Chapter I

INTRODUCTION

Chapter l.— INTRODUCTION

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Introduction

Small solar energy units attached to or located near individual buildings, industries, or groups of buildings (called "onsite" energy systems throughout this work) must be considered potentially important additions to the limited number of opportunities for meeting the world's demand for energy both in the next few decades and into the indefinite future. This study examines a set of these technologies characterized by the fact that they convert the Sun's energy directly into useful thermal and electric energy; the study does not examine wind power, systems using biological materials as fuels, or other concepts for using the Sun's energy indirectly.

The major barrier to the widespread use of onsite solar energy is its cost. Developments in research can lead to reduced costs and improved performance, but the fundamental feasibility of the technology is well established. Onsite solar devices are technicality capable of meeting virtually all residential, commercial, and industrial energy requirements; they can provide heating and air-conditioning, hot water for residences, heating for industrial and agricultural processes, and mechanical and electrical power.

The energy supplied by these systems is expensive by today's standards. The extent to which this continues to be a barrier depends in part on the success of numerous programs designed to reduce the cost of solar equipment. It will also depend heavily on changes in the price of conventional energy. The market for new types of energy producing and consuming devices is likely to change rapidly in the next two decades as energy costs increase and become a major concern. In many ways it is easier to make confident predictions about the future costs of solar energy—which depend for the most part on predictable manufacturing techniques —than it is to estimate the cost of fuels whose price may depend on monopoly price manipulation, international competition over diminishing energy supplies, the stringency of federally imposed environmental controls, and other problems which are difficult to anticipate.

The issue of costs is treated in much more detail in later sections of this report, but the only fair way to summarize the results of the analysis is to note that the range of possible costs of solar energy overlaps the range of possible costs of energy from conventional sources in a large number of cases. It is simply not possible to make dogmatic statements about the conclusions. The significance of the fact that solar and nonsolar costs overlap, however, *should not be* **underestimated since this overlap means that it may be necessary to choose future energy options on the basis of criteria other than the estimates of future costs (the cost analysis being indecisive). At a minimum it implies that the solar energy alternative should be supported with at least as much attention and care as other options for meeting energy needs in the future.**

The analysis indicated, for example, that solar systems for providing domestic hot water and building heat are marginally competitive with electric heating in many parts of the Nation today, These systems may be competitive with oil and gas (where it is available) in many parts of the country with; n a decade if solar prices fall and the price of oil and gas rises at rates which appear in reasonable forecasts. Solar equipment should be able to compete with synthetic fuels. Electricity from solar sources is now only attractive in remote areas where alternate energy sources are very expensive. There are sound reasons to speculate, how-

ever, that the price of solar electricity may fall by a factor of 15 or more by the mid-1980's and reach a price where solar electric devices could be installed to provide supplemental electricity to houses and commercial buildings.

Inflation resulting from increases in energy prices may have the effect of offsetting some of the cost reductions expected from new designs. It is entirely possible, however, that even the price of solar equipment now in mass production will rise more slowly than the price of conventional energy. Processes used to manufacture the components of solar devices are likely to make more efficient use of energy if energy prices rise since there is clearly considerable room for improving the energy efficiency of American industry. The design of solar devices can also be changed to minimize the use of components whose costs are linked most closely to energy costs. Frames for solar collectors, for example, can be made from steel, aluminum, concrete, plastic, wood, and many other materials. Ultimately, of course, it would be possible to manufacture solar equipment using solar energy.

A number of the advantages of solar energy equipment are not comfortably expressed in the strict economic terms discussed above. For example, widespread use of onsite solar equipment could have a favorable impact on American labor — by creating attractive new jobs, on international stability — by easing the competition for conventional energy sources without increasing opportunities for proliferation of nuclear weapons, and on the environment — by replacing polluting energy sources. (These advantages are discussed at some length in chapter `Vii.) The use of solar energy during the next two decades will depend largely on the value which society attaches to these advantages.

Widespread use of onsite solar equipment [or indeed of onsite energy equipment of any kind) would reverse a 40-year trend toward centralization of energy sources. The larger plants tended to be less expensive to build per unit of output, more efficient, and able to use a greater variety of fuels. Siting problems (for large plants) tended to be minimized by the ability to choose a few remote locations. Conventionally fueled onsite facilities were often abandoned because their owners were concerned about the cost of maintaining equipment and the chance that a system failure would be expensive. Investments in onsite equipment were usually not as attractive as investments in areas more directly related to the business and a feeling emerged that energy generation was best left to the expertise of utilities. As a result, most design improvements in the past few decades have occurred in the technology of larger generating equipment, and the bulk of Federal research activity in energy has been conducted in large systems.

There are, however, reasons to suppose that the unique nature of onsite solar energy equipment may offset some of the advantages which impelled centralization:

- The basic solar resource is distributed. Solar units on individual buildings could in some cases reduce transmission and distribution costs and losses. Integrating the equipment with a building roof or with a parking facility can minimize the land required for solar equipment.
- Location of equipment onsite greatly increases design opportunities and makes it easier to match the energy equipment designs to specific onsite energy demands; in particular, it is easier to use the thermal output of the collectors. A great deal of overlap exists between techniques and devices being developed for onsite solar systems and equipment used for energy conservation. The solar designs are usually most successful when integrated into a coherent plan for matching energy resources to the end use.
- Smaller equipment can be built more quickly than larger facilities, thereby reducing interest and inflation during construction. This equipment can be added in relatively modest increments.

- Onsite systems can also match reliability to local needs. A highly sophisticated industry, for example, may not be able to tolerate power failures lasting a few hours per year while some areas in developing countries may be very pleased with systems which may not provide power for a few days each year—particularly if there are significant savings associated with accepting this level of reliability. Centralized systems force all customers to accept the highest level of reliability demanded by any customer.

