scale solar energy implementation alternatives strategies.

A minimum but significant solar alternative strategy would be to have the best marginal solar applications replace about 6 x 10^9 kWh per year (20 billion cubic feet per year) of natural gas. Achievement of this goal would be equivalent to completing a typical gas exploration and development project in the south-western or Rocky Mountain areas of the United States. These projects typically provide 1 to 2% of the 1975 California usage of natural gas (which was 1680 billion cubic feet per year in 1975). This also represents about 8% of the natural gas used in residential applications in 1975. The cost of the minimum cost solar energy alternative is in the range of 0.6 to 1.2 billion 1976 dollars. If a 10-year implementation period is assumed, such a development would require between 60 and 120 million dollars per year. This investment would produce solar energy for about $0.02 per kWh or $5 per million Btu (see Figures 5-1 and 5-2).

An alternative strategy that could be established for solar energy would be the replacement of the equivalent of 10% of the 1975 natural gas supply. This is about 170 billion cubic feet per year (51 x 10^9 kWh/yr) and is roughly the size of proposed LNG imports or twice the size of a coal gasification plant. To reach this goal over a twenty-year period, strategy 7 from Table 5-5 could be initiated. This strategy requires the use of solar water plus space heating in all new units and retrofit of water heating on all existing units. The investment cost of this level of solar energy implementation would be about 8-13 billion dollars* as can be seen from the cumulative cost curves.

The cumulative cost curves can also be used to determine the energy displacement potential of different levels of investment in the "best" solar energy applications. The investment level is the total cost of installing the solar energy applications and is paid for by private individuals directly, unless there is some form of financial incentive or utility financing. In these cases,

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*The same cost of a 10% replacement can be approximated using the marginal cost curves as follows:

$$\text{for \$15 collectors} - \$8\ \frac{\text{dollars}}{\text{MBtu}} \times 3413\ \frac{\text{Btu}}{\text{kWh}} \times 51 \times 10^9\ \frac{\text{kWh}}{\text{Yr.}} = 13.9 \times 10^9 \text{ dollars}$$

$$\text{for \$5 collectors} - \$5\ \frac{\text{dollars}}{\text{MBtu}} \times 3413\ \frac{\text{Btu}}{\text{kWh}} \times 41 \times 10^9\ \frac{\text{kWh}}{\text{Yr.}} = 8.7 \times 10^9 \text{ dollars}$$

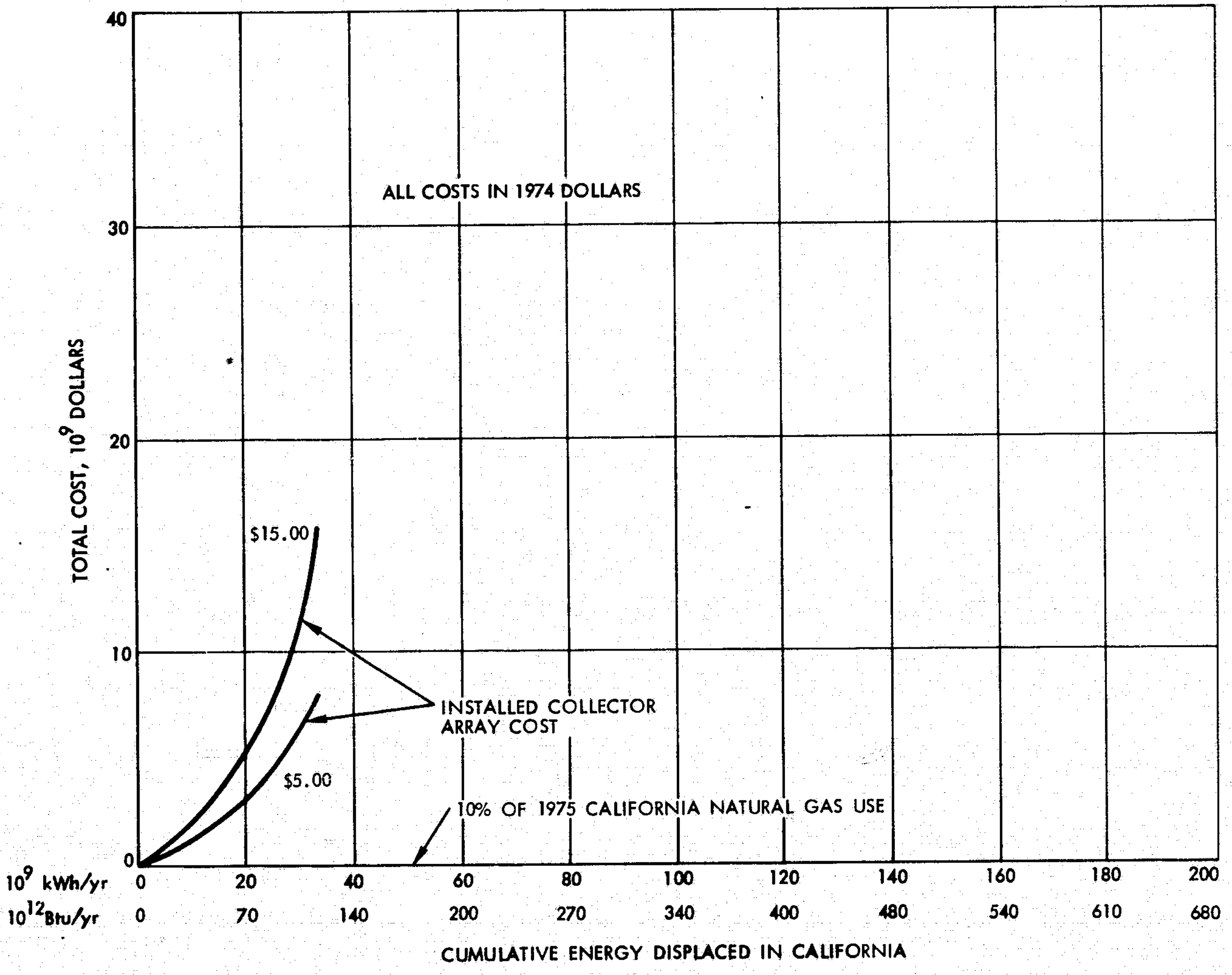

Figure 5-4. Total Investment Required to Replace Given Amount of Energy; Multiple Family Water Heating and Space Heating

