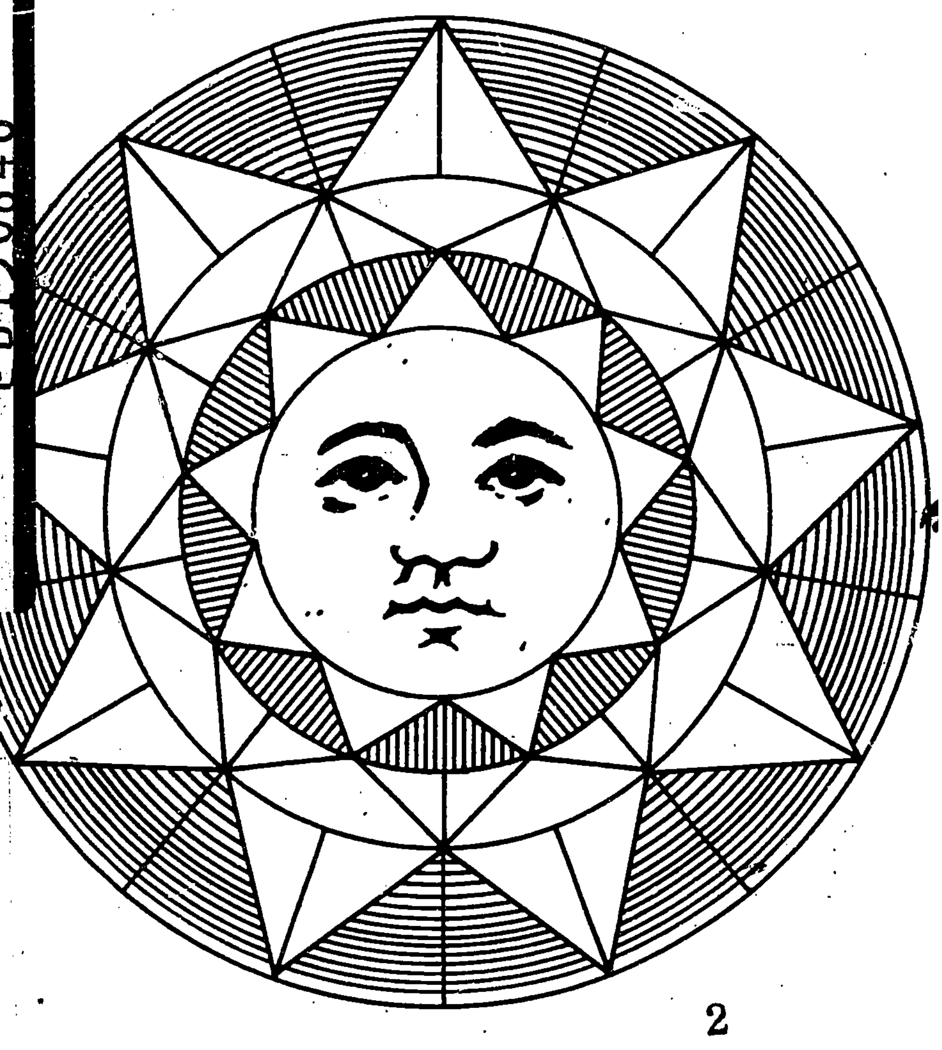
AUTHOR	Eaton, William W.
TITLE	Solar Energy.
INSTITUTION	Energy Research and Development Administration, Washington, D.C.
PUB DATE	76
NOTE	56p.; Photographs may not reproduce well; Contains occasional small print
EDRS PRICE	MF-$0.83 HC-$3.50 Plus Postage.
DESCRIPTORS	*Energy; *Environment; General Science; *Instructional Materials; *Natural Sciences; *Physical Sciences; *Solar Radiation

ABSTRACT

Presented is the utilization of solar radiation as an energy resource principally for the production of electricity. Included are discussions of solar thermal conversion, photovoltic conversion, wind energy, and energy from ocean temperature differences. Future solar energy plans, the role of solar energy in plant and fossil fuel production, and public participation in solar energy development are also presented. Diagrams illustrating solar collectors, availability of solar and wind energy, operation of ocean thermal power plants, and an appendix listing the basic units of energy are provided for reference. (SL)

Solar Energy



The Energy Research and Development Administration publishes a series of booklets for the general public.

Please write to the following address for a title list or for information on a specific subject:

ERDA–Technical Information Center
P. O. Box 62
Oak Ridge, Tennessee 37830

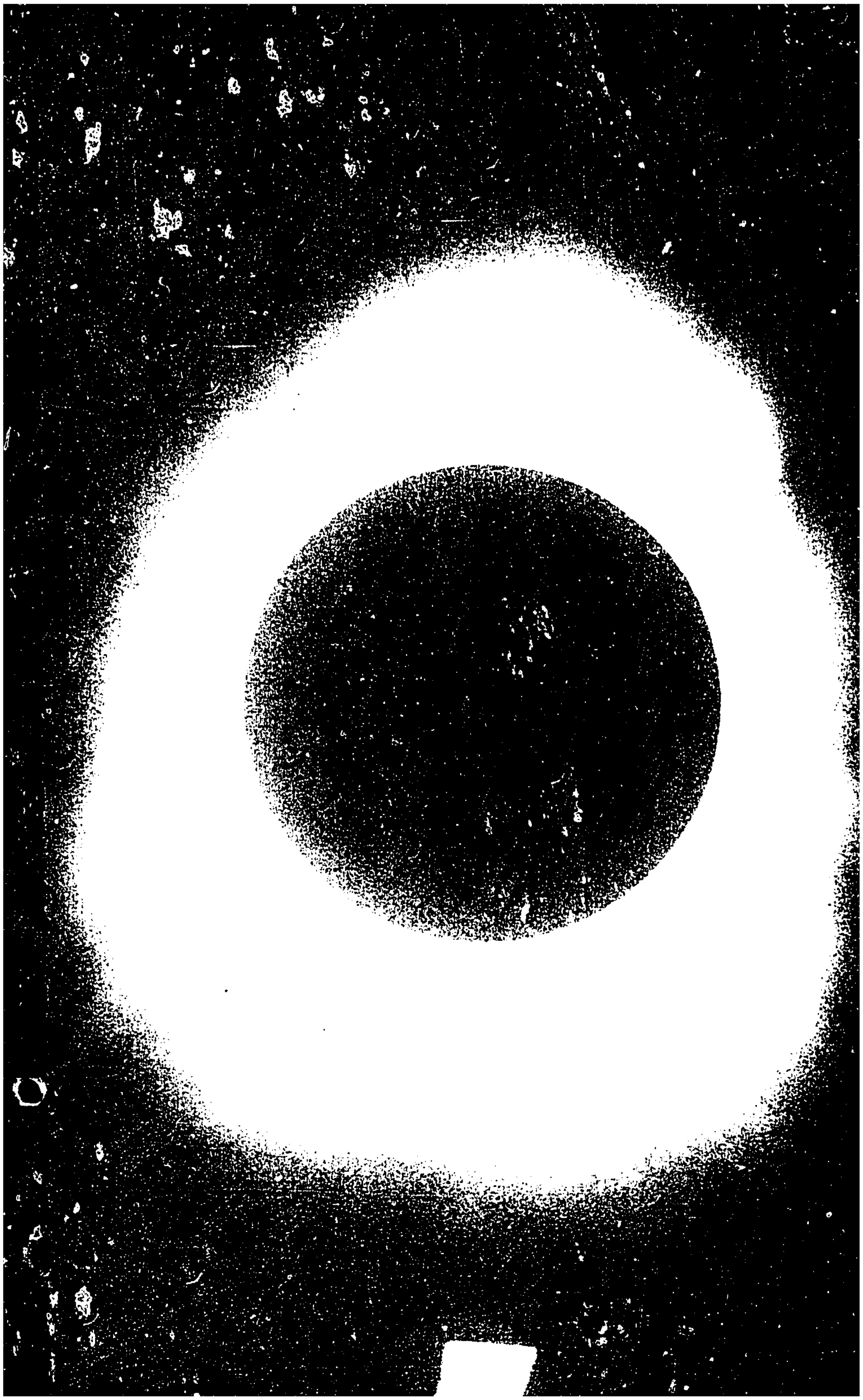
Solar Energy

by William Eaton

Contents

Energy Research and Development Administration
Office of Public Affairs
Washington, D. C. 20545

Library of Congress Catalog Card Number: 74-600179
1976



Chapter I. Introduction

Solar energy—the energy received by the earth from the sun—has provided, directly or indirectly, almost all the sources of energy for the earth since its creation.

Sunshine consists of a wide variety of electromagnetic waves that are similar in many ways to radio and TV waves. Its three main components are invisible heat waves, visible light rays of various colors, and invisible ultraviolet rays. Most of the ultraviolet portions are absorbed by the earth's atmosphere.

This energy travels from the sun through space at a speed of 300,000 kilometers (186,000 miles) per second, and for practical purposes it is inexhaustible.

For millions of years, sunlight has been captured by photosynthesis in plants. Through the slow action of heat, pressure, and aging, plant substances have turned into coal, petroleum, and natural gas—the fossil fuels—which now provide over 95% of the energy used by civilized man.

The human race, and indeed all animal and plant life upon the earth, has always depended for existence on the sun's energy. Most importantly, the sun's rays provide the heat necessary to maintain the temperature required for human, animal, and plant survival. Photosynthesis enables sunlight to provide the energy needed to convert atmospheric carbon into organic forms, which animals use as food, and is a key element in the ecological balance of nature. Solar radiation also produces combustible materials—chiefly wood—that provide heat for cooking and other uses.

The amount of energy reaching the earth's surface is so vast as to be almost incomprehensible. Two examples may make this clear. On a global scale, the solar energy that arrives in 1–2 weeks is equivalent to the fossil energy stored in all the earth's known reserves of coal, oil, and natural gas. In the United States, the solar energy that reaches $\frac{1}{500}$th of the country—an area smaller than that of Massachusetts—could, if converted at 20% efficiency, satisfy all our present needs for electric power.

