95th Congress }
1st Session }

JOINT COMMITTEE PRINT

THE ECONOMICS OF SOLAR HOME HEATING

A STUDY

PREPARED FOR THE USE OF THE

JOINT ECONOMIC COMMITTEE
CONGRESS OF THE UNITED STATES

MARCH 13, 1977

Printed for the use of the Joint Economic Committee

U.S. GOVERNMENT PRINTING OFFICE
85-329 O WASHINGTON : 1977

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price $1.35

LETTERS OF TRANSMITTAL

March 11, 1977

To the Members of the Joint Economic Committee:

Transmitted herewith is a study entitled, "The Economics of Solar Home Heating." This study was prepared for the use of the Committee in its consideration of the potential to utilize solar energy.

This study reviews the economics of solar energy used to heat residential structures and to heat water. It analyzes the extent to which such solar applications can economically substitute for more conventional residential heating and hot water systems. The analysis is done on a state-by-state basis, and covers the period, 1976-1990. I believe that Members of the Joint Economic Committee and other Members of Congress will find this study useful and informative.

The views expressed in this study are those of the authors and do not necessarily represent the views of the Committee Members or the Committee staff.

Sincerely,

Richard Bolling
Chairman, Joint Economic Committee

March 8, 1977

The Honorable Richard Bolling
Chairman
Joint Economic Committee
U. S. Congress
Washington, D. C.

Dear Mr. Chairman:

Transmitted herewith is a study entitled, "The Economics of Solar Home Heating," by Professor William D. Schulze and the staff of the Resource Economics Program at the University of New Mexico. It was prepared for the full Committee at my request last year.

The study extensively evaluates the cost of solar and conventional energy for space and water heating purposes. It determines the date, under regimes of both gas price control and decontrol, when solar energy for such purposes becomes cheaper than conventional energy. The determination is on a state-by-state basis.

This study is a necessary and excellent addition to solar energy literature. It includes the most recent energy cost calculations and should be viewed as the definitive work to-date on solar energy economics. Among other things, the study will require us to sharply reduce the time period when solar energy will become competitive with conventional energy sources.

The views expressed in this study are those of the authors and do not necessarily represent the views of the Committee Members or the Committee staff.

Sincerely,

Hubert H. Humphrey
Vice Chairman, Joint Economic
Committee

CONTENTS

THE ECONOMICS OF SOLAR HOME HEATING

Paper prepared for the Joint Economic Committee of the United States Congress

January 1977

William D. Schulze
Associate Professor of Economics
University of New Mexico

Shaul Ben-David
Professor of Economics
University of New Mexico

J. Douglas Balcomb
Assistant Division Leader for Solar Energy
Los Alamos Scientific Laboratory

Roberta Katson, Scott Noll, Fred Roach, and Mark Thayer
Research Associates, Department of Economics
University of New Mexico

EXECUTIVE SUMMARY OF CONTENTS*

The rapid depletion of our domestic fossil fuel resource base has been and continues to be an issue of great concern. Shortages, curtailments, and increased dependence upon foreign sources of energy are becoming the rule rather than the exception. This study examines the role of residential solar water and space heating as an alternative source of energy.

Now that some experience has been gained both in manufacturing and installation of solar systems it is apparent that the cost of solar collectors installed, but excluding fixed costs, will be about $10/ft^2$. Although this may seem high in comparison to estimates as low as $3/ft^2$ used in previous studies, we find that feasibility does occur for solar water and space heating systems between now and 1990 if either decontrolled prices of traditional energy sources are used as the basis of comparison or where curtailments of natural gas occur. The importance of this finding is diminished by the federal government's failure to assist in making capital available for energy conservation. If interest rates are kept high and if money (capital) remains in short supply, the prospects for capital intensive systems in homes, such as solar energy, are diminished greatly.

*The research reported here has been funded as part of an NSF-RANN project entitled "An Economic and Environmental Evaluation of Solar and Geothermal Energy Sources". Also, solar energy performance analysis developed under ERDA supported research projects at Los Alamos Scientific Laboratory has been employed in our research. Thanks go to Jim Hedstrom, Larry Bickle, Jake Gaultney,and Wanda English for their contributions. Additionally, Allen Kneese provided helpful comments for which we are grateful. All opinions and remaining errors are, of course, the sole responsibility of the authors.

85-329 O - 77 - 2

In this study a scenario of future energy prices both for decontrol and for curtailments with continued controls is developed and consumer costs from traditional sources are projected both on an annualized (life cycle) basis and on a current cost basis for residential space heating and domestic hot water. These costs are developed by state through 1990 and are compared to the cost and performance of solar energy systems on a $\$/10^6$ BTU basis to determine year of feasibility for solar energy by state and optimal system design (least cost) given projected energy prices. Potential energy savings in 1990 resulting from utilization of solar energy are also discussed. Finally, policy suggestions to speed the development of solar energy are made both for scenarios of continued price controls and for decontrols.

Regional energy prices for space heating and domestic hot water are developed from an econometric fossil fuel simulation model. The model is based upon estimated relationships which describe the fossil fuel energy sector of the U. S. economy and projects future fossil fuel prices, demand, discovery, and reserves on the assumption of "business as usual". Deregulation of wellhead prices, the ability of OPEC to maintain control of world petroleum prices, and capacity conditions within the energy extraction industry were adopted as basic assumptions. The results for decontrol presented in the study are based on a scenario which assumes: total deregulation of natural gas prices by 1978; a five year (1977-1981) deregulation period in which the price per barrel of domestic crude petroleum is allowed to seek a level consistent with the OPEC price; and the ability of OPEC to maintain the price per barrel at a constant level, adjusted only for inflationary changes.

The results of the fossil fuel model are summarized as follows:

- Field prices in dollars per million BTUs show an increasing trend associated with the inevitable exhaustion of nonrenewable fossil fuel energy resources.
- Total consumption of fossil fuel energy resources is projected to increase by almost 40 percent in the time span considered.
- Domestic discovery of natural gas and crude petroleum is projected to follow a long-run downward trend, although short-run discovery of petroleum is stimulated with deregulation.
- With the projected levels of future consumption and the downward trend in discoveries and reserves, natural gas will rapidly approach exhaustion even with price decontrol.

As a result of these conditions solar energy will have its primary near term impact in the areas of residential water and space heating applications as a substitute for natural gas. Therefore, the future of solar energy will, to a great extent, be determined by the structure of the natural gas industry and by federal pricing policies which pertain to the flow of natural gas. However, because natural gas is in a state of rapid depletion, its price is expected either to rise much faster than other energy sources under decontrol, thereby relinquishing its comparative cost advantage, or with continued controls large scale curtailments will occur. Thus, it was necessary to calculate the price of a competing energy substitute which might replace natural gas. For this purpose, the price per 10^6 BTU of electric heat pumps to provide both space heating and domestic hot water was selected. Oil prices were excluded from the feasibility analysis of solar energy for two reasons. First, as natural gas is exhausted the OPEC determined price of oil might well be expected to rise to match the increase in gas prices. Second, foreign oil can not reasonably be expected to replace natural gas for home heat and industrial process energy because of the balance of payments problem.

A comparison between decontrolled natural gas and heat pump prices yields the least cost energy alternative to solar. A comparison to the cost in dollars per BTU of solar energy then determines the economic desirability of solar energy. It should be understood that under a policy of complete price decontrol for natural gas, curtailments will not occur because all potential users, wherever they might be located, would be able to competitively bid for natural gas. The feasibility study initially focuses on this idealizied situation.

If natural gas prices remain controlled near current (1977) levels, homeowners who can obtain natural gas will have no incentive to substitute solar energy which will invariably cost more on a $/BTU basis. But, even though some homeowners will be able to obtain very cheap energy, others will be forced by curtailment or through moratoriums on new gas hookups to find an alternative energy source for space and water heating. Since we have assumed heat pumps provide the best estimate of future fuel energy costs (excluding natural gas) the appropriate criterion under continued controls is to compare solar energy to electric heat on a regional basis, realizing that some consumers will not consider solar energy systems because of the availability of a declining quantity of cheap gas.

Solar feasibility analysis requires that the performance of a solar energy system be known in terms of the collector area required to provide a given percentage of the space or domestic hot water heating requirements. Although the operation of a solar heating system can be readily understood in a qualitative fashion, the quantitative analysis of a system (i.e., sizing of collector array) involves computer simulation of solar performance using actual hour by hour weather data, and is considerably more difficult. A fairly general method developed at Los Alamos Scientific Laboratories (LASL) was employed to supply the necessary quantitative analysis. The heating load must also be known for the performance analysis. For purposes of this study we assume for space heating that we are solar heating an energy efficient, well insulated house with a load of 10 BTUs per degree day per square foot and that the house has 1500 square feet of living area. For the domestic hot water analysis we assume a constant daily requirement of 80 gallons at 120°F where the input temperature is 60°F. This results in an annual hot water load of 15×10^6 BTUs.

Cost estimates of solar installations described below are then annualized at some interest rate -- in other words the yearly payment required to pay off a loan on the solar system is determined -- and this amount adjusted to include operating costs is divided by the BTUs of energy provided by the solar system over a year to determine the cost per BTU for comparison to fossil fuel costs. If annualized fossil fuel costs are used for comparison, and solar energy is cheaper, then feasibility is accepted on a life cycle costing basis. If current fossil fuel costs are used for comparison, then feasibility is determined on a current cost basis. Economists advocate the former as the appropriate criterion but consumers are likely to respond to the latter, so both criterion are used.

Inflation has been removed from the analysis by specifying all costs and prices in <u>real</u> terms (1974 dollars). Therefore, <u>real</u> interest rates are used in the feasibility analysis. Because solar energy systems are capital intensive, a narrow range of 2.5 to 4.0 percent real rate of interest typical of the home mortgage market was chosen to test the sensitivity of results (note that these correspond to an 8.5 and 10.0 percent nominal interest rate with 6 percent inflation). The cost of installation for solar space heating on new tract homes in 1974 (1977) dollars was assumed to be $1100 ($1350) as the fixed cost component plus a cost of $9.50 ($11.70) per square foot of collector installed. The cost associated with each square foot of collector installed is assumed to drop to $8.00 ($9.80) by 1990. These collector dependent costs include the cost of storage which we assume to be proportional to collector area. Flat plate, air type collectors are assumed in the analysis so operating and maintanence costs per year were assumed to be quite low, .75 percent of total installed cost per year, and the system was assumed to last thirty years. For retrofit of space heating the same collector dependent costs were used. However, it was assumed that the fixed cost component would increase to $3400 ($4200) to account for the individualized engineering and design work required for retrofit. For provision of domestic hot water where liquid collectors are used no difference between new home or retrofit installations was assumed. Here fixed costs were assumed to be $300 ($370) and collector dependent costs to be $11.00 ($13.50) per square foot. Operation and maintenance costs each year were assumed to be 1 percent of installed cost and the water system is assumed to have a twenty year life time.

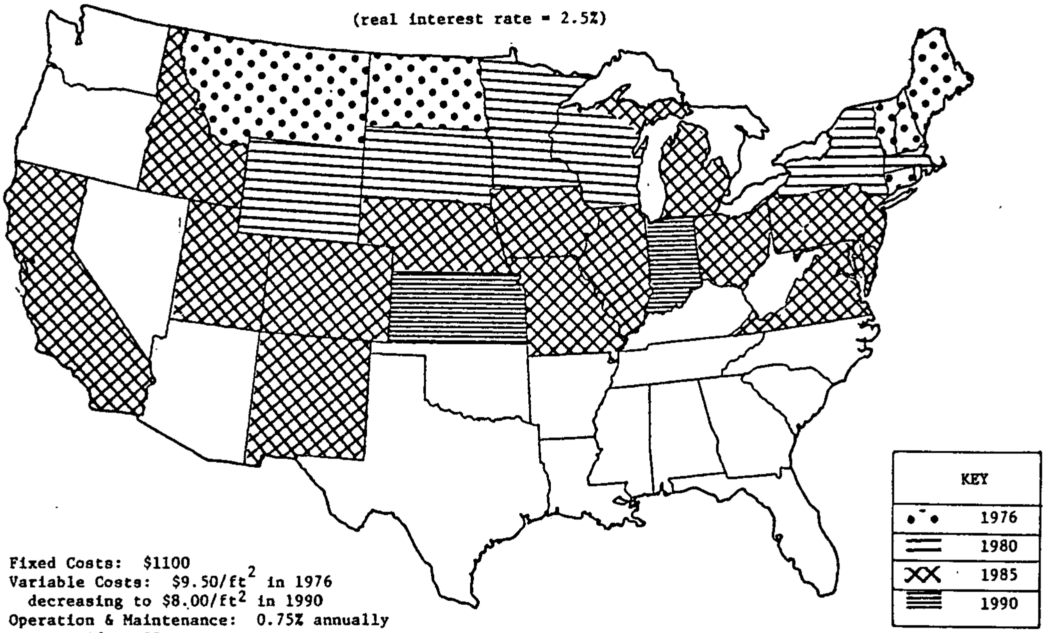
Typical results for decontrolled energy prices and residential new tract home space heating are shown in Map 2 from the report which employs life cycle costing and a 2.5 percent real interest rate. Raising the interest rate or using current costing generally delays feasibility and eliminates some marginal states, but the pattern of feasibility is similar.

Map 2

SOLAR FEASIBILITY - RESIDENTIAL SPACE HEATING

STANDARD AIR SYSTEM*

(real interest rate = 2.5%)



* Fixed Costs: $1100
Variable Costs: $9.50/ft^2 in 1976
decreasing to $8.00/ft^2 in 1990
Operation & Maintenance: 0.75% annually
System Life: 30 years

The most important result of the space heating feasibility analysis is the clear picture which emerges: solar feasibility begins in the northern tier of states and with very few exceptions systematically moves southward! There are several important reasons for this type of emerging pattern.

- Under a decontrolled energy scenario, conventional fuel prices begin to increase at such a pace that consumers are provided with larger economic incentives to look elsewhere for space heating systems. The cost of natural gas delivered to the states is dependent upon two components; the price at the wellhead plus the price adjustment for transportation and distribution. Thus, with most gas supplies located in the South Central and Southwestern states, prices generally increase as one moves into the Midwestern, North Central, Northeastern and Northwestern states.

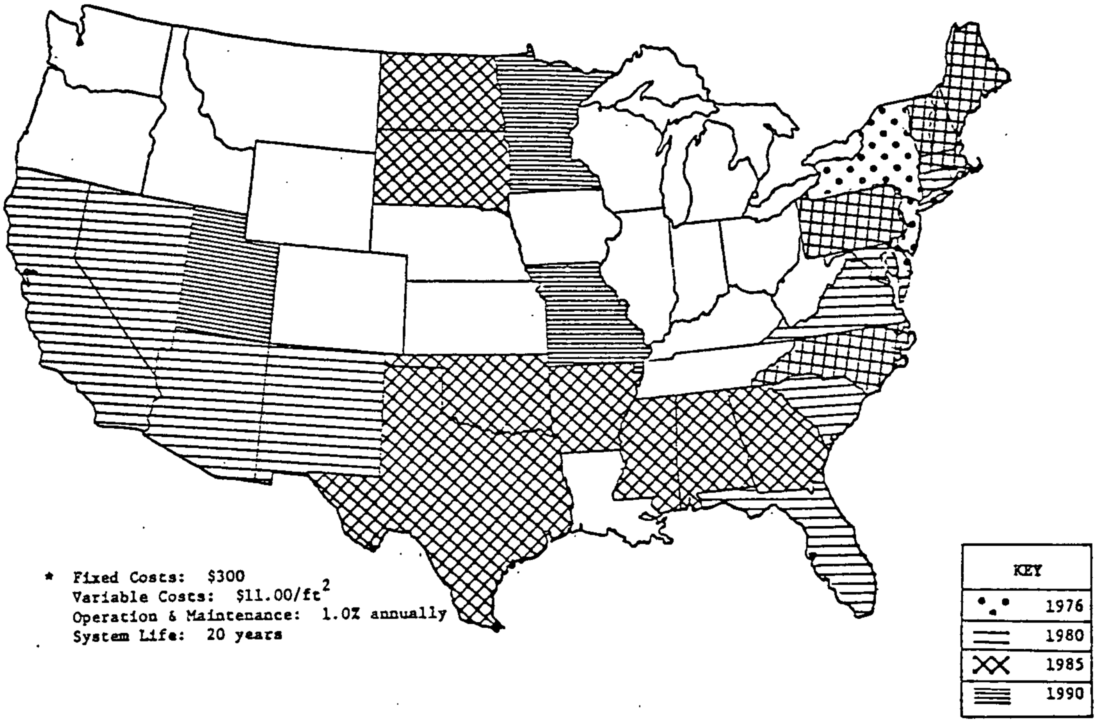
- Solar energy systems include a fixed cost component, giving rise to a situation in which minimum heating demands will be required to make solar energy competitive. Higher heating loads are evident as one moves northward, allowing the fixed costs to be spread over a larger BTU base.

The results of the feasibility analysis under decontrol for domestic hot water heating as shown in Map 5 for the 2.5 percent real interest rate case do not present as well defined a picture as that exemplified by the north to south movement portrayed for residential space heating. Rather, there is a mixture of Southern and Eastern states demonstrating feasibility in the late 1970s and early 1980s. Generally, Midwestern, Mountain and Northwestern states are excluded during the period of analysis (1976 to 1990).

Major reasons for this type of pattern are based primarily upon three considerations:

- Due to higher solar incidence in the Southern and Southwestern states, solar collector areas necessary to deliver a given fraction of domestic hot water demands are measurably lower than elsewhere. This, of course, results in lower costs for the solar systems.
- Alternative heating costs in the Eastern states are considerably higher than in most of the remaining states. This makes solar energy competitive in the East Coast states even though larger collector areas are required and subsequently solar costs are greater than in many other states.

Map 5
SOLAR FEASIBILITY - DOMESTIC HOT WATER*
(real interest rate = 2.5%)



* Fixed Costs: $300
Variable Costs: $11.00/ft^2
Operation & Maintenance: 1.0% annually
System Life: 20 years

- Within the states where solar energy was shown not to be competitive by 1990, the combination of higher solar costs due to relatively large collector arrays and alternative backup costs which are not signinificantly different than those found in the southern tier of states, forced solar feasibility into the 1990s. Further, relatively cheap electricity prices in the Northwestern states kept the alternative energy costs at levels sufficiently low to preclude solar systems during the period of analysis.

Given that solar energy is feasible under decontrol for some portion of residential water and space heating demand, and given better insulated structure potential, the realized energy savings can be fairly significant in many states when contrasted with the possible demand without solar energy systems or better insulation. Based on life cycle costing with a 2.5 percent real interest rate:

- Realized energy savings in 1990 from the better insulated residences built between 1976 and 1990 imply a 41 percent reduction in energy demand for space heating. Assuming a midpoint housing production estimate of 1.3 million units annually, and the average residence of the past decade, energy savings in 1990 due to improved insulation of homes constructed during the period of analysis could be 1.04 quads.
- Energy savings due to utilization of solar energy for space heating was calculated on the basis of the standard air system analysis. If 85 percent of all new, single-family houses fit solar space heating systems when feasible, the savings in 1990 will be 0.49 quads.
- In 1990, energy savings due to utilization of solar energy for domestic hot water will be as much as 0.40 quads (50 percent fit) and 0.69 quads (85 percent fit) or 25 and 41 percent, respectively, of total energy demanded for domestic water heating.