In evaluating the advantages and problems of onsite solar equipment, it is important to recognize that solar equipment differs from conventional systems in several significant ways:

In the first place, the systems which are examined in this study do not really represent a single technology, but rather an enormous range of technologies, A great variety of equipment components have been developed (many of which are reviewed in later sections of this study) and these components can be combined in many different ways to meet specific energy requirements in specific climates.

A second unique characteristic of onsite systems is the number of arrangements which can be made for owning and operating onsite equipment, The small scale of the devices makes it possible for individuals or institutions other than utilities and major oil companies to invest in equipment capable of generating useful energy. This does not necessarily mean that investor-owned utilities will not play a useful role in the development of the technology; there are cases where there may be advantages associated with utility ownership and maintenance of onsite equipment. It is also possible that municipal utilities, nonregulated companies selling or renting onsite equipment, or even neighborhood cooperatives will play a role in owning and managing the equipment, Each of these possibilities raises different legal and regulatory issues.

Another singular feature of the small solar devices is that, in comparison to larger energy equipment, they are relatively unsophisticated and would probably be manufactured, financed, insured, and maintained by the people and institutions now performing the same kinds of services for conventional heating and cooling systems or industrial equipment.

A fourth distinction between using solar energy and energy derived from conventional fossil fuels is that the cost of solar energy typically depends on temperature and on when the energy is needed. Solar energy is best suited for meeting energy demands during daylight hours. Fossil fuels typically burn at temperatures near 2,000 ‘C, whether this high temperature is needed or not. There is no great penalty associated with operating an industrial process at high temperatures up to this threshold. While solar energy can provide high temperatures (indeed, one of the first sophisticated uses of direct solar energy was a facility for high-temperature metallurgy), fluids at such temperatures are expensive to collect, transport, and store. The implications of having energy costs depend on temperature and time have never been seriously evaluated. It is an issue which may be of increasing concern regardless of whether solar energy is used, since there are many ways of recovering relatively low-temperature energy from commercial and industrial processes. If an economy began to reflect this new set of costs, the relative values of energy-intensive materials and sources could change significantly. It may be necessary to reevaluate the techniques used for each industrial process to make maximum use of the solar resource. (Development of a successful thermochemical or photochemical reaction which can use solar collectors to produce chemicals capable of being transported, stored, and later reacted to produce high temperatures would do much to eliminate the penalty paid for high-temperature solar energy.)

While the cost of solar energy may depend on temperature, it may not depend on the size of the system employed. Economies of scale in solar equipment are very difficult to establish, particularly if it is possible to connect several small generating and consuming facilities with a common electrical or thermal distribution system.

Solar collectors are generally modular and typically the only economies of scale in collector arrays result from price reductions obtained through large single purchases. This also applies to solar cells used to generate electricity since even the largest solar cell systems consist of arrays of small, individual generating units. Large heat engines are typically less expensive per unit of output than small systems of identical design, but the cost of these engines is typically a small part of the overall cost of the solar energy system; the cost of these systems is usually dominated by the price paid for collectors. It may also be possible to produce small heat engines which are as efficient as larger engines. The cost per unit of output could be comparable to that of large engines if mass-production techniques are used. Many types of storage systems, however, do show significant economies of scale at least up to a size where they are capable of storing enough energy for several hundred typical residences. Much more work needs to be done to determine the best size and placement of storage devices of all kinds.

All onsite solar facilities will face the difficulties which have led to the steady decline in conventional onsite generating faciiities: poorly engineered designs, inability of organizations other than utilities to raise capital for investments with relatively long payback times, uncertainties about maintenance costs, and numerous other concerns. Given the uncertainties inherent in an analysis of this type, it was simply not possible to establish that there either clearly were or were not economic advantages for small solar systems.

Even if onsite solar energy systems could be unambiguously shown to be a preferred energy source, it is clear that they would have a long way to go before they could provide a major fraction of the energy used in the United States, For example, the combined output of all solar heating and hot water systems used in the United States during 1977 displaced about 1 billion kilowatt hours of thermal energy and this is less than 1/200 of 1 percent of total U.S. energy requirements in 1977. The peak electrical output of all solar electric systems was about 1,500 kilowatts. Starting from this small base, solar sales would need to increase by about 50 percent per year for 20 years to achieve an output equivalent to 10 percent of U.S. energy requirements. Achieving this level of output would require an investment of more than $500 billion.

While the growth rates and the investments required to increase use of onsite equipment seem ambitious, and would clearly require an enormous growth in the infrastructure of manufacturers, installers, and salesmen needed to make, market, finance, and service the solar equipment, it must be recognized that any technology which will supply a large fraction of U.S. energy needs by the turn of the century will require an enormous growth rate and investment; yet some new technology must be available during this period as the world reaches the physical limits of low-cost supplies of oil and gas. The transition cannot be a painless one since all of the new energy sources are likely to be more expensive than current energy. The major remaining question is whether we will be able to take advantage of the warning which the geologists have given us, reflect on the options available, explore their potential, and prepare a strategy for a graceful transition to energy sources we can live with, or, whether energy policy will be guided by inadvertence, chance, and reactions to sudden crises and shortages.

The remainder of this study is devoted to defining the circumstances in which onsite solar technologies, with their rather curious set of characteristics, could play a significant role in supplying energy. It examines the technical opportunities now available and under development; reviews the current and potential future cost of integrated systems based on these technologies operating in several representative cities in the United States; explores the legal and regulatory problems encountered by operators of small generating equipment units; tries to explain the impact which widespread use of onsite solar technology might have on the quality of the environment, on the American labor force, and on the achievement of major U.S. foreign policy objectives; and finally, it attempts to define the role and responsibility of the Federal Government in regulating and promoting the technology. Some of the major results of this analysis are outlined in the present chapter.