But there are two disadvantages of solar energy. One is that the sun's energy is diffuse, i.e., it is spread out very thinly. It must therefore be collected by some means because only a small amount arrives at one place. The second problem is that it is *intermittent*. The sun shines only by day and is often obscured by clouds. Thus its energy must be *stored* until it is needed.

Sunlight arriving at the edge of the earth's outer atmosphere carries energy at an approximately constant rate of 1.36 kilowatts per square meter (130 watts per square foot) of area covered. In terms of heat, this is equivalent to 428 British thermal units (Btu) per square foot per hour. (One Btu will raise 1 pound of water 1°F.)

Measurements in various locations all over the U. S. have shown that, on the average, over an entire year (including night and day, winter and summer, cloudy and clear conditions) about 13% of the sun's original energy arrives at ground level. (The actual amount at any particular spot at any given moment ranges from much higher to much lower than this average value. See Figure 2.) This average is equivalent to about 177 watts per square meter (16.4 watts or 58.5 Btu per square foot) per hour.

If arrangements can be made to collect even this diffuse energy over a relatively large area, tremendous quantities can be made available. For example, the average rate at which solar energy falls on just 0.4 hectare (1 acre) is equivalent to about 710 kilowatts (950 horsepower).

To deal with the other basic problem—the intermittent characteristic of solar energy at ground level—inexpensive techniques are required to store large quantities of energy. The cost of storage is usually a significant fraction of the cost of operating a solar energy installation. Thus major efforts are under way in energy storage research and development.

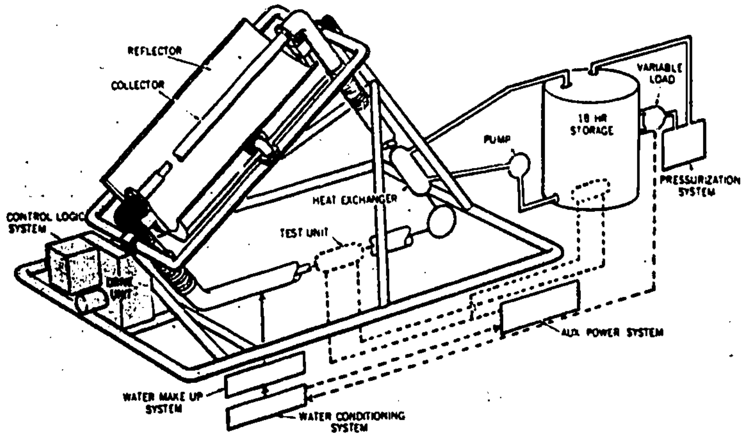
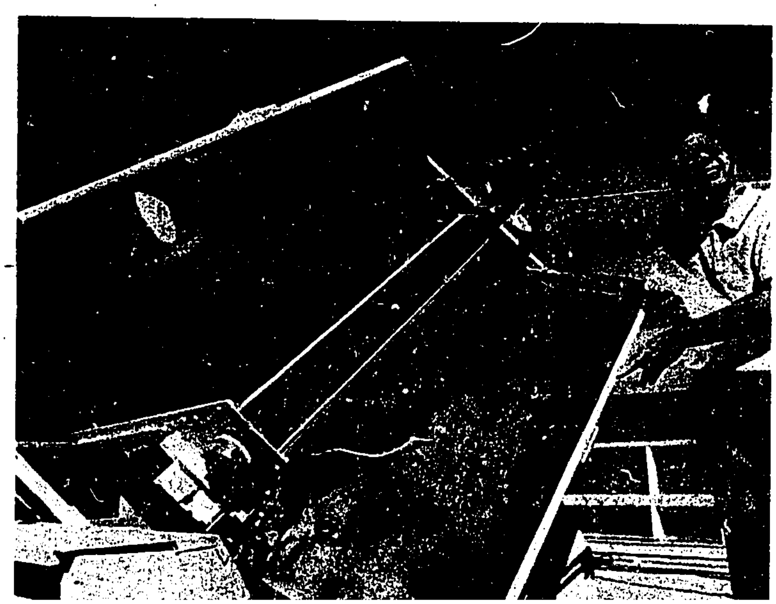


Figure 1 *The highly reflective curved metal plates on this solar collector cause the sun's rays to converge on the glass tube in the center. Water or another suitable fluid in the tube is heated by the sun, circulated through the tubes of the heat exchanger, and recirculated to pick up more heat. The heat is transferred in the heat exchanger to another fluid that is pumped to the storage tank where it can be used to produce electricity, provide air conditioning, and furnish hot water and heating for homes and other buildings. The work at ERDA's Sandia Laboratories in New Mexico is typical of research under way in university, industry, and national laboratories throughout the United States.*



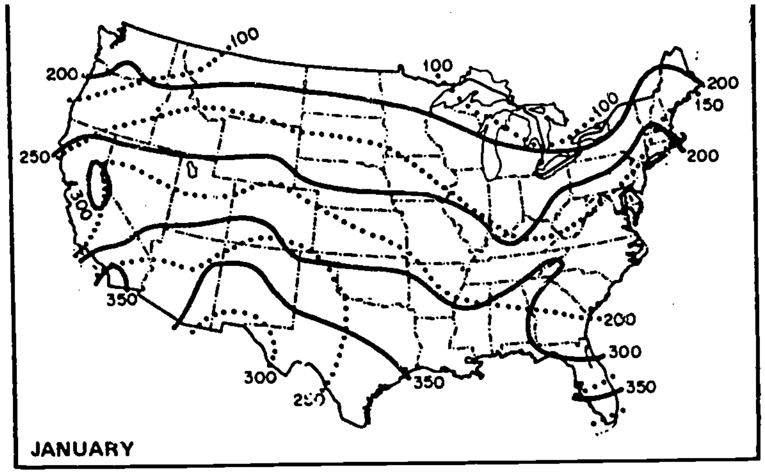


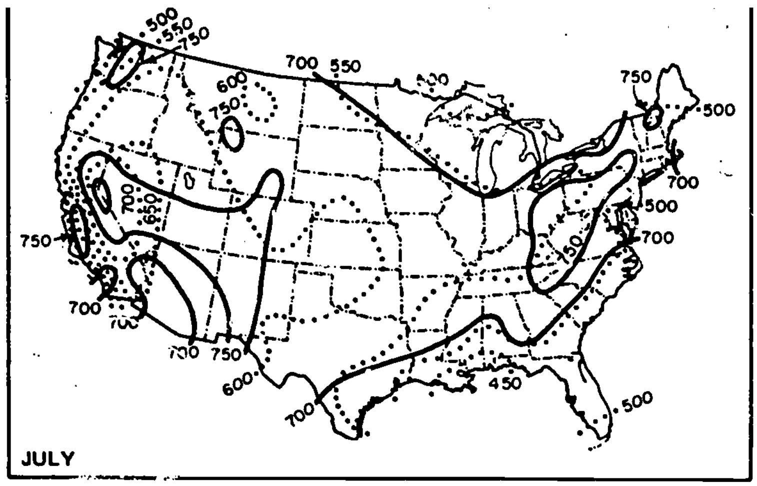
Figure 2 *Lines of equal total daily solar energy at the ground on cloudless days (solid lines) and on days of average cloudiness (dotted lines) in January and July. Units are calories per square centimeter per*

Of course, mankind has used solar energy for thousands of years. The winds, produced by unequal amounts of solar energy falling in different geographical locations, have been an important tool since earliest recorded history.

Winds that moved ships around the globe were the main source of energy for transportation for many centuries. Windmills are also an ancient way of harnessing solar energy. Even though windmills in many parts of the world have given way slowly to other kinds of energy sources, there is considerable interest now in reviving them as a supplementary source of energy; this is covered in more detail in Chapter III.

The sun's energy has also been used extensively by man simply as heat for a wide variety of applications. These are covered in Chapter II. The use of solar energy to generate electricity is outlined in Chapter III, while Chapter IV describes the possibilities of using solar energy to produce high quality fuels.

All these solar energy applications have a number of advantages in common: sunlight is inexhaustible compared with almost all other known available energy sources; it is



day. The annual average for the United States is 377, corresponding to 13% of the original energy of the sun. Expressed in American units, this is 58 Btu per square foot per hour.

constant as it arrives in the vicinity of the earth, even if the amount reaching the ground varies; and it is clean. The only environmental impact of significance to initial applications is aesthetic, i.e., there is a need to design solar energy facilities so that they are attractive.

One other advantage of solar energy is that the cost of the "fuel"—the rays of the sun—is zero. But that is counterbalanced by the initial cost of installing the equipment. Thus, for example, a homeowner using solar energy for heating will save on his bills for oil, gas, coal, or electricity. But this saving may be more than counterbalanced by the payments on the bank loan needed to pay for the installation of the solar heating plant. Nevertheless, the energy is there and, in a time of national and world energy supply problems, the United States has undertaken programs to harness it.

The purpose of this booklet is to present some basic information about the various applications of solar energy and the developments in technology that will be needed to use it more effectively for the benefit of mankind. Since our supplies of oil and natural gas are being rapidly depleted, it is

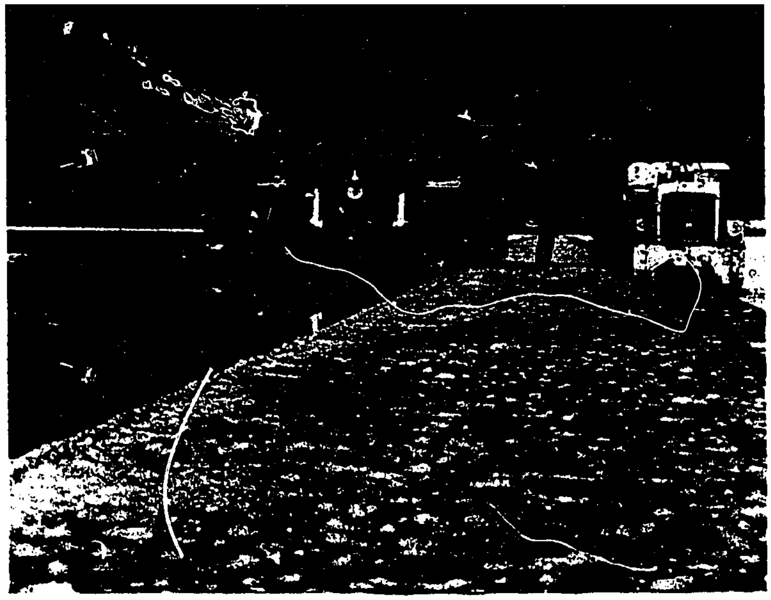


Figure 3 *Along the shore of San Francisco Bay, salt is harvested after seawater has been evaporated by solar heat. Between September and December this special machine sweeps up the 5- to 6-inch-thick layer of salt crystals and transfers it to the miniature train that runs on portable tracks across the salt beds. The machine is moving away from the camera and has already cleared the area to the left.*

necessary to develop other possible sources of energy—solar, nuclear, coal, geothermal, etc. Accordingly, this booklet covers what is being done in solar energy research, development, and demonstration programs under the leadership of a new agency of the Federal Government, the Energy Research and Development Administration (ERDA), which was formed in 1975.