The total national fossil fuel demand in 1990 is projected to be about 90 quads. Although percentages supplied by solar energy appear small at first glance, the economic impact of the industry should not be underestimated. For example, the energy savings due to solar domestic hot water at 85 percent fit (.40 quads) represents 69.5 million barrels of oil saved for the one year. The savings resulting from solar space heating and proper insulation at 85 percent fit (1.33 quads) represents a savings of 229.3 million barrels of oil in 1990. However, it should be made clear that these are upper bound estimates for the role of solar energy in domestic uses, excluding retrofit of space heating.

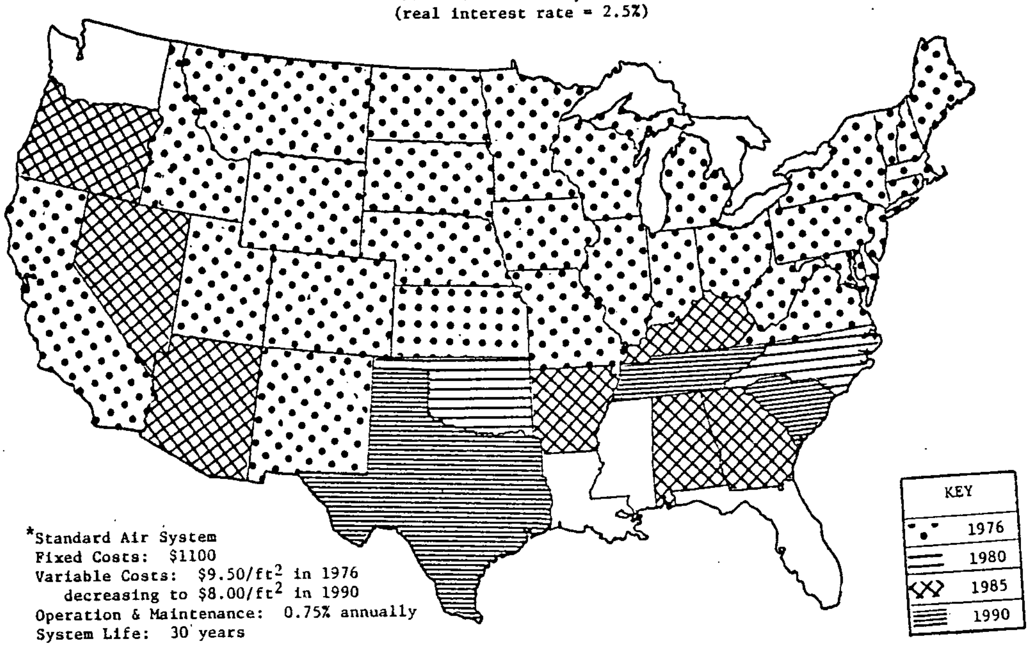
In the event that price controls are continued, homeowners will need to examine the feasibility of solar energy systems against electricity -- either heat pumps or resistance heat. We also examine the more realistic situation of continued control of natural gas prices and the inevitable curtailments in supply which will result. This analysis is also applicable to retrofits of solar space heating systems for homes that do not presently use natural gas so we consider retrofit as well.

If we assume that natural gas becomes unavailable for home use either through curtailments or moratoriums on new gas hookups as has already occurred periodically throughout the country, solar energy becomes feasible very quickly. Map 9 shows the space heating feasibility pattern for new tract homes using life cycle costing and a 2.5 percent real interest rate. In Map 11 we represent available retrofit system costs. Here we assume the backup system to be electric resistance with a COP of 1.0. This comparison was made because many homes in states currently suffering curtailments of natural gas already use electric resistance heat. Also, when compared to either form of electric heat solar energy becomes feasible at a much larger fraction of space heat provided, which makes electric heat pumps a rather expensive backup system.

- Under the assumptions in Map 9 and with a backup system employing electric heat pumps, two-thirds of the continental United States is already feasible for solar space heating. All but four states demonstrate feasibility by 1990.
- When compared to electric resistance heat, even using current prices and the higher 4.0 percent real interest rate (Map 11), we find that a total of thirty-eight states attain feasibility by 1990 with twenty-seven of these states already feasible for this system.

Map 9

SOLAR FEASIBILITY
SOLAR RESIDENTIAL SPACE HEAT* - vs. - ELECTRIC HEAT PUMPS**
Annualized for 30 years
(real interest rate = 2.5%)

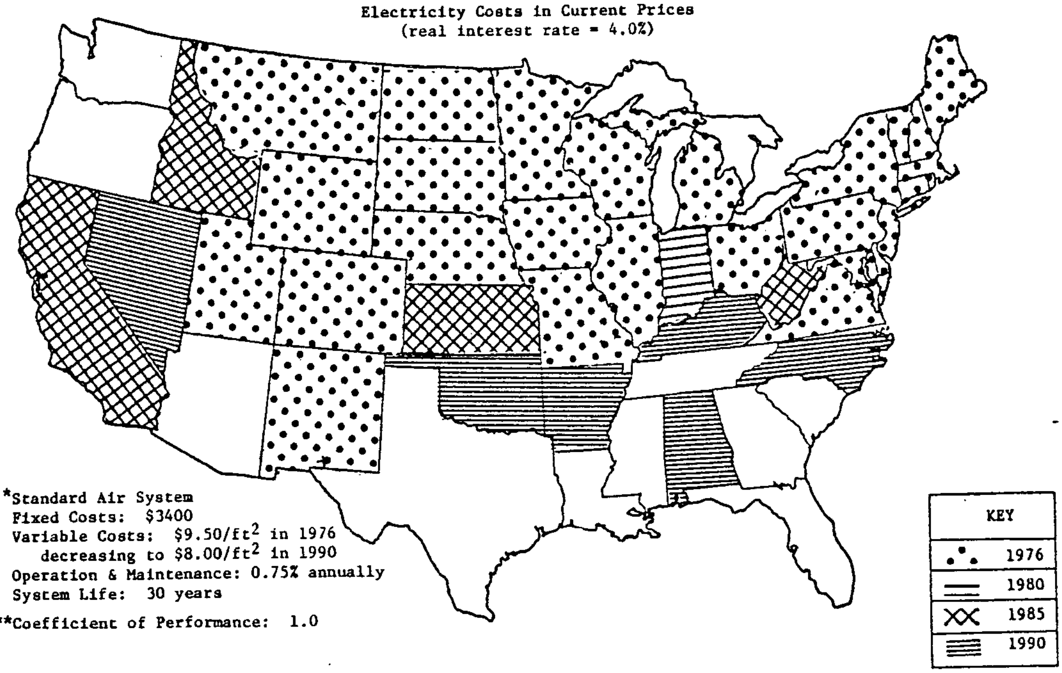


*Standard Air System
Fixed Costs: $1100
Variable Costs: $9.50/ft^2 in 1976
decreasing to $8.00/ft^2 in 1990
Operation & Maintenance: 0.75% annually
System Life: 30 years

**Coefficient of Performance (COP) varies by state

Map 11

SOLAR FEASIBILITY
SOLAR RESIDENTIAL SPACE HEAT* - vs. - ELECTRIC RESISTENCE HEAT**
Electricity Costs in Current Prices
(real interest rate = 4.0%)



*Standard Air System
Fixed Costs: $3400
Variable Costs: $9.50/ft^2 in 1976
decreasing to $8.00/ft^2 in 1990
Operation & Maintenance: 0.75% annually
System Life: 30 years

**Coefficient of Performance: 1.0

- In the case of natural gas curtailment, domestic water heating by solar energy is already feasible compared to electric heating in all states in the continental U. S. except Washington, where it will be feasible by 1983.

Again, in both cases depicted in Maps 9 and 11 it is the northern tier of states, including almost all states which experienced energy emergencies during the winter of 1976-1977 where solar energy is already feasible. This analysis suggests that retrofit of space heating may well be more feasible than is currently accepted. This is an important point because the potential energy savings of such retrofit systems are very large. In summary, the primary result of our analysis is that solar energy for space heating and domestic hot water is widely feasible throughout the continental U.S.

Even with decontrol of traditional energy sources, solar energy will not be competitive unless action is taken to remove the financial and institutional constraints on its efficient use. A federally coordinated program is necessary to facilitate the smooth transition from non-renewable to renewable energy sources. Under a policy of continued price controls, residential users of natural gas must be encouraged to make the transition to solar energy systems before they are faced with the inevitable curtailments of natural gas for home use.

Given the way our financial institutions function it is extremely difficult for homeowners to compare fuel cost savings with either the additional mortgage payment which would be associated with adding solar systems to homes, or the annual cost of the money one might borrow to retrofit such a system to a residence. The reason for this, quite simply put, is that inflation distorts the pattern of yearly payments over time.

Thus, where payments on mortgage loans which include solar applications are defined in nominal rather than real dollars, payments actually are biased toward the early years of the loan period. This makes it impossible for the average homeowner to compare the first monthly payment on a solar system with expected annualized energy costs over time for the home. The Graduated Mortgage is a proposal currently under investigation by the Federal Home Loan Bank which would help alleviate this problem.

Although we advocate decontrol of energy prices, we recognize that this may be politically infeasible unless the regressive income effects of such a policy can be corrected. As a viable alternative for the subsidization of solar energy we propose that guaranteed low interest loans be made available for potential solar energy users until such time as other energy prices are fully decontrolled. At that time such subsidies become unnecessary. It is clear from our analysis that interest rate manipulation is the most powerful tool for achieving economic feasibility of solar systems under continued price control of other energy sources. Guaranteed low interest loans would also encourage other important energy conserving technologies such as increased home insulation.

The questions addressed in this study point to the complex interdependencies involved in the transition from exhaustible fossil fuels to renewable energy resources. We strongly recommend that the appropriate agencies and policy making bodies:

- Totally deregulate wellhead prices of oil and natural gas by 1981.
- Implement a policy which taxes windfall profits accrued by firms as a result of deregulation. These taxes should be effectively transferred to lower income groups to offset adverse income distribution effects associated with higher energy prices.

- Provide federal guarantees for loans made on solar installations.
- In the event energy price deregulation does not occur:
  - Design and implement a program which would enable residential homeowners and commercial establishments to obtain low interest rate loans for installing solar devices and investing in energy conserving measures. These loans should also be guaranteed.
  - Offer economic incentives which would give solar energy the same preferential treatment as enjoyed by the oil and natural gas companies for so many years. These incentives would include income tax credits, property and sales tax exemptions, and other fiscal devices.

  Again we stress that such policies are much less efficient than de-control of energy prices.
- Encourage the use of life cycle costing techniques within the public and private sectors:
  - Require industrial and commercial establishments and government agencies to use life cycle costing in all calculations that pertain to energy financing.
  - Require all financial institutuions to present life cycle costing techniques to clientele considering energy capital investments.
  - Disseminate information on a widespread national basis concerning the level of future energy prices through the period of deregulation.
- Establish new mortgage programs which enable average homeowners to compare their first year's payments for a solar installation with the expected annualized home energy cost over time. Such programs will ameliorate inflationary distortions in the financing of solar home heating units.

I. INTRODUCTION

The economics of active solar energy systems for residential use was first explored by Tybout and Löf in a study supported by Resources for the Future during the 1960s. Since that time, studies by Westinghouse, TRW, and General Electric* have also looked at the potential future feasibility of solar water and space heating. Unfortunately, however, these studies preceded and could not effectively take into account the events of 1973 which led to the formation of OPEC, nor did any of them take into account the extent of domestic depletion of oil and natural gas in the United States. In all of these studies the factors above led to the expectation of continuing cheap energy supply from traditional sources. This, in turn, resulted in poor projections of feasibility for solar energy, or perhaps even worse, to drastic and what seem now to be obvious understatements of the costs of solar energy.

Now that some experience has been gained both in manufacturing and installation, it is apparent that the cost of solar collectors installed, but excluding fixed costs, will be about $\$10/ft^2$ with little real hope of long run cost reduction given materials and labor requirements. Although this may seem high in comparison to estimates as low as $\$3/ft^2$ used in previous studies,** we find that feasibility does occur for solar water and space heating systems between now and 1990 if decontrolled prices of traditional energy sources are used as the basis of comparison

---

*Tybout and Löf, "Solar House Heating," Natural Resources Journal, Vol. 10, April 1970; The General Electric Company, "Commercial Diffusion-Problems and Solutions," Solar Heating and Cooling of Buildings, Phase 0, Feasibility and Planning Study - Final Report, May 1974; Westinghouse Electric Corporation, Solar Heating and Cooling of Buildings - Executive Summary, May 1974; and TRW, Solar Heating and Cooling of Buildings (Phase 0), May 1974.

**Ibid

or where curtailments of natural gas occur. The importance of this finding is diminished by the federal government's failure to assist in making capital available for energy conservation. If interest rates are kept high and if money (capital) remains in short supply, the prospects for capital intensive systems in homes, such as solar energy, are diminished greatly.

The next section of this report develops a scenario of future energy prices both for decontrol and for curtailments and projects consumer costs from traditional sources both on an annualized (life cycle) basis and on a current cost basis for residential space heating and domestic hot water. These costs are developed by state for the continental United States through 1990. Section III develops cost and performance for solar energy systems while Section IV then compares fossil fuel costs on a $\$/10^6$ BTU basis under decontrol to the costs of solar alternatives, determining year of feasibility by state and optimal system design (least cost) given projected energy prices. In Section V projected energy savings in 1990 resulting from utilization of solar energy are discussed. Section VI considers the future of solar energy under continued price controls and, finally, Section VII considers the role of economic policy in defining future energy alternatives.

85-329 O - 77 - 4

II. REGIONAL ENERGY PRICES FOR SPACE HEATING AND DOMESTIC HOT WATER

To evaluate the feasibility of solar energy sources under a variety of policy options an econometric simulation model for fossil fuels which allows cost comparisons was constructed.* The model is based upon behavioral and technical relationships which describe the energy sector of the U.S. economy. These relationships were estimated from a forty year time series data base. The econometric model provides projections of future fossil fuel prices, demand, discovery, and reserves on the assumption of "business as usual". These results are then used to develop projected water and space heating costs by state in the 1976-1990 interval.

For the case of energy decontrol of wellhead prices, the ability of OPEC to maintain control of world petroleum prices and capacity conditions within the energy extraction industry were adopted as basic assumptions. An implicit assumption of the "business as usual" condition is that little allowance is made for the development of alternative energy sources.** Rather, the econometric model concentrates upon the conventional fossil fuel energy sector comprised of coal, petroleum, and natural gas.

The results of the simulation modeling presented here are based on a scenario which assumes: (i) total deregulation of natural gas prices

---

*A detailed discussion of this model can be found in Solar Energy: Policy and Prospects, First Year Report to the National Science Foundation on Project #APR75-18249, July 1976.

**Since the focus is on near term (through 1990) applications of solar energy this assumption will unfortunately hold true in the viewpoint of the authors.

by 1978; (ii) a five year (1977-1981) deregulation period in which the price per barrel of domestic crude petroleum is allowed to seek a level consistent with the OPEC price; and (iii) the ability of OPEC to maintain the price per barrel at a constant level, adjusted only for inflationary changes. An element of conservatism for future energy price levels is introduced by our assumption of a constant real price for OPEC oil. It is believed that as the price of natural gas, the major source of residential, commercial and industrial process heat, catches up to the current OPEC price for oil, OPEC's prices will again increase substantially. A better assumption, which is employed by excluding oil prices from the following feasibility analyses for solar energy, is that the OPEC price will follow the projected natural gas prices in the late 1980s. The results of the simulation under the above conditions are presented in figures 1, 2, 3, and 4. Projected field prices, fossil fuel demand, reserves and discovery are shown for the years 1974 to 1990.

The analysis indicates that production of natural gas is determined by reserves and implies capacity conditions within the industry. Therefore, the structure of the natural gas industry is such that the reserve base constrains production. Thus, the declining rate of discovery results in decreasing production over time. Unlike several other studies which incorrectly forecast increases in gas discoveries with increased prices, we find discovery insensitive to price and have, with reasonable accuracy, projected the declining trend in domestic gas discovery.

This situation translates into curtailments of natural gas under a policy of price control. On the other hand, the deregulated price scenario results in rapid price increases which discourage demand but which provide windfall profits for domestic producers of natural gas.

FIGURE 1

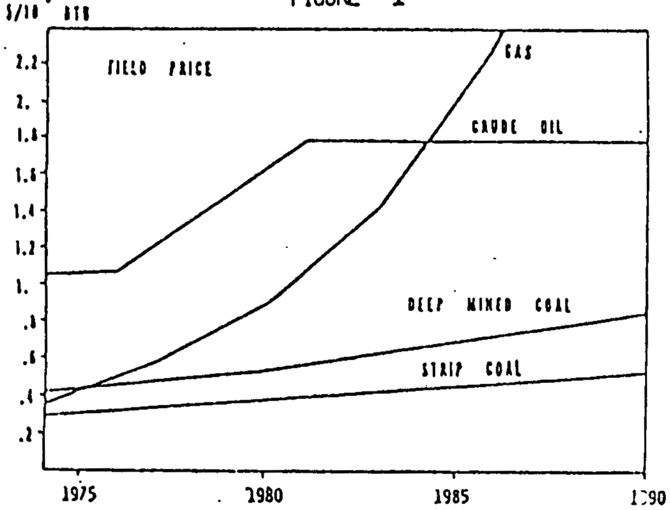


FIGURE 2*

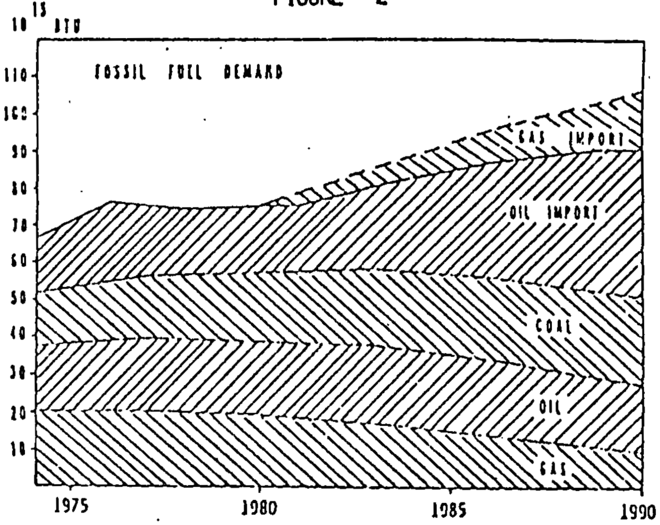


FIGURE 3

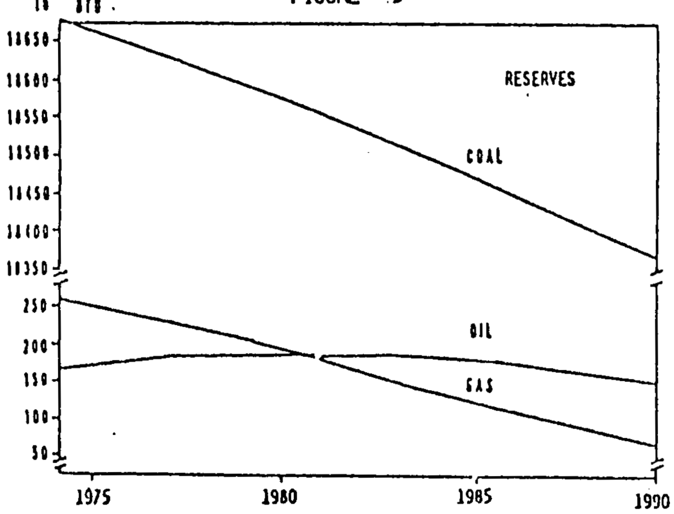
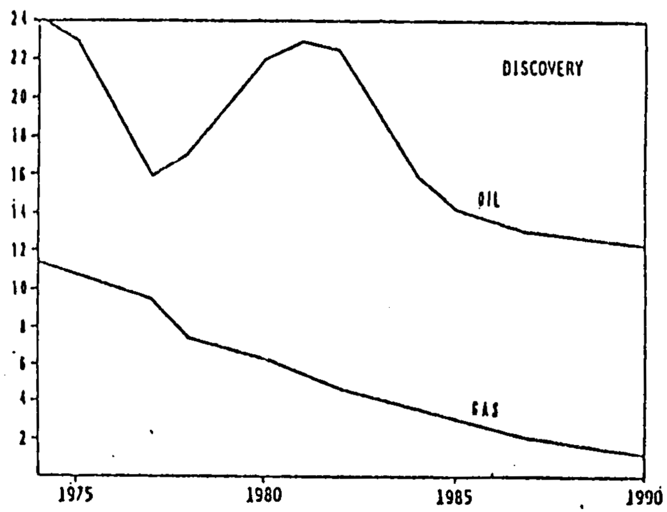


FIGURE 4



* Hypothetical natural gas imports, valued at $2.00/MCF are excluded from the analysis.