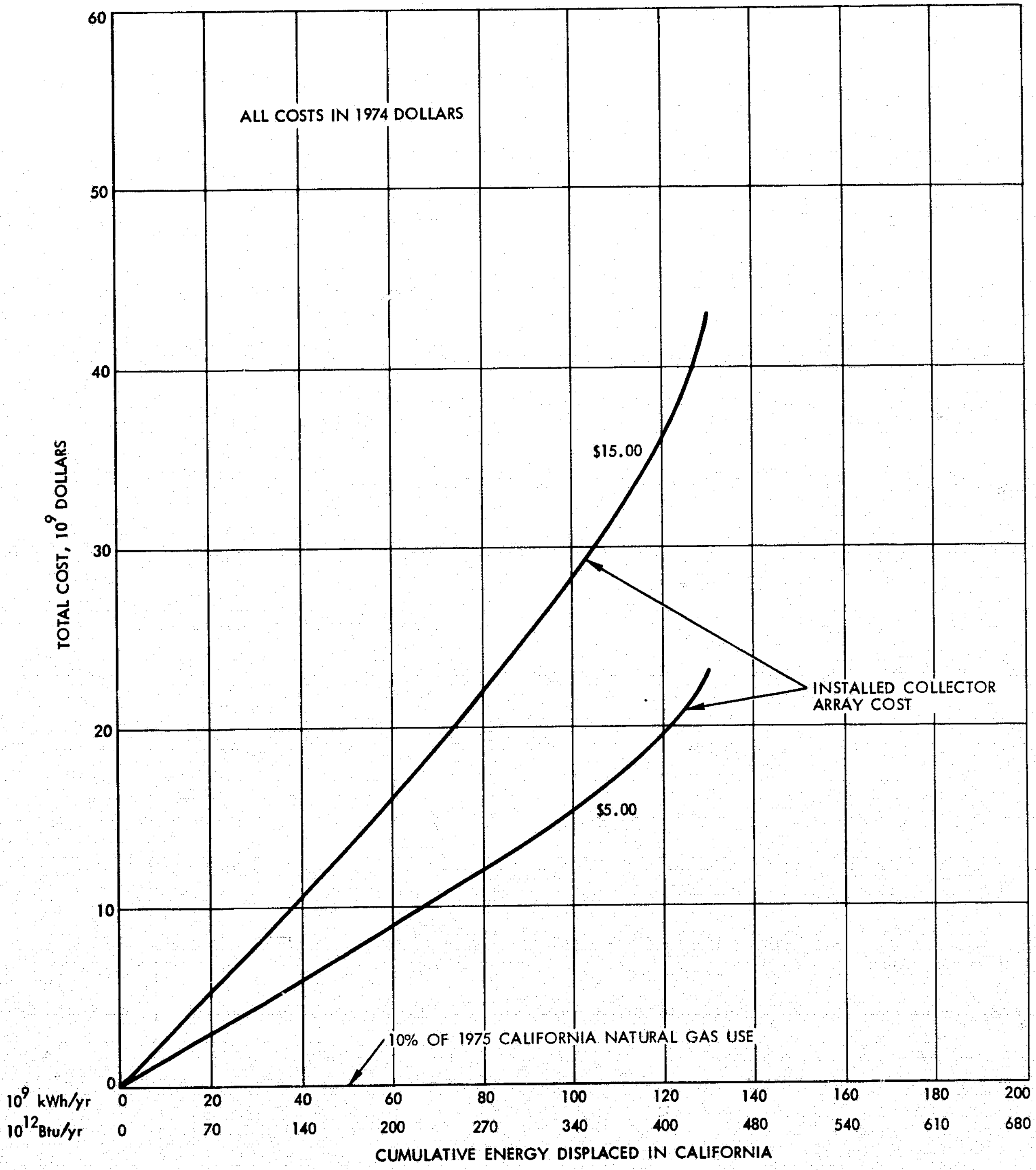

Figure 5-5. Total Investment Required to Replace Given Amount of Energy; Single Family Water Heating and Space Heating.

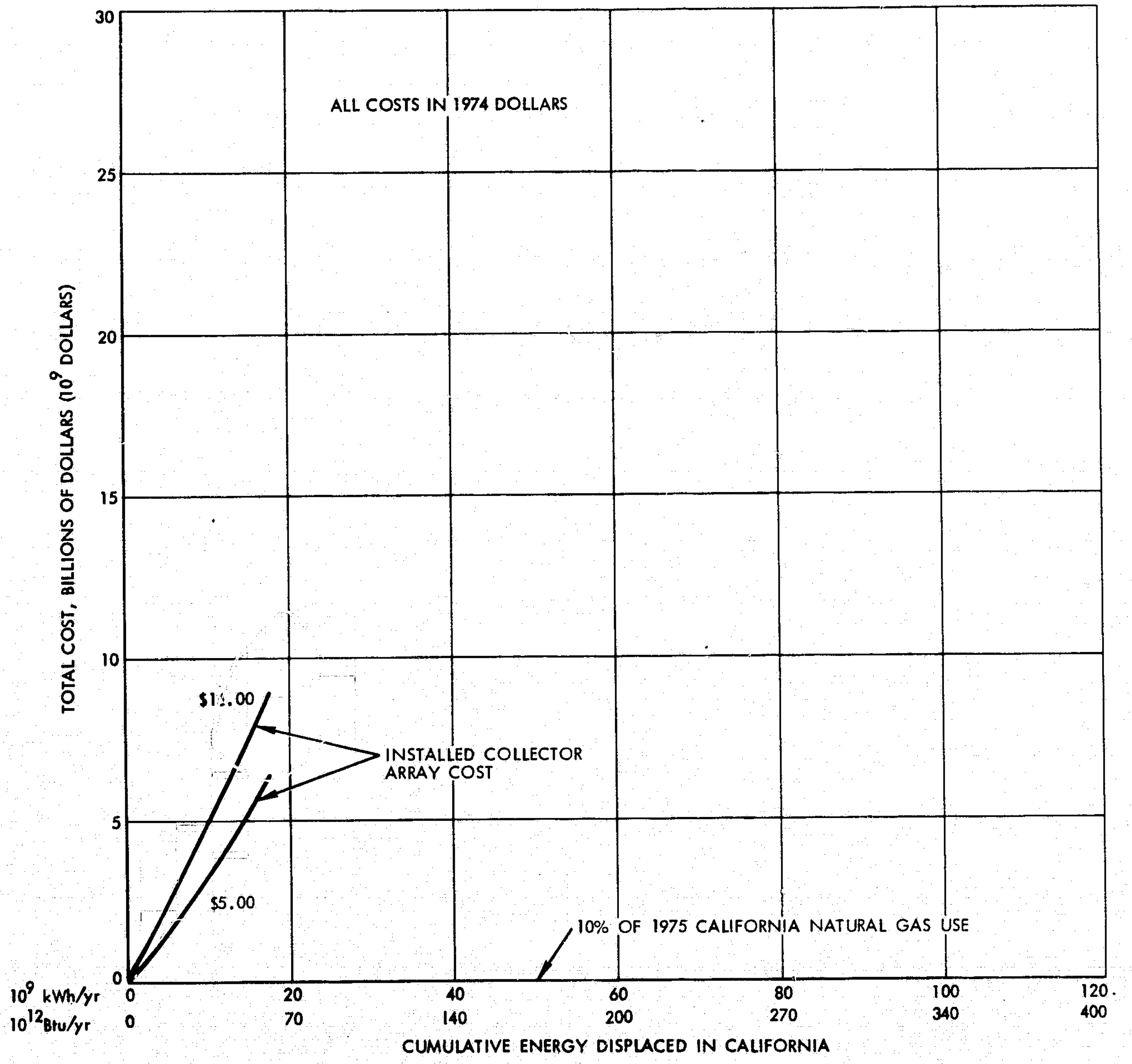

Figure 5-6. Total Investment Required to Replace Given Amount of Energy; Multiple Family Water Heating Only

the costs are also paid by private individuals but indirectly (through tax structure or utility rates). Even though the investment is paid for by individuals, government policy can have a large effect on the level of investment in solar energy systems as Section IV illustrated. The impact of encouraging a given level of investment in solar energy is therefore interesting from a policy perspective. Table 5-7 identifies the impact of three different levels of solar energy investment in the "best options" (strategies 9, 10, and 11).

A two-billion dollar investment strategy could put one billion into solar energy for single family units and one billion into solar energy for multiple family units. The energy displaced would range from 11 to 16 billion kWh per year (38 to 55 billion cubic feet per yr). This displaces about 1% of total 1975 California energy use or between 4 and 7 percent of 1975 residential energy use.

A ten-billion dollar investment in the "best" solar energy options will produce a displacement of 41 to 64 billion kWh annually (140 to 218 billion cubic feet per yr.). The investment will be divided as approximately 75% to single family and 25% to multiple family buildings. The displacement level is equivalent to 3 to 4 percent of the total 1975 California energy use or 16 to 25 percent of the 1975 residential energy use. Because investments in the "best" solar energy applications will displace natural gas almost exclusively, the natural gas savings of a ten-billion dollar investment would produce annual savings, for the 20 year life of the solar equipment, equivalent in size to an LNG import project. The solar investment would produce less environmental risk and require little operating expense.

A twenty-billion dollar investment will produce between a 74 and 125 billion kWh displacement annually. Most of the investment (over 80%) will be used in single family buildings. The displacement levels are equivalent to a 5 to 8 percent of total 1975 California energy use or 30 to 50 percent of 1975 residential energy use.

7. Utility Involvement in Solar Water Heating and Space Heating Systems

Utility ownership of space heating and water heating systems provides an avenue for supplying society with the lowest possible cost of energy. A utility is in a position to trade-off solar versus new conventional energy sources and to deploy solar when a cost advantage is evident.

Data to support trade-off studies involving solar energy in various markets has been included in Tables A-1 through A-6 in the Appendix. Solar costs have been estimated assuming low cost collectors, 5 $/ft^2, and high cost collectors, 15 $/ft^2. Marginal costs of solar energy are presented assuming typical private utility company capital recovery factors (CRF) of 0.17 and 0.2. For specific ground rules; i.e., collector costs, CRF's, and costs of new conventional energy, attractive markets for utility ownership can be found by comparing marginal costs of solar with the marginal cost of new conventional energy.