(In this book, metric units are given first followed by U. S. units in parentheses. For example, 61 meters (200 feet). Please note that all the units have in general been rounded off to the same number of significant figures. See Appendix I on page 41 for a listing of basic units related to energy.)

Chapter II. Solar Energy Used as Heat

Aside from the more obvious uses of the sun's direct heat, such as drying food and warming people, the most common method of using solar energy directly has been in a greenhouse, which consists principally of glass and provides a controlled climate for growing plants.

While nothing could be much simpler than a greenhouse (see Figure 4), it is a surprisingly effective method of converting and trapping the sun's radiation in the form of heat. This is largely because ordinary glass can transmit the shorter wavelength visible portions of sunlight and at the same time prevent the passage of longer wavelength invisible heat waves.

The greenhouse principle is based on this specific property of common glass. A large portion of the visible energy of the sunlight enters the greenhouse through the

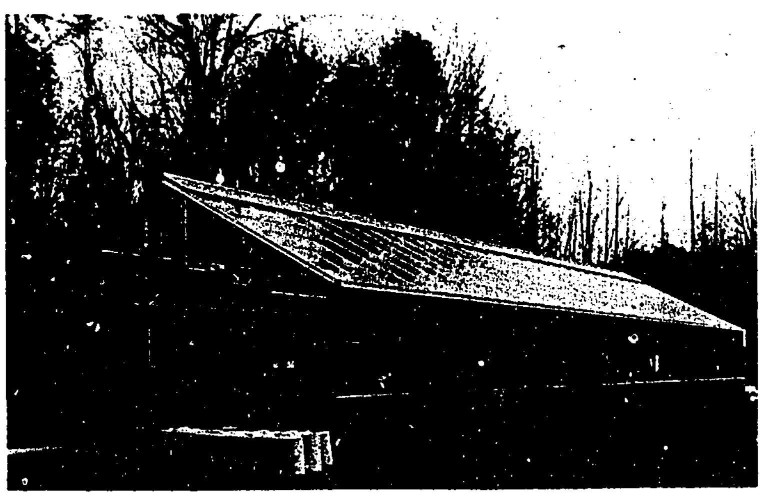


Figure 4 *One of the most common direct uses of solar energy is the greenhouse.*

Figure 5 *This augmented flat-plate solar energy collector is being tested at ERDA's Sandia Laboratories*

Figure 6 *Pupils and teachers at Timonium Elementary School in Maryland play volleyball in front of the wing that is heated by a solar energy system. Glass panels on the roof trap the sun's warmth, which then heats piped water.*

glass. When it is absorbed by the plants, ground, and fixtures of the interior, it is changed to longer wavelength heat waves that are retained by the glass and raise the temperature of the greenhouse interior. The principle operates on cloudy as well as sunny days and accounts for the effectiveness of this kind of building.

In order to capture the sun's energy for household and hot water heating, the same basic idea has been applied in the simple solar heat collector unit shown in Figure 7. A substantial part of the sun's energy passes through the glass cover plate, but after it is absorbed by the black background material, it cannot escape and heats the water circulating through the tubes. The heated water is then piped to storage tanks or radiators.

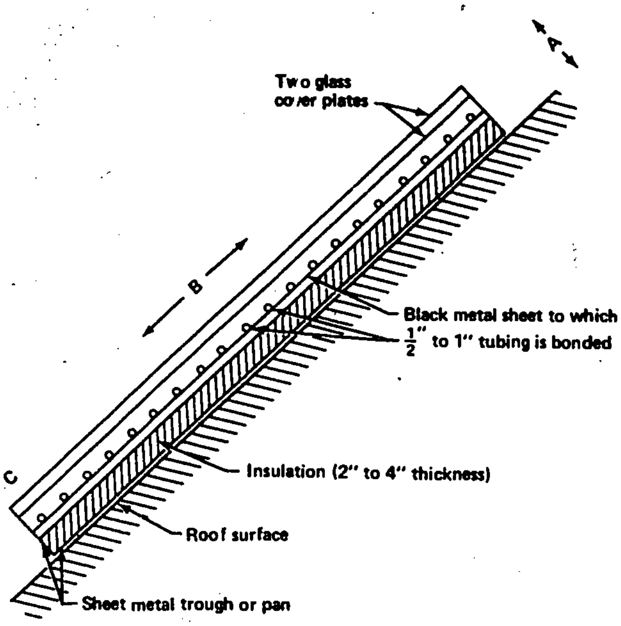
This type of collector unit, which can yield water with temperatures of 38°–93°C (100°–200°F), depending on conditions, has been employed extensively to supply domestic hot water in many portions of the world where sunlight is prevalent. Units of this kind are manufactured and sold in Australia, Israel, Japan, Russia, and to a very limited extent in the U. S.

Roughly one quarter of all United States energy consumption is related to space heating, water heating, and air conditioning. As U. S. energy supply problems have grown in recent years, interest has developed in the potential use of devices such as these to supply space heating needs as well as hot water. Several major experiments were carried out in 1974, and planning and construction work is under way on others.

In January 1974 the Federal Government issued contracts for the installation of solar heating to augment the conventional heating plants in four public schools. The first of these was completed in 6 weeks at the Timonium Elementary School in Timonium, Maryland, near Baltimore. The others were in operation before the end of the winter heating season of 1974 at the Grover Cleveland Junior High School in Boston, Massachusetts; the Fauquier County High School in Warrenton, Virginia; and the North View Junior High School in Brooklyn Park, a suburb of Minneapolis, Minnesota.

All the systems, using different kinds of collectors and with different capacities to store heat energy, worked satisfactorily. During the 1974-75 heating season, extensive data were collected on the operation and costs of the four systems.

The recent widespread use of air conditioning in the United States has focused attention on using solar energy for cooling instead of heating. Solar cooling, which is another important use of this resource, uses absorption refrigeration equipment of the type employed in gas-burning refrigerators and air conditioners. The solar heat simply substitutes for the gas flame.



Notes: Ends of tubes manifolded together one to three glass covers depending on conditions

Dimensions: Thickness (A direction) 3 inches to 6 inches
Length (B direction) 4 feet to 20 feet
Width (C direction) 10 feet to 50 feet
Slope dependent on location and on winter-summer load comparison

Figure 7 *Basic design of a solar collector for residential heating and cooling.*

For solar cooling, the engineering design challenge is somewhat greater than for solar heating. While lower temperatures are satisfactory for heating, cooling requires that the working fluid must be raised to a temperature of between 88°–93°C (190°–200°F). Solar air conditioners have been tested and operated at various locations for many months, and the test results indicate that they are quite effective. Air conditioning appears to be an attractive use of solar energy because cooling requirements for buildings are apt to be highest during the daylight hours and in the summer, when available solar energy is at its peak, and so there is not as great a need to store heat as there is when solar energy is used for winter heating.

If the design and production problems can be worked out successfully, the use of sunlight for both heating and cooling in a single installation seems to offer the greatest ultimate economic benefit. Such a system is shown in Figure 8 below.

Another important experiment, which was begun in 1974, uses a solar heating and cooling system and instruments to measure solar radiation. This equipment is carried

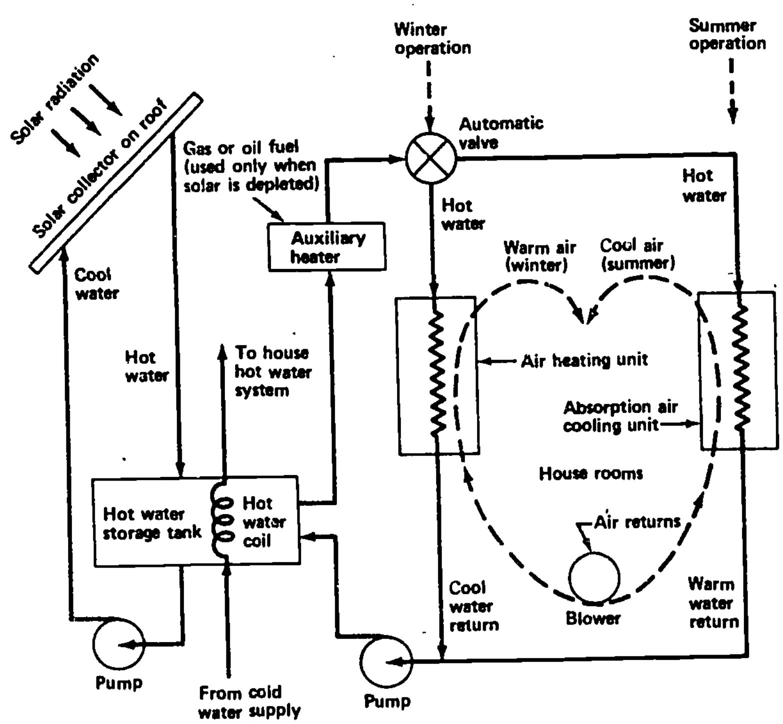


Figure 8 *This diagram shows a system that combines residential heating and cooling with solar energy.*

from place to place in two large trailers that join into a single structure at each location. By mid-1975, this laboratory had gathered data in a dozen states in the southwestern, southern, and Atlantic coastal regions of the United States, and was scheduled to cover the entire country by 1976.