ONSITE SOLAR TECHNOLOGY

Adequately assessing the opportunities presented by onsite technology is enormously difficult because there is such a diversity of approaches, many of which have never been adequately investigated. The number of options is increased by the fact that, by its nature, onsite equipment is tailored to specific applications in specific climates, since the equipment is much more efficient if care is taken to integrate the onsite equipment into the building or industrial apparatus to which it provides energy.

The number of technical alternatives in onsite solar equipment is astonishingly great, in part because research in these areas is on a scale where a small firm or individual inventors can develop useful concepts. Concepts have been developed by groups ranging from backyard inventors to well-funded Government and industrial laboratories. More than 200 firms are now manufacturing solar collectors, and competition will probably eliminate many of the products on the market, This fact presents a particularly difficult problem for Federal planners attempting to develop a coherent research program.

TECHNIQUES FOR ASSESSING ONSITE TECHNOLOGY

It is important to compare competing technologies on the basis of their ability to perform a specific set of tasks in a specific location – generalizations and simple “measures of merit” can be very misleading. This is particularly true when the costs of onsite systems are compared with the cost of centralized generating facilities; an accurate estimate of the cost of energy from a central unit should include an analysis of all losses in transmission and inefficiencies encountered when the energy from the central facility is converted to useful energy at the site. In the analysis presented in this report, systems have been compared on the basis of their ability to meet all of the energy requirements of a single family house, an apartment building, and other defined patterns of energy consumption. Computer analysis has been used to evaluate the performance of equipment operating in Albuquerque, N. Mex., Boston, Mass., Fort Worth, Tex., and Omaha, Nebr. The performance of a system component cannot be fairly evaluated without examining its performance as a part of an integrated system. The utility of a collector design, for example, cannot be assessed without understanding how it will perform when connected to thermal storage devices and subjected to the winds, temperature changes, cloud patterns, and fluctuating energy demands that characterize actual installations.

INTEGRATION OF ONSITE FACILITIES WITH OTHER ENERGY SOURCES

Carrying the logic of this thesis one step further, it can be seen that it is also necessary to review the performance of onsite energy equipment as an element of a system capable of providing all of the energy requirements of a region. Because most onsite devices will be connected with conventional energy sources which provide backup power, the performance characteristics of the onsite devices can affect costs of energy delivered to all parts of the community. This is particularly true if electricity is used to provide backup power since the cost of electric power increases significantly if it is required to meet irregular demands; it is very costly to maintain generating equipment which will only be used during cloudy periods.

The question of providing backup power to solar energy systems is intimately connected with the problem of determining whether energy generated from onsite solar equipment should be stored, or whether it should be transmitted to other consumers who may have a need for the excess onsite energy. Analysis conducted for this study indicates that it is usually preferable to allow the onsite unit to sell energy to a community-wide electric distribution grid than to store the excess electricity in onsite battery equipment (although this result could be reversed if very low-cost batteries are developed). In general, if energy transmission is relatively inexpensive, it is preferable to connect as many customers and producers together as possible. The value of the excess energy sold from onsite generating equipment depends on the nature of the conventional generating equipment in the region, the local climate, and a number of other factors. The analysis indicates that electric companies should be able to purchase excess electricity generated by residential and commercial onsite solar facilities for 25 to 100 percent of the price at which they sell energy. Determining a just rate for purchases and sales can be extremely complex and in some States, legal and regulatory problems may have to be overcome to achieve a just relationship. Presently few utilities are willing to purchase energy from onsite generating systems. (These issues are discussed in detail in chapters V and VI.)

None of the technical problems associated with connections to existing electrical grids should present major problems. Relatively inexpensive devices are on the market which will disconnect onsite equipment from utility lines so that linemen can perform repairs safely, and meters are available which can monitor the production of thermal energy and the purchase and sale of energy from onsite systems. Moreover, onsite equipment should not create insurmountable load management problems for utilities, even if a relatively large number of their customers use onsite devices.

The relatively low cost of onsite thermal energy storage creates a situation where it may be preferable to store electrical energy generated in central electric-generating facilities during the night (when electric demands are low) in onsite thermal storage when this energy is to be used for heating. The storage tanks typically associated with solar heating systems provide an ideal opportunity for this kind of storage but conventional buildings can be equipped with storage facilities which are charged only with electricity from conventional sources. When a careful analysis is made of all of the costs incurred in meeting the energy needs of typical buildings (including both onsite costs and the real costs undertaken to provide backup power) it appears that costs of both solar and conventional buildings are reduced when energy used for heating (or backup heating for the solar system) is stored onsite during periods when demands on the electric utilities are low. The costs of conventional systems were reduced more than the costs of the solar systems, however, and solar heating systems compared less favorably with conventional systems when these methods were used. There were, however, a number of cases where the solar equipment still was economically preferable.

It is important to recognize that while the relatively uneven loads imposed by providing backup power to solar energy equipment can have an adverse effect on overall utility costs, many other kinds of energy-consuming devices also impose very uneven loads on a utility. Insulating a building, for example, tends not to decrease the peak electrical demand significantly during the summer (the period when most utility peaks are highest), but does decrease demands during the winter, resulting in increased utility costs. Similarly, electric heat pumps impose much more uneven loads than baseboard resistance heating. (In fact, when all costs are evaluated, heat pumps may be more expensive to operate than electric resistance heating systems which purchase electricity only at night.)

In evaluating costs, it was assumed that the electric utility used a set of central generating systems which were optimally chosen to meet each type of demand, This is the only valid way to compare costs over the long term, It is tautological that equipment designed to minimize costs for a conventional load pattern will be less efficient if it is used to meet a different load pattern (e. g., loads which include a large amount of solar backup demands). Admittedly, regulatory delays and the mortmain of existing plants and equipment will always prevent utilities from optimizing their facilities to new load patterns over the short term.