For example, see Table A-1. If new natural gas supplies have a marginal cost of 6 $/10^6 Btu, and solar collectors are available at 5 $/ft^2, then utility involvement in solar is justified in the multiple family water heating market in

Table 5-7. Impact of three Different Levels of Solar Energy Investment

Strategy		Total Energy Displaced			
		$5 Collector		$15 Collector	
		x 10^9 kWh/yr	Bcf/yr	x 10^9 kWh/yr	Bcf/yr
9. 2 Billion Investment in "Best Options"		16.0	54.6	11.0	37.5
Multiple Family	1 billion	10		7	
Single Family	1 billion	6		4	
10. 10 Billion Investment in "Best Options"		64.0	218	41.0	140
Multiple Family	2 to 3.2 billion	14		19	
Single Family	8 to 6.8 billion	50		27	
11. 20 Billion Investment in "Best Options"		125.0	427	74.0	253
Multiple Family	2 to 3.2 billion	14		14	
Single Family	18 to 16.8 billion	111		60	

all zones of California in both new and retrofit installations. Total gas energy displacement by solar in 1996 can be as high as 11 x 10^9 kWh/yr (6.6 kWh/yr new market or 37 x 10^{12} Btu/year. At high collector costs of 15 $/ft^2, Table A-2, attractive markets for gas utility involvment disappear.

By similar reasoning electric utility involvement in solar water heating in multiple family dwellings looks good with a 5 $/ft^2 collector (Table A-3), and not good with a 15 $/ft^2 collector (Table A-4).

Utility involvement in the single family market, Tables A-5 and A-6, does not appear to be justified under the assumptions used in the exercise considered in the appendix.

B. MARKET PENETRATION AND THE ROLE OF SOLAR ENERGY IN BUILDINGS

To provide insight into the potential behavior of a rational market against a background of different energy scenarios, a market penetration model was developed. The model provides a way of assessing the impact of solar energy under normal market conditions using what have been historically acceptable buying criteria by the building industry and consumers. In addition, the model provides a means of estimating the impact of different incentive levels on the acceptance of solar energy. First cost incentives of 25% and 50% are considered. Two scenarios for the price and availability of natural gas and electricity have been formulated: A "gas curtailment" scenario, and a "business as usual" scenario. These scenarios bracket the range of possible futures for the price and availability of conventional fossil fuels and electricity. They provide a means for estimating the sensitivity of solar energy market penetration to different future prices and availability of natural gas and electricity.

Both scenarios postulate a nominal price for natural gas at the city gate price of $1.75 per million cubic feet in 1977 (i.e., $1.37 per million cubic feet in 1974 dollars). This price could result from deregulation or other action by the Federal Power Commission (FPC). Both scenarios assume that all new buildings are energy conserving; that all existing electric buildings are energy conserving; and that gas buildings are retrofitted with ceiling insulation.

The "gas curtailment" scenario postulates a continuing reduction in the supply of natural gas so that by 1978 there is an embargo on all new natural gas hookups. The result is a switch in fuel use for new buildings to 100% electric (all-electric residential buildings comprise about 10-15% of the new market as of 1974). Electricity starts at a price of $0.035/kWh in 1975. The price escalates at a 4% annual rate in real 1974 dollars for 10 years. This is followed by a period in which the rate of escalation of electric price drops to 1.5% annually. Because the pressure to expand the natural gas supply is off, an escalation of only 3% per year is postulated for the city gate price of natural gas.

The "business as usual" scenario postulates a continuation of historical trends in the split between the use of electricity and natural gas in buildings. The average city gate price of "natural gas" is postulated to escalate at a compounded annual rate of 5% in real dollars. Since the demand for electricity is reduced, the price of electricity is postulated to remain constant in real dollars. These two scenarios are illustrated graphically in Figure 5-7.

The nominal market penetration analysis assumes a solar collector array can be purchased and installed on the roof of a building for approximately $5.00 per ft^2 (1974 dollars - not including the cost of plumbing, storage, and controllers). For solar installations constructed in 1974 and 1975, solar energy costs have exceeded $15 per ft^2 of installed collector; however, we estimate that these costs can be brought down to the $5.00 per ft^2 level without major new technical breakthroughs (see Sections II and III).

The market penetration model assumes historical rates of product substitution and is consistent with the previous solar energy commercial sales experience in Florida. The market penetration analysis indicates the time scale which will probably be required for widespread solar energy use without government incentives. The model assumes that the essence of the product substitution is an investment decision in which the decision maker chooses between solar energy and either natural gas or electricity. The critical before-tax payback period for adoption is assumed to be 7.5 years in the single family market and 5 years in commercial markets (including multiple family residential) which are equivalent to 12% and 19% rates of return on investments for 20-year life equipment, respectively.

Based on the result of the market penetration analysis, financial incentives are found to have a significant effect on the role of solar energy in California buildings. The results state what the results are in terms of energy displaced from the overall market analysis, presented in Table 5-8, are useful in assessing the implications of different incentive levels on the role of solar energy. Six scenarios for energy saved are of particular interest and are contained in the last two columns: The scenarios for the three incentive levels under the "electricity markets assuming gas curtailment" and a similar set of scenarios

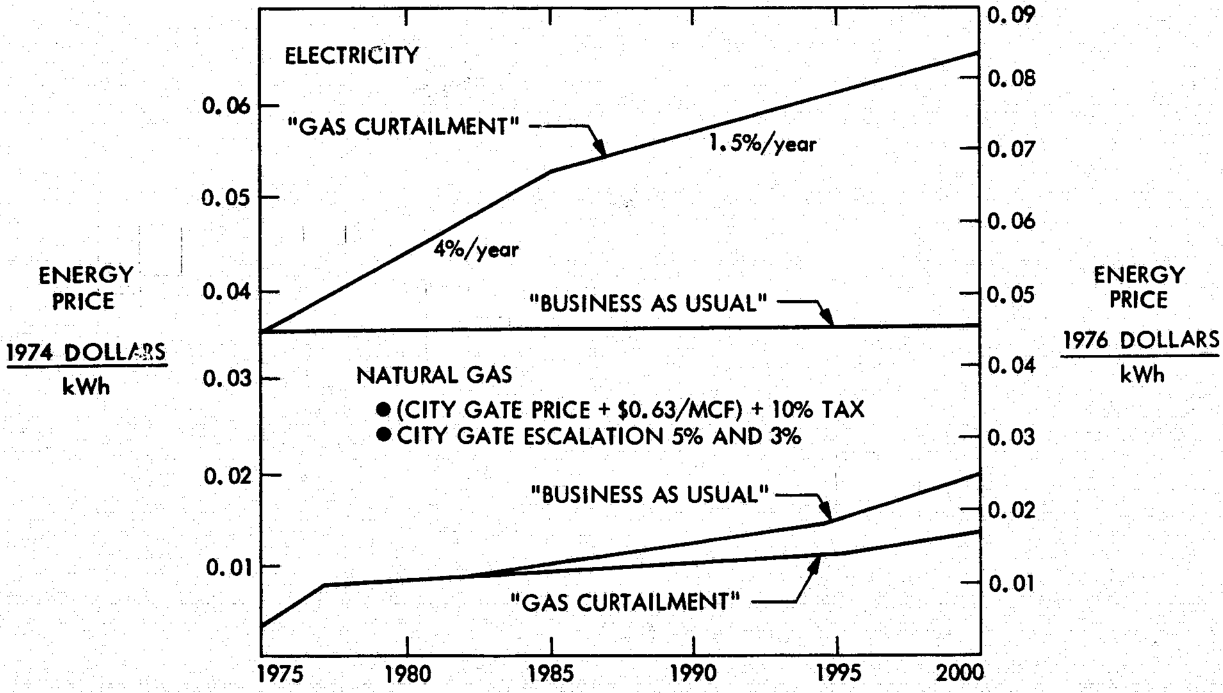

Figure 5-7. Scenarios for Future Energy Prices

Table 5-8. Market Penetration Estimates for Solar Energy in California Residential and Commercial Buildings, Assuming Five-Dollar Collectors

	Year	Natural Gas Alternates		Electricity Markets		Total Market			
		Business as Usual	Gas Curtailment	Business as Usual	Gas Curtailment	Business As Usual		Gas Curtailment	
						Total Energy	% of 1975 Res.	Total Energy	% of 1975 Res.
		x 10^9 kWh	x 10^9 kWh	x 10^9 kWh	x 10^9 kWh	x 10^9 kWh	%	x 10^9 kWh	%
No Incentive	1980	-	-	0.20	0.88	0.20	0.08	0.88	0.35
	1985	-	-	1.10	4.33	1.10	0.44	4.33	1.7
	1990	0.066	-	2.04	11.1	2.1	0.84	11.1	4.4
	1995	0.29	-	4.08	21.3	4.1	1.6	21.3	8.5
	2000	2.22	-	7.2	35.7	7.6	3.0	35.7	15.
25% Incentive	1980	-	-	0.65	1.62	0.65	0.26	1.6	0.64
	1985	0.066	-	2.06	5.91	2.1	0.84	5.9	2.4
	1990	0.60	-	4.46	13.5	5.1	2.0	13.5	5.4
	1995	3.3	-	13.8	40.8	26.0	10.4	40.8	16.
	2000	12.1	-	2.0	64.8	34.2	14.	40.8	26.
50% Incentive	1980	0.45	-	1.07	2.34	1.5	0.6	2.34	0.94
	1985	2.40	-	3.02	8.45	5.4	2.2	8.45	3.4
	1990	8.54	-	5.98	19.0	15.0	6.0	19.0	7.6
	1995	21.8	0.90	10.5	34.1	32.0	12.8	35.0	14.0
	2000	45.7	2.40	16.8	54.4	62.0	24.8	56.8	23.0