However, the rising prices associated with the latter case would permit a more widespread and rational introduction of alternative energy resources, whereas price control would inhibit the adoption of substitutes.

The projected wellhead prices of natural gas and other energy sources shown in figure 1 must be adjusted on a regional basis to provide delivered rates. States that are located close to major producing areas -- notably the Gulf Coast states -- are able to obtain natural gas at a lower price since pipeline transmission costs are minimal. The opposite holds true for states far removed from the source areas, such as New England, the Northern Plains, and the Pacific Northwest regions.

Anomalies to this general price trend naturally occur and are to be expected. Rate structures and levels vary from state to state, as well as allowances for fuel price and cost of service adjustments. For the purposes of this study, general price levels of residential natural gas for each of the forty-eight states in the continental United States were identified. Data from the U.S. Department of Labor, Bureau of Labor Statistics (BLS) were obtained to provide price information for twenty cities across the United States. In addition, residential block rate schedules were obtained from gas and utility companies which served cities not included in the BLS surveys. Using these schedules, the price of natural gas per thousand cubic feet (MCF) was calculated, based on average monthly consumption levels within each city. Where wide variations occurred among two or more cities in one state, a weighted average price was figured to give one price for that state. All price calculations were based upon data from the first quarter of 1976.*

---

*Current delivered rates for natural gas are also affected by the mix between inter- and intra-state sources. This mix was accounted for in the analysis of delivery costs but has no impact once decontrol is completed.

Using these residential prices, the residential cost adjustment to the wellhead price was computed for each of the forty-eight states. Using constant 1974 dollar figures and assuming that these residential cost adjustments would not change by significant amounts over time, residential prices were derived under a scenario of total wellhead price decontrol for the period 1974 to 1990. We assume a natural gas conversion efficiency of .75 typical of new gas furnaces for space heat and an efficiency of .60 for gas water heaters in the analysis.

Natural gas, while it maintains its least cost advantage, is the primary alternative to solar energy. However, because natural gas is in a state of rapid depletion, its price is either expected to rise much faster than other energy sources under decontrol, thereby relinquishing its comparative cost advantage, or with continued controls large scale curtailments will occur. Thus, it was necessary to calculate the price of a competing energy substitute which might replace natural gas. For this purpose, the price per 10^6 BTU of electric heat pumps to provide both space heating and domestic hot water was selected. A projected COP of 2.5* for electric heat pumps was used in both cases since it was assumed that when electricity is used for space heating, a heat pump large enough to heat both water and air would be installed. Other alternatives would include fuel oil, gasified coal, propane, etc. Heat pumps seem to offer the cheapest available alternative to natural gas, even with the expected rise in electricity prices in the future.**

---

*COP denotes Coefficient of Performance and measures heat pump efficiency.

**Currently, projected energy prices for heat pumps, coal gasification, and liquid fuels from coal fall in a wide but overlapping range on a $/$10^6$ BTU basis. Of these, heat pumps are believed to provide the most reliable estimates of future energy costs.

Regional variations in electricity prices and increases in real capital and fuel costs were incorporated in developing heat pump energy price projections. Irving Bupp* has shown that fossil fuel electrical generation plant capital costs are increasing at a real rate of \$13/KW per year. Assuming a 17 percent real fixed charge rate (considered an upper limit for privately owned utilities) and a 70 percent load factor, which translates into 6132 yearly hours of operation (.7 x 8760), capital cost increases per kilowatt-hour of baseload electricity are:

$$\frac{13 \text{ \$/KW} \times .17}{6132} = .00036 \text{ \$/KWh.}$$

Mine mouth coal fuel costs now run .0068 \$/KWh** and are projected to increase by 3.7 to 4.5 percent annually over the next fifteen years, for an average of 4.1 percent annually. The fuel cost increase ratio over fifteen years is then:

$$e^{.041 \times 15} = 1.849.$$

The average annual fuel cost increase is therefore

$$\frac{.849 \times .0068}{15} = .000385 \text{ \$/KWh.}$$

Summation of these two components gives an approximate annual increase in electricity prices of \$.000745 per KWh per year or $\$.218/10^6$ BTU per year. This increase is added annually to each state's average residential electrical rate*** to give an estimated cost for delivered electricity prices.

---

*Irving Bupp, *et al.*, "The Economics of Nuclear Power," *Technology Review*, February 1975.

**This cost is based upon a current mine-mouth price of $\$.45/10^6$ BTU and a combustion efficiency factor of 23 percent.

***State electricity rates were derived from *Typical Electric Bills - 1975*, Federal Power Commission and were based upon 250 KWh monthly consumption by residential users.

After dividing these prices by the COP to account for heat pump performance, a comparison between natural gas and heat pump prices yields the least cost energy alternative to solar. A comparison to the cost in dollars per BTU of solar energy then determines the economic desirability of solar energy, based upon current cost criteria. However, the cost analysis detailed above is inadequate for long-term investment decisions. Therefore, life cycle costing techniques are also used in making cost comparisons.

The development of the annualized life cycle costing procedure follows essentially the same path as that of the current price analysis. The projected price of the least cost alternative to solar energy, whether it be natural gas or heat pumps, is annualized* based upon a fixed charge rate

---

*For any given state, annualized energy prices are then determined by the procedure detailed below:

$$\sum_{t=0}^{T} \bar{P} \left(\frac{1}{1+r}\right)^t = \sum_{t=0}^{T} P_t \left(\frac{1}{1+r}\right)^t$$

$$\bar{P} = \frac{1}{\sum_{t=0}^{T} \left(\frac{1}{1+r}\right)^t} \sum_{t=0}^{T} P_t \left(\frac{1}{1+r}\right)^t$$

$$\bar{P} = CR \left[\sum_{t=0}^{T} P_t \left(\frac{1}{1+r}\right)^t \right]$$

where:

P_t = projected price of the least cost energy alternative (adjusted for conversion efficiency) delivered to residential users in a given state in year t [$\$/10^6$ BTU; constant 1974 dollars].

$\bar{P}$ = annualized price of the least cost energy alternative.

r = the real interest rate (nominal interest rate less the rate of inflation).

T = life of the solar installation: water system → T = 20; air systems → T = 30.

CR = capital recovery factor.

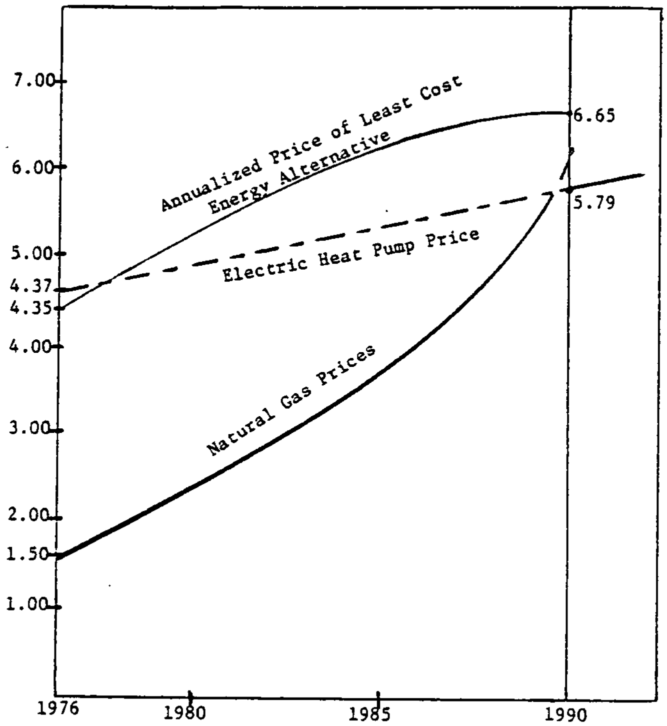
consistent with a given system life and a .025 (or other) real rate of interest. Annualized energy prices for space heating are calculated, assuming a thirty year system life and gas efficiency of .75. Annualized energy prices used for domestic hot water heating are calculated assuming a twenty year life and a gas efficiency of .60. Current and annualized prices for space and water heating are presented for the years 1976 and 1990 in the appendix.

Comparing annualized prices and current prices, one can see the discrepancy between current and life cycle costing within each state. Figure 5 shows that in New Mexico for example, the current price for space heating rises from $1.50 in 1976 (on the natural gas price trend) to $5.79 in 1990 (now following the heat pump cost trend). The annualized price, on the other hand, starts at the higher value of $4.35 in 1976 and increases at a decreasing rate to $6.65. In figure 5, 1989 is the year in which electric heat pumps become the least cost energy alternative to solar energy in New Mexico, thereby replacing the use of natural gas for residential space heating.

If homeowners and the housing industry react to current energy costs, as is usually the case, the desirability of a solar heating installation is diminished. But when making an investment decision, the proper criterion should be to look at total life cycle costs or savings; that is, to look at values of annualized prices rather than current prices. In New Mexico, for example, an annualized price of $4.35 in 1976 is not matched by current costing until 1987. _If_ solar home heating were feasible at $4.35, there would be an eleven year delay by using the current price criterion.

It should be understood that, under a policy of complete price decontrol for natural gas, curtailments will not occur because all potential

FIGURE 5



CURRENT VERSUS ANNUALIZED PRICE COMPARISONS FOR RESIDENTIAL SPACE HEATING IN NEW MEXICO
(All prices adjusted for combustion efficiency)

users, wherever they might be located, would be able to competitively bid for natural gas. Our feasibility study initially focuses on this idealized situation. Note that in figure 5 the price of natural gas rises to its assumed next best alternative, electric heat pumps, as gas approaches exhaustion.

On the other hand, if natural gas prices remain controlled near current (1977) levels, homeowners who can obtain natural gas will have no incentive to substitute solar energy which will invariably cost more on a $/BTU basis. But, even though some homeowners will be able to obtain very cheap energy, others will be forced by curtailment or through moratoriums on new gas hookups to find an alternative energy source for space and water heating. Since we have assumed heat pumps provide the best estimate of future fossil fuel energy costs (excluding natural gas) the appropriate criterion under continued controls is to compare solar energy to electric heat pumps on a regional basis, realizing that some consumers will not consider solar because of the availability of a declining quantity of cheap gas.

III. PERFORMANCE AND COST OF SOLAR HEATING SYSTEMS

This section describes performance and cost parameters for the two most promising and best known short run uses of solar energy; domestic hot water and space heating of residences. Additionally, a methodology for analyzing the economic feasibility of solar energy is developed.

The solar energy incident on the outside of a building can be used to provide a major fraction of space heating and domestic hot water requirements in large portions of the United States. A solar heating system generally consists of solar collectors to absorb the sun's heat energy and a heat storage medium to hold excess heat for release during periods when the sun does not shine. Since weather, solar insolation, and energy cost patterns vary significantly from place to place it is desirable to base the design of a solar system on the local situation.

Although the operation of a solar system can be readily understood in a qualitative fashion, the quantitative analysis of a system (e.g., sizing of collector array) involves computer simulation of solar performance using actual hour by hour weather data, and is considerably more difficult. A fairly general method developed at Los Alamos Scientific Laboratories (LASL) was employed to supply the necessary quantitative analysis.* LASL developed standard parameters for both residential space heating systems and for domestic hot water systems which serve as the basis for the performance simulation work being done at Los Alamos and for the economic analysis reported here.

---

*Balcomb, J. Douglas and James C. Hedstrom, "A Simplified Method for Sizing a Solar Collector Array for Space Heating," Los Alamos Scientific Laboratory, Los Alamos, New Mexico.

The cost of solar energy systems can and has been computed by a variety of generally accepted methodologies. These costs, when contrasted with projected prices of alternative energy systems, give the investigator a picture of potential solar penetration in various regional markets. This section is concerned with constructing realistic cost estimates of a solar domestic hot water system and a solar air heating system designed solely to meet some fraction of a residence's (single-family detached for this study) hot water or space heating demand over a normal year.

Performance Parameters

The first consideration in the thermal design of the building should be to minimize the load within the constraints imposed by economics and architecture. The thermal load is defined as the total heat required by the building per day per degree fahrenheit temperature difference between the inside temperature and the outside temperature (frequently expressed in units of BTU/Degree-Day). For a small, single story, well insulated building, the thermal load should be in the range of 10 BTUs per degree day per square foot of floor area (BTU/DD/Ft^2). It is important to minimize the building load through adequate insulation, double glazing, control of infiltration, and passive control of the solar gains since the area of solar collector required to obtain a given fraction of the heating requirements is directly proportional to the building load.

Design optimization usually involves a tradeoff between cost and performance. For most locations it is uneconomical to design solar heating to provide for 100 percent of the heating requirements because of the necessarily large collector area and storage volume that would be required.

85-329 O - 77 - 5

A solar system should always be designed with a full capacity auxiliary heating unit for periods of extended cloudiness. At some point the extra performance which can be achieved by adding on more equipment or material will exceed the savings incurred. This is true of extra insulation, extra collector area, and many other design variables.

Component lifetime and maintenance should receive major consideration in the design. The solar energy which falls on a building may be free but the equipment involved can represent 5 to 15 percent of the building cost and must have a lifetime approaching thirty years to warrant the investment.

There exists today very little hard data on the cost of solar energy systems designed solely for residential space heating. The systems available now are usually designed and delivered with at least a hot water pre-heater* and most components of the backup or auxiliary heating system. In addition, the systems are generally site specific; that is, there are large design, engineering, and supervision costs inherent within the installed system. In addition, initial unit fabrication costs and the training required for proper installation increase total system costs significantly.

In a system employing an air heating collector as depicted in figure 6, air passes through channels in the collector, is heated, and the heat is transferred to a heat storage system. Air has a low heat transfer coefficient, but air-heating collectors can be properly designed to have adequate performance.

---

* It is recognized that an integrated solar system designed for hot water and space heating purposes will almost always be more competitive and hence closer to an "optimal" total energy system within a family residence than one designed solely for space heating. To keep the analysis to a minimum, however, space heating and hot water heating will be examined separately.

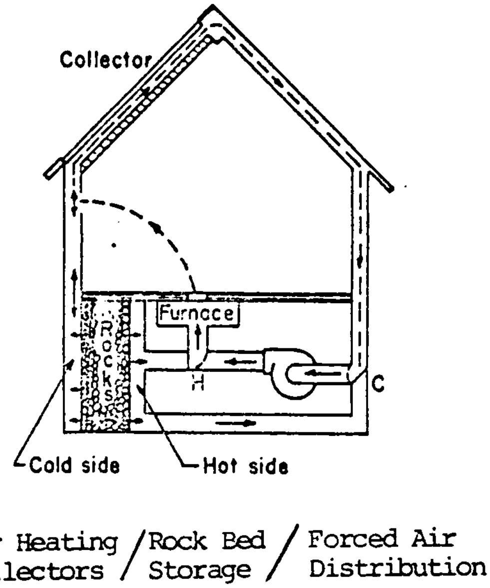


FIGURE 6. SPACE HEATING SYSTEM USING AIR HEATING COLLECTORS

The common thermal storage medium for air heating collectors is a bin full of rocks which is heated by the hot air from the collector. Space heating is accomplished by blowing cooler air from the room through either the heated rock-bin or directly through the collector itself. If room temperature falls below a chosen level, an auxiliary space heater is used to maintain room temperature.

The system requires only one fan and two double-dampers. When the collector temperature exceeds the rock bed exit temperature (left side), the collector is on and Damper C is in the position shown. Otherwise the collector is off and Damper C is in the upper position.

When the building requires heat, Damper H is in the position shown. Otherwise Damper H is in the upper position. The furnace is operated when necessary to satisfy the building load. The fan is on when either the collector is on or the building needs heat.

When the collector is on, the solar heated air is routed either to the building space directly (when the building needs heat) or to the rock bed. When the collector is off, the building is heated by blowing air through the rock bed in the reverse direction and directly into the building space. The standard air system parameters developed by LASL are given in Table 1.

Domestic solar water heaters are attractive because they work year round and can usually be retrofitted to existing dwellings. Compared to space heating, they require a relatively small amount of energy and, therefore, a correspondingly smaller solar collector array and storage tank. Although not explicitly considered in the LASL simulation analysis, domestic hot water heating is a natural and almost universal add-on to a space heating system.

Liquid cooled collector designs enjoy a natural advantage in a situation where <u>only</u> domestic hot water is generated: there is no air-to-liquid transfer required anywhere within the system. A liquid-to-water heat exchanger is considered desirable to avoid a water cooled collector and the associated problems of freezing, corrosion and scaling. The thermal load is quite different for water heating than for space heating. An assumed profile of hot water demand shown in figure 7 was deduced based on personal experience and estimation. The simulations were run for this profile. The profile is assumed to be the same for every day of the year.

The nominal design parameters for the collector are given in Table 2. Since the storage tank is relatively small, the heat loss from the tank

TABLE 1

STANDARD AIR SYSTEM PARAMETERS*

Solar Collectors		
Number of glazings	1	
Glass transmissivity (at normal incidence)	0.86	(6% absorption 8% reflection)
Glass absorptance	0.98	
Glass emittance	0.89	
Back insulation U-value	0.083	BTU/hr-°F-ft_c^2
Heat capacity	0.5	BTU/°F-ft_c^2
Air flow rate	2	CFM/ft_c^2
Heat transfer coefficient to air	4	BTU/hr-°F-ft_c^2
Tilt	Latitude + 10 degrees	
Orientation	Due south	
Collector Air Ducts		
Heat loss coefficient (to ambient)	0.1	BTU/hr-°F-ft_c^2
Thermal Storage		
Heat capacity	15	BTU/°F-ft_c^2
Heat loss coefficient (i.e., assuming all heat is lost to heated space)	0	BTU/°F-hr-ft_c^2
Dimensionless rock-bed heat transfer length**	10	
Heat Distribution System		
Air flow rate	2	CFM/ft_c^2
Controls		
Building maintained at 68°F		
Collectors on when advantageous		

*Values are normalized to one square foot of collector (ft_c^2).