There are circumstances where it may be preferable to transmit thermal energy rather than to store it onsite since there are very significant economies of scale in thermal storage. The analysis in this study discovered several areas where 100 percent of the heating and hot water requirements of individual houses could be met by solar energy if a number of homes were connected to a large central storage tank. Distributing energy in thermal form instead of electrical form was also found to be attractive in a number of conventional solar energy systems designed to meet all of the energy needs of a large community. I n these cases, the thermal energy was very inexpensive because it was a byproduct of generating electricity and the bulk of the cost of the energy was the cost of delivery.

The difficulties encountered in providing backup power from electric utilities to onsite solar facilities, characterized by large, expensive generating equipment, may create a situation where it is preferable to provide backup entirely from natural or even synthetic oil or gas. In several cases examined, it was less expensive to provide backup from these chemical sources than from electricity even if it was assumed that the chemical systems' fuels increased rapidly in price.

RESEARCH AND DEVELOPMENT

in a surprising number of cases, onsite solar technologies are not economically attractive because of the high costs of such mundane processes as installing and aligning collectors and bending metal in fabricating facilities. If these costs cannot be reduced with some ingenious procedures, it is difficult to imagine a research breakthrough which would radically reduce the cost of solar energy derived from such systems. If these costs can be reduced, a number of attractive devices are possible with existing technology. What is needed is perhaps more the genius of the man who invented the zipper than the genius of an Einstein.

There are a number of areas where research and development seem particularly important.

- Determining the best way to design a building structure to maximize natural heating and cooling,
- Developing simple collectors from extremely low-cost materials (e. g., cheap, durable plastic films),
- Developing techniques for reducing the cost of manufacturing simple tracking and concentrating collectors,
- Developing economical techniques for storing large amounts of energy in hot water or rocks in order to meet all of the annual thermal demands of buildings,
- Improving techniques and materials for laying insulated pipes for thermal distribution systems,

- Developing chemical reactions which can be used to store or transfer thermal energy,

- Developing advanced electrochemical storage devices,

- Designing an inexpensive and reliable heat engine capable of working at relatively low temperatures (e. g., below 2500 F),

- Designing an inexpensive, reliable, high-efficiency engine capable of working at very high temperatures (e. g., 1,4000 to 2,0000 F),

- Developing low-cost materials for solar cells, and

- Developing dyes for a simple concentrating collector.

It is also vitally important that a strong program in basic research accompany these applied development projects. Research in sol id state physics, surface chemistry, metallurgy, thermochemical and photochemical reactions and heat transfer is of particular interest.

ECONOMICS

Table I-I indicates the size of different energy markets in the United States, summarizes the potential of direct solar energy in each market, and estimates when solar equipment could begin to enter this market.

Direct onsite solar energy equipment is likely to make its first major impact by providing supplemental heat and hot water for residential and commercial buildings. This is not an insignificant market since demand for energy in this category represented about 20 percent of all energy consumed in the United States in 1975. There is already a growing market for solar hot water systems in regions with plentiful sunlight and high electric rates where natural gas is not available for new buildings. A market for solar heating systems is also developing in these areas. If it was assumed that electric rates increased 45 percent by the year 2000, solar heating and hot water systems with plausible near-term costs showed lower life-cycle costs than heat-pump systems in houses in three of the four cities examined in this study. The solar system was competitive in all four cities when a 20-percent investment tax credit was given to the solar system.

Solar energy was found to become an attractive alternative to oil and gas heating of hot water in the mid-1980's, if consumers are convinced that oil prices will increase to $23 to $35 per barrel by the year 2000, or that gas prices will reach an equivalent level. Fuel prices would probably rise at least as rapidly as this if a major fraction of U.S. liquid fuels were derived from synthetic sources by the year 2000.

Most of the solar heating and hot water systems installed today are not capable of meeting all of the heating requirements of the buildings they serve; a conventional furnace or baseboard heaters must be used during periods of prolonged cloudiness. This limits the fraction of the energy consumed for building heat which solar devices can replace. It is possible, however, to construct solar systems providing 100 percent of a building's heating demands by using a sufficiently large storage facility. The analysis conducted for this study indicated that within 3 to 5 years it should be possible to construct systems capable of supplying all of the heating and hot water requirements of large buildings at prices which would be competitive with conventional electric heating in three of the four cities examined. The systems would be competitive in all four cities if a 20-percent investment tax credit was granted to the solar equipment.