1975 Total California Energy Use = 1570 x 10^9 kWh
1975 Total California Gas Use = 1680 x 10^9 Cu Ft ≅ 508 x 10^9 kWh
1975 Residential Energy Use = 250 x 10^9 kWh

under "gas plus electricity" markets assuming the "business as usual" scenario. For the range of prices postulated by the "gas curtailment" and "business as usual" scenarios, solar energy can be expected to be substituted for electricity and natural gas under various circumstances. Contrary to the opinion of the critics, solar energy is likely to be voluntarily adopted by a significant share of that market if natural gas is curtailed. As indicated in Table 5-8, the energy equivalent of 1% of 1975 California natural gas use or 5.1×10^9 kWh (17 billion cubic feet per year) would come from solar energy in the 1987-92 time period.* However, under the "business as usual" scenario, a 50% incentive is needed to assure that this level of energy would be supplied by solar energy in the same time period. At the 50% incentive level, solar energy could be contributing over 5% of the 1975 natural gas use or 25.5 billion kWh (89 billion cubic feet per year) in the 1992-96 time period, if natural gas is curtailed.

Financial incentives are effective both in expanding the market in which solar energy is economically viable, and in advancing the date when solar energy can make a significant contribution to the energy budget of the state. Three classes of financial incentives have been receiving attention at State and Federal levels: income tax credits, tax exemptions, and low interest loans. Over 100 pieces of legislation to promote solar energy have been introduced in the legislatures of 32 states and in Congress. California has passed an income tax credit for solar energy (Ref. 6) and is considering action on low interest loans (Ref. 7). All of these incentives have a financially equivalent reduction in the first cost of the solar energy hardware.

The qualitative effects of financial incentives on the market dynamics of solar energy in California are easier to illustrate in a single scenario. One good example is the model for the business as usual scenario. The results for total energy saved are presented in Figure 5-8. Even without any incentive, some market penetration is achieved, although, a 1% penetration is not achieved until after 1995 in the "business as usual" scenario. A twenty five percent incentive steps up market penetration by about five to seven years. With a twenty five percent incentive a one percent penetration is achieved by 1990. A fifty percent incentive increases the market penetration in the "business as usual" scenario by another 5 years. Only with a fifty percent incentive will solar energy achieve a 1% market penetration before 1985.

It should be emphasized that market penetration analysis is an inexact art and that these conclusions are qualitative and should not be taken as quantitatively precise. The value of the market penetration model is the insight it provides into the qualitative behavior of the market.

Comparing the market potential with the market penetration, we see that given the "normal" operation of the market place, solar energy applications though competitive with many new fossil and electric supply projects and having large potential for displacing energy, will not achieve significant market penetrations until the mid 1990s unless financial incentives are provided.

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*In 1975 natural gas use exceeded 1680×10^9 cubic ft/yr; 1% of this amounts to 17×10^9 cubic feet or 51×10^9 kWh/yr.

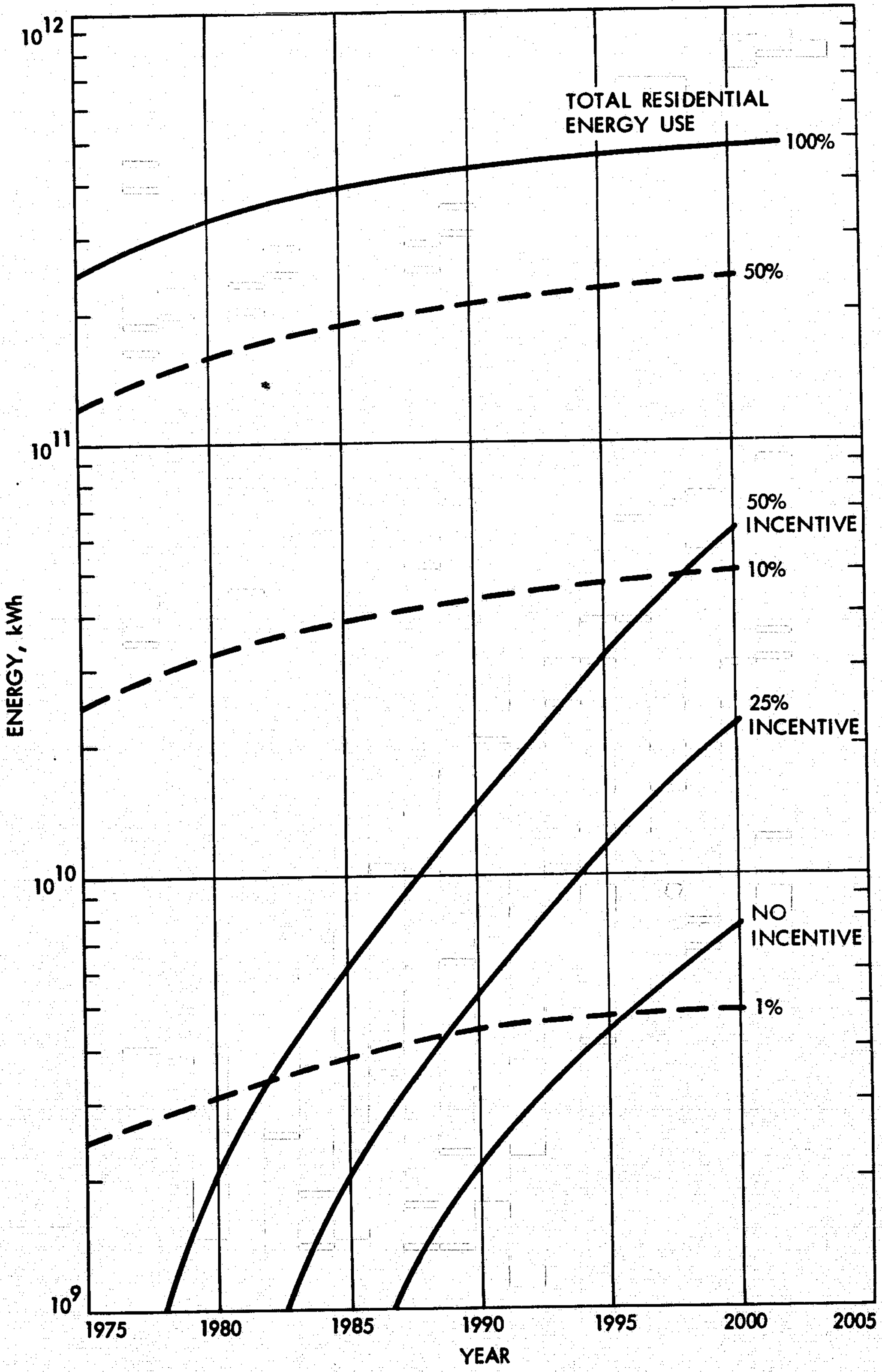

Figure 5-8. Market Penetration of Solar Energy Under the Business as Usual Scenario ($5 Collectors)

The potential for solar energy is quite large but the signals given in the market place will effectively discourage purchase of solar energy systems unless institutional means are found to alter the signals. Incentives, utility purchase and/or ownership of solar equipment and removal of non-market barriers are needed to allow solar energy to begin to approach its energy displacement potential in this century.

C. THE COMPATIBILITY OF WIDESPREAD USE OF SOLAR ENERGY WITH CALIFORNIA ELECTRIC UTILITIES

1. Summary

a. Impact on Peak Load. A concern has been expressed that electric utilities may be adversely affected by solar energy. This concern is based on the fact that energy from the sun is often interrupted by adverse weather conditions, and that auxiliary energy is needed during these periods. Since solar energy is most economically attractive if electricity is the only available energy for the auxiliary function, the use of solar energy can potentially exacerbate utility peak loads. For space heating and water heating systems the additional peak load would occur in winter and present a problem to a winter peaking utility. For summer peaking utilities there can be some potential for using electricity to back up solar heating and water heating systems without requiring additional plant capacity.