**The rock-bed length (distance in the direction of flow) is greater than 5 times the relaxation length for heat transfer (15 was used in the model). Physically this means that the bed is at least 12 times as long as the rock diameter. It is important to note that the flow direction is <u>reversed</u> in the rock bed, being in one direction during the charging period and in the opposite direction during discharging.

TABLE 2

STANDARD LIQUID SYSTEM PARAMETERS*

Solar Collectors		
Number of glazings	1	
Glass transmissivity (at normal incidence)	0.86	(6% absorption, 8% reflection)
Surface absorptance (solar)	0.98	
Surface emittance (IR)	0.89	
Back insulation U-value	0.083	BTU/hr-°F-ft_c^2
Coolant flow rate	20	BTU/hr-°F-ft_c^2
Heat capacity	1	BTU/°F-ft_c^2
Heat transfer coefficient to liquid coolant	30	BTU/°F-ft_c^2
Tilt (from horizontal)	Latitude + 10 degrees	
Orientation	Due south	
Collector Plumbing		
Heat loss coefficient (to ambient)	0.04	BTU/hr-°F-ft_c^2
Heat Exchanger		
Heat transfer effectiveness	10	BTU/°F-hr-ft_c^2
Thermal Storage		
Heat capacity	15	BTU/°F-ft_c^2 (1.8 gallons H_2O/ ft^2 collector)
Heat loss coefficient (i.e., assuming all heat loss is to heated space)	0	
Heat Distribution System		
Design air distribution temperature**	120°F	

*The values are normalized to one square foot of collector (ft_c^2).

**The coil and air circulation are sized to meet the building load with an outside temperature of -2°F with 133°F water and an air flow rate adequate to make up the space heat losses at an air discharge temperature of 120°F. This corresponds to a finned-tube coil effectiveness of 80%.

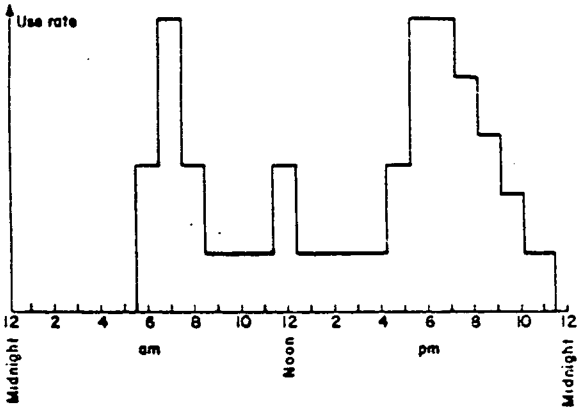


FIGURE 7. ASSUMED USE PROFILE FOR DOMESTIC HOT WATER

surface is relatively larger than for a space heating system and is explicitly accounted for in the analysis. A tank surface of $0.5 ft^2/ft_c^2$ is assumed with a tank insulation heat loss coefficient of .083 BTU/°F-hr-ft_c^2.

For the two-tank system, depicted in figure 8, the solar-heated storage tank acts as a source of preheated water for the second tank, a conventionally fired, domestic hot water tank. A control scheme was adopted in which auxiliary heat is added to the second tank as necessary to maintain the storage temperature at 120°F. A nominal thermal storage heat capacity was chosen for the solar storage tank equal to 15 pounds (1.8 gallons) of water per square foot of collector. For the second, auxiliary-fired tank, a nominal capacity equal to one-half the daily usage was chosen. In this analysis the daily hot water usage is 80

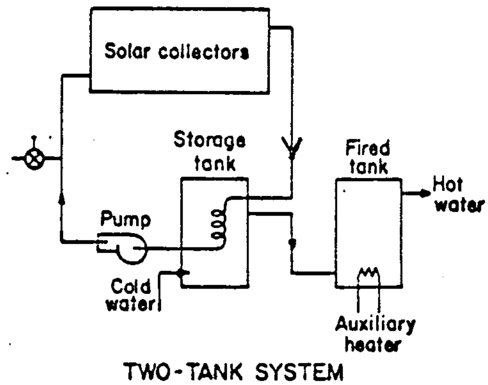


FIGURE 8. DOMESTIC HOT WATER SCHEMATIC

gallons per day, therefore, the second storage tank is 40 gallons.

The two-tank domestic hot water system can be expected to perform at higher overall efficiency than a one-tank system. Since the auxiliary heat is supplied at the second tank, not at the solar heated tank, the solar heated portion of the two-tank system can operate at a lower storage (and hence collector) temperature and higher heat collection efficiency. By proper adjustment of the solar storage tank temperature, the overall efficiency of the two-tank system can be raised over that of the one-tank system.

Incorporation of domestic hot water heating into an air space heating system would involve an air-to-liquid heat exchanger at the collector outlet, a small pump to circulate the water, and a single-tank hot water system. The air-heating collector system would provide domestic hot water at lower efficiencies than the liquid-heating collector system because of the collector-to-air and air-to-water heat-exchangers. On the other hand, air systems avoid the possibility of contamination of the domestic hot water system with the collector coolant liquid which may be toxic (e.g., ethylene glycol). Shown in figure 9 is a one-tank domestic hot water system connected to an air-heating collector system.

Cost Parameters

On the basis of the design parameters supplied by LASL, cost data were obtained from many individuals and firms in the Southwest engaged in designing, engineering, marketing and installing solar energy systems. Although there was much disagreement on actual dollar figures that may be representative of mass produced systems of the very near future, the general consensus was that total fixed costs, independent of storage and

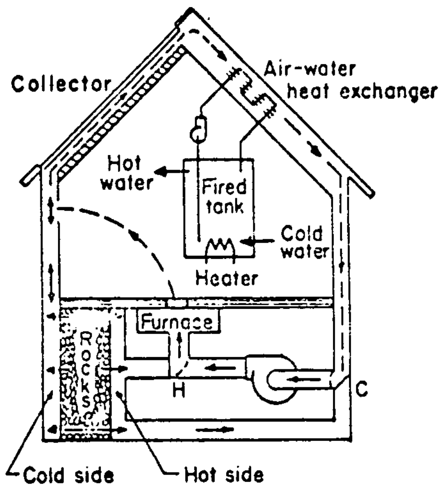


FIGURE 9. CONNECTING DOMESTIC HOT WATER TO A SPACE HEATING SYSTEM USING AIR HEATING COLLECTORS

85-329 O - 77 - 6

collectors, would run approximately $1100 for residential space heating* and $300 for domestic hot water.**

Given sufficient demand and mass production schedules, collector area costs have been estimated to be in the neighborhood of $8.50*** and $9.50† per square foot installed (single pane). Storage costs for a rock storage bin when designed, engineered, and installed on a large scale basis should be no more than $1.00 per square foot of collector. With the same considerations storage costs for an insulated water tank should be no more than $1.50 per square foot of collector. This results in collector dependent cost of $9.50 and $11.00 per square foot installed (space heating and hot water respectively).†† In our space heating

---

*Near term fixed costs for a conventional tract home where installation of the required duct work and air handling control system is commonplace, and where the collector area, auxiliary heating unit, storage bin, and forced air distribution system are all designed and engineered as a compact integrated unit in the center of the structure have been estimated at approximately $600 for the air handling system and $500 for the insulated duct work required by the solar space heating system.

**Near term fixed costs for a pump, controller, pipes, and their installation.

***Air type collectors installed as integral roof units.

†Water type collectors installed as independent units.

††The $1100 fixed cost and $9.50 per square foot of collector variable costs for air space heating systems are estimates made for the near term future. Past studies have projected a decrease in collector area costs to two to three dollars per square foot by the year 2000 or 2020. We, as well as every individual or firm contacted for this study, believe that these projections are unattainable. Collectors are made from common materials employing relatively common manufacturing techniques in the fabrication, construction, and integration of their components, although not necessarily integrated at any one facility. It is difficult to project and substantiate large scale reductions in costs based upon vast improvements in the manufacturing process and/or healthy reductions in the real costs of the common material inputs over and above what is both implicitly and explicitly accounted for within the near-term estimates above.

case real cost per square foot of installed collector (including storage) was projected to approach $8.00 by 1990 from the current estimate of $9.50. This represents a 15 to 16 percent reduction in real cost; optimistic, but not impossible by any means, given recent projections and estimates by others for collector costs in the next two decades.

The final cost component of solar energy systems included in this analysis is the annual operation and maintenance (O & M) expenses over an air system's expected thirty year life for residential space heating, and twenty year life for domestic hot water system. Because so little is actually known about possible maintenance, repair, and replacement costs for the various components of a solar system, large expenditures were allowed at certain intervals and towards the end of the life cycle. Summing the expenditures over the expected life and computing a yearly average gives an estimate of annual operation and maintenance costs of 0.75 percent of total system costs for the residential space heating air system, and 1.0 percent for the domestic hot water system.

Although LASL has not yet completed a performance analysis of an integrated solar system to provide both space heat and domestic hot water, it was believed necessary to make an estimate of a very simplified integrated system. For this purpose it was assumed that whenever solar space heating is feasible in a state, homeowners can add on a solar domestic hot water system to provide 100 percent of the household's hot water needs during the three summer months. This means that the homeowner would take advantage of the large collector arrays which would otherwise be idle during those months.

The additional fixed costs necessary to add on an air-to-water heat exchanger, a small pump, thermostat, plumbing and to install these items was estimated to be \$250. There would be no additional variable costs since no change in collector area is assumed. As for the solar domestic hot water system, operation and maintenance costs would be 1.0 percent of the additional cost and the assumed life of the additional components would be twenty years.

Feasibility Analysis

The feasibility of solar energy for residential space heating and domestic hot water will be examined on a state by state basis. To keep the computations at a minimum and to give the reader a much broader geographical basis for interpretation, it was felt that basic trends and results would not be affected by lack of more precise specification of sites.* Map 1 displays the location of each city used along with heating degree days. Although construction and insulation standards vary across the country, an average heat load** for space heating was assumed applicable. Therefore, we assumed a standard single family residence of 1500 square feet with a building thermal load of 10 $BTU/DD/Ft^2$, or 15,000 BTUs for each degree day. For domestic hot water heating an average daily demand of 80 gallons at 120° F was used for each site. A

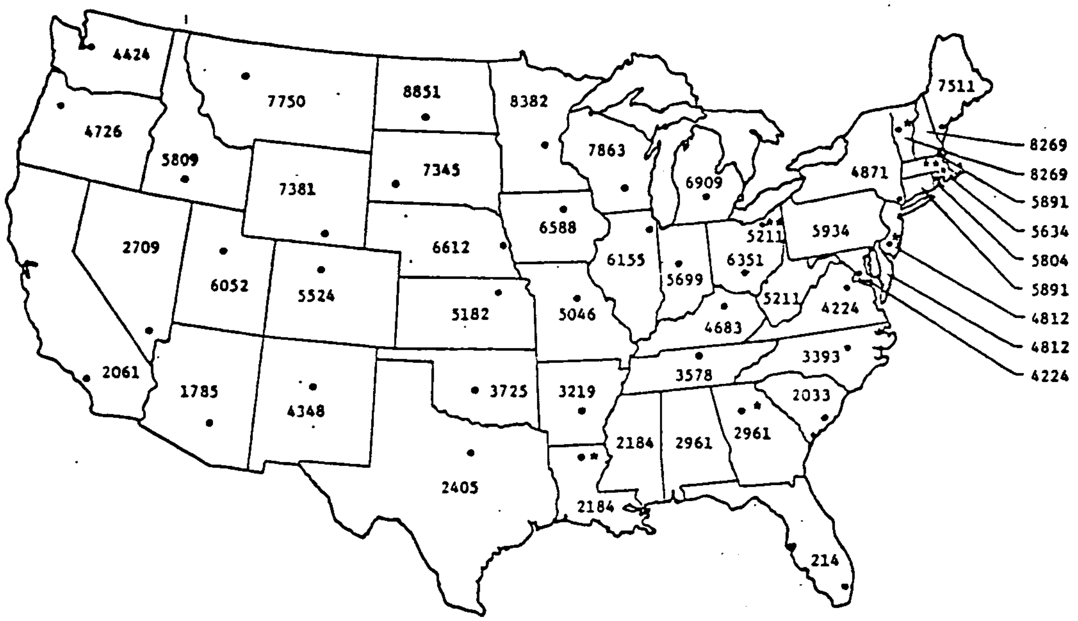
---

*Within each state a city was chosen to be the average or representative site. For many states this choice was simple because there was only one city within the LASL data set for that state. Where there was more than one, the city chosen was either the most populated and/or centrally located. Where there were no data available for a particular state, a city in a neighboring state with similar climatic characteristics to the state in question was chosen.

**Thermal load is defined as the total heat required by the building per day per degree farenheit temperature difference between the inside temperature and the outside temperature.

Map 1

Cities and Heating Degree Days



* City represents nearby state as well as state in which it is located.

** City represents nearby state only

constant differential between the input and output temperatures (60° F) was assumed. This translates into an average yearly requirement of 15×10^6 BTUs. The heat load for an integrated system was assumed to be 3.75×10^6 BTUs added on to the space heating load. This is based on the assumption of 80 gallons per day at 60° F temperature rise for three months.

Table 3 presents collector area requirements from the LASL simulation based on the assumptions noted above for solar water and space heating for each state, given long term normal weather data. The square footage requirements to meet 25, 50, and 75 percent of a residence's space heating and hot water demand are given in the table. Although not a precise relationship, collector area sizes at least double from

Table 3

Collector Area Requirements* for 25, 50, and 75 Percent Solar Fraction

State	Residential Space Heat**			Domestic Hot Water***		
	25%	50%	75%	25%	50%	75%
Alabama	98	254	525	12.2	28.1	52.4
Arizona	50	127	255	9.0	20.7	38.6
Arkansas	119	312	634	12.3	28.3	52.9
California	35	93	195	10.2	23.4	43.6
Colorado	126	218	651	16.2	39.3	62.4
Connecticut	154	405	842	18.5	44.9	71.4
Delaware	155	407	850	12.9	29.7	55.9
Florida	11	26	50	11.1	25.5	47.1
Georgia	98	254	525	12.2	28.1	52.4
Idaho	139	387	867	15.2	36.9	59.0
Illinois	190	506	1064	18.9	45.9	72.9
Indiana	174	473	1009	18.4	44.7	70.9
Iowa	192	506	1059	18.2	44.1	70.0
Kansas	152	396	823	17.6	42.8	68.0
Kentucky	171	459	979	14.0	32.5	61.6
Louisiana	97	252	510	13.4	30.9	58.0
Maine	176	462	964	17.5	42.6	67.6
Maryland	135	348	725	12.4	28.5	53.3
Massachusetts	175	457	948	19.4	47.0	74.7
Michigan	197	537	1139	19.2	47.4	75.3
Minnesota	205	547	1153	17.0	41.3	65.5
Mississippi	97	252	510	13.4	30.9	58.0
Missouri	147	390	819	16.8	40.8	64.8
Montana	161	428	920	15.7	38.2	60.9
Nebraska	168	438	912	16.1	39.2	62.2
Nevada	69	178	361	8.6	19.7	36.7
New Hampshire	236	638	1355	20.3	49.3	78.2
New Jersey	155	407	850	12.9	29.7	55.9
New Mexico	93	236	483	8.7	19.9	36.9
New York	170	443	922	13.5	31.2	58.9
North Carolina	113	288	588	12.2	28.1	52.4
North Dakota	193	520	1100	15.4	37.4	59.4
Ohio	210	586	1281	20.3	49.2	79.0
Oklahoma	111	284	582	11.2	25.6	47.6
Oregon	124	359	827	12.9	30.5	60.1
Pennsylvania	193	518	1101	19.6	47.6	75.6
Rhode Island	155	403	838	18.7	45.4	72.2
South Carolina	71	183	363	11.7	26.7	49.6
South Dakota	154	404	839	15.6	37.8	60.0
Tennessee	128	342	716	12.6	29.1	54.9
Texas	80	205	411	10.9	25.1	46.8
Utah	130	350	751	13.8	33.5	53.1
Vermont	236	638	1355	20.3	49.3	78.2
Virginia	135	346	713	12.5	28.7	53.7
Washington	137	408	984	15.9	37.6	74.6
West Virginia	195	526	1134	22.0	53.4	85.5
Wisconsin	196	532	1129	17.4	42.3	67.2
Wyoming	141	358	728	15.3	37.2	59.1

*Collector areas are in square feet for each fraction to be provided by solar energy.

**Assuming a 10BTU/DD/ft^2 Single-family Residence (1500 sq. ft.)

***Assuming a constant load of 80 gallons per day to be heated 60°F.

25 to 50 percent and approximately double again going from 50 to 75 percent solar fraction. These collector areas provide the basis for our feasibility analysis.

Solar energy feasibility will occur when the cost of providing energy for either residential space heating and/or domestic hot water becomes economically competitive with alternative energy sources. That is, for purposes of this report, whenever the cost of solar energy is equal to or less than the cost of providing the same quantity of energy by an alternative, then the concept of solar feasibility will be accepted. Comparisons can be made for energy price decontrol for annualized (life cycle) or current costs in this analysis.

With life cycle analysis the methodology employed involves the computation of an annualized price per 10^6 BTU for a solar energy system. For any given year this involves applying a fixed charge rate (FCR), used to convert capital expenditures to annual costs, and operation and maintenance expenditures (expressed as a percentage of total capital costs) to the total system costs. The resulting figure is then divided by the quantity of energy to be supplied by the solar system (some fraction or proportion of total yearly energy requirements). The resultant figure is the annualized cost per 10^6 BTU for the solar system under examination where fixed and variable costs are given for each fraction of total demand.

Actual procedures employed to perform the feasibility analysis (determining the year and associated solar fraction at which economic competitiveness is reached) can be summarized as follows. We assume an increasing alternative energy price over time, either annualized or current, as presented in the previous section on decontrol. If future fuel prices are known (projected or estimated for this study) over the fixed collector life, one can optimize collector area. (Readers who are not interested in the technical details of the feasibility analysis may proceed to the next section.)

We define the relevant variables as follows:

r = the real rate of interest*

VC = variable costs associated with each square foot of collector (collector plus storage)

FC = fixed costs (collector independent)

P_t = cost of backup heat per 10^6 BTU (adjusted for furnace and water heater efficiency)

A = collector area in square feet

F = fraction of space water heating requirements to be provided by solar energy

LOAD = 10^6 BTUs required per year

t = year

T = system life (20 or 30 years)

CR = capital recovery factor = $\dfrac{1}{\sum_{t=0}^{T} \left(\dfrac{1}{1+r}\right)^{t}}$

OP = operation and maintenance expenditures expressed as a percent of total capital investment

From the LASL program, we know the relationship between collector area and the fraction of solar heat provided, A(F). Therefore, we can minimize the present value of heating cost (space or water) over system life, or the discounted backup heating and solar costs

* Use of the real interest rate as opposed to the nominal rate eliminates the need to forecast inflationary influences and associated price adjustments.

$$\sum_{t=0}^{T} \left(\frac{1}{1+r}\right)^{t} \cdot P_t \cdot \text{LOAD} \cdot (1-F) + VC \cdot A(F) + FC \qquad (1)$$

with respect to the fraction (F) of solar heat provided.* This cost minimization implies that

$$-\sum_{t=0}^{T} \left(\frac{1}{1+r}\right)^{t} \cdot P_t \cdot \text{LOAD} + VC \cdot (dA/dF) = 0 \qquad (2)$$

which is the derivative of (1) with respect to F set equal to zero. In section II we defined the annualized price of energy as

$$\overline{P} = CR \sum_{t=0}^{T} \left(\frac{1}{1+r}\right)^{t} P_t$$

or, equivalently

$$\frac{\overline{P}}{CR} = \sum_{t=0}^{T} \left(\frac{1}{1+r}\right)^{t} P_t \,. \qquad (3)$$

Thus, using equation (2), this implies*

$$dA/dF = \frac{\overline{P} \cdot \text{LOAD}}{FCR \cdot VC} \,. \qquad (4)$$

The A's are known for values of F between .05 and 1.0 in .05 increments from the LASL simulation. We can calculate the change in A (ΔA) for the corresponding change in F where $\Delta F = .05$. Thus, the optimum value of F and consequently the optimal collector area is determined where:

*We ignore the installation cost of the backup heating system because such a system is required with or without solar heating and so cancels out in making cost comparisons.