Table I-1.—The Potential of Onsite Solar Energy Equipment

Demand type	Percentage of total U.S. energy demand in 1975	Potential of onslte solar energy equipment
1. RESIDENTIAL AND COMMERCIAL	(36)	
a. Hot water	3.5	Competitive now with electric hot water heating on life-cycle cost basis and with oil and gas if year 2000 prices expected to reach$15-20/bbl equivalent.
b. Space-heating	17.8	Combined hot water and heating systems marginally competitive with resistance heating and heat pumps now or in the near future, competitive with oil and gas if solar prices drop, or, if year 2000 prices expected to reach $23-35/bbl equivalent. Many "passive" approaches clearly attractive.
c. Electricity for lighting and other miscellaneous demands	9.0	Possibly competitive by mid- to late-1980's if electric rates increase by 50 percent by the year 2000. Competitive in remote areas today.
d. Air-conditioning	4.3	Some systems available, but economically attractive systems unlikely until early or mid-1980's.
e. Gas cooking and other miscellaneous uses	1.2	Cooking conveniently available from direct solar sources only through electricity.
II. TRANSPORTATION	(26)	No major role probable for direct, solar energy. Some market possible for electric vehicles charged from on-site electric systems or vehicles using chemical energy generated on site.
Ill. INDUSTRY	(38)	
a. Electric motor drives, electrolytics, & misc. electrical demands	8.7	Penetration of this market unlikely until 1990's unless research progresses faster than expected. Solar cogeneration systems may be attractive in some areas by the mid-1980's.
b. Process heat at temperatures below 2120 F	2.0 (7.0)'	Possibly competitive with oil and gas by 1980's if prices are expected to increase to $14-16/bbl equivalent by the year 2000. Competition with direct combustion of coal unlikely in large plants unless conversion to coal is very expensive.
c. Process heat at temperatures of 2120 to 5500 F	5.3 (6.5)*	Possibly competitive in 1980's with oil and gas if prices reach $19-25/bbl equivalent by 1985 and $30-40/bbl by 2000.
d. Process heat at temperatures greater than 550° F	18.6 (12.4)*.	Probably competitive only when onsite solar energy for electric motor drives is competitive.
e. Chemical feedstocks	3.3	No market for direct solar energy.

"If heat used to raise the temperature of materials from 600 F is Included

. . Nearly 90 percent of the process heat used at these temperatures is consumed in blast furnaces, steel mills! stone, glass, and clay processing, and petroleum refining

SOURCES. Total energy requirements for Industry, transportation, residential, and commercial consumers obtained from U S Department of the Interior (Bureau of Mines) News Release March 14, 1977

Details for residential and commercial consumption patterns obtained from

J R Jackson and W S Johnson, *Commercial Energy Use A Disaggregation by Fuel, Building Type, and End Use,* Oak Ridge National Laboratory (ORNLICON-14) February 1978, page 9

E Hirst and J Carney, *Residential Energy Use to the Year 2000 Conservation and Economics,* Oak Ridge National Laboratory (ORNL/CON 13) September 1977, page 9

Details of industrial energy consumption based on

D S Freeman, (ed) *A Time to Choose,* Ballinger, Cambridge, Mass , 1974, p 456

InterTechnology Corporation, *Analysis of the Economic Potential of Solar Thermal Energy to Provide Industrial Process Heat* (ERDA COO/2829.1}, p 53 (This survey included Institutions using 59 percent of U S Industrial process heat)

Electricity used in residences and commercial facilities for lighting, television sets, dishwashers, and other appliances is expected to represent about 9 percent of the primary energy consumed in the United States in 1985. Residences and commercial buildings pay the highest rates for electricity since these rates must include charges for the costly equipment needed to distribute the electricity to a large number of small consumers. It is likely, therefore, that devices for generating electricity from sunlight will find their first large markets in this sector. (Solar electric devices will find substantial markets in remote military outposts, signalling devices, and other installations before the large residential market can be approached. The market for systems in remote areas could, however, amount to several hundred millions of dollars of annual sales, particularly if markets in nonindustrial countries can be captured.) Within 10 to 15 years it may be possible to develop onsite solar devices capable of producing electricity for $0.04 to $0.10/khVh, rates which may be competitive with the cost of electricity delivered to residential and commercial customers from new utility generating plants.

There is also a potentially large market for direct solar energy equipment in industry and agriculture. Table l-l indicates that 2 to 7 percent of U.S. energy is consumed in these sectors at temperatures below the boiling point of water, and 7 to 13 percent is consumed at temperatures below 3500 F. Solar equipment is now available which can easily provide fluids or direct heating at these temperatures. In many ways, industrial and agricultural markets are more attractive than the residential and commercial markets since the residential and commercial customers are much more diverse and will probably require a more complex and expensive infrastructure for sales and installation. The larger customers are also likely to be confronted with gas curtailments during the next decade and will be in the process of selecting a replacement for natural gas.

There are, however, several major obstacles to solar use in industry and agriculture. Consumers in these categories can use a variety of different conventional fuels (many can burn coal directly) and pay much less for electricity than residential and commercial customers. Moreover, they typically expect payback times on the order of 1 to 3 years for investments in new plant equipment. The cost of industrial solar heat can also be somewhat higher than solar heat provided for homes and residences if it is necessary to install collectors in fields where land, footings, and other aspects of site preparation must be charged to the solar equipment and where piping heat to the factory can be expensive. Smaller installations can be supported by building roofs and heat is generated close to the site where the energy is used.

Analysis of the cost of providing electricity and process heat to a large three-shift industry from different kinds of energy equipment which began operating in 1985 indicated that direct solar heat for low-temperature applications would be competitive with oil if it was assumed that oil prices increase to $15 to $20 per barrel by the year 2000 and if the solar equipment is financed by a private utility. Solar heat at temperatures in the range of 3500 F was competitive only if it was assumed that oil prices reach $19 to $25 per barrel by 1985, and are $30 to $40 per barrel by 2000. Competition with natural gas and coal was possible for systems starting in 1985 only if it was assumed that the prices of these fuels increase by a factor of nearly three (from 1976 levels) by the year 2000 (e.g., coal costing $60 per ton). While such price increases are possible for natural gas, it seems unlikely that coal prices will increase at this rate. It is also possible that solar heat at temperatures below 5000 to 6000 F will be competitive with heat derived from synthetic hydrocarbons made from coal.

While most solar heating systems for large industrial or agricultural facilities may not be fully competitive with conventional fuels before the mid-1980's, it will almost certainly be possible to find industries whose specific problems are well suited to the use of solar energy in the near future. There may well be a large near-term market for grain drying systems in less-developed countries, for example. Near-term markets for solar equipment in the industrial sector could also result from existing environmental legislation; solar energy may prove to be an attractive way to expand industrial capacity while minimizing increases in emissions.