In California, all of the major electric utilities except for SDG&E experience their peak load in the summertime. But, additional generating capacity is also available during the summer from local hydro plants, and the Northwest Power Pool. The utilities also make all fossil and nuclear capacity available to meet the summer peak by scheduling maintenance during the winter months. Although these factors complicate the problem of assessing the potential for using electricity to back up solar energy in California, these factors have all been considered in Western System Coordinating Council (WSCC) forecasts (Ref. 58). Using the WSCC forecasts for 1985, an estimate for the potential in 1985 for the use of electricity to back up solar energy systems has been made under the following assumptions:

(1) The heating or water heating peak demand is coincident in time with the utility winter peak load and, simultaneously, solar energy is unavailable over the entire southwest area.

(2) Solar energy systems are designed with total disregard for their impact on utility peak load; i.e., they do not incorporate load management devices of any kind.

(3) All generation resources are allocated to meet a summer peak load; i.e., all scheduled maintenance continues to be done in the winter.

(4) Adverse Hydro conditions prevail.

(5) California can be represented by Pacific Southwest Power sub areas A, B & D. (The error introduced by this assumption is about 3%, because most of Nevada is also included in these sub areas.)

(6) The projected generation margin over the firm load in August 1985 is an adequate margin for any other month of the year. (The projected margin over the firm load is 17.3%.)

The first four assumptions admittedly result in a low estimate. The sixth assumption makes it possible to quantify a significant leve 1 of excess generating capacity in the winter months. However, the reliability of service would be reduced and some additional capacity may be needed to bring the level of service to a comparable level.

A detailed and complex analysis is needed to conclusively determine the amount of additional generation capacity needed when the market penetration approaches levels which would convert California to a winter peaking utility area. Lacking this analysis, the market penetration required to cause California to convert to a winter peaking utility area will be used to get a first order handle on the scale of compatible deployment of solar energy systems.

In November 1984 through March 1985, California is projected to have over 5000 MW of extra reserve generating capacity which could be used to back up solar heating systems. In the months of July and September 1985 the extra reserve generating capacity is expected to be 1400 and 1900 MW respectively (See Table 5-9).

Under hypothetical circumstances, where electricity is the only back up to solar energy systems and all the homes simultaneously demand 100% backup, it is estimated that over 700,000 single family homes could be using solar energy without converting California to a winter peaking utility area. This represents about 15% of the existing single family homes in California. If it is assumed that solar energy is available to provide water heating during summer peak load periods, then it is estimated that there is the potential to install solar water heating systems in 12,500,000 dwelling units. This represents all existing units, plus all units which might be constructed in the next 20 years assuming a 2.8% annual exponential growth rate.

b. Solar Water Heating Compatibility and Electric Rate Structures. Widespread use of solar water heating is particularly compatible with summer peaking electric utilities. Summer peaking electric utilities have the potential to supply the backup energy in the winter time. In addition, substituting solar water heating for existing electric water heating would relieve these utilities of some of the peak load experienced on hot (sunny) summer days. The reduction of summer peak would detract somewhat from the size of the market for which solar waters would be compatible with utilities. However, the market would still be immense. The combination of load management techniques with solar water heaters could enhance the size of the compatible market but this seems like a moot point at this time given the potential without load management. If the downward trend in the supply of natural gas continues, solar water heating with electric backup is a promising alternative.

The economic viability of solar water heating in electric markets depends on the rate and rate structure for electricity. Seasonal and time of day rate structure have been proposed as a means of signaling the true cost of electricity consumption to the consumer. Such rate structures would work against widespread adoption of solar water heating by forcing water heating to compete with

Table 5-9. Idle California Electrical Generating Capacity in 1985

Table 5-9. California Electrical Generating Capacity in 1985

	Months 1985											
	J	F	M	A	M	J	J	A	S	O	N	D
						Firm Loads**						
(p.114)*A	16439	15597	15665	15782	16417	17740	18551	19559	18158	17151	16618	17687
(p.131) B	6045	6073	5707	5714	6441	7750	8317	8687	7827	6734	6400	6859
(P.165) D	19581	18906	17750	17534	19533	22315	24003	24018	21693	18938	19894	21776
Total	42065	40576	39122	39035	42451	47805	50871	52264	47678	42823	42912	46325
						Margin**						
(p.114) A	5290	4033	4273	3356	3326	4655	4338	3915	4221	5231	4588	5278
(p.131) B	3392	2740	2215	1667	1979	2068	1917	1271	1179	1863	2685	3291
(p.165) D	4545	4726	4728	4390	4772	4549	3980	3852	4713	4592	5241	5189
Total	13227	11499	11216	9413	10077	11272	10235	9038	10113	11686	12514	13758
Margin %	31	28	29	24	24	24	20.1	17.3	21	27	29	30
17.3% Margin	7274	7016	6765	6750	7341	8266	8797	9038	8244	7405	7284	8014
Extra Reserve Generating Capacity	5952	4482	4450	2662	2735	3005	1437	0	1868	4280	5229	5743

*Refers to page number in "Summary of Estimated Loads and Resources" Western Systems Coordinating Council, April 1976.

**All units in megawatts.

electricity on a fuel displacement basis. Solar water heating will compete best with electricity if the current rate structure is unchanged, or if time of day rates are instituted only during the summer period.

2. Solar Heating, Load Management, and Rate Structures

For the sake of argument assume that a residential structure contains an off-peak-power cooling system. The system stores chilled water, produced by an air conditioner operating at night, in a tank. During the day the chilled water from the tank is used to air condition the dwelling. The existence of such an off-peak power cooling system would improve the economic attractiveness of a solar heating system. In California, solar heating systems will only need 200 to 300 ft^2 of collector area in an energy conserving home. In this size range, a water storage tank, heat exchanger, and the plumbing needed to transfer solar energy heat to a forced air duct is approximately 1/2 the total cost of the solar heating system. These components can also be used in connection with an electric air conditioner operating at night for off-peak-power cooling. The payback period on the incremental cost of adding a solar heating system to an off-peak-power cooling system is, thus, reduced by a factor of two. Therefore, even though solar heating with electric back-up only saves fuel, it comes close to being attractive when coupled with off-peak-power cooling. Solar heat is stored in winter and electrically produced "coolness" is stored in summer. This combined system can displace both fuel and peak load on the utility.

The electric utility compatible market potential for the combined system would be less than the 17% calculated above. But it still could represent a substantial market. However, the current rate structure does not provide any incentive for the consumer to adopt the off-peak-power cooling subsystem. A summer season time of day rate structure could help the adoption of the off-peak-power cooling sbusystems and thereby enhance the economic viability of solar heating systems.

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APPENDIX

SOLAR ENERGY POTENTIAL, SUPPLEMENTARY DATA

The data presented in Figures 5-1, 5-2 and 5-3 present potential energy displaced by solar as a function of marginal cost for a specific set of assumptions; i.e., capital recovery factor (CRF) equal to 0.1, 1996 building distribution and population and consolidated building classes. Tables A-1 through A-6 in this appendix, present an expanded data set which can be used for more detailed and independent analyses. Solar applications have been seggregated by building - HVAC classes, new and retro-fit markets, and conventional energy categories. In addition, solar market potential in both 1986 and 1996 has been included.

Table Explanation

The entries in the tables are ordered by increasing marginal cost. Each entry represents a specific building, HVAC configuration, climatic weather zone and solar system design. The tables do not include all possible buildings but do present all of the practical and near practical applications (marginal cost below ~ 8 $\$/10^6$ Btu and 0.07 \$/kWh).

Column 1 - the marginal cost rank ordering of solar applications in each market.

Column 2 - the general weather zone of the application; SB - Southern and central California beach zone, IV - Southern California inland valleys, CV - Northern California inland valleys, San Juaquin Valley and Southern California high deserts.

Column 3 - The initial cost of installing the solar system on one building (1974 dollars).

Column 4 - Annual energy displaced by the solar system.

Column 5 and 6 - Marginal cost of the solar energy for a) CRF = 0.17 and b) CRF = 0.2; A range typically applicable to private utility ownership.

Columns 7 and 8 - From a consumer point of view, this is the solar system first cost discount required to equalize the cost of energy from solar and from the conventional fuel. A CRF of 0.1 amortizes the discounted initial investment over 20 years at an 8% interest rate and a CRF of 0.2 amortizes the discounted initial investment over 10 years at a 15% interest rate.

Columns 9 - 14 - Data reflecting 1986 projections.

Column 9 - number of buildings constructed between 1975 and 1986, viewed as new building market.