Major significant solar cooling experiments were also begun in 1975. A cooling system was added to the school in Timonium, Maryland, and a combined solar heating and cooling system was installed at the Towns Elementary School in Atlanta, Georgia. These were the first tests of solar energy air-conditioning units of commercial size. The rated capacity of the Timonium unit is 126 kilocuries per second (150 tons) and that of the Atlanta unit 84 kilocuries per second (100 tons). Thus far, these absorption cooling units cannot be run at full capacity with solar power.

Congress and the Executive Branch of the Federal Government have begun to examine the problems of establishing the necessary industrial capacity for rapidly expanding the use of solar energy for heating and cooling. The first result, called "The Solar Heating and Cooling Demonstration Act of 1974", became law in September 1974 and ERDA is working in cooperation with other federal agencies to implement it. This legislation calls for two major demonstrations of the practical use of solar energy on a large scale as follows:

- Solar heating technology within 3 years.
- Combined solar heating and cooling technology within 5 years.

There is more to do, however, than merely solve design and production problems. Ways must be found to establish conditions under which banks and other lending institutions will provide funds for the purchase of equipment, both to be installed in new buildings and to be retrofitted on existing ones. Architects, builders, and heating and cooling engineers have to learn to use this new technology and to keep up to date with developments. Local building codes need to be

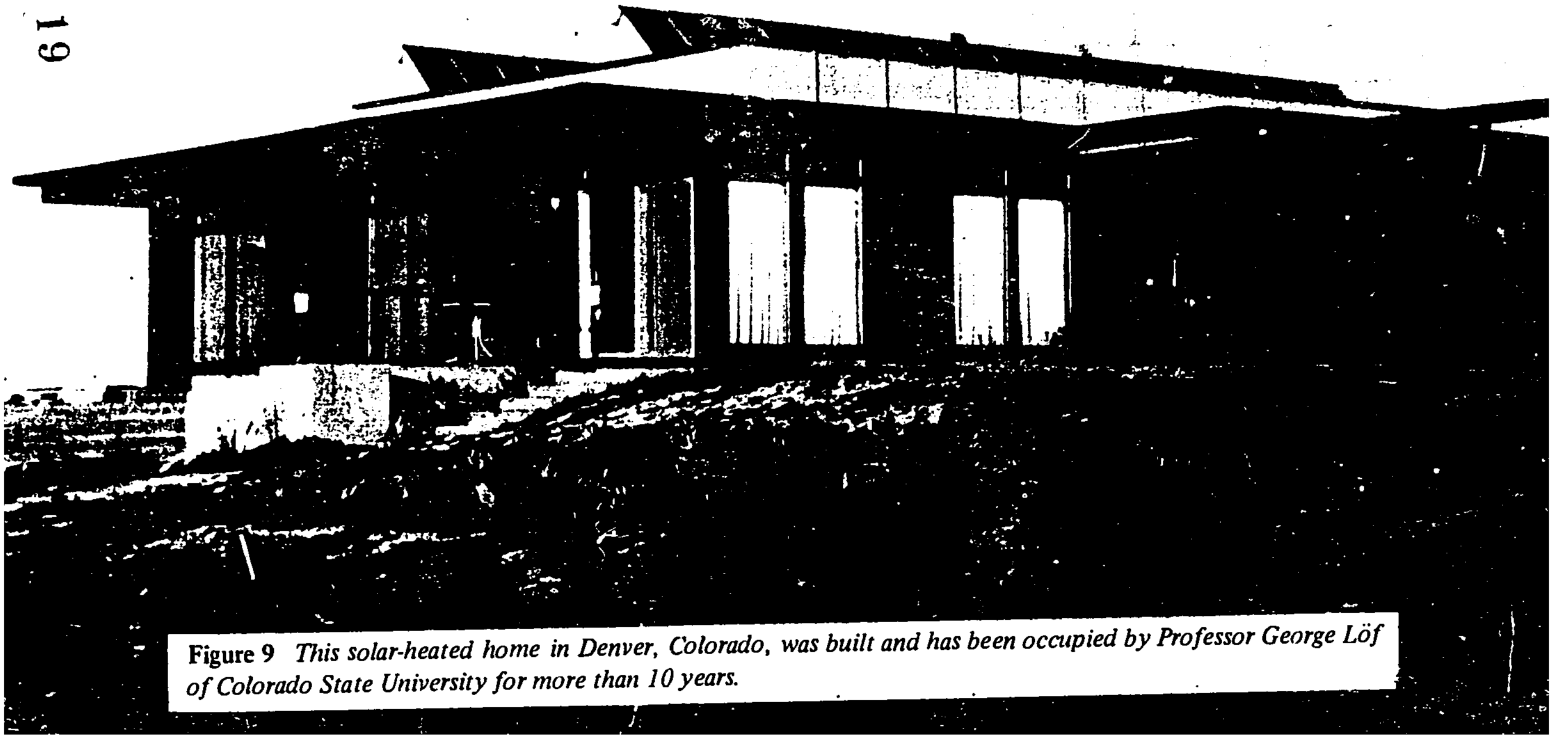


Figure 9 *This solar-heated home in Denver, Colorado, was built and has been occupied by Professor George Löf of Colorado State University for more than 10 years.*

studied to determine whether changes are needed. There is a need to consider whether laws should protect a building owner against the possibility that someone may build a high-rise just to the south that cuts off his supply of solar energy. Architects face a challenge in designing building modifications and buildings that are sufficiently attractive to potential residents as well as to neighbors.

Chapter III. Converting Solar Energy to Electricity

There are a number of different methods, direct and indirect, for converting solar energy into electricity (see Figure 10). This chapter will concentrate on four different techniques that have not been used extensively, but which show promise of expanded application as a supplement or possible replacement for other resources that produce electricity. (Plants and synthetic fuels produced by solar energy could quite possibly be used to generate electricity as well as to produce heat for other purposes. But since the primary objective in these processes involving photosynthesis is to produce general purpose fuels, rather than electric power as such, they have been treated separately in Chapter IV.)

Wind Energy

It is hard to believe that the fury and destruction of a tornado are the result of anything so benign as sunlight. However, the unequal heating of the earth's surface produces air masses of differing heat content and density (reflected in the pressure on a barometer) and creates a simple atmospheric heat machine that drives the winds. The problem is how to use them, since the winds are highly variable in place, time, and intensity.

Windmills were extensively used in Europe from the 12th to the 18th centuries, mainly for pumping water and operating machinery. They were eventually replaced by steam and diesel engines.

As the U.S. expanded in the 19th century, windmills again became popular, at first for pumping water and later for generating electric power.

Thus, there is nothing really new about using the wind to generate electricity or other useful forms of energy. The main reason windmills have been out of style for some time is that

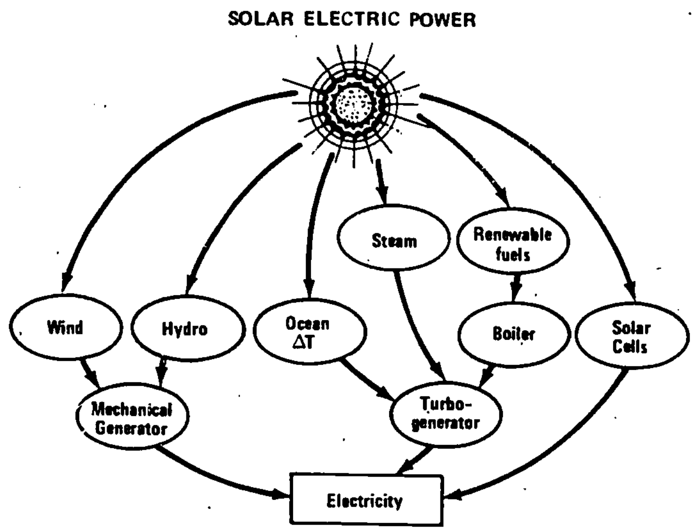


Figure 10 *This diagram shows the various routes by which solar energy can be converted to electricity.*

other energy sources, particularly centrally generated electricity now distributed to over 98% of U. S. farms, became relatively cheap.

Recent attempts to construct windmills of larger size to produce greater quantities of electricity have not been economically successful. In Denmark in 1915, wind power generated over 134,000 horsepower (100 megawatts), but cheaper hydroelectric power eventually became too competitive. In the U. S. in the 1940s, a 1675-horsepower (1.25-megawatt) machine in Vermont became inoperable because of structural failure, and it was never restored to full operation. Again, the primary deterrent to restoration was an economic one.