Solar cogeneration devices using solar cells or Stirling engines may be attractive in roughly the same circumstances that found solar hot water competitive, although the solar systems were less attractive when compared with cogeneration systems using conventional fuels. It seemed unlikely that solar electric systems which did not cogenerate would be able to compete with the low cost of electricity delivered to industrial facilities from conventional sources until at least the mid-1 990's, although unexpected progress in research could well accelerate the rate at which the solar electric systems become competitive.

Solar energy used for direct heat in blast furnaces, glass plants, and other facilities requiring heat at very high temperatures (uses representing 12 to 19 percent of U.S. energy consumption) are unlikely to be competitive before solar electric systems. Development of an efficient thermochemical process, which could be conducted in a solar collector and reversed in a special burner at high temperature when heat is needed, would greatly improve the prospects for using direct solar energy in high-temperature applications.

Direct solar energy is unlikely to be used as a substitute for any of the chemical feedstocks which now consume about 3 percent of U.S. energy. Biomass would clearly seem to be the preferred solar source for feed stocks.

Similarly, transportation, which consumes about 25 percent of U.S. energy, is unlikely to provide a major near-term market for onsite direct solar energy. There may be some circumstances where electric vehicles could be charged from solar-generated electricity. Development of a thermochemical reaction which yields a portable chemical with a high-energy density would also make "direct" solar transportation a possibility. It is unlikely that the direct solar sources would be preferred to synthetic fuels from biological or other sources.

Considerable caution must be exercised in interpreting statements about the "competitiveness" of solar energy systems. First, the benefits of solar equipment can only be realized if the prospective owners compare solar and alternative systems on the basis of life-cycle costing. Life-cycle costs will, in turn, depend on the type of owner since each will have a different tax status, sources of capital, and economic expectations. Solar devices may be owned by the residents of the building, a private corporation, or a municipal or privately owned utility. Each will make different estimates of the advantages of the solar investment. Whether prospective solar customers will actually employ such a procedure is difficult to anticipate and will depend to some extent on the skill with which the solar equipment is sold.

It is difficult to establish a fair basis for computing the cost of nonsolar equipment since the performance of nonsolar equipment is likely to improve as the price of conventional energy increases. There is also great variation in the cost of energy around the country; regional differences in energy prices are greater than differences in the amount of sunlight available.

it must be recognized that if onsite solar energy is to make a major impact on the U.S. energy economy by the turn of the century, it will be necessary to find ways of installing solar equipment on existing buildings. This process can be difficult: such installations are likely to be more expensive than devices attached to new structures, although there is at present no reliable information about the additional costs which could be expected. It is likely that the percentage increase in costs would be smaller in larger buildings, There may well be situations where it is not possible to retrofit an existing structure with solar equipment. Densely populated urban areas and heavily treed suburbs present particularly difficult problems, and solar energy used at these sites is unlikely to come from onsite systems. Building orientation may present difficulties in some cases but a roof must have a particularly poor orientation or roof shape to present a major problem for a solar installation.

POSSIBLE IMPACTS OF ONSITE SOLAR ENERGY

Since onsite solar equipment would undoubtedly be designed, manufactured, financed, installed, and operated by the same organizations currently associated with the construction of buildings and industrial facilities, the impact on American society as a whole will probably be very minimal. Several areas, where impacts would probably be greatest, have been identified and studied in some detail.

U.S. SECURITY AND WORLD TRADE

Extensive worldwide development of solar energy systems would, in time, relieve some of the strain imposed on international stability by competition for energy resources, reducing economic difficulties faced by oil-importing nations. It could provide a reliable source of power not dependent upon imports, and the necessary technology would be accessible without a need for large numbers of highly trained engineers or foreign technicians to operate them. It should be possible for many countries to manufacture solar equipment using existing industrial and construction skills and facilities. Solar energy will be economically attractive in most other countries before it is competitive in the United States where energy is relatively plentiful and inexpensive. The development of indigenous energy sources abroad should also reduce pressures to accelerate the development of nuclear power, thereby reducing opportunities for the proliferation of the technology and materials required to make nuclear weapons.

In spite of the development of indigenous solar industries abroad, foreign markets for solar energy devices may provide an excellent opportunity for U. S. exports, Since many nations will find it desirable and possible to manufacture solar equipment locally, the sale of licenses, patents, and turn-key plants may dominate exports. The international utilization and impact of solar energy, however, may depend critically on U.S. initiatives over the next few years. In most areas, U.S. research is the most advanced in the world, so many nations will look to the United States for guidance in this field. A U.S. commitment to solar power would encourage foreign commercialization of the technology, if only by giving it prestige.

LABOR

Onsite solar technology appears to be more labor-intensive than contemporary techniques for supplying energy, thus, in the short term, the introduction of solar energy devices will create jobs in trades now suffering from serious unemployment. Jobs would also be created by replacing imported oil and gas with solar energy derived from domestically produced equipment. Jobs would be created in the following areas:

- Manufacturing of components (solar collectors, heat engines, photovoltaic devices, storage batteries, controls, etc.),
- Installation of systems (plumbing, sheet-metal work, steamfitting, electrical work, carpentry, excavation, and grading), and

- Maintenance of installed systems (including routine adjustments and repairs for small systems and full-time operators for larger units).

The work created in these areas will be distributed widely across the country, allowing most workers to find jobs in areas close to their homes, and the jobs created should be relatively safe. One effect of emphasizing onsite solar energy, for example, would be to create more new construction jobs than new coal-mining jobs. It is also interesting to notice that nearly a third of the employment associated with a conventional electric utility involves transmission and distribution of energy and billing and other services — services which would probably not be affected in any way by a shift to onsite power. There would be no need for laborers to live in remote or temporary construction sites. Work on solar equipment should require only simple retraining programs for most construction trades. There may, however, be shortages both of engineers and architects qualified to design solar equipment, and of operators trained in the maintenance of some of the larger and more sophisticated solar devices that have been proposed.