Column 10 - number of buildings constructed prior to 1975 that remain in use in 1986, viewed as retrofit market.

Column 11 - energy which will be displaced by solar if solar penetration is 100% in the 1986 new building market.

Column 12 - cumulative sum of column 11.

Column 13 - energy which will be displaced by solar if solar penetration is 100% in the 1986 retrofit market.

Column 14 - cumulative sum of column 13.

Column 15 - number of buildings constructed between 1975 and 1996, viewed as new building market.

Column 16 - number of buildings constructed prior to 1975 that remain in use in 1996, viewed as retrofit market.

Column 17 - energy which will be displaced by solar if solar penetration is 100% in the 1996 new building market.

Column 18 - cumulative sum of column 17.

Column 19 - energy which will be displaced by solar if solar penetration is 100% in the 1996 retrofit market.

Column 20 - cumulative sum of column 19.

Discussion

Much of the data presented in Tables A-1 through A-8 has been generated to provide lower and upper bounds. For example, Table A-1 and A-2 reflect the same market. The costs in Table A-1 are based upon a 5 $\$/ft^2$ collector while the costs in Table A-2 are based upon a 15 $\$/ft^2$ collector. Similarly, within each table upper and lower bounds are provided by evaluations at two CRF's.

The marginal cost of solar energy, columns 7 and 8, provides a useful mechanism for comparing the cost of solar energy to energy alternations. This data is most useful to government policy markers and utilities. The lower marginal costs generated from a CRF of 0.17 annualizes the initial cost of solar over a 15 year interval at a discount rate of 15%. The higher CRF of 0.2 reduces the time interval to 10 years while holding the discount rate of 15%.

When low cost natural gas is available, an incentive or first cost discount will be required to stimulate private investment in solar systems. Columns 7 and 8 were generated to bound the problem and provide some insight into the magnitude of the discount required to incentivate consumer adoption. The discounts were generated assuming natural gas is available at 1.50 $\$/10^6$ Btu and electricity at 0.035 \$/kWh. A CRF of 0.1 reflects a 20 year life expectancy and an interest rate of 8% while a CRF of 0.2 reflects a 10 year life and a 15% interest rate. To achieve penetration into the gas market via private ownership, discounts between 30 to 70% will be required. In the electric market, solar penetration will be easier to achieve and in some cases no discounts are necessary. The effect of the collector cost (5 $\$/ft^2$ or 15 $\$/ft^2$) on the required discount is surprisingly small.

Potential solar displacement of conventional energy and building population numbers are presented in the tables at two time frames, 1986 and 1996. The 1996 data is supportive of Figures 5-1 through 5-3 but is presented here in more detail and in separated markets.

Table A-1. Multiple Family Dwelling, Solar Water Heating in the Gas Market, 5 $/ft^2 Collector

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
				Marginal Cost $/10^6 Btu		Customer Discount For Equivalence %		1986						1996					
								Number of Bldgs		Potential Energy Displ. 10^9 kWh/yr				Number of Bldgs		Potential Energy Displ. 10^9 kWh/yr			
										New Install.		Retrofit Install				New Install		Retrofit Install	
Number	Zone	First Cost $	Energy Displaced per bldg. kWh/yr	CRF = .17	CRF = .2	CRF = .1	CRF = ·-	Post 1975	Pre 1975	Per bld Class	Cum	Per bld Class	Cum	Post 1975	Pre 1975	Per bld Class	Cum	Per bld Class	Cum
1	CV	1900	24770	3.82	4.49	33	66	4309		0.107	0.107			11800		0.292	0.292		
2	CV	1900	24770	3.82	4.49	33	66	2155		0.053	0.160			5898		0.146	0.438		
3	CV	1900	24770	3.82	4.49	33	66	2677		0.066	0.226			4259		0.105	0.543		
4	CV	1900	24770	3.82	4.49	33	66	1747		0.043	0.269			4014		0.099	0.642		
5	CV	1900	24770	3.82	4.49	33	66	1339		0.033	0.302			2129		0.053	0.69		
6	CV	1900	24770	3.82	4.49	33	66	8287		0.205	0.507			19360		0.479	1.17		
7	IV	1900	24610	3.84	4.52	33	67	5251		0.129	0.636			14470		0.356	1.53		
8	IV	1900	24610	3.84	4.52	33	67	2625		0.064	0.700			7234		0.178	1.71		
9	IV	1900	24610	3.84	4.52	33	67	3260		0.080	0.780			5204		0.128	1.84		
10	IV	1900	24610	3.84	4.52	33	67	2128		0.052	0.832			4918		0.121	1.96		
11	IV	1900	24610	3.84	4.52	33	67	1630		0.040	0.872			2602		0.064	2.02		
12	IV	1900	24610	3.84	4.52	33	67	10100		0.248	1.12			23720		0.584	2.61		
13	CV	2546	32210	3.94	4.63	35	68	15720		0.506	1.63			36120		1.163	3.77		
14	IV	2546	32000	3.96	4.66	36	68	1630		0.052	1.68			2602		0.083	3.85		
15	IV	2546	32000	3.96	4.66	36	38	19150		0.613	2.29			44260		1.416	5.27		
16	SB	1900	22460	4.21	4.96	39	70	2671		0.060	2.35			7264		0.163	5.43		
17	SB	1900	22460	4.21	4.96	39	70	1336		0.030	2.38			3632		0.081	5.51		
18	SB	1900	22460	4.21	4.96	39	70	1661		0.037	2.42			2632		0.059	5.57		
19	SB	1900	22460	4.21	4.96	39	70	1083		0.024	2.44			2474		0.055	5.63		
20	SB	1900	22460	4.21	4.96	39	70	830		0.019	2.46			1316		0.029	5.65		
21	SB	1900	22460	4.21	4.96	39	70	5138		0.116	2.58			11930		0.268	5.92		
22	SB	2546	29200	4.34	5.11	41	71	830		0.024	2.60			1316		0.038	5.96		
23	SB	2546	29200	4.34	5.11	41	71	9747		0.285	2.886			22270		0.65	6.61		
24	CV	2375	24770	4.77	5.62	47	73		1719			0.042	0.042		1376			0.034	0.03
25	CV	2375	24770	4.77	5.62	47	73		860			0.021	0.060		688			0.017	0.05
26	CV	2375	24770	4.77	5.62	47	73		1719			0.043	0.11		1376			0.034	0.08
27	CV	2375	24770	4.77	5.62	47	73		860			0.021	0.13		688			0.017	0.10

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Table A-1. Multiple Family Dwelling, Solar Water Heating in the Gas Market, 5 $/ft^2 Collector (contd)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
								1986						1996					
			Energy Displaced per bldg. kWh/yr	Marginal Cost $/10^6 Btu		Customer Discount For Equivalence %		Number of Bldgs		Potential Energy Displ. 10^9 kWh/yr				Number of Bldgs		Potential Energy Displ. 10^9 kWh/yr			
		First Cost $								New Install.		Retrofit Install				New Install		Retrofit Install	
Number	Zone			CRF = .17	CRF = .2	CRF = .1	CRF = .2	Post 1975	Pre 1975	Per bld Class	Cum	Per bld Class	Cum	Post 1975	Pre 1975	Per bld Class	Cum	Per bld Class	Cum
28	CV	2375	24770	4.77	5.62	47	73		860			0.021	0.15		688			0.017	0.12
29	CV	2375	24770	4.77	5.62	47	73		4298			0.106	0.25		3440			0.085	0.20
30	IV	2375	24610	4.80	5.66	47	73		2034			0.050	0.30		1620			0.040	0.24
31	IV	2375	24610	4.80	5.60	47	73		1017			0.025	0.33		811			0.020	0.26
32	IV	2375	24610	4.80	5.66	47	73		2034			0.050	0.38		1620			0.040	0.30
33	IV	2375	24610	4.80	5.66	47	73		1017			0.025	0.40		811			0.020	0.32
34	IV	2375	24610	4.80	5.66	47	73		1017			0.025	0.43		811			0.020	0.34
35	IV	2375	24610	4.80	5.66	47	73		5085			0.125	0.55		4052			0.100	0.44
36	CV	3182	32210	4.92	5.79	48	74		7737			0.249	0.80		6191			0.199	0.64
37	CV	3182	32000	4.95	5.83	49	74		61020			1.953	2.76		48620			1.556	2.20
38	CV	3182	32000	4.95	5.83	49	74		1017			0.032	2.79		811			0.025	2.22
39	CV	3182	32000	4.95	5.83	49	74		9153			0.293	3.08		7292			0.231	2.46
40	CV	2546	24770	5.12	6.02	50	75	1339		0.033	2.92			2129		0.053	6.66		
41	SB	2375	24460	5.27	6.20	52	76		1098			0.025	3.11		882			0.020	2.48
42	SB	2375	22460	5.27	6.20	52	76		549			0.012	3.12		441			0.010	2.49
43	SB	2375	24460	5.27	6.20	52	76		1098			0.025	3.14		882			0.020	2.51
44	SB	2375	22460	5.27	6.20	52	76		549			0.012	3.15		441			0.010	2.52
45	SB	2375	22460	5.27	6.20	52	76		549			0.012	3.17		441			0.010	2.53
46	SB	2375	22460	5.27	6.20	52	76		2745			0.062	3.23		2206			0.049	2.58
47	SB	3182	29200	5.43	6.38	53	77		32950			0.962	4.19		26480			0.773	3.35
48	SB	3182	29200	5.43	6.38	53	77		549			0.016	4.21		441			0.013	3.36
49	SB	3182	29200	5.43	6.38	53	77		4942			0.144	4.35		3972			0.116	3.48
50	SV	3182	24770	6.39	7.53	60	80		51580			1.277	5.63		41280			1.022	4.50
51	CV	3182	24770	6.39	7.53	60	80		860			0.021	5.65		688			0.017	4.52
											. . .		. . .				. . .		. . .
	TOTAL MARKET POTENTIAL										2.92		5.65				6.67		4.52