A large wind-powered electric generator under the joint sponsorship of NASA and ERDA is at the Sandusky, Ohio, site of the Government's Lewis Research Center. A 38-meter (125-foot) diameter rotor blade mounted on top of a 38-meter tower is designed to generate 134 horsepower (100

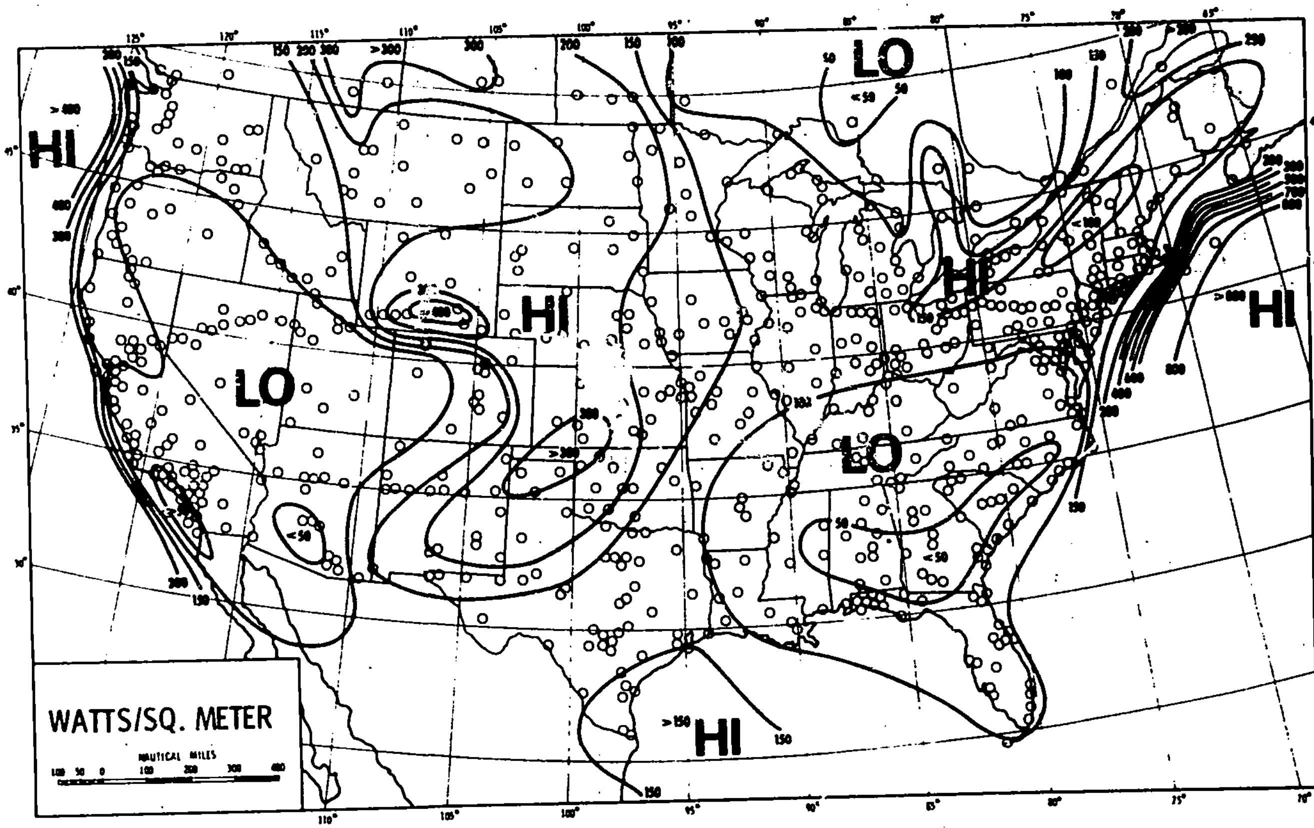


Figure 11 *Annual average of available wind power.*

kilowatts) of power. Work is also under way on a much larger machine that will use blades up to 61 meters (200 feet) in diameter. In addition, researchers in university, industrial, and national laboratories throughout the U. S. are carrying out a wide range of studies and experiments in wind energy conversion technology, wind characteristics, mission analyses, applications and systems analyses, as well as large wind energy systems for various purposes.

It remains to be seen how much of the total available wind power can really be utilized. Much depends on the size and number of windmills and their location. The challenge to proponents of wind energy is to design systems that work effectively with existing power distribution networks. As other energy sources become relatively scarce and more expensive, there could be a significant return to this ancient power source with its variable but often predictable output integrated with more common means of generating electricity.

Solar Thermal Conversion

Since lenses or mirrors can focus the sun's rays so as to set combustible materials on fire, it seems logical that the same method could also be used to create steam and produce mechanical forces. This is the basis for the concept involving the concentration of solar radiation by lenses, curved mirrors, or other collectors so that high enough temperatures can be reached to produce steam for a turbogenerator that produces electricity. To obtain sufficient energy for such purposes the solar collectors must be distributed over a broad area. This energy is brought together by one of two approaches: Either the energy is reflected from the field of collectors to a single receiver or a working fluid carries it through an insulated heat pipe to the location where it is utilized. Figure 12 shows one concept for a central receiver.

There are no basic technical limitations in this method. The main questions are overall efficiency and economics. As long ago as 1913, a solar power plant built in Egypt used a curved reflecting mirror to focus the sun's rays on a pipe carrying water. The steam thus generated operated a 37-kilowatt (50-horsepower) steam engine (see Figure 13).

As a result of high-temperature selective coatings developed in the space program, temperatures can now be reached that make possible the use of standard steam turbogenerators. This makes it practical to use lower precision—and hence less expensive—lens and mirror systems for concentrating the sun's heat. Researchers in university, industrial, and national laboratories throughout the country are investigating a wide variety of imaginative approaches to this problem.

Solar thermal conversion systems have the following basic elements: (1) A concentrator to focus the sun's rays; (2) a receiver to absorb the radiant energy; (3) a means for transmitting the heat to either a storage facility or directly to the turbogenerator; (4) a means for storing the heat for use at night and while the sun is not shining; and (5) a turbogenera-

Figure 12 *Concept of a solar thermal central receiver.*

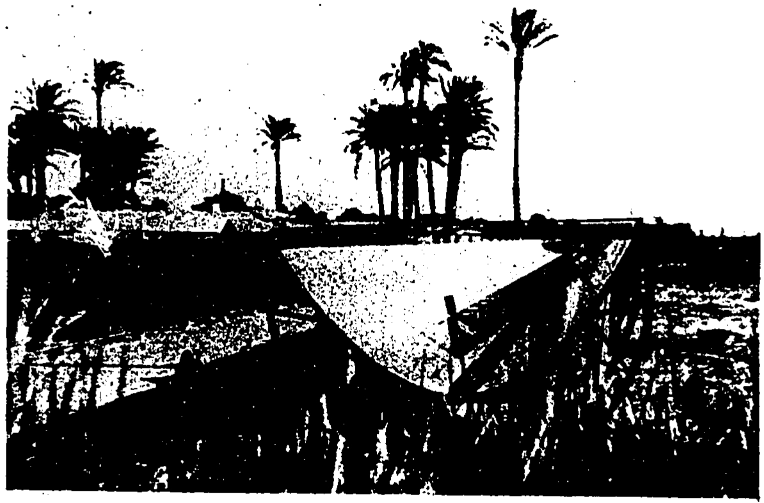


Figure 13 *In 1913, the Shuman-Boys solar power plant in Meadi, Egypt, was successfully powered by solar steam along the banks of the Nile River.*

tor that converts the heat energy of the steam into mechanical energy and, in turn, electricity.

There are many variations of this concept. One of the objectives in all such systems is to produce steam at as high a temperature as possible. When steam is used to produce mechanical work, the higher the initial steam temperature, the more efficient will be the conversion of heat to work.

As mentioned earlier, sunlight is diffuse and must be collected over a wide area. It is estimated that in the southwestern part of the U. S., approximately 26 square kilometers (10 square miles) would be needed to operate a 1,340,000-horsepower (1000-megawatt) plant working at an average capacity of 60%. (This is enough power to supply a city of 1 million people.) The initial cost of such a system would be several times that of a conventional power plant, but, as in all solar energy utilization schemes, the "fuel" (sunshine) is free. The principal aim of the research and development in progress is to find ways to build such systems that will operate reliably at costs low enough to make them economically attractive.

Substantial technical progress has been made in materials that reflect and absorb solar energy (items 1 and 2 above) and in developing heat transfer technology (item 3), but there is no present economically attractive solution to the storage problem (item 4). Turbogenerator technology (item 5) is well developed. The ERDA program includes demonstrations of technical feasibility by small solar thermal pilot plants, which will also assist in determining the economic feasibility of these concepts.

The environmental aspects of this method are generally favorable. The main environmental problem would be the

Figure 14 *This experimental four-bedroom, full-basement house at the University of Delaware obtains 80% of its power, heat, and air conditioning from the sunshine that falls on its roof and front walls. Part of this is converted directly to electricity, with a reserve stored in batteries; part is stored as heat in a 6-foot cube of special salts from which heat is withdrawn as needed.*

proper disposition of the heat given off by the condensers of the steam turbines, which is an important problem for all steam-electric plants. The ERDA program includes the design and demonstration of total energy systems in which this "surplus" heat would be used for the heating and cooling of buildings and for industrial purposes.

Photovoltaic Conversion (Solar Cells)

For millions of years, the solar energy in the winds has been creating electricity indirectly in the form of lightning, but it has only been since man has gone into space that he has developed the technology for converting the sun's radiation directly into electricity on a significant scale. The basic units that accomplish this are called solar cells.

In certain substances, the absorption of light creates an electrical voltage that can be used to generate electric current in an external circuit without any additional power sources. This process is called the photovoltaic effect. At the present time, the materials that are used commonly are silicon, cadmium sulfide, cadmium telluride, and gallium arsenide.

The most familiar applications to date for solar cells have been in the space program and in photographic light meters. These cells have supplied most of the electricity for a variety of space vehicles, which could not have operated without them.

Solar cells also have important potential applications on earth in such diverse applications as remote sensing devices, harbor and buoy lights, fire telephones, and microwave repeater stations, where in most cases they are connected to batteries that store the electrical energy for use when the sun is not shining. The size and type of the solar-cell panel and battery needed depend on the power required, the sunlight available, and the geographical location.

To make large central installations of solar cells economically attractive, the cost must be reduced very substantially. At present an array of silicon solar cells measuring 25 centimeters (10 inches) square and costing about $50 would be needed to generate 1 watt. It is generally considered that this cost must be reduced by at least a factor of 100 before solar cells could compete for widespread use as substantial producers of electricity. However, research has produced significant improvements in manufacturing methods and quality control, and the outlook seems good for further progress. Hopes for lowering the cost of solar collectors were raised when recent experiments showed that continuous ribbons of crystalline silicon could be produced routinely in large quantities if more automated equipment were adapted to a mass production system.