The long-term applications for employment of solar and other new energy technologies cannot be reliably assessed with contemporary economic methods. Long-term labor impacts will depend on forecasts of future growth rates, both in the economy and in U.S. energy consumption — subjects about which there is great confusion and disagreement.

UTILITY PARTICIPATION

Utility participation in onsite generating facilities offers several advantages:

- The utiiity is i n the best position to optimize the size and placement of all generating, storage, and transmission equipment in the region;
- Utilities alone can compare the cost of energy from new onsite equipment with the cost of energy from new central facilities — al I other owners will compare onsite costs with the lower, average cost of energy from all central generating facilities;
- Utilities can offer the equivalent of 100 percent financing for new generating plants (onsite or otherwise) and are able to raise capital for investments with long-term paybacks–something which few other institutions can do; and
- Utilities already have maintenance crews and billing services, which could be expanded to cover the operation of onsite generating equipment.

A number of these advantages could be realized without utility ownership of onsite systems if care is taken in the design of utility rates.

Municipal utilities may be able to play an important role in regional planning for onsite solar energy systems and their access to relatively low-cost capital may make municipal financing of solar energy projects attractive.

ENVIRONMENT AND LAND USE

While solar energy equipment is not completely free of adverse environmental effects, providing energy from sunlight will have a much smaller environmental impact than conventional sources providing equivalent amounts of energy.

Solar energy may provide an opportunity to expand population and increase industrial capacity in areas where such growth may be constrained by the Clean Air Act. Large-scale conversion to the direct combustion of coal will make it difficult to maintain current levels of air quality unless solar energy, or some other nonpolluting energy source, is introduced to reduce the demand for energy from fossil sources. The use of solar energy can also reduce the net releases of carbon dioxide. The significance of this depends on the extent to which greatly increased CO_2 releases could adversely affect world climates— and this is not well understood now.

The primary environmental effect of utilizing onsite solar energy will be reduction of the potential adverse environmental effects associated with other energy sources. The negative environmental effects of solar energy devices stem primarily from two sources: (1) land-use requirements, which could compete with other, more attractive uses of land near populated areas, and (2) emissions associated with the mining and manufacture of the materials used to manufacture solar equipment (e. g., manufactured steel, glass, aluminum, etc.) In most of the cases examined, however, the reduction in emissions attributable to operating a solar facility instead of a conventional one can equal the extra emissions associated with the manufacture of the solar device in 3 to 9 months. In addition to these primary effects, a number of the specific storage and energy conversion systems discussed in later sections of this report could have adverse environmental effects because of noise, minor emissions (associated primarily with manufacturing components), and use of toxic chemicals.

The land-use impact of onsite solar equipment can be less serious than the problems associated with isolated solar equipment, since in most cases the onsite equipment can be integrated into buildings or local landscapes and extensive transmission facilities are not required. If additional surface area is required, however, lack of suitable land close to populated areas could place major constraints on the use of onsite solar equipment.

FEDERAL POLICY

One of the attractive features of onsite solar equipment is that it may be the only new energy source that can be developed, financed, and installed without Federal assistance of any kind; it is simply an extension of existing construction industries. Federal energy policy will, however, affect the rate at which onsite solar energy enters the market, regardless of whether an attempt is made to develop a specific policy for solar energy. Federal poticies have made the market in which solar technologies compete an artificial one. Energy prices are influenced by a bewildering array of regulations, subsidies, and controls which, in several instances, have had the inadvertent effect of reducing the attractiveness of solar equipment. Examples include the policy of maintaining residential energy rates at artificially low levels, decisions to support larger types of energy equipment with preferential tax credits, and disproportionate amounts of research funding given to larger energy equipment.

There is little doubt that without Federal assistance, solar markets will grow relatively slowly. Legislation can greatly accelerate the rate at which this market grows if this is judged to be a desirable objective.

The following types of policies can be effective.

1. Direct incentives to potential customers (chiefly tax incentives, loan subsidies, and allowances of accelerated depreciation).
2. Assistance to manufacturers (including incentives for purchase of manufacturing equipment, research and development grants, and Federal purchases) and assistance for testing laboratories certifying the performance of onsite equipment.
3 Support of basic research and development programs in fields related to onsite solar energy.

4. Legislation which might eliminate some barriers to usage of onsite solar systems (this would include freeing onsite equipment from regulation as a public utility and assisting States in designing local procedures for protecting the "sun rights" of owners of solar equipment).
5. Encouragement of the use of solar energy in other countries through foreign assistance grants, joint research programs, and other techniques.
6. Programs to support education and training in fields related to solar energy.

Tax credits, low interest loans, accelerated depreciation allowances, and exemption from property tax can be powerful tools in reducing the perceived cost of solar energy. A 20-percent investment tax credit, for example, could reduce the effective cost of solar energy in residential applications by 15 to 30 percent; the combination of a 20-percent investment tax credit; 5-year depreciation allowance, and an exemption from property tax, could lower the perceived cost of solar energy by 50 to 80 percent. A program making 3-percent loans available to homeowners would be equivalent to an investment tax credit of about 34 percent. These subsidies would have the effect of increasing sales, resulting therefore in a decrease in the cost of individual components if they stimulate mass production.