Table A-2. Multiple Family Dwelling, Solar Water Heating in the Gas Market, 14 $/ft^2 Collector

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
								1986						1996					
Number	Zone	First Cost $	Energy Dis-placed per bldg. kWh/yr	Marginal Cost $/10^6 Btu		Customer Discount For Equivalence %		Number of Bldgs		Potential Energy Displ. 10^9 kWh/yr				Number of Bldgs		Potential Energy Displ. 10^9 kWh/yr			
										New Install.		Retrofit Install				New Install		Retrofit Install	
				CRF = .17	CRF = .2	CRF = .1	CRF = .2	Post 1975	Pre 1975	Per bld Class	Cum	Per bld Class	Cum	Post 1975	Pre 1975	Per bld Class	Cum	Per bld Class	Cum
1	CV	4116	32210	6.36	7.5	60	80	15720		0.506	0.51			36120		1.163	1.16		
2	IV	4116	32000	6.36	7.5	60	80	1630		0.052	0.56			2602		0.083	1.24		
3	IV	4116	32000	6.36	7.5	60	80	19150		0.613	1.17			44260		1.42	2.66		
4	CV	3520	24770	7.07	8.3	64	82	4309		0.107	1.28			11800		0.292	2.95		
5	CV	3520	24770	7.07	8.3	64	82	2155		0.053	1.33			5898		0.146	3.10		
6	CV	3520	24770	7.07	8.3	64	82	2677		0.066	1.40			4259		0.105	3.21		
7	CV	3520	24770	7.07	8.3	64	82	1747		0.043	1.44			4014		0.099	3.31		
8	CV	3520	24770	7.07	8.3	64	82	1339		0.033	1.47			2129		0.053	3.36		
9	CV	3520	24770	7.07	8.3	64	82	8287		0.205	1.68			19360		0.479	3.84		
10	SB	4166	29200	7.10	8.4	64	82	831		0.024	1.70			1316		0.038	3.87		
11	SB	4166	29200	7.10	8.4	64	82	9747		0.285	1.99			22270		0.650	4.53		
12	IV	3520	24610	7.12	8.4	64	82	5251		0.129	2.12			14470		0.356	4.88		
13	IV	3520	24610	7.12	8.4	64	82	2625		0.065	2.18			7234		0.178	5.06		
14	IV	3520	24610	7.12	8.4	64	82	3260		0.080	2.26			5204		0.128	5.19		
15	IV	3520	24610	7.12	8.4	64	82	2128		0.052	2.31			4918		0.121	5.31		
16	IV	3520	24610	7.12	8.4	64	82	1630		0.040	2.35			2602		0.064	5.37		
17	IV	3520	24610	7.12	8.4	64	82	10100		0.248	2.60			23720		0.584	5.96		
18	SB	3520	22460	7.8	9.2	67	84	2671		0.060	2.66			7264		0.163	6.12		
19	SB	3520	22460	7.8	9.2	67	84	1336		0.03	2.69			3632		0.082	6.20		
20	SB	3520	22460	7.8	9.2	67	84	1661		0.037	2.73			2632		0.059	6.26		
21	SB	3520	22460	7.8	9.2	67	84	1083		0.024	2.75			2474		0.056	6.32		
22	SB	3520	22460	7.8	9.2	67	84	830		0.019	2.77			1316		0.029	6.34		
23	SB	3520	22460	7.8	9.2	67	84	5138		0.115	2.88			11930		0.268	6.61		
24	CV	5207	32210	8.1	9.5	68	84		7737			0.249	0.25		6191			0.199	0.20
25	IV	5207	32000	8.1	9.5	68	84		61020			1.953	2.20		48620			1.556	1.76
26	IV	5207	32000	8.1	9.5	68	84		1017			0.032	2.23		810			0.026	1.78
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	TOTAL MARKET POTENTIAL										2.92		5.65				6.67		4.52

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Table A-3. Multiple Family Dwelling, Solar Water Heating in Electric Market, 5 $/ft^2 Collector

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
								1986						1996					
			Energy Dis-placed per bldg. kWh/yr	Marginal Cost $/kWh		Customer Discount For Equivalence %		Number of Bldgs		Potential Energy Displ. 10^9 kWh/yr				Number of Bldgs		Potential Energy Displ. 10^9 kWh/yr			
		First Cost $								New Install.		Retrofit Install				New Install		Retrofit Install	
Number	Zone			CRF = .17	CRF = .2	CRF = .1	CRF = .2	Post 1975	Pre 1975	Per bld Class	Cum	Per bld Class	Cum	Post 1975	Pre 1975	Per bld Class	Cum	Per bld Class	Cum
1	CV	2546	16100	0.027	0.032	0	0	1088		0.017	0.02			5024		0.081	0.08		
2	CV	2546	16100	0.027	0.032	0	0	9898		0.159	0.18			22740		0.366	0.45		
3	CV	2546	16100	0.027	0.032	0	0	5648		0.091	0.27			13930		0.224	0.67		
4	CV	2546	16100	0.027	0.032	0	0	4016		0.065	0.33			6388		0.103	0.77		
5	IV	2546	16100	0.027	0.032	0	0	1327		0.021	0.35			6175		0.099	0.87		
6	IV	2546	16000	0.027	0.032	0	0	12060		0.193	0.55			27870		0.446	1.32		
7	IV	2546	16000	0.027	0.032	0	0	6881		0.110	0.66			17070		0.273	1.59		
8	IV	2546	16000	0.027	0.032	0	0	4890		0.078	0.73			7807		0.125	1.72		
9	SB	2546	14600	0.030	0.035	0	0	673		0.010	0.74			3088		0.045	1.76		
10	SB	2546	14600	0.030	0.035	0	0	6137		0.089	0.83			14020		0.205	1.97		
11	SB	2546	14600	0.030	0.035	0	0	3502		0.051	0.89			8580		0.125	2.09		
12	SB	2546	14600	0.030	0.035	0	0	2492		0.036	0.92			3948		0.058	2.15		
13	CV	3182	16100	0.033	0.040	0	11		5158			0.083	0.08		4128			0.066	0.07
14	CV	3182	16100	0.033	0.040	0	11		5158			0.083	0.17		4128			0.066	0.13
15	CV	3182	16100	0.033	0.040	0	11		2579			0.042	0.21		2064			0.033	0.16
16	CV	3182	16100	0.033	0.040	0	11		0			0	0.21		0			0	0
17	CV	3182	16100	0.033	0.040	0	11		2579			0.042	0.25		2064			0.033	0.20
18	IV	3182	16000	0.034	0.040	0	12		6102			0.097	0.35		4862			0.070	0.28
19	IV	3182	16000	0.034	0.040	0	12		6101			0.097	0.44		4861			0.078	0.35
20	IV	3182	16000	0.034	0.040	0	12		3051			0.049	0.49		2431			0.039	0.39
21	IV	3182	16000	0.034	0.040	0	12		3051			0.049	0.54		2431			0.039	0.43
22	SB	3182	14600	0.037	0.044	0	20		3294			0.048	0.59		2647			0.039	0.47
23	SB	3182	14600	0.037	0.044	0	20		3295			0.048	0.64		2648			0.039	0.51
24	SB	3182	14600	0.037	0.044	0	20		1647			0.024	0.66		1324			0.019	0.53
25	SB	3182	14600	0.037	0.044	0	20		1647			0.024	0.69		1324			0.019	0.55
⋮											⋮		⋮			⋮			⋮
											0.92		0.69			2.15			0.55
	TOTAL MARKET POTENTIAL																		