**CR can be expanded into the notion of FCR, fixed charge rate, relatively easily by including the O & M, taxes, etc. Here we will include only O & M because of the majority of other factors are either generally quite transparent to or not applicable for the average homeowner. By adding O & M expenses (symbol OP), a percent of total capital expenditures, we will define our FCR as CR + OP. For simplicity we have ignored operating costs in the derivation above.

$$\Delta A \approx \left[\frac{\overline{P} \cdot LOAD}{FCR \cdot VC} \right] \cdot (.05) \quad . \tag{5}$$

Feasibility, however, is not insured by this process. Rather, given an annualized price of energy, collector area will be optimally sized. To check for feasibility one must compute the optimum percentage of space or water heating requirements to be met by solar energy (fraction of solar heat provided) and the associated collector area and, using that percentage, calculate the annualized cost of solar energy ($\overline{P}_s$) for each site.

The annualized cost of solar energy is determined as:

$$\overline{P}_s = FCR \left(\frac{VC \cdot A + FC}{LOAD \cdot F} \right) \tag{6}$$

If this annualized cost of solar energy is less than or equal to the annualized cost of backup heat ($\overline{P}_s \leq \overline{P}$), then the percentage of space or water heating requirements to be met by solar energy determined above is correct, and therefore solar energy for residential space heating and/or domestic hot water is feasible. If, however, the annualized cost of backup heat is less than the annualized cost of solar energy then solar energy is not feasible and so we set the solar fraction equal to zero.* Minimum annualized cost for each state, both for solar water and space heating, are shown in the appendix. Note that if we are interested in current cost comparisons, the current price of alternative energy can be substituted for $\overline{P}$.

* In the economist's terminology one determines the fraction of solar heat provided by adjusting collector area such that the marginal cost/ 10^6 BTU of solar energy equals the annualized alternative energy cost. However, installation is not feasible unless the unit or average cost of solar energy is less than the annualized alternative cost.

As F increases from .05 to 1.0 for each site, A increases at an increasing rate, making ΔA a monotonically increasing function. This means that total variable cost (VC•A) is also increasing monotonically, whereas FC by definition is constant. We obtain traditional cost curves as depicted in figure 10, where MC and AC represent the annualized cost in 10^6 BTUs of a specific solar system. If we now introduce $\overline{P}$, the annualized price of backup energy, into figure 10 one can readily see what is meant by economic feasibility. In figure 11 A, B, and C, represent $\overline{P}$ for three consecutive years. A is less than $\overline{P}_s$ and therefore one would not choose to install this particular solar system for this year. However, B is equal to $\overline{P}_s$ and so solar energy is economically competitive with alternative energy prices (annualized). In the third year a larger fraction of solar energy is competitive, and therefore as annualized energy prices increase through time one would expect more solar units to be installed. Figure 11 also shows that at least some fraction greater than or equal to F_B will be installed given feasibility.

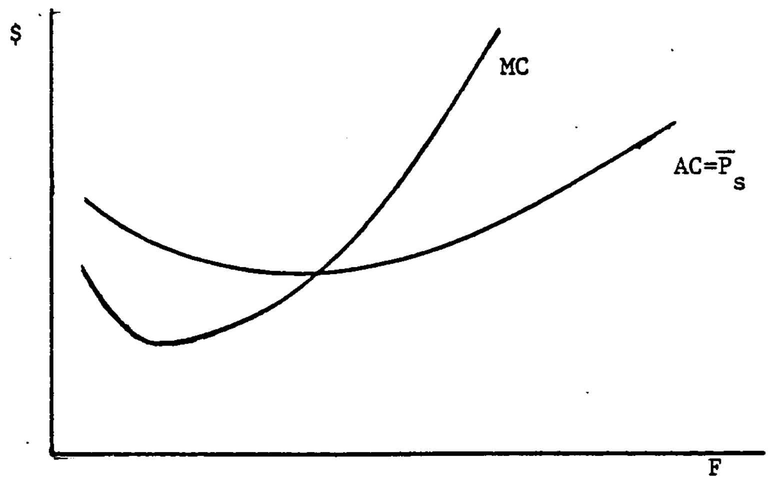


FIGURE 10

MARGINAL AND AVERAGE COSTS OF SOLAR SYSTEMS

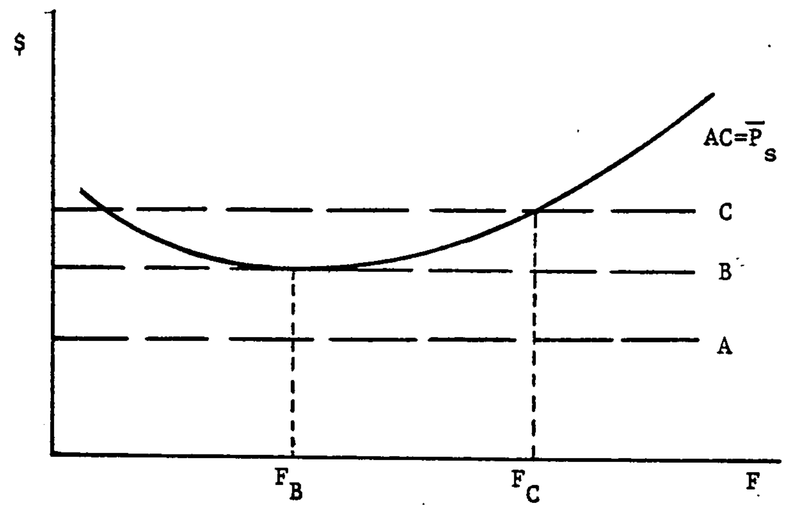


FIGURE 11

DETERMINATION OF SOLAR FEASIBILITY

With increasing energy prices it becomes rather simple to determine the year of feasibility for each site and therefore the optimal fraction of solar energy in that year. Only the increasing portion of the average cost curve to the right of F_B (minimum point on cost curve where AC = $\overline{P}_s$ for each F and AC is less than MC) is relevant, and thus the annualized energy prices ($\overline{P}$) could be compared to fewer possibilities.

With increasing energy prices, the year of feasibility for each site and the fraction of solar energy feasible in that year is determined. The ratio of fixed cost to variable cost (collector dependent) determines the fraction where minimum cost is found. Generally, the larger the ratio of fixed cost to variable cost the greater will be the fraction where minimum cost occurs. This comes about because for any given site, fixed cost must be spread across the BTUs supplied by solar energy; i.e., the larger the fraction, the smaller will be the amount of fixed costs charged on a BTU basis. However, this runs up against the steadily increasing variable costs and at some point is overtaken by its effect.

IV. FEASIBILITY WITH DECONTROLS

Economists advocate energy price decontrol because this policy will -- abstracting from the possibility of monopoly behavior on the part of domestic producers -- result in the most efficient use of resources. Thus, higher energy prices would induce homeowners to conserve energy through reductions in use, through modification of existing residences (including retrofit of insulation and solar energy), and through construction of new energy conserving homes which might also use solar energy. The resulting geographic pattern of solar feasibility which we present in this section then represents the least cost or most efficient pattern of development as best we can determine. However, the increases in natural gas prices associated with decontrol are enormous and will cause hardships for individuals. The implied policy trade-off is one between efficiency and equity and is therefore difficult to make. In a later section, therefore, we analyze solar feasibility under the assumption of continued price controls.

It is worth noting that inflation has been removed from the analysis by specifying all costs and prices in real terms (1974 dollars). Therefore, real interest rates are used in the feasibility analysis. Because solar energy systems are capital intensive, a narrow range of 2.5 to 4.0 percent real rate of interest (typical of home mortgages) was chosen to test the sensitivity of results.

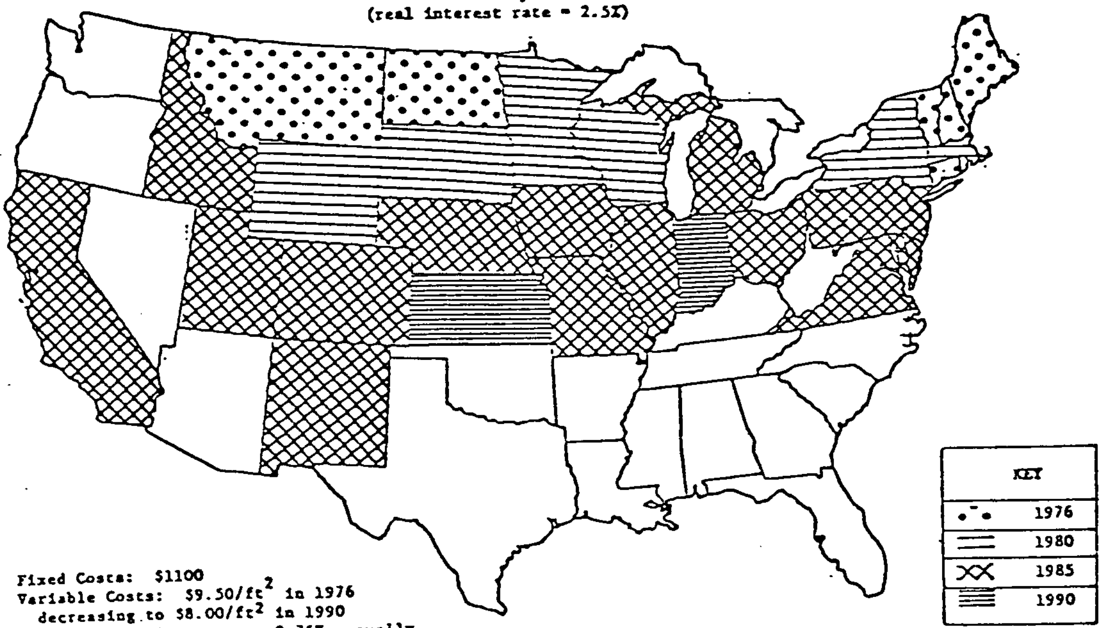
First, examine the results of the feasibility analysis for space heating of new homes with life cycle costing. Maps 2 and 3, representing the 2.5 and 4.0 real interest rates respectively, were constructed by assuming that costs per square foot of collector plus storage area decrease from $9.50 in 1976 to $8.00 in 1990. Comparisons were made at

Map 2

SOLAR FEASIBILITY - RESIDENTIAL SPACE HEATING

STANDARD AIR SYSTEM*

(real interest rate = 2.5%)



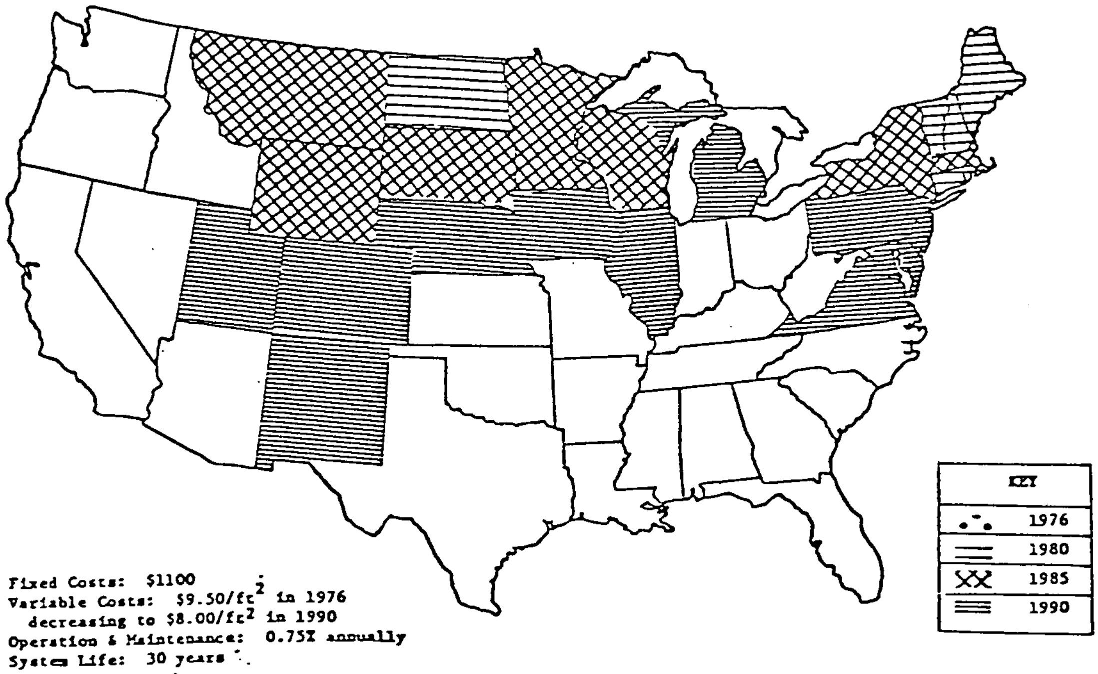
* Fixed Costs: $1100
Variable Costs: $9.50/ft^2 in 1976
decreasing to $8.00/ft^2 in 1990
Operation & Maintenance: 0.75% annually
System Life: 30 years.

Map 3

SOLAR FEASIBILITY - RESIDENTIAL SPACE HEATING

STANDARD AIR SYSTEM*

(real interest rate = 4.0%)



* Fixed Costs: $1100
Variable Costs: $9.50/ft^2 in 1976
decreasing to $8.00/ft^2 in 1990
Operation & Maintenance: 0.75% annually
System Life: 30 years.

five year intervals, thus the stepwise pattern. One interesting result which is not evident in the maps is the fact that in each succeeding year the design of the solar system for new homes is changed such that the fraction of solar supplied heat increases. For example, Maine which is feasible today at a 2.5 real interest rate with 45 percent of space heating requirements supplied by solar energy, increases to a solar fraction of 50 percent by 1985. Similarly, New Mexico is feasible with a solar fraction of 50 percent in 1982 increasing to 55 percent by 1985.

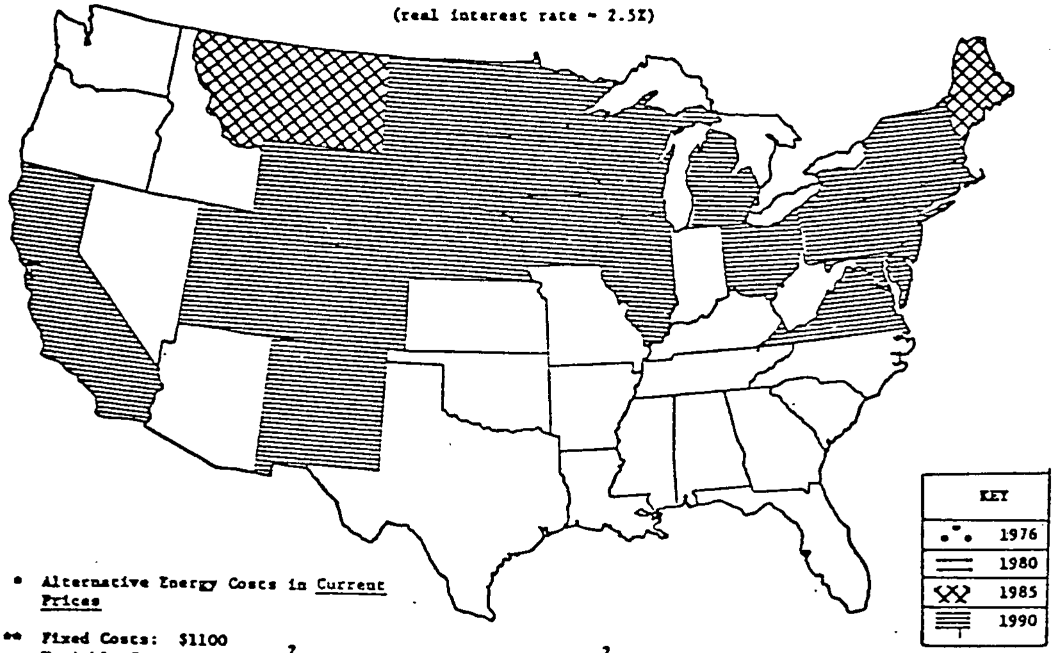
The most important result, however, is the clear picture which emerges. Solar feasibility begins in the northern tier of states and with very few exceptions, systematically moves southward! This pattern results primarily from the higher alternative energy prices and larger heating loads in the northern states.*

Current prices, those energy prices projected for each and every year to 1990, were examined vis-à-vis the annualized solar prices. Consumers many times see only the present, so their decisions may in fact be based solely upon today's costs and prices especially when energy pricing policies are uncertain. Therefore, the standard air system for residential space heating was compared to current period, decontrolled

---

*A few statements of caution when reviewing and interpreting the results are in order. First, the city selected as a representative site for each state may not be representative of climatic conditions everywhere within the state. Secondly, the energy price scenario was based upon an average or representative quote from each state. Third, from the previous cautionary statements it can be shown that the northern portion of California does demonstrate solar feasibility years ahead of its counter-part, the Los Angeles area. Thus, when New Mexico has demonstrated solar feasibility under the present scenario, it will hold true only for the northern part of the state. On the other hand, in Arizona where solar is portrayed as always more expensive than alternatives, in actuality, portions of Northern Arizona (Flagstaff) do become competitive at about the same time as Albuquerque, New Mexico.

Map 4
SOLAR FEASIBILITY - RESIDENTIAL SPACE HEATING
STANDARD AIR SYSTEM*
(real interest rate = 2.5%)



* Alternative Energy Costs in Current Prices

** Fixed Costs: $1100
Variable Costs: $9.50/ft^2 in 1976 decreasing to $8.00/ft^2 in 1990
Operation & Maintenance: 0.75% annually
System Life: 30 years

prices of energy. Map 4 portrays the feasibility results using the 2.5 percent real interest rate, demonstrating that even when such current energy prices are used solar energy will be economically competitive by 1990 for a number of states, but is delayed compared to life cycle analysis.

It is worth repeating the main thrust of the results obtained from the preceding analysis. For a solar energy system devoted to residential space heating only, economic feasibility begins in the northern tier of states and moves southward through time. There are several important reasons for this type of emerging pattern. First, under a decontrolled energy scenario, present fuels begin to increase at such a rate that consumers are provided with larger economic incentives to look elsewhere for space heating systems. The cost of natural gas delivered to each state has two components: the price at the wellhead plus the price adjustment for transportation and distribution. Thus, with most gas supplies located in the South Central and Southwestern states, prices generally increase as one moves into the Midwestern, North Central, Northeastern, and Northwestern states. Secondly, solar energy systems include a fixed cost component which gives rise to a situation in which minimum heating demands will be required to make solar energy competitive. Higher heating loads are evident as one moves northward, allowing the fixed costs to be spread over a larger BTU base. Third, exclusion of the Northwestern states is due primarily to the availability of large amounts of cheap hydroelectric power. Electrical heating replaces natural gas much sooner and because use of hydroelectric power keeps the price of electricity down, solar systems cannot compete. As demonstrated, it is in those states with high demands coupled with greatly increased prices of alternative fuels that solar energy feasibility for residential space heating occurs.