If the cost of solar cells is sufficiently reduced and economical storage techniques become available, solar cells could be used on a large scale, either as elements in the central power system of a utility network or as on-site power supplies to meet the requirements of individual residences

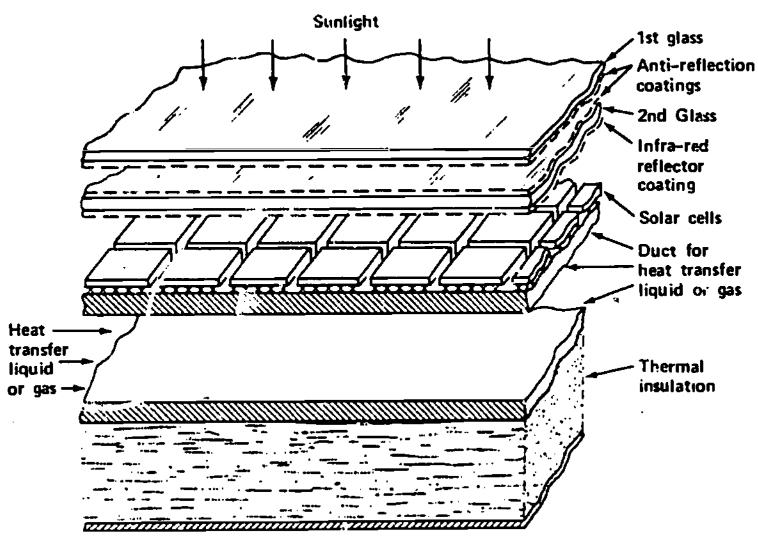


Figure 15 *Combination collector arrangement to extract both electrical and heat energy from sunlight.*

and other buildings. For example, a 6- x 9-meter (20- x 30-foot) panel of solar cells operating at an efficiency of only 10% and with a peak output capacity of about 6 horsepower (5 kilowatts) at midday in the northeastern U. S., would yield an average of approximately 1 kilowatt over the entire year. This is more than the electrical consumption of the average house. However, since it is unlikely that it will be economically attractive to store electricity on a large scale to make up for the variations in available sunlight throughout the year, auxiliary electricity sources would probably also be required.

Looking to the future, however, when heat and electric storage technology is improved and the cost of solar cells is sharply reduced, the concept of a combination solar battery and heat collector for an individual residence or other building offers attractive possibilities.

A combination thermal-photovoltaic solar collector is shown in Figure 15. Under favorable conditions of cost and technology, a panel or array of such collectors mounted on the roof or in some other place would be capable of supplying the total power requirements of the interior of a house. This would eliminate the need for many electrical transmission lines and central power generating stations with their environmental problems and large fuel requirements. It is estimated that such combination cells could extract as much as 60% of the incident solar energy.

A schematic presentation of the overall arrangement visualized in this concept is shown in Figure 16.

Included for completeness are such features as auxiliary power connections, the possibility of using organic wastes (see Chapter IV), the use of an electric vehicle, and the provision for air conditioning as well as heating functions.

The system described above represents a fully integrated combination of a number of different subsystems. Such a complex arrangement would not be necessary, however, to use solar cells on a more limited basis to produce electricity

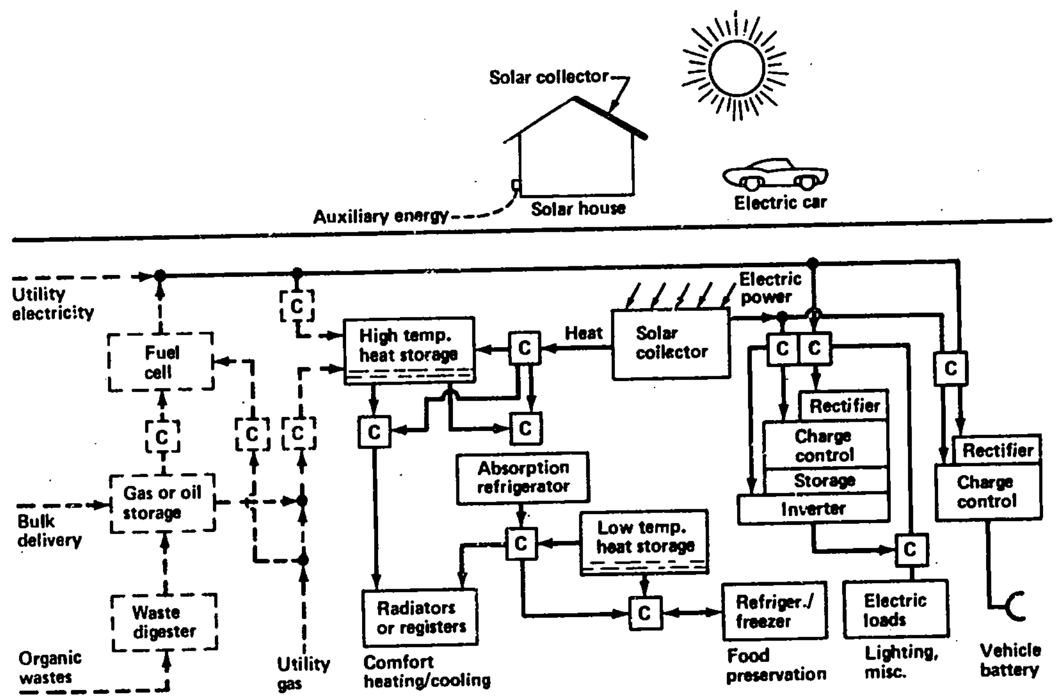


Figure 16 *System for comprehensive utilization of solar energy in a residential building.*

for localized use in buildings of various kinds to supplement other sources.

The ERDA program also includes wide-ranging studies and experimentation aimed at large-scale, low-cost generation of electricity by photovoltaic means.

Energy from Tropical Ocean Temperature Differences

A large portion of the total solar energy received by the earth is absorbed in the waters of the tropical oceans, and thus the surface temperature of these oceans is maintained at about 28°C (82°F).

At the bottom of these oceans, however, are the much colder waters, which are produced by the alternate melting of the northern and southern polar ice caps during their respective summers. Thus, beneath 58 million square miles of tropical ocean, there is a continuously replenished supply of water at 1°–3°C (35°–38°F). Much of this is as close as 610 meters (2000 feet) below the surface level of the warm water described above. Both the warm and the cold water layers are replenished continually by the direct or indirect effects of solar energy. The problem is to find a way of using this 27°C (45°F) temperature difference to operate a heat engine, even if only at low efficiency.

It was suggested in 1881 and shown experimentally in 1930 that significant amounts of heat could be converted to electricity by using the warm surface water of the sea as a heat source and the cold water pumped from the depths as a heat sink.

This thermal energy can be converted to electrical energy by using the open or closed cycle methods. In the open cycle, seawater is used as the working fluid. The warm water is flash-evaporated in partial vacuum, the water vapor runs a turbine, and the vapor is cooled in a condenser using cold water. In the closed cycle, a working fluid, such as ammonia or propane, is vaporized by the warm water, the vapor propels a turbine, and the vapor is cooled in a condenser

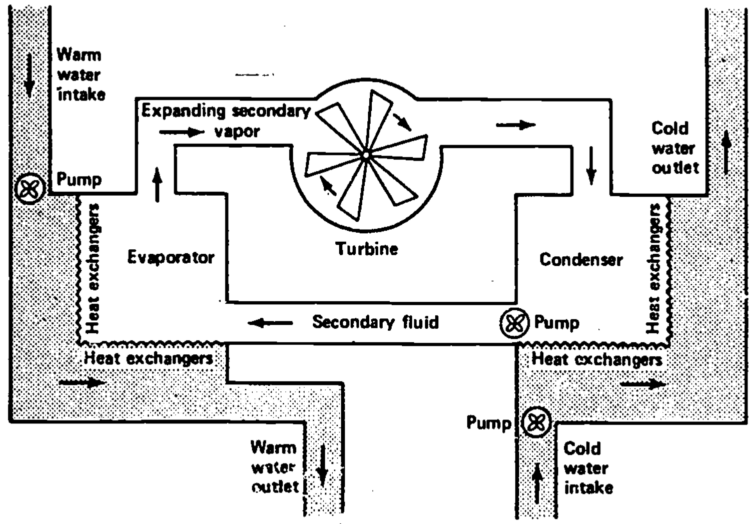


Figure 17 *Diagram of a closed cycle ocean thermal power plant.*

using cold water. This cycle, shown in the figure, resembles a refrigeration cycle and is the one that will probably be used when ocean thermal plants are built. These plants will be incorporated in a floating hull containing heat exchangers, one or more turbines, generators, and pumps.

Large floating power plants, located close to populated areas, could extract large quantities of ocean thermal energy and transmit electrical energy to shore via a submarine cable. A likely outgrowth of this research will be the development of land-based ocean thermal power plants. However, there are a limited number of suitable locations for these plants because of a scarcity of shore-front land with a steep off-shore gradient and an adequate year-round thermal energy resource. The thermal energy resource of the oceans is thus available mainly at sea in the tropical and temperate latitudes.

Chapter IV. Converting Solar Energy to Plants and Fossil Fuels

The "magic" action of sunlight in stimulating the growth of plants is one of the most fascinating phenomena of nature. This process, called photosynthesis, occurs when sunlight interacts with chlorophyll, water, and carbon dioxide to produce the great variety of organic materials that compose plants.

As pointed out in Chapter I, the conversion of solar energy into organic plant materials and their subsequent transformation in prehistoric times into natural gas, petroleum, and coal, has provided the world with its fossil-fuel energy supply.

In addition to using solar energy to produce direct heat or electricity, as discussed in Chapters II and III, there is the possibility of providing large additional supplies of high-quality concentrated fuels through the managed production of various kinds of plant tissue formed by photosynthesis. These materials would include trees, grasses, and various water plants, such as kelp, water hyacinths, and microscopic algae.

These plant materials, which hopefully would be grown under conditions in which solar energy is used more efficiently than it is under natural conditions, have a relatively low heat content per unit of weight. An essential part of the whole process, as now conceived, would be to devise methods of converting these basic plant materials into higher heat content fuels, such as gases, liquids, and solids, which would be similar in many ways to the natural fossil fuels found in the earth.