Table A-4. Multiple Family Dwelling, Solar Water Heating in Electric Market, 15 $/ft^2 Collector

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
								1986						1996					
				Marginal Cost $/kWh		Customer Discount For Equivalence %		Number of Bldgs		Potential Energy Displ. 10^9 kWh/yr				Number of Bldgs		Potential Energy Displ. 10^9 kWh/yr			
										New Install.		Retrofit Install				New Install		Retrofit Install	
Number	Zone	First Cost $	Energy Dis-placed per bldg. kWh/yr	CRF = .17	CRF = .2	CRF = .1	CRF = .2	Post 1975	Pre 1975	Per bld Class	Cum	Per bld Class	Cum	Post 1975	Pre 1975	Per bld Class	Cum	Per bld Class	Cum
1	CV	4166	16100	0.044	0.052	0	32	1088		0.017	0.02			5024		0.08	0.08		
2	CV	4166	16100	0.044	0.052	0	32	9898		0.159	0.18			22740		0.366	0.045		
3	CV	4166	16100	0.044	0.052	0	32	5648		0.091	0.27			13930		0.224	0.67		
4	IV	4166	16000	0.044	0.052	0	33	1327		0.021	0.29			6175		0.098	0.77		
5	IV	4166	16000	0.044	0.052	0	33	12060		0.193	0.48			27870		0.446	1.22		
6	IV	4166	16000	0.044	0.052	0	33	6881		0.110	0.59			17070		0.273	1.49		
7	IV	4166	16000	0.044	0.052	0	33	4890		0.078	0.67			7807		0.125	1.61		
8	SB	4166	14600	0.048	0.057	0	39	673		0.01	0.68			3088		0.045	1.66		
9	SB	4166	14600	0.048	0.057	0	39	6137		0.089	0.77			14020		0.205	1.86		
10	SB	4166	14600	0.048	0.057	0	39	3502		0.051	0.82			8580		0.125	1.99		
11	SB	4166	14600	0.048	0.057	0	39	2492		0.036	0.86			3948		0.057	2.05		
12	CV	5207	16100	0.055	0.065	0	46		5158			0.083	0.08		4128			0.066	0.07
13	CV	5207	16100	0.055	0.065	0	46		5158			0.083	0.17		4128			0.066	0.13
14	CV	5207	16100	0.055	0.065	0	46		2579			0.042	0.21		2064			0.033	0.16
15	CV	5207	16100	0.055	0.065	0	46		2579			0.042	0.25		2064			0.033	0.20
16	IV	5207	16000	0.055	0.065	0	46		6102			0.098	0.35		4862			0.078	0.28
17	IV	5207	16000	0.055	0.065	0	46		6101			0.098	0.45		4861			0.078	0.35
18	IV	5207	16000	0.055	0.065	0	46		3051			0.049	0.39		2431			0.039	0.39
19	IV	4207	16000	0.055	0.065	0	46		3051			0.049	0.45		2431			0.039	0.43
. . .	TOTAL MARKET POTENTIAL										. . . 0.92		. . . 0.69				. . . 2.15		. . . 0.55

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Table A-5. Single Family Dwelling, Solar Water Heating and Space Heating in the Gas Market, 5 \$/ft^2 Collector

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
								1986						1996					
			Energy Displaced per bldg. kWh/yr	Marginal Cost \$/10^6 Btu		Customer Discount For Equivalence %		Number of Bldgs		Potential Energy Displ. 10^9 kWh/yr				Number of Bldgs		Potential Energy Displ. 10^9 kWh/yr			
		First Cost \$								New Install.		Retrofit Install				New Install		Retrofit Install	
Number	Zone			CRF = .17	CRF = .2	CRF = .1	CRF = .2	Post 1975	Pre 1975	Per bld Class	Cum	Per bld Class	Cum	Post 1975	Pre 1975	Per bld Class	Cum	Per bld Class	Cum
1	SB	4062	25960	7.79	9.17	67	84		65940			1.71	1.71		57750			1.49	1.49
2	SB	4062	25960	7.79	9.17	67	84		667600			17.33	19.04		584700			15.18	16.67
3	CV	3250	20520	7.89	9.28	68	84	72080		1.48	1.48			148000		3.04	3.04		
4	CV	3250	20520	7.89	9.28	68	84	311900		6.40	7.88			560200		11.49	14.53		
5	CV	6437	39440	8.13	9.56	69	84		152500			6.01	25.05		130800			5.15	21.82
6	CV	6437	39440	8.13	9.56	69	84		1245000			49.1	74.15		1068000			42.12	63.94
7	IV	4062	24780	8.16	9.60	69	84		156000			3.86	78.01		135600			3.36	67.3
8	IV	062	24780	8.16	9.60	69	84		1326000			32.86	110.87		1153000			28.57	95.9
9	SB	2000	11630	8.56	10.08	70	85	28940		0.33	8.21			58430		0.68	15.21		.
10	SB	2000	11630	8.56	10.08	70	85	62450		0.72	8.93			114100		1.33	16.54		
11	IV	2000	11390	8.75	10.28	71	85	83540		0.95	9.88			182300		2.07	18.61		
12	IV	2000	11390	8.75	10.28	71	85	189000		2.15	12.03		.	312500		3.56	22.17		.
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.	TOTAL MARKET POTENTIAL										12		111				22,2		95.[illegible]

Table A-6. Single Family Dwelling, Water Heat and Space Heat in Electric Market, 5 $/ft^2 Collector

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
								1986						1996					
			Energy Displaced per bldg. kWh/yr	Marginal Cost $/kWh		Customer Discount For Equivalence %		Number of Bldgs		Potential Energy Displ. 10^9 kWh/yr				Number of Bldgs		Potential Energy Displ. 10^9 kWh/yr			
		First Cost $								New Install.		Retrofit Install				New Install		Retrofit Install	
Number	Zone			CRF = .17	CRF = .2	CRF = .1	CRF = .2	Post 1975	Pre 1975	Per bld Class	Cum	Per bld Class	Cum	Post 1975	Pre 1975	Per bld Class	Cum	Per bld Class	Cum
1	CV	1732	6583	0.045	0.053	0	33	10190		0.067	0.07			28040		0.18	0.18		
2	IV	1371	4542	0.051	0.060	0	42	44900		0.204	0.27			103300					
3	CV	2165	6583	0.056	0.066	0	47		31120			0.205	0.21		26700			0.17	0.17
4	CV	3250	11690	0.047	0.056	0	37	16430		0.192	0.046			44190		0.516	1.17		
5	CV	3250	11690	0.047	0.066	0	37	93450		1.092	1.55			254300		2.97	4.14		
6	SB	1335	3977	0.057	0.067	0	48	4739		0.019	1.57			9654		0.04	4.18		
7	IV	1714	4542	0.064	0.075	0	54		39000			0.177	0.38		33910			0.154	0.324
8	SB	2000	6630	0.051	0.060	0	42	13710		0.091	1.67			28460		0.188	4.36		
9	SB	2000	6630	0.051	0.060	0	42	59360		0.393	2.06			122400		0.811	5.17		
10	IV	2000	6495	0.052	0.062	0	43	51160		0.332	2.39			127500		0.828	6.00		
11	IV	2000	6495	0.052	0.062	0	43	62000		0.403	2.79			135200		0.878	6.88		
12	CV	4062	11690	0.059	0.069	0	50		18670			0.218	0.60		16020			0.187	0.511
13	CV	4062	11690	0.059	0.069	0	50		108900			1.273	1.87		93440			1.092	1.60
14	SB	1669	3977	0.071	0.084	16	58		8242			0.033	1.91		7219			0.028	1.63
15	SB	2500	6630	0.064	0.075	7	54		8242			0.055	1.96		7219			0.048	1.68
16	SB	2500	6630	0.064	0.075	7	54		74180			0.492	2.45		64970			0.431	2.11
17	IV	2500	6495	0.065	0.077	9	54		65000			0.422	2.87		56510			0.367	2.47
18	IV	2500	6495	0.065	0.077	9	54		147300			0.957	3.83		128100			8.32	3.30
⋮											⋮		⋮				⋮		⋮
	TOTAL MARKET POTENTIAL										2.79		3.83				6.88		3.3