As expected, solar energy feasibility is highly influenced by the rate of interest introduced into the analysis. The higher the rate, the greater the annualized price of solar energy and the lower the annualized energy price generally, thereby forcing them apart. The opposite of course, is true for the lower rate. It should be stressed that a 2.5 percent real rate of interest corresponds to a 8.5 percent nominal interest rate with annual inflation at 6.0 percent.

With fixed costs always present in these types of solar systems, the fraction of residential space heating provided by solar energy will increase as they become a larger proportion of the total. This particular point has tremendous implications for potential solar feasibility in other than the residential space heating market. Apartments, commercial establishments and schools would appear to be even better candidates for solar systems because of the larger total thermal load. This allows the fixed cost of any system to be charged against a larger load, thereby reducing its annualized cost. More analysis is needed, however, before any solar feasibility pattern in this area can be established.

Next, we examine the results of the feasibility analysis for separate domestic hot water heating. Maps 5 and 6 representing the 2.5 and 4.0 real interest rates respectively were constructed by assuming that the cost per square foot of collector plus storage area is $11.00, and fixed costs are $300. As in the residential space heating analysis, comparisons were made at five year intervals. In this case the fraction of annual hot water demand supplied by the solar system fell in the range of 60 to 85 percent. With increasing alternative energy prices, this fraction will increase through time.

The pattern that emerges for solar domestic hot water feasibility is not as well defined as that exemplified by the north to south movement portrayed for residential space heating. Rather, there is a mixture of Southern and Eastern states demonstrating feasibility in the late 1970s and early 1980s. Generally, Midwestern, Mountain, and Northwestern states are excluded during this period of analysis (1976 to 1990); North Dakota, South Dakota, and Minnesota being the exceptions.

Major reasons for this type of pattern are based primarily upon three considerations. First, due to higher solar incidence in the Southern and Southwestern states, solar collector areas necessary to deliver a given fraction of domestic hot water demands* are measurably lower than elsewhere. This, of course, results in lower costs for the solar systems. Second, alternative heating costs in the Eastern states are considerably

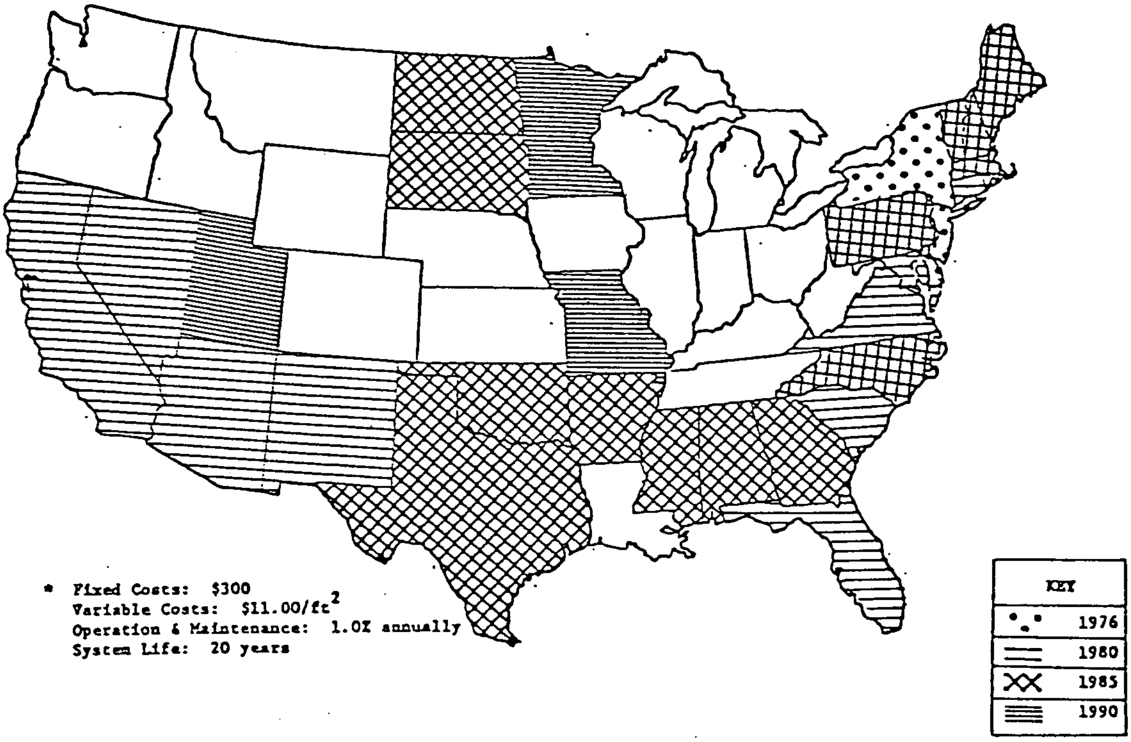
---

*A constant yearly requirement of 15 x 10^6 BTUs was assumed for all states.

Map 5

SOLAR FEASIBILITY - DOMESTIC HOT WATER*

(real interest rate = 2.5%)

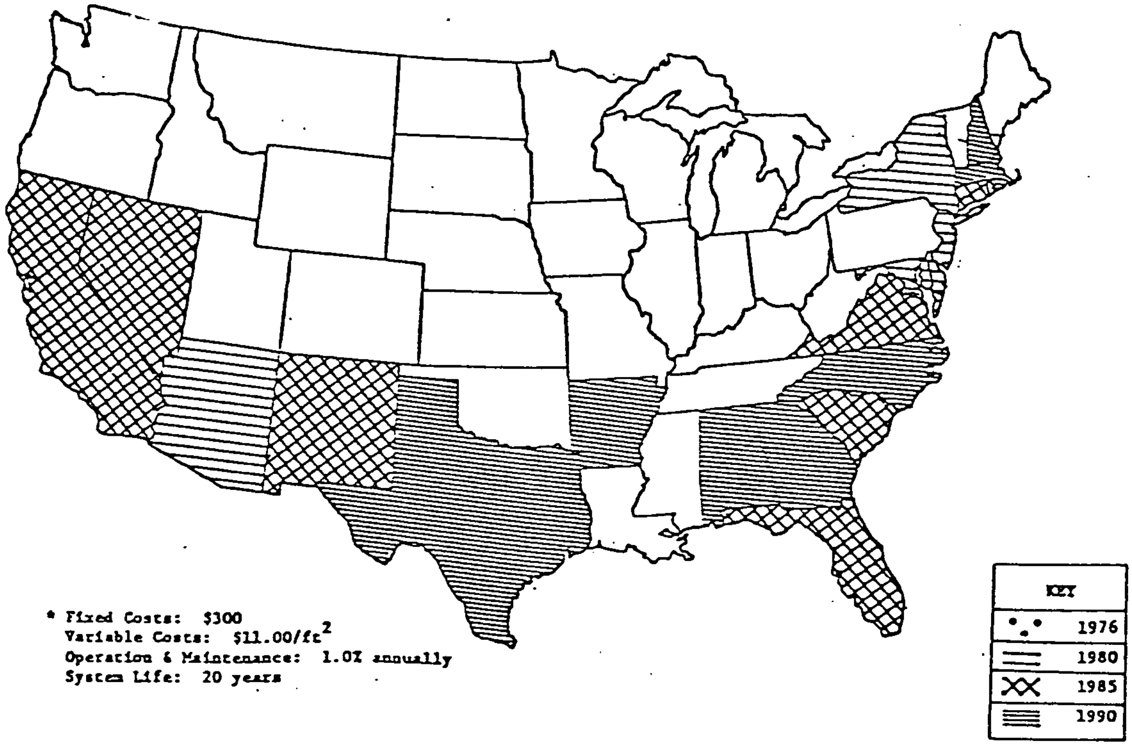


* Fixed Costs: $300
Variable Costs: $11.00/ft^2
Operation & Maintenance: 1.0% annually
System Life: 20 years

Map 6

SOLAR FEASIBILITY - DOMESTIC HOT WATER*

(real interest rate = 4.0%)



* Fixed Costs: $300
Variable Costs: $11.00/ft^2
Operation & Maintenance: 1.0% annually
System Life: 20 years

higher than in most of the remaining states. This makes solar energy competitive in the East Coast states even though larger collector areas are required and subsequently solar costs are greater than in many other states. Third, within the states where solar energy was shown not to be competitive by 1990,* the combination of higher solar costs due to relatively large collector arrays and alternative backup costs which are not significantly different than those found in the southern tier of states, forced solar feasibility into the 1990s. Further, relatively cheap electricity prices in the Northwestern states kept the alternative energy costs at levels sufficiently low to preclude solar systems during the period of analysis.

Again, current prices were examined vis-à-vis the annualized solar energy prices. Map 7 portrays the feasibility results using the 2.5 percent real interest rate, demonstrating that even when such current energy prices are used solar energy will be economically competitive by 1990 for a number of states, but is delayed compared to the life cycle analysis discussed above.

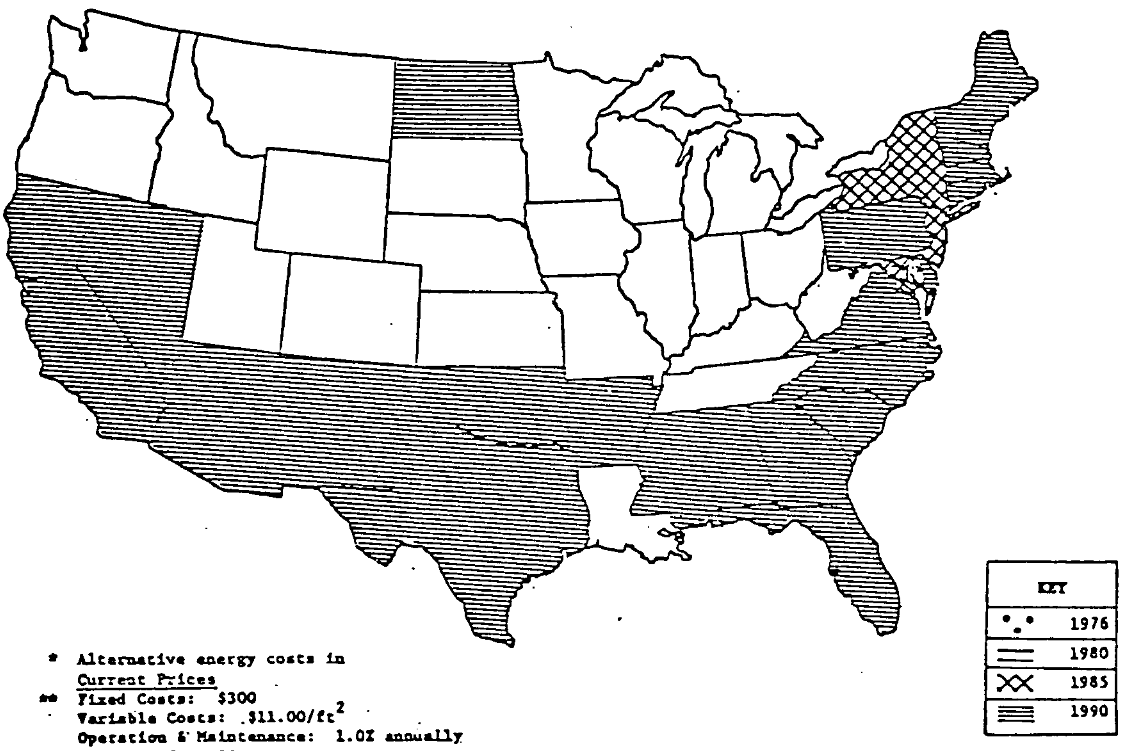
Arguments presented earlier for the solar residential space heating feasibility analysis concerning interest rates, fixed costs, and larger heating loads (such as apartments and motels) hold true for domestic hot water as well. As stated earlier, further analysis is needed to determine the effect of varying heating loads for solar systems designed to meet domestic hot water needs. For example, one would expect higher heating

*In North and South Dakota the representative sites selected are generally at higher altitudes than sites in surrounding states, thus smaller collector sizes are possible implying lower total systems costs for domestic hot water. Minnesota demonstrates solar competitiveness at the very end of our period of analysis, only slightly earlier than surrounding states.

Map 7

SOLAR FEASIBILITY* - DOMESTIC HOT WATER**

(real interest rate = 2.5%)



* Alternative energy costs in
Current Prices

** Fixed Costs: $300
Variable Costs: $11.00/ft^2
Operation & Maintenance: 1.0% annually
System Life: 20 years

loads for the same quantity of water when moving from Southern to Northern states.

Finally, for the integrated system, by calculating the price of solar energy for domestic hot water as an add-on to space heating and checking to make sure that it is less than the cost of providing the hot water by traditional energy sources (e.g., $\overline{P}_s \leq \overline{P}$), it was found to be feasible in all states where solar space heating is feasible. In only four states,* it was not economically desirable to install this type of integrated system in the first year of solar space heating feasibility.

---

*Montana, North Dakota, South Dakota, and Wyoming.

In each of these states, however, the integrated system was justified within a few years of space heating feasibility. Thus, for practical purposes, solar domestic hot water is feasible in conjunction with solar space heating whenever space heating is feasible.

Given that solar energy is widely feasible for some portion of residential space heating and domestic hot water demand and given better insulated structure potential, the realized energy savings can be fairly significant in many states. In the next section the potential energy savings in 1990 resulting from utilization of solar energy for domestic hot water and for space heating of residences will be examined.

V. ENERGY SAVINGS UNDER DECONTROL

The turnover in the nation's housing inventory will have a great impact upon potential energy savings brought about from both better insulated residences and the use of solar energy systems to meet a portion of residential space heating demands. The addition of more insulation and the retrofitting of solar energy systems to the existing housing stock could have far more potential impact on total energy demand than impacts from new construction. However, the proportion of the existing housing stock which can be retrofit for space heating is unknown at this time, although recent retrofits of several collector types look promising. Map 8 shows that by 1990 solar space heating and/or solar hot water heating will be feasible in all but six states. In this section potential energy savings in 1990 from new construction of single-family residences in the continental United States will be examined for space heating. The total single-family detached housing market will be examined for domestic hot water systems.

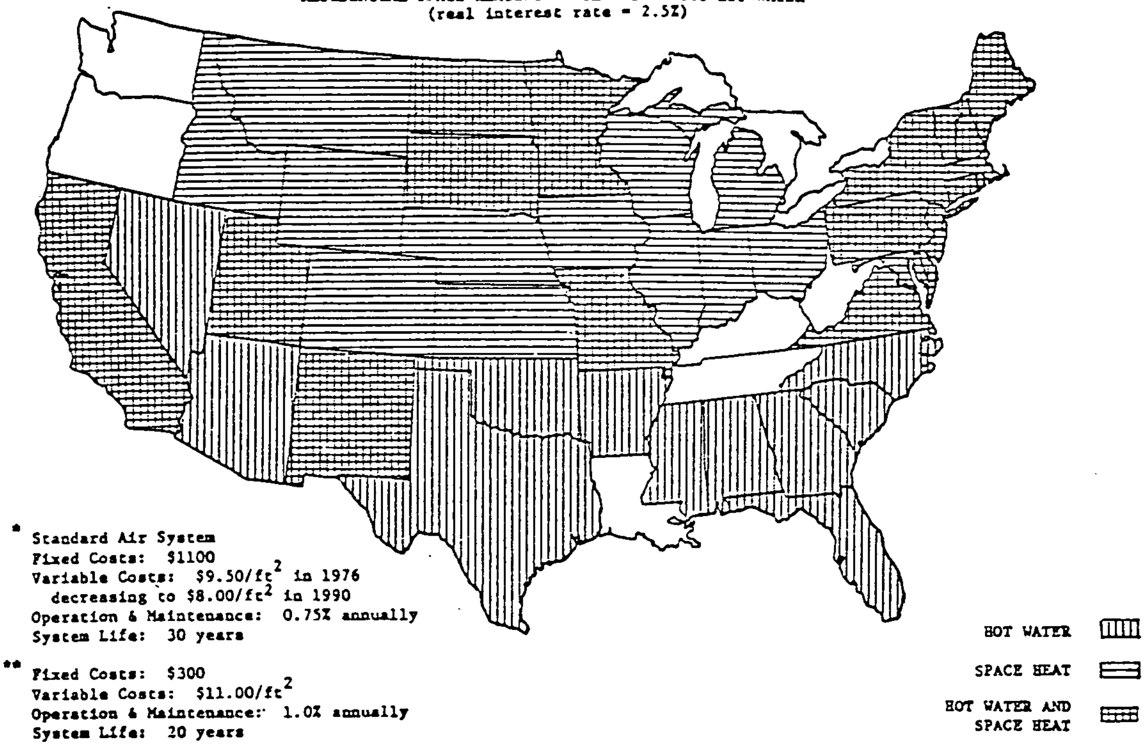
In previous discussion of solar feasibility, thermal load was assumed to be 10 $BTU/DD/Ft^2$. Prior to 1974, both standards and practices were such that higher thermal loads were characteristic. Although an average load across builders, types of mortgages, and regions of the country would be impossible to construct, a thermal load of 17 $BTU/DD/Ft^2$ is a reasonable estimate for the aggregate average in the late 1960s and early 1970s.

Assuming the same thermal load per structure is carried into the future, realized energy savings in 1990 from the better insulated residences built between 1976 and 1990 imply a 41 percent reduction in energy demand for space heating. Thus, with projected construction of single-

Map 8

1990 SOLAR FEASIBILITY

RESIDENTIAL SPACE HEATING* - OR - DOMESTIC HOT WATER**
(real interest rate = 2.5%)



family residences running between 0.9 and 1.7 million units annually,* in 1990 total projected energy consumption for space heating would be at a level 41 percent less than might have been expected had the homes been built to early 1970 standards. Assuming a midpoint housing production estimate (1.3 million units annually), and the average residence of the

*Some of the models and their respective forecasts reviewed are the Chase Econometrics model, the National Planning Association forecasts which utilize the Chase model, the Data Resources Incorporated (DRI) model, and the Wharton Forecasting Associates (WFA) model which utilizes an updated version of the original Wharton Econometrics model. The authors are extremely indebted to Wharton Forecasting Associates, Data Resources Incorporated, Chase Econometrics, National Planning Association, and individuals within several divisions at HUD for furnishing us with their forecasts.

past decade (17 BTU/DD/Ft^2 thermal load), space heating demand in 1990 for residences constructed between 1976 and 1990 will be 2.51 quads. Energy savings in 1990 due to improved insulation resulting in a 10 BTU/DD/Ft^2 thermal load house could be 1.04 quads. Table 4 summarizes both these and the following calculations.

Next, energy savings due to utilization of solar energy for space heating were calculated on the basis of the standard air system analysis. Since we believe that not all new construction will be able to fit solar space heating systems, energy savings were calculated for a range of 50 to 85 percent of new construction. If 85 percent of new, single-family houses fit solar space heating systems, the savings in 1990 will be 19.5 percent or 0.49 quads.

Finally, for space heating demand, the savings due to improved insulation and utilization of solar energy were calculated. In this case, as much as 52.9 percent of the space heating demand can be saved through proper insulation and use of solar energy.