Theoretically, it has been calculated that the entire electrical needs of the country could be met by the

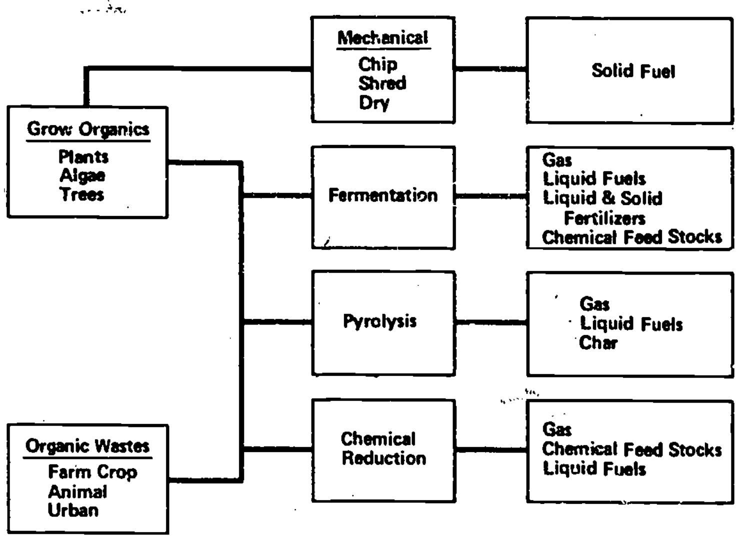


Figure 18 *Various methods of producing different kinds of fuels from solar energy.*

large-scale cultivation of plants over a moderate portion of the land and water in the U. S., particularly if efficiencies of solar energy conversion could be achieved that are greater than those now common in agriculture. Although some of the resulting substances could be used directly as fuels in power plants, they could alternatively be converted into more concentrated fuels of higher quality, by drying, heating, fermentation, thermal conversion, or chemical reduction. Chemical feedstocks for industry could also be derived.

The overall concept includes the feasibility of applying conversion processes to other available organic materials, particularly the solid wastes (agricultural, animal, industrial, and urban), which are now causing serious environmental problems and a loss of valuable energy resources.

A schematic diagram showing the production of fuels by these various methods is shown in Figure 18.

The amount of energy available from the total quantity of animal and urban wastes now being produced (assuming that collection of these materials could be economically accomplished) has been calculated to represent about 6% of present energy requirements for generating electric power. The pyrolysis (high-temperature decomposition) of organic wastes to produce various fuels has already been demonstrated in several countries, including the United States. Laboratory experiments have also established the feasibility of thermal-chemical treatment of organic fuels to produce liquid fuel, such as methanol, and biological treatment to produce methane gas, simple sugars, and ethyl alcohol.

Also under investigation is the possibility of producing hydrogen gas by photosynthetic processes as applied to plants or algae. Such a process has been demonstrated in small-scale laboratory experiments. The advantages of hydrogen as a clean fuel and a means of generating electricity through fuel cells makes the idea attractive. Substantial

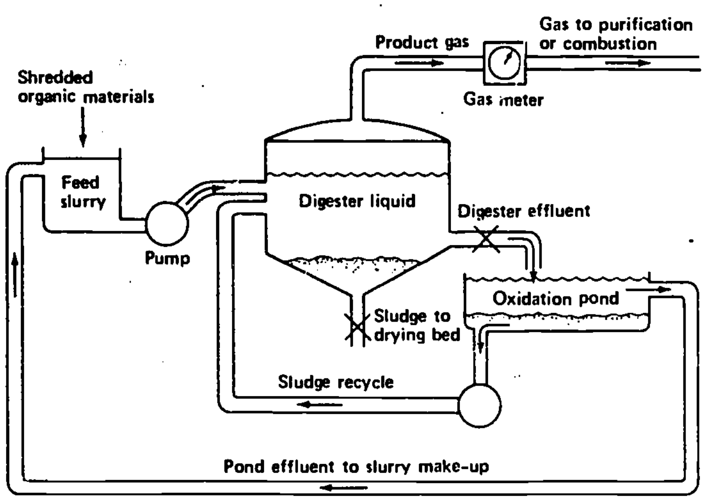


Figure 19 *Concept of a unit for continuous conversion of organic material to methane by anaerobic fermentation (without oxygen).*

additional research, pilot plant operations, and economic studies will be required, however.

Still another concept is the idea of converting various organic materials to methane—which is a clean, high heat content fuel—by fermentation or similar processes. One proposed process is shown in Figure 19.

It has been calculated that if the entire amount of economically recoverable solid organic waste (agricultural, animal, industrial, and urban) could be subjected to such a fermentation process, it would represent about 5% of the current yearly consumption of methane in the U. S. Technical feasibility has already been established, and the next logical step is to evaluate the economic aspects of the process.

There are many different variations and possibilities for producing much larger quantities of fuel by the improved use of solar energy and the application of photosynthetic and various other chemical processes, but these require much further technical and economic study. The collection and processing of all the various materials involved, even assuming they could be grown and processed efficiently, constitutes a substantial challenge, and there are also other difficulties. A program of this kind can succeed only if the economic and other nontechnical problems are solved. Current estimates indicate that about 15% of the projected energy requirements of the U. S. could easily be satisfied within the next 30–35 years by energy sources resulting from bioconversion to fuels.

Chapter V. Energy Planning for the Future

The basic problem of energy planning for the nations of the world is to provide for future energy supplies on an earth that is rapidly depleting its limited deposits of oil and natural gas, while demanding constantly increasing amounts of energy.

This booklet has attempted to show the role for solar energy by outlining facts about various possibilities and technical challenges for its more efficient use in the future.

The fact that our fossil fuels were indirectly formed by solar energy is interesting historically, but does not help much in solving future energy supply problems. The production of fossil-like fuels to meet our mounting needs would probably require devoting such extensive land areas to energy-related plant growth that other vital land uses would be severely and unacceptably affected.

However, the total solar energy falling upon the earth is very much greater than current or projected demands by mankind. The challenge is how to use even a small fraction of this vast energy resource effectively and economically.

In trying to meet this challenge, the following oversimplified but objective summary of the good and bad news about solar energy may help to develop a balanced view regarding its future potential.

The good news is that solar energy is free, clean, and inexhaustible. The bad news is that it is intermittent, undependable in many locations, and diffuse. Many solar energy applications involve the use of techniques that need to be improved and made more economical through research, development, and demonstrations.

With regard to current U. S. energy use, it would be reasonable to describe our present situation as a kind of

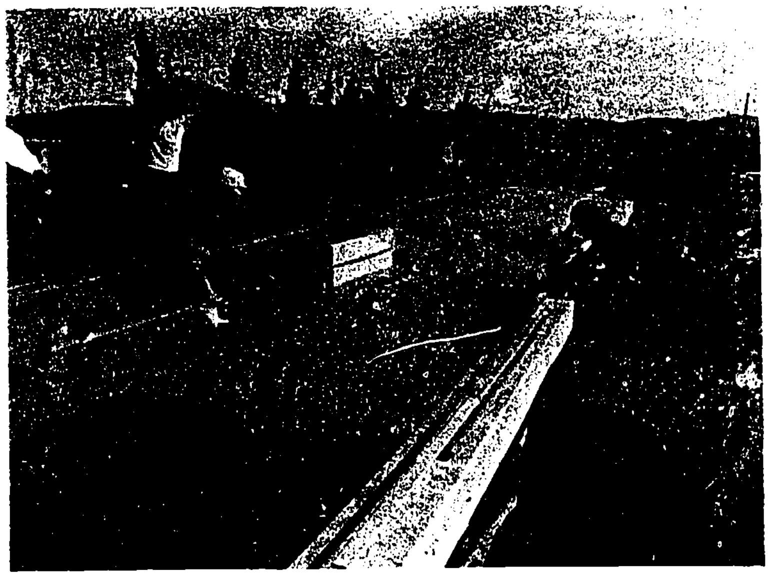


Figure 20 *At ERDA's Lawrence Livermore Laboratory in California, water passing slowly through these shallow ponds, which are insulated and covered with plastic, is heated by the sun up to 170°F. This hot water is estimated to cost one-third as much as fuel-heated water. The possibilities of its practical use for industrial processes, or to boil a refrigerant fluid to turn a turbine and generate electricity, are being investigated.*

"fossil" economy, since about 95% of the energy we use comes from such sources. There is also little doubt that our overwhelming dependence on these limited fuels must soon give way to other sources. Since no single source is certain to provide for all of our needs in fully acceptable fashion, several different alternative energy sources are being explored. A partial solution is to use nuclear fuel, whose contribution to electric power generation has already grown from 2% in 1970 to 6% in 1974 and is expected to continue to increase. Another new and growing source is geothermal energy, the natural heat of the earth, which, if it can be tapped and distributed economically, will also provide significant quantities of heat and electricity.

A complete picture of the projected energy flow in the U. S. in 1970, including the major inputs and outputs, is shown in Figure 21.

The generation of electricity in the U. S. has roughly doubled every decade for the last half century. Only 6% of the world's population lives in the U. S., yet we generate and use one-third of all the electric power in the world. The main reasons for this continued rise have been:

1. The steady population growth, although this is now at a much lower rate.

2. The increased use of electricity in the average household for laborsaving and convenience equipment and devices, especially air conditioning.