Tax credits reduce Federal revenues but the net cost of the credits to the Government is difficult to calculate, The Federal subsidy per unit of energy produced by subsidized solar equipment is roughly equal to the difference between the costs (with or without incentives) of a unit of solar energy perceived by equipment owners. That is, if a policy has the net effect of reducing the customer's perceived costs by $0.01/kWh, the Government will lose approximately $0.01/kWh in tax revenues for each kWh generated by the solar system receiving the subsidy. The Government's costs, however, will be compensated to some extent by the fact that solar-related businesses would be stimulated by the subsidy, thus producing increased tax revenues. This analysis of costs does not attempt to attach a monetary value to the health benefits of reduced air pollution and other social benefits

Federal support of small solar energy systems has been consistently hampered by the small staff available to DOE's Division of Solar Energy Small staffs make it difficult to manage a large number of innovative projects.

STANDARDS

A difficulty encountered with any new technology, and particularly one involving as many small and inexperienced manufacturers as in the current solar energy industry, is that it is necessary that standard testing procedures be developed rapidly, and in step with the development of each type of technology. It is also necessary, however, that these standards be reviewed constantly so that new and different design approaches are not inadvertently ruled unacceptable. Small firms are frequently in such a weak financial position that it is difficult for them to offer acceptable guarantees. A reputation for failed installations could be a serious barrier to the rapid expansion of the solar industry,

Standards have been slow to develop and inspectors frequently do not know what to look for in novel systems.

OTHER SPECIALIZED LEGAL AND REGULATORY PROBLEMS

Onsite solar facilities are currently controlled by laws and regulations written with entirely different energy systems in mind. Although that is the case, this study finds surprisingly few barriers to large-scale installation and operation of onsite solar facilities. The legal barriers which do exist can, in most cases, be removed with routine regulatory review. Resistance to changes in zoning

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or building codes, for example, generally arise when an interested party will be adversely affected; it is not likely, however, that builders, owners, labor unions, or public officials will perceive onsite solar generation as a threat.

Some concern has been expressed about the fact that owners of solar facilities have no legal grounds for objecting to construction projects which would have the effect of shading their collectors. While this may present a serious problem, the skillful application of existing legislation, local covenants, zoning authorities, and building code regulations will probably provide as much protection as it is reasonable to expect. The analysis conducted for this study found no need for Federal action in this area.

The regulatory problems which may present the greatest problems for onsite solar energy devices, and the ones which it may be most difficult to resolve, involve the laws and rulings governing public investor-owned gas and electric utilities. If it becomes possible to generate energy at competitive prices using onsite solar energy equipment, the "natural monopoly" of utility generation of electricity, which forms the basis of most utility law, would be called into question; the only real "natural monopoly" may be equipment for transmitting and distribution of energy.

Problems in this area fall primarily into three categories: 1) establishing just rates for power sold as backup power for onsite solar installations and just rates for utility purchases from onsite facilities, 2) resolving the regulatory problems faced when an individual or institution other than a utility attempts to sell electricity or thermal energy (utilities are given a monopoly on such sales in many regions), and 3) resolving the regulatory problems confronted when existing utilities attempt to own and operate onsite energy equipment. Resolving these issues requires a clear concensus about the proper role of utilities in onsite equipment.

COMPARISON WITH CURRENT POLICY

This report does not make prescriptive recommendations, but presents three points of view which give rise to a range of specific poticies affecting onsite solar power generation. The discussion (which appears in chapter III of this report) is intended to illustrate the policy alternatives available and to assess their relative effectiveness. This analysis found several broad approaches to be potentially effective which do not play a significant role in current Federal programs. As a consequence, the emphasis of this report differs in several significant respects from Administration policy.

1. The policies examined here would place greater emphasis on accelerating a wide variety of onsite solar energy systems (including solar electric systems) during the next decade; the existing program appears to stress heating and cooling systems, relegating most other applications of solar power to longer-term research programs and placing major emphasis on the development of large, centralized electric-generating systems.
2. The policies examined here place a high priority on bringing life-cycle costing techniques to the attention of consumers, investors, and other groups in a position to make decisions about energy equipment.
3. In contrast to the Administration's plan, which concentrates exclusively on consumer incentives, the policies examined here will include a number of techniques for providing direct assistance to equipment manufacturers.
4. Policies examined here place major emphasis on the problem of ensuring an equitable relationship between onsite solar equipment and existing utilities, with particular emphasis on establishing reasonable rates both for the purchase of backup power from the utility and for the sale of power generated by onsite equipment to utilities. More at-

tention is paid to providing backup from natural gas and chemical fuels rather than electricity and more attention is paid to the opportunities for distributing thermal energy.

5. Policies here emphasize the encouragement of foreign sales of onsite generating equipment, licenses, and patents and of providing assistance to nations attempting to acquire a reliable, indigenous source of power.

Onsite solar energy has unique features as an energy source, so Federal policy must have unique features to encourage its development. Unfortunately, precedents for Federal programs, which have succeeded in encouraging the development of a commercial product, are almost impossible to find; products developed and promoted by agricultural extension services are perhaps the only clear exception. Badly managed Federal intervention in the market can do more harm than good. At a minimum, it must be recognized that developing and promoting a diverse set of technologies to be manufactured, installed, financed, and owned by a diverse set of institutions will be very different from the programs designed to develop new central generating plants which will clearly be designed for use and operation by utilities.

What will be needed is an unprecedented amount of bureaucratic flexibility, imagination, and care in determining where Federal intervention can help and where the best policy is restraint.

There will be no way to avoid taking risks. The bulk of this report attempts to provide the basis for comparing the risks associated with onsite solar energy equipment with the risks which must be taken in supporting other energy sources. If nothing else, the study indicates that the potential of onsite solar energy systems cannot be easily dismissed and that it is dangerous to be dogmatic about the subject at this early stage. There is enough uncertainty about the future of the world's energy supplies, and enough problems have developed with conventional solutions, that it is necessary to be a little humble about the extent to which fundamental questions about supplying and consuming energy are understood.