Energy demand for a separate domestic hot water system was analyzed under the previously discussed assumption of a constant load of 15 x 10^6 BTUs/household/year. In this case, it was assumed that all new construction of single-family residences from the first year of feasibility in each of the forty-eight states would incorporate solar energy to meet some portion of the energy demand for hot water. Further, the demand was analyzed at 2.5 and 4.0 percent real rate of interest and potential retrofit applications were considered under a variety of additional assumptions.

The potential retrofit market for solar domestic hot water systems has been estimated to be between 50 and 85 percent of the existing stock

TABLE 4

1990 ENERGY SAVINGS (Quads)

(Single Family, Detached Housing: 2.5% Real Interest Rate)

	WATER HEATING (All Residences)		SPACE HEATING (Cumulative New Construction 1976-1990)				
				Solar		Solar & Insulation	
	85% fit	50% fit	Insulation	85% fit	50% fit	85% fit	50% fit
TOTAL 1990 DEMAND	.983	.983	2.51	2.51	2.51	2.51	2.51
SAVINGS	-.403	-.242	-1.04	- .49	- .29	-1.33	-1.21
NET DEMAND	.580	.741	1.47	2.02	2.22	1.18	1.30
PERCENT REDUCTION IN TOTAL DEMAND	40.9	24.6	41.4	19.5	11.5	52.9	48.2
PERCENT OF 1990 NATIONAL FOSSIL FUEL DEMAND	0.4	0.3	1.1	0.5	0.3	1.5	1.3

of single-family detached residential units. Obstructions which cause shading and the orientation of the structure on the lot are the primary factors preventing a 100 percent retrofit market. Therefore, energy demand for hot water was analyzed for a potential retrofit market of 50 to 85 percent of the stock existing in each state in the first year of solar feasibility. The time at which a solar energy system is retrofit is also important in calculating the energy savings which might be expected. The most optimistic assumption is that all retrofits will be performed in the first year that solar hot water is feasible in each state.

Using the midpoint estimate of new housing, for the 2.5 percent real interest rate case it was found that in 1990 energy savings due to utilization of solar energy will be as much as 24.6 percent (50 percent fit) and 40.9 percent (85 percent fit) of total energy demanded for domestic water heating.

As indicated in figure 2, the total national fossil fuel demand in 1990 is projected to be 90.6 quads. The percent of this total national demand represented by the energy savings from the utilization of solar energy and improved insulation are indicated in Table 4. Although the percentages appear small at first glance, the economic impact of the industry should not be underestimated. For example, the energy savings due to solar domestic hot water at 85 percent fit (.403 quads) represents 69,482,759 barrels of oil saved for the one year. The savings resulting from solar space heating and proper insulation at 85 percent fit (1.33 quads) represents a savings of 229,310,345 barrels of oil in one year. However, it should be made clear that these are upper bound estimates for the role of solar energy in domestic uses, excluding retrofit of space heating.

VI. THE CURRENT SITUATION -- FEASIBILITY WITH CURTAILMENTS AND PRICE CONTROLS

Thus far we have examined the feasibility of solar water and space heating under the idealistic assumption that natural gas will be deregulated. In the event that price controls are continued, homeowners will need to examine the feasibility of solar energy systems against electricity -- either heat pumps or resistance heat. In this section we examine the more realistic situation of continued control of natural gas prices and the inevitable curtailments in supply which will result. This analysis is also applicable to retrofits of solar space heating systems for homes that do not presently use natural gas so we consider retrofit in this section as well. Finally, we compare our assumptions on costs of solar installation to current experience.

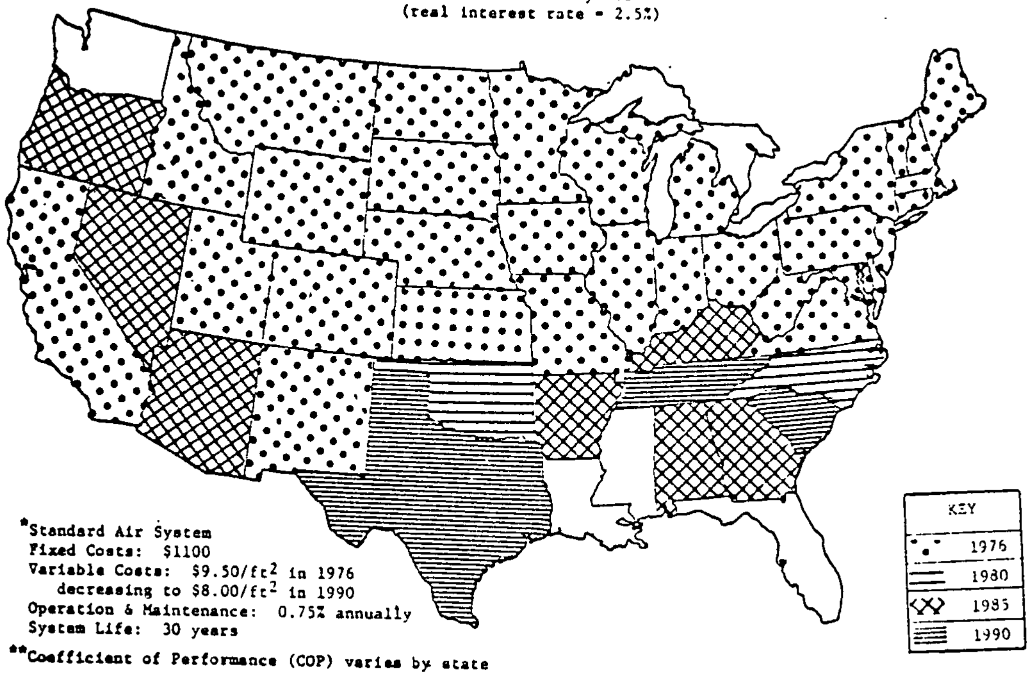
Feasibility With Price Controls

Again using the LASL standard air system for residential space heating, we examined a scenario of non-availability of natural gas for home use. As in our previous analysis variable costs are assumed to be $9.50/ft^2 of collector area in 1976 decreasing to $8.00/ft^2 in 1990. Annual operation and maintenance expenditures are 0.75 percent of the installed system cost, and the solar system has an expected life of thirty years. Again, we have assumed a standard single-family residence of 1500 square feet with a building thermal load of 10 BTU/DD/ft^2.

If we assume that natural gas becomes unavailable for home use either through curtailments or moratoriums on new hookups as has already occurred periodically throughout the country, solar energy becomes feasible very quickly. In Maps 9 and 10 the coefficient of performance (COP) of

Map 9

SOLAR FEASIBILITY
SOLAR RESIDENTIAL SPACE HEAT* - vs. - ELECTRIC HEAT PUMPS**
Annualized for 30 years
(real interest rate = 2.5%)

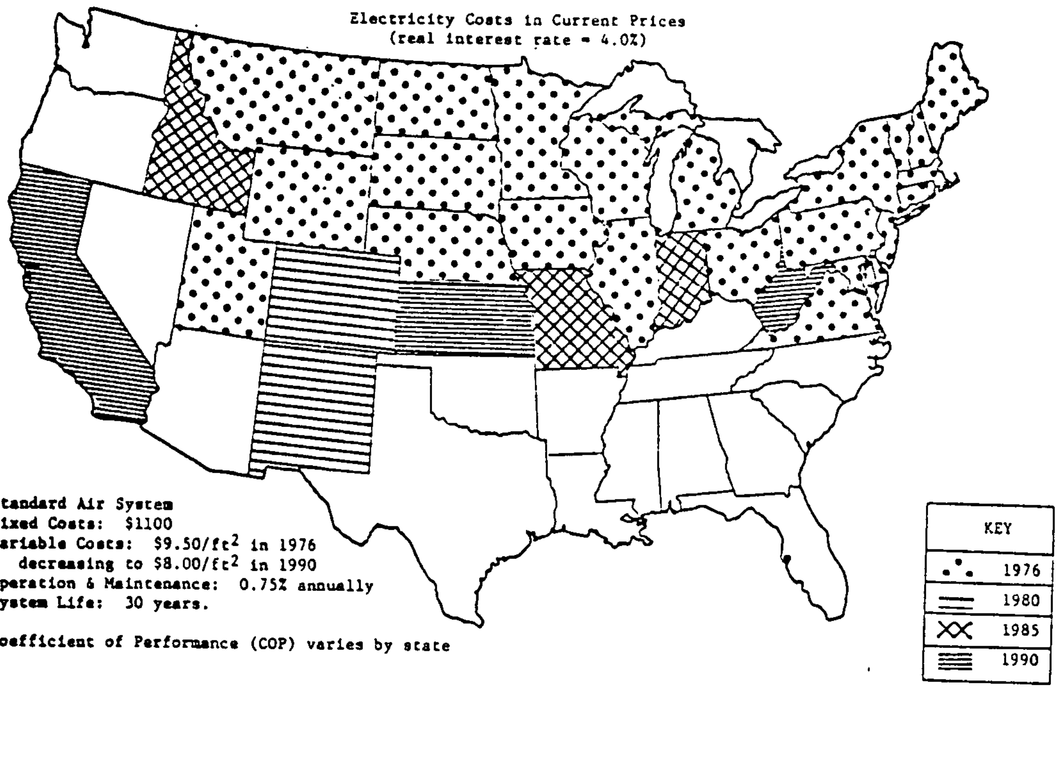


*Standard Air System
Fixed Costs: $1100
Variable Costs: $9.50/ft^2 in 1976
decreasing to $8.00/ft^2 in 1990
Operation & Maintenance: 0.75% annually
System Life: 30 years

**Coefficient of Performance (COP) varies by state

Map 10

SOLAR FEASIBILITY
SOLAR RESIDENTIAL SPACE HEAT* - vs. - ELECTRIC HEAT PUMPS**
Electricity Costs in Current Prices
(real interest rate = 4.0%)



*Standard Air System
Fixed Costs: $1100
Variable Costs: $9.50/ft^2 in 1976
decreasing to $8.00/ft^2 in 1990
Operation & Maintenance: 0.75% annually
System Life: 30 years.

**Coefficient of Performance (COP) varies by state heat pumps was varied by states based upon the degree days for each location and, therefore, on performance attainable today rather than projected performance.* In Map 9, representing the most optimistic case examined here, a solar space heating system with $1100 fixed cost (as in Section IV) was compared to life cycle electricity prices at 2.5 percent real interest rate. Under these assumptions and with a backup system employing electric heat pumps, two-thirds of the continental United States is already feasible for solar space heating. All but four states demonstrate feasibility by 1990.

Map 10 again depicts feasibility results under the assumption of $1100 fixed costs but employs current electric heat pump prices for comparison. We found that when solar energy is compared to current heat pump electricity prices at 4.0 percent real rate of interest solar energy for residential space heating is already feasible in twenty-four states and will soon be feasible in several more. The higher interest rate as well as current rather than life cycle costs delays feasibility beyond the period of analysis in only a few states. Again, in both cases depicted in Maps 9 and 10, it is the northern tier of states, including almost all states which experienced energy emergencies during the winter of 1976-1977 where solar energy is already feasible.

In Map 11 we represent available retrofit system costs with fixed costs of $3400 and variable costs of $9.50/ft^2 in 1976 decreasing to $8.00/ft^2 by 1990. The higher fixed costs cover the necessary individualized

---

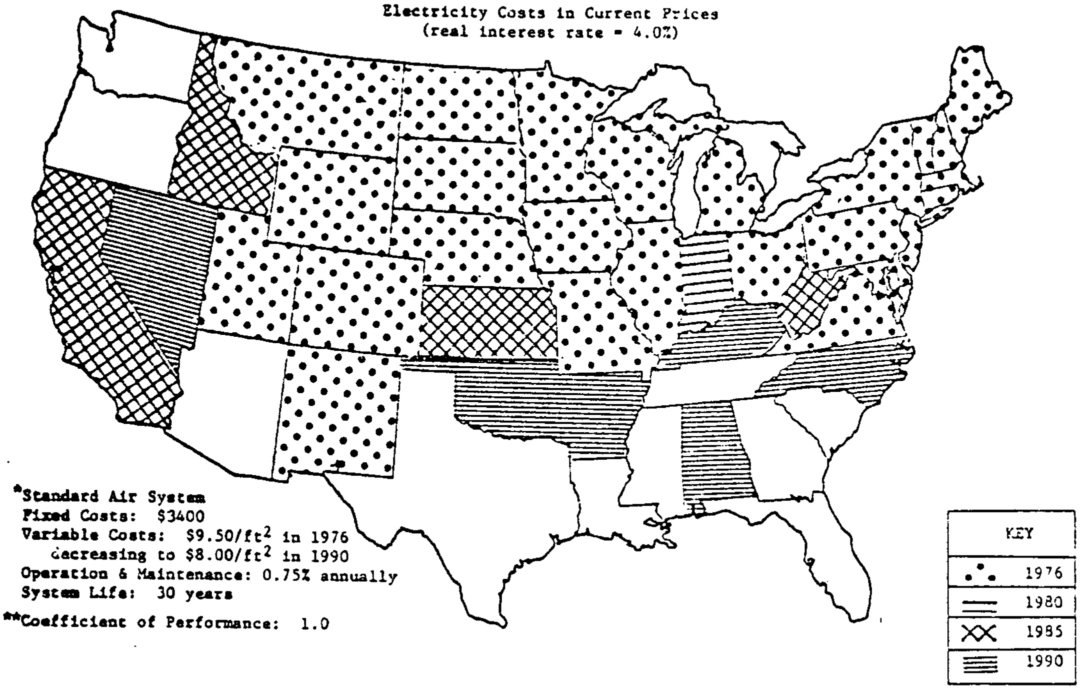
* $COP = 2.276 - \frac{\text{Heating degree days}}{1000} * .1168$. This formula was derived from current heat pump data over seven cities and provides a good approximation of heat pump performance which deterioates in colder climates.

Map 11

SOLAR FEASIBILITY

SOLAR RESIDENTIAL SPACE HEAT* - vs. - ELECTRIC RESISTENCE HEAT**

Electricity Costs in Current Prices
(real interest rate = 4.0%)



engineering, design, and installation costs for retrofit systems. Here we assume the back-up system to be electric resistance with a COP of 1.0. This comparison was made because many homes in states currently suffering curtailments of natural gas already use electric resistance heat. Also, when compared to either form of electric heat solar energy becomes feasible at much larger fractions* of space heat provided, which makes electric heat pumps a rather expensive backup system.

When compared to electric resistance heat, even using current prices and the higher 4.0 percent real interest rate, we find that a

*Solar energy becomes feasible for residential space heat at solar fractions of 65 - 90 percent when compared to electricity for back-up systems.

total of thirty-eight states attain feasibility by 1990 with twenty-seven of these states already feasible for this system. Furthermore, the solar system is feasible for approximately 70 percent of the heating load in most of the states demonstrating feasibility within the period of anaylsis. This is in strong contrast to the 35 to 50 percent solar fractions feasible in our idealized case of natural gas backup systems and decontrolled prices.

Finally, the feasibility of solar domestic hot water systems with curtailments of natural gas was examined for the least optimistic case -- current electricity prices at 4.0 percent real interest rate. We assumed the back-up system to be electric resistance with a COP of 1.0. As in our previous analysis we assumed fixed costs of $300, a variable cost component of $\$11.00/ft^2$, annual operations and maintenance expenditures of 1.0 percent of the installed system cost, and a system life of twenty years. With these assumptions, solar domestic hot water systems are already feasible throughout the continental United States with 75 to 90 percent of the heat load supplied by the solar system. The only exception to this is the state of Washington which does not demonstrate feasibility until 1983 due to the availability of cheap hydro electricity in the state. No further hot water system analysis is presented here since it is obvious that wherever natural gas is not available, solar domestic hot water systems are immediately feasible.

Retrofit of Space Heating*

It is generally accepted that, since collector areas are very large, retrofitting solar space heating is likely to be infeasible in all but a few cases. This assumption -- that development of a successful

*We would like to thank Jake Gaultney for his assistance in preparing this section.

solar space heating retrofit market is unlikely -- deserves more investigation, especially since retrofit appears widely feasible in our analysis even with high fixed costs. The potential energy savings of retrofit space heating are considerably greater than those shown previously for new construction.

The standard objections to widespread retrofit of solar space heating to residences and small buildings include:

1) Collector areas are sufficiently large that rooftop installations are difficult unless the house is accidently oriented in the proper direction.

2) Large collector areas are likely to be at least partly shaded by neighboring trees, shubbery, or structures.

3) Costs of installation are likely to be much higher than for newly constructed homes.

4) Since older homes are generally poorly insulated, heating loads are large, necessitating a large and expensive (in terms of total cost) solar installation.

5) Financing retrofit solar installations may be difficult compared to financing a solar system on a new home.

The authors are most familiar with the solar heating industry in one region of the U.S., the Southwest, where some of these "problems" have surprisingly failed to develop. For example, in New Mexico where solar energy is currently feasible in some applications (e.g., vs. bottled gas or electricity), a vigorous young industry has formed which, in fact, is having difficulty keeping up with the growth in demand for solar space, swimming pool, and water heating installations. This spurt in growth began during the summer of 1976 having been encouraged both by a state tax break for solar installations and by the recent Federal Power Commission ruling in favor of an increase in the price of natural gas. New Mexico is also unique, in that by having most favored nation clauses for its own gas producers, the full impact of this increase was faced immediately by consumers. The increased prices have actually exceeded our projections for decontrolled natural gas prices.

In contrast to most expectations for this new market, several firms are currently installing about 90 percent of active solar space heating applications as retrofits and are encountering comparative market resistance for new home installations. The reasons for this current situation can be contrasted to the list of problems noted above.

First, at least in the Southwest, many homes have flat roofs which allow easy installation of either tracking parabolic troughs or flat plate collectors tilted in banks facing south. Additionally, a number of systems, especially of the focusing trough type, have been placed at ground level.

Second, in the Southwest many homes have substantial surrounding yard area. Clearly, if individuals desire solar heating, removal of their own shading obstructions is likely to be less difficult than convincing a neighbor to remove an obstruction. Utton and Eisenstadt* have pointed out that solar rights can be purchased through easements, so theoretically a legal mechanism exists to allow monetary

---

*A.L. Utton and M. Eisenstadt, "Solar Rights and Their Effect on Solar Heating and Cooling," The University of New Mexico, Bureau of Engineering Research, Technical Report No. ME-66 (75)ERB-360-1, November 1975.

compensation -- although additional costs will certainly delay solar feasibility.*

Third, several systems, including a large trough type system and a small modular flat plate unit, have no cost differential between new or retrofit installations as they are currently sold. At least one solar water and space heating system is currently being installed for a total cost of $18 per square foot in retrofit or new installations. For comparison, our total costs for space heating used in the feasibility study as shown below, when adjusted from 1974 to current (1977) dollars, are about $15.00 per square foot, not far from the $18 per square foot now attainable for retrofit installations. Retrofit systems will retain some fixed cost penalty for specialized, site specific design and engineering requirements compared to new tract homes. However, older homes are often difficult to retrofit insulation to meet new home standards so heating loads will be higher. This brings us to the next point.

Fourth, one factor not developed in our preceding analysis of space heating for new construction is that although high heating loads imply large, expensive systems, the cost per BTU delivered by a solar system decreases with the size of the system. Although our analysis for new homes assumed a well insulated, cost effective house for solar installations, the smaller heating loads penalized solar energy in terms of comparative costs per BTU. The large fixed cost of installation assures that the total cost per square foot decreases with system size. Thus, poorly insulated older homes with flat roofs and large glass areas (the cardboard castles associated with cheap energy supplies), are hard to

*As part of our ongoing research we are planning to test a survey questionnaire methodology to estimate the cost of obtaining such easements.

retrofit with insulation but are ideal candidates for retrofitting solar space heat. In fact, the cost per BTU will be lower than for a new installation with the ideal mix of thermal insulation and solar energy.

Finally, and this is perhaps the most unexpected point of all, financial institutions are reluctant to lend money for solar systems to new home buyers for the simple reason that they do not wish to assume the risk of financing a large expenditure which may not add to the market value of the house.* On the other hand, owners of homes who have built up some equity can either take out a second mortgage or refinance their home -- now often at lower interest rates -- to finance the cost of a retrofit solar installation. The last point is critical in understanding current institutional barriers to solar energy. For the present at least, retrofits are institutionally made more likely than new home applications for solar heating.

Retrofits of space heating are now more feasible than new home installations in the Southwest for both economic and institutional reasons and -- unless financial barriers are removed -- the situation is unlikely to change. One suggestion to solve the problem of financial barriers is to federally insure loans for solar equipment thus reducing apparent risk to lending institutions while costing government little compared with other programs to stimulate solar energy.

---

*A few lending institutions have made partial loans to preferred customers.

Comparative Costs

How do our assumptions on the cost of solar installations compare to actual solar systems available today? To answer this question we need to do two things. First, to avoid incorporating inflation in our analysis, we used constant 1974 dollars. Since mid 1974 the consumer price index has risen about 23 percent. Thus, to obtain current (1977) dollars we must raise our assumed costs by this amount. The assumed total cost now becomes: for new home space heating installations -- $1350 fixed cost plus $11.70 per square foot of collector area; for retrofit of space heat -- $4200 plus $11.70 per square foot; and for domestic hot water -- $370 plus $13.50 per square foot. The second adjustment for making comparisons is to calculate the total cost per square foot including fixed costs. Although in fact fixed and variable costs are separate, it is more common to look at total costs per square foot in making cost comparisons. To do this, however, we need to specify system size since our assumed total cost per square foot will decline with system size in square feet (ft^2). Taking typical percentages of heat supplied from our previous analysis the average system size for a new home installation is about 350 ft^2; for retrofit of space heat about 725 ft^2; and for domestic hot water about 50 ft^2. Total costs per square foot of installed system are then about $15.50 for space heating of new homes, $17.50 for retrofit of space heat, and $21.00 for hot water.

A recent survey by The MITRE Corporation found average costs for all types of systems across the U.S. to be about $28.00 per square foot total cost, installed.* The most inexpensive space and water heating

*Personal Communication with Marty Scholl, MITRE Corporation.

system of which we are aware sells for about $18 per square foot in large retrofit home installations, not far from the $17.50 assumed in our analysis, and close to the $15.50 assumed for new home installations. Costs are dropping rapidly as firms become experienced in design and installation. One indication of this trend is a drop in costs of swimming pool collectors from $10 to $5 per square foot in Albuquerque over the last year as these units changed from specialty items to become commonplace. The same phenomenon appears to be occuring now for space and domestic hot water installations.

VII. POLICY ISSUES

Evaluation of the policy issues relevant to solar energy development must be viewed with respect to the entire national energy policy, particularly the question of decontrol of natural gas and other energy prices. Even with decontrol of traditional energy sources, solar energy will not be competitive unless positive action is taken to remove the financial and institutional constraints on its efficient use. The incentives which were instrumental in the development of the fossil fuel industry are noticeably lacking in solar energy development. What is needed now is a federally coordinated program to facilitate the transition from non-renewable to renewable energy sources. The remainder of this paper presents a brief overview of a few economic incentives and disincentives to solar energy development which have not been examined by the many other solar energy research efforts.*

Financing Solar Energy

For all practical purposes the cost of solar energy is the cost of the associated capital. For life cycle cost analysis, one must compare the annualized capital cost of a solar energy system with the alternative annual fuel costs on a life cycle basis. If the annual capital payment for the solar system is less than the annualized yearly life-cycle costs for a traditional energy source then the solar energy system is economically competitive. In the case of residential space heating the annual capital costs of the solar system actually represent the monthly payments over a

*Many of the national policy issues we believe important, areas such as consumer protection, a solar energy information data bank and utility rate structures, to list only a few, are examined in other papers submitted to the Joint Economic Committee.

year for the money borrowed to finance the solar heating system. Unfortunately, given the way our financial institutions function it is nearly impossible for homeowners to compare fuel cost savings with either the additional mortgage payment which would be associated with adding solar heating to homes, or the annual cost of the money one might borrow to retrofit such a system to a residence. The reason for this is that inflation distorts the pattern of yearly payments over time.

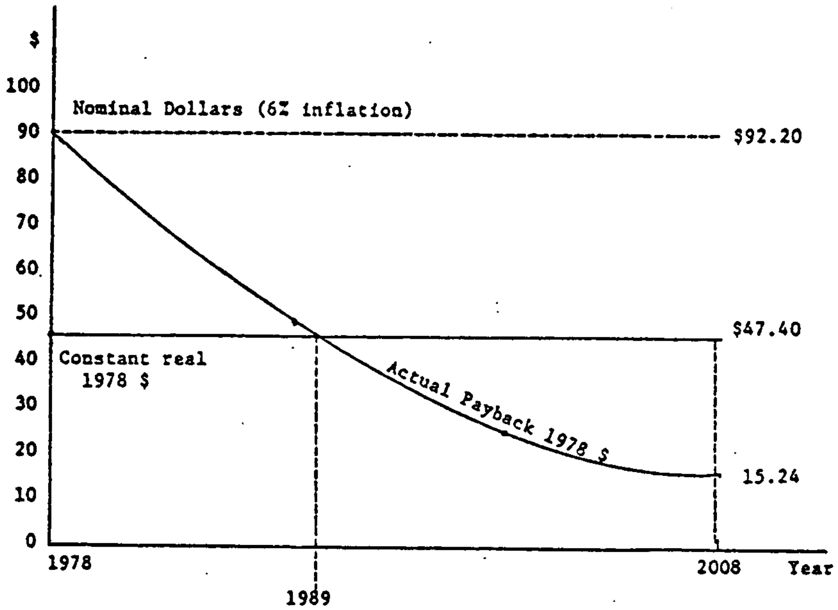
As has been mentioned in previous sections, this distortion centers on the difference between the real interest rate and the nominal interest rate. For example, if the inflation rate is 6 percent and the real interest rate is 2.5 percent then the effective nominal interest rate is 8.5 percent. Given an 8.5 percent nominal interest rate, if an individual borrows $1,000 on a thirty year loan, the yearly payment would be $92.20. On the other hand, if there were no inflation and the corresponding real interest rate of 2.5 percent were used, the yearly payment for $1,000 would be $47.40. Thus, in the case with no inflation, the first year of the loan the homeowner would pay $47.40 in real purchasing power. In the thirtieth year of the loan he or she would also pay $47.40 in real purchasing power to pay off the loan. This is in great contrast to the case where we assume a 6 percent rate of inflation (8.5 percent nominal interest rate), and the first yearly payment is $92.20. If we account for the fact that inflation is occuring at 6 percent and we value the annual payment in the thirtieth year in the base year dollars, the last year's payment is worth only $15.24 in base year purchasing power.

What this implies is that where payments are defined in constant nominal dollars, inflation tilts the pattern of payments over time. This situation is shown graphically in figure 12. For all intents and purposes,

FIGURE 12

FINANCING SOLAR ENERGY

Yearly Payment on $1000 Loan for 30 Years - 2.5% Real Interest



with a 6 percent inflation rate the first year's payment is over $90.00 while the last year's payment on a thirty year loan drops to a little over $15.00. Obviously then, to compare $92.20 per year for solar energy to an equivalent annualized fuel cost is entirely improper, because in terms of constant real dollars the annual payment is only $47.40. Thus, where payments are defined in nominal rather than in real dollars on mortgage loans which include solar applications, payments actually are biased towards the early years of the loan period. This makes it impossible for the average homeowner to compare the first payment on a solar system with expected annualized energy costs over time for the home.

One of several solutions which have been suggested for this problem is the Graduated Mortgage. This proposal is defined in nominal dollars allowing lower monthly payments in the beginning of the mortgage, rising at a predetermined rate over time. Clearly, this plan which is currently under investigation by the Federal Home Loan Bank Board would help alleviate the problem outlined above and give consumers a better opportunity to evaluate their real energy alternatives in housing design and construction. We strongly recommend that special legislation be enacted to provide financing for solar energy along the lines indicated in the Graduated Mortgage plan which could also provide the necessary loan guarantee to reduce the reluctance of financial institutions to make loans for solar energy.

Economic Incentives

State legislatures have been very active in promoting the use of solar energy. At the state level these well intentioned incentives have been justifiable since the states cannot make national policy. We suggest, however, that this piecemeal fashion of promoting solar energy cannot have the desired impact. The federal government must take the initiative in co-ordinating a national effort which considers the optimal solar policy in relation to the continuation or elimination of controls on natural gas and other energy prices and also considers interest rate policy and capital availability.

One important question is whether governments -- federal, state or local -- should exempt residential solar installations from property taxation or subsidize the development of solar energy through income tax credits? Recently, many states have decided to do just that. At least a dozen states have opted to encourage the installation of solar units through property tax incentives, in most cases exempting all or part of the solar equipment. These efforts are noteworthy under the current situation, but we believe a broader perspective must be taken. Major steps have been taken toward removing subsidies and internalizing pollution costs in extractive industries. Further steps in this direction are not very likely. Therefore, a subsidy for solar installations can be justified to offset the remaining subsidies to extractive industries and to reflect the external economies of solar installations, such as reduced dependence on risky oil sources, new technology demonstration, and market development.

Although we would advocate energy price decontrol, it may be politically infeasible unless the regressive income effects in instituting such a program can be corrected. If this is the case, an alternative set of policies must be developed to achieve economic efficiency in the relationship between energy conserving capital stocks and energy prices. Thus, if the price of traditional energy sources such as oil and gas are not allowed to rise over time as domestic exhaustion approaches, another strategy must be found to make competing energy sources such as solar energy and increased conservation of energy economically competitive. Exemptions from sales, property, and income taxes for solar investments are not sufficient, however, to make up the difference between controlled energy prices and decontrolled prices. As a viable alternative for the subsidization of solar energy we propose that low interest rate loans be made available until such time as other energy prices are fully decontrolled.

A simple example will illustrate that low interest loans are capable of subsidizing solar energy to an extent sufficient to compensate for the lack of price decontrols. Consider a hypothetical case of residential space heating where, under our decontrolled price scenario, the price of natural gas for space heating rises to $5.00/million BTUs delivered in 1984. Assume also that solar space heating becomes competitive with the backup costs of heating with natural gas at a real interest rate of 2.5 percent. Now assume instead, that under a policy of continued price controls the price of natural gas in 1984 has only risen to $3.50 or about 70 percent of the decontrolled price. At this price, solar energy can be made competitive by reducing the interest rate, and thus the annual payments, on the hypothetical loan financing the solar energy system. The real interest rate that reduces the annual payments on a solar energy system by 30 percent, so that the price is reduced to competitiveness with natural gas, happens to be 0.0 percent. In other words, the price of solar energy is reduced from $5.00/million BTUs at a 2.5 percent real interest rate to $3.50/million BTUs at a 0.0 percent real interest rate. This implies that if the nominal interest rate is equal to the expected rate of inflation rather than equal to the expected rate of inflation plus 2.5 percent, solar energy will be competitive with controlled natural gas in 1984. Further, if the price of natural gas were controlled at less than 70 percent of the decontrolled price, a negative real rate of interest could be used to achieve economic feasibility for solar energy*

It is clear that interest rate manipulation is the most powerful tool

---

*Negative real rates of interest can be achieved by setting the nominal rate of interest below the expected rate of inflation.

for achieving economic feasibility under continued price control of other energy sources. Low interest rate loans would also encourage other important energy conserving technologies such as increased home insulation. Thus, we strongly recommend that a federal program of low interest rate loans be developed to finance all energy conserving alternatives until such time as energy prices are fully decontrolled. We emphasize that this policy will further distort the market with respect to yet other energy conserving alternatives. The best policy remains total decontrol of energy prices with taxes on windfall profits of energy producers and correction of the regressive impact on low income groups.

Conclusion

The results of this study show that residential use of solar energy is feasible and could become widespread by 1990 with energy price decontrols or in areas which suffer natural gas curtailment. Further, the penetration of solar technologies beyond areas which are most favorable, either because of high alternative energy prices or incidence of solar radiation, depends on interest rate policy. The range of real home mortgage interest rates has been 2.5 to 4.0 percent over the last twenty-five years and as we have shown, solar feasibility is significantly affected in this range. This occurs because of all energy sources, solar energy is the most sensitive to the availability of capital. For other sources of energy there are both fuel and capital costs associated with delivering useful energy. In the case of solar energy there are, in effect, no fuel costs. Therefore, nearly all of the costs of providing solar energy are capital costs. As a result, the feasibility of solar energy can be determined almost solely by interest rates. In other words, if either the cost of capital or the rate of interest doubles, the cost of solar energy nearly doubles. If, solar energy is to play a major role in solving our energy problems, interest rates as well as price decontrol policies will be critical.

Although we advocate decontrol of energy prices on grounds of economic efficiency, we are also aware that such a policy has severe regressive effects on low income groups. An alternative strategy to price decontrol is to make low interest rate loans available for energy conservation. In any case, loan guarantees for new energy conserving technologies are needed to reduce apparent risk for conservative financial institutions.

Energy Prices* for Residential Space Heating and Domestic Hot Water

($\$/10^6$ BTU in 1974 Dollars)

State	Current Prices				Annualized Prices**					
	1976		1990		1976		1990		Solar Heating	
	Space	Hot Water	Space	Hot Water	Space	Hot Water	Space	Hot Water	Space	Hot Water
Alabama	1.41	1.76	6.08	6.08	4.44	4.12	6.94	6.77	8.72	5.71
Arizona	1.86	2.33	6.86	6.86	5.04	4.76	7.72	7.55	9.41	4.77
Arkansas	1.36	1.69	6.10	6.10	4.41	4.09	6.95	6.79	9.21	5.74
California	2.02	2.53	6.32	6.32	4.48	4.70	7.17	7.01	6.82	5.12
Colorado	1.48	1.84	5.35	5.35	4.13	3.91	6.21	6.04	5.48	6.36
Connecticut	3.36	4.19	8.09	8.09	6.41	6.41	8.95	8.78	6.06	7.15
Delaware	2.74	3.43	8.28	8.82	6.38	6.13	9.66	9.51	8.28	5.93
Florida	1.96	2.44	6.43	6.43	4.89	4.69	7.29	7.12	34.99	5.37
Georgia	1.84	2.29	5.86	5.86	4.56	4.38	6.72	6.55	8.72	5.71
Idaho	2.62	3.28	4.88	4.88	4.40	4.36	5.74	5.57	5.81	6.25
Illinois	2.08	2.59	6.17	6.17	4.83	4.68	7.03	6.86	6.72	7.23
Indiana	1.84	2.29	5.75	5.75	4.50	4.34	6.61	6.44	6.88	7.08
Iowa	1.72	2.14	6.09	6.09	4.60	4.38	6.95	6.78	6.31	6.96
Kansas	1.53	1.91	5.24	5.24	4.10	3.90	6.10	5.93	6.77	6.79
Kentucky	1.48	1.84	5.24	5.24	4.07	3.86	6.10	5.93	8.26	6.29
Louisiana	1.36	1.69	5.39	5.39	4.08	3.83	6.25	6.08	11.78	6.06
Maine	3.36	4.19	6.94	6.94	5.86	5.92	7.80	7.63	5.20	6.74
Maryland	2.74	3.43	7.54	7.54	5.83	5.72	8.40	8.23	7.60	5.76
Massachusetts	3.36	4.19	8.09	8.09	6.41	6.41	8.95	8.78	6.88	7.32
Michigan	2.33	2.91	6.05	6.05	4.90	4.82	6.91	6.74	6.21	7.44
Minnesota	2.02	2.53	6.11	6.11	4.77	4.62	6.97	6.80	5.22	6.64
Mississippi	1.36	1.69	6.08	6.08	4.41	4.08	6.94	6.77	10.60	6.06
Missouri	1.72	2.14	6.04	6.04	4.58	4.36	6.90	6.73	6.85	6.59
Montana	2.74	3.43	5.37	5.37	4.74	4.72	6.23	6.06	4.73	6.34
Nebraska	1.66	2.08	5.36	5.36	4.22	4.05	6.22	6.05	5.69	6.37
Nevada	1.72	2.14	5.56	5.56	4.35	4.17	6.41	6.25	7.58	4.64
New Hampshire	3.36	4.19	8.24	8.24	6.47	6.46	9.09	8.93	5.88	7.60
New Jersey	3.17	3.96	8.09	8.09	6.41	6.41	8.95	8.64	7.44	10.16
New Mexico	1.50	1.88	5.79	5.79	4.35	4.10	6.65	6.48	5.67	4.65
New York	3.17	3.96	8.71	9.36	6.85	6.67	10.20	10.05	7.81	6.12
North Carolina	2.26	2.83	6.08	6.08	4.89	4.78	6.94	6.77	8.32	5.71
North Dakota	2.26	2.83	6.40	6.40	5.04	4.91	7.26	7.09	4.74	6.21
Ohio	1.84	2.29	6.48	6.48	4.85	4.61	7.34	7.17	7.09	7.70
Oklahoma	1.36	1.69	5.42	5.42	4.09	3.84	6.27	6.11	7.49	5.39
Oregon	2.74	3.20	4.32	4.32	4.10	3.89	5.18	5.01	6.70	6.11
Pennsylvania	2.57	3.21	7.76	7.76	5.83	5.65	8.62	8.45	7.09	7.46
Rhode Island	3.36	4.19	8.17	8.17	6.45	6.44	9.03	8.86	6.13	7.12
South Carolina	2.02	2.53	6.87	6.87	5.13	4.90	7.73	7.56	10.26	5.54
South Dakota	1.72	2.14	6.05	6.05	4.58	4.36	6.91	6.74	4.84	6.16
Tennessee	2.69	3.36	4.99	4.99	4.50	4.46	5.85	5.68	8.78	5.86
Texas	1.36	1.69	5.86	5.86	4.31	4.01	6.72	6.55	9.34	5.33
Utah	1.96	2.44	5.32	5.32	4.34	4.23	6.17	6.01	5.26	5.76
Vermont	3.36	4.19	7.72	7.72	6.24	6.26	8.58	8.41	5.88	7.60
Virginia	2.33	2.91	7.54	7.54	5.59	5.38	8.39	8.23	7.58	5.79
Washington	2.65	2.65	3.77	3.77	3.76	3.34	4.63	4.46	7.68	6.96
West Virginia	2.26	2.83	6.14	6.14	4.91	4.81	7.00	6.83	8.17	8.18
Wisconsin	2.33	2.91	5.73	5.73	4.74	4.67	6.59	6.42	5.42	6.80
Wyoming	2.08	2.59	4.84	4.84	4.14	4.07	5.69	5.53	4.46	6.05

*Lesser of natural gas or electricity prices
Natural gas prices adjusted for conversion efficiency of gas furnaces (.75) and gas water heaters (.60)
Electricity prices adjusted for a COP of 2.5.

**Annualized for 30 years at 2.5% for space heating
Annualized for 20 years at 2.5% for domestic hot water