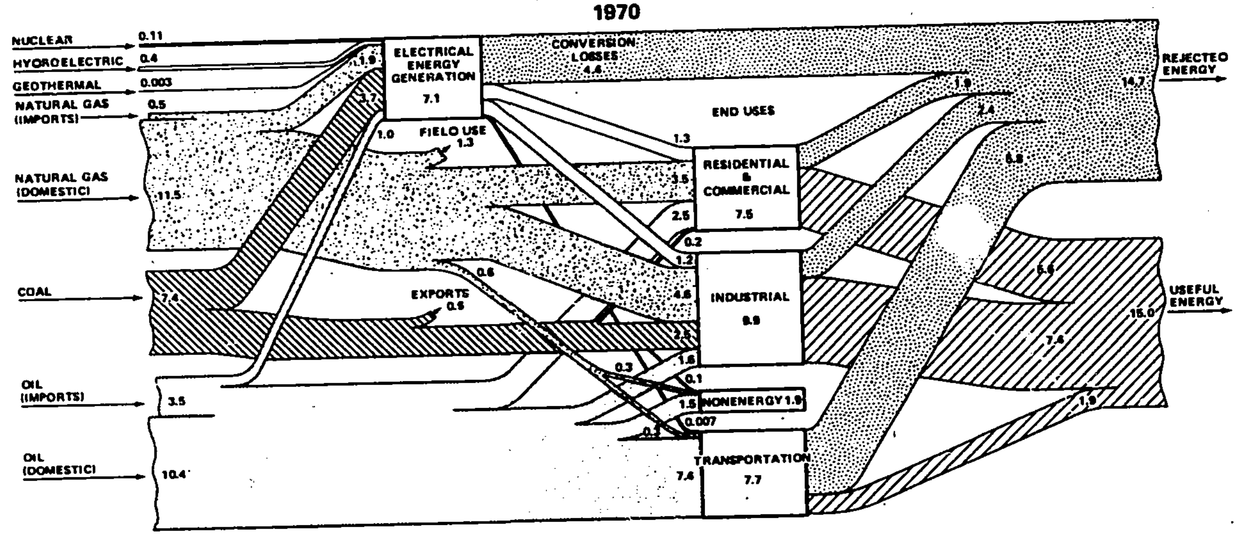
3. The extension of the benefits of electricity to a wider segment of the population (for example it now goes to 98% of all farms) and particularly to those at lower income levels.

This steady uninterrupted growth of the generation and use of electricity has led to the idea that we are entering an era that could be called an "electric economy," which might eventually become distinct and different from the fossil economy.

Today, about one quarter of all energy resources are consumed in the generation of electricity. In the preceding sections of this booklet, we have seen how solar energy can also be applied in many different ways, directly and indirectly, so that its utilization in the future can be flexible and varied. If machinery to convert solar energy into electricity can be produced at competitive prices, a substantial and useful total contribution to tne electric economy will result.

If much improved electricity storage techniques are developed, the utility of solar conversion units would be still further enhanced, and they could take over, for instance, a significant portion of the electricity requirements of individual households.

U. S. ENERGY FLOW
1970



(UNITS: MILLION BBLS./DAY OIL EQUIVALENT)

Figure 21

41

In the future, solar energy might also play an important part in what has been called the hydrogen economy, a term that describes the situation that might develop in the future as a kind of alternative to the electric economy. The hydrogen economy would be based on the large-scale distribution, storage, and varied end use of hydrogen as an intermediate and final energy source. Conceivably, hydrogen could be the end product of central nuclear, fossil, geothermal, and solar power plants. Thus hydrogen may be a solution to the problem of storing solar energy until it is needed.

It therefore seems evident that solar energy utilization would have a role to play in either an electric or a hydrogen economy. It is still too early to predict which of these conditions might develop in the future or whether the outcome would involve some combination of the two.

It is reasonable to hope that the solar energy programs will succeed and that this alternative will indeed be used much more effectively for mankind in the foreseeable future. To the extent that solar energy can substitute for fossil and nuclear fuels, their depletion will be reduced and associated environmental problems alleviated.

Conclusion

Of the various solar applications, heating and cooling is the one that can make the most immediate impact. The widespread use of energy from the sun to heat and cool buildings and to supply energy for commercial applications would have a significant effect on the Nation's supply and consumption of energy. If only 1% of the buildings in the U. S. were now equipped with solar heating and cooling systems, about 30 million barrels of oil would be saved annually. In general the problem is to stimulate the production and marketing of reliable, low-cost solar heating and cooling systems. Wind energy and production of fuel by biological processes also give promise of relatively near-term benefits.

In the total energy picture, solar is one of the major alternative sources and offers the promise of making significant and long-range contributions to the solution of our energy problems. Therefore, it is essential to move ahead in research, development, and demonstration of potential solar applications.

Bibliography

Reports

These reports are available from the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402:

Solar Energy As A National Energy Resource (3800-00.64), National Science Foundation/National Aeronautics and Space Administration Solar Energy Panel, December 1972, 85 pp., $1.20.

Solar Energy (4118-00012), submitted by Interagency Task Force to the Federal Energy Administration for Project Independence Blueprint, November 1974, $6.20.

Solar Energy Utilization for Heating and Cooling (3800-00188), American Society of Heating, Refrigerating and Air Conditioning Engineers, 1974, 20 pp., $0.70.

These reports are available from the ERDA Technical Information Center, P. O. Box 62, Oak Ridge, Tennessee 37830:

National Program, Solar Heating and Cooling (ERDA-23-A), September 1975, 130 pp., free.

Solar Energy Program (ERDA-15), March 1975, 15 pp., free.

National Solar Energy Research, Development, and Demonstration Program: Definition Report (ERDA-49), June 1975, 100 pp., free.

Books

Direct Uses of the Sun's Energy, Farrington Daniels, Ballantine Books, Westminster, Maryland, 1974, 271 pp., $1.95.

The Coming Age of Solar Energy, Daniel S. Halacy, Avon Books, New York, 1975, 248 pp., $1.95.

Energy Primer: Solar, Water, Wind and Biofuels, Portola Institute, 1974, The Whole Earth Truck Store, 558 Santa Cruz Avenue, Menlo Park, California, 94025, 200 pp., $4.50.

Solar Science Projects, Daniel S. Halacy, Scholastic Book Services, 900 Sylvan Avenue, Englewood Cliffs, New Jersey 07632, 1974, 96 pp., $0.75.

Appendix I: Basic Units Related to Energy

Electrical

The number of amperes in an electrical circuit multiplied by the voltage equals the number of watts of power or the rate at which energy is being consumed.

More briefly:

volts x amperes = watts
1000 watts = 1 kilowatt
1000 kilowatts = 1 megawatt (one million watts)

The number of watts multiplied by the time in hours equals watt-hours or the total energy expended in that time.

More briefly:

watts x hours = watt-hours
kilowatts x hours = kilowatt-hours
megawatts x hours = megawatt-hours

Note: Watts can be visualized as similar to the speed (mph) of a moving automobile, whereas watt-hours are similar to the total distance the automobile travels in a number of hours (corresponding to the total energy consumed on the trip).

Example: A car doing a steady 40 mph will go 40 miles in 1 hour, 80 miles in 2 hours, etc. Similarly, an electrical device using energy at the rate of 40 watts will consume a total of 40 watt-hours in 1 hour, 80 watt-hours in 2 hours, and so on.

Heat

A British Thermal Unit (Btu) is the amount of heat energy that will raise the temperature of 1 pound of water 1° Fahrenheit.

A calorie is the amount of heat energy that will raise the temperature of 1 gram of water 1°Celsius (Centigrade Scale).

Temperature

On the Fahrenheit scale, water freezes at 32°F and boils at 212°F.

On the Celsius (or Centigrade) scale, water freezes at 0°C and boils at 100°C.

To convert a temperature from Fahrenheit to Celsius, subtract 32 and multiply by $\frac{5}{9}$.

Example:

$$86°F - 32 = 54$$
$$54 \times \frac{5}{9} = 30°C$$
$$86°F = 30°C$$

To convert a temperature from Celsius to Fahrenheit, multiply by $\frac{9}{5}$ and add 32.

Example:

$$20°C \times \frac{9}{5} = 36$$
$$36 + 32 = 68°F$$
$$20°C = 68°F$$

Mechanical

One horsepower (hp) is arbitrarily defined as the rate of expenditure of energy required to raise a 550-pound weight 1 foot in 1 second.

Length

1 inch	= 2.54 centimeters
1 foot	= .3048 meters
1 mile	= 1.609 kilometers
1 centimeter	= .394 inches
1 meter	= 3.28 feet
1 kilometer	= .624 mile (about 5/8)

Useful Conversions

746 watts	= 1 horsepower (hp)
1 kilowatt (1000 watts)	= 1 1/3 hp
1 Btu	= 252 calories
1 Btu per hour	= .2931 watts
1 watt	= 3.412 Btu per hour

Appendix II: Management of Solar Energy Activities

The research, development, and demonstration of solar energy utilization make up a complex undertaking involving all levels of government as well as wide representation from industry, universities, and private individuals. At the federal level, significant research activities in the use of solar energy on earth were begun in 1971 by the National Science Foundation (NSF) and the National Aeronautics and Space Administration (NASA). Lead federal responsibility was held by NSF from 1973 until the establishment of the U. S. Energy Research and Development Administration (ERDA) in 1975.

The Department of Housing and Urban Development (HUD) shares with ERDA the responsibility for carrying out residential demonstrations of solar heating and cooling. The Department of Defense is selecting and conducting a substantial number of solar heating and cooling demonstrations on military installations. The General Services Administration is recommending federal buildings for installation of demonstration systems. The Postal Service and the Department of Agriculture are considering use of solar heating and cooling systems in their facilities. The National Bureau of Standards is at work on performance criteria and test procedures for solar heating and cooling equipment. NASA supports ERDA in several areas of the utilization of solar energy—providing testing, evaluation, and development of heating and cooling equipment, conducting wind energy research and development, and carrying out research and development of photovoltaics. Several other federal departments and agencies are active in solar energy in areas related to their basic missions.

State and local governments are involved in many areas of the economic, legal, and financial aspects of solar energy. Industrial concerns and trade associations are engaged in design and development, as well as commercial manufacturing and building. Electric utilities will be involved in large-scale use of solar-generated power.

Appendix III: Public Participation in the Research, Development, and Demonstration Program

The Energy Research and Development Administration (ERDA), the principal agency in solar energy research and development, is the source of funding for most solar energy projects. The Solar Energy Program of ERDA includes direct thermal applications (solar heating and cooling of buildings, and agricultural and industrial process heat), solar electric applications (wind energy conversion, solar photovoltaic conversion, solar thermal and ocean thermal energy conversion), and fuels from biomass. The solar heating and cooling of buildings subprogram is presently divided into three categories: residential demonstrations, commercial demonstrations, and research and development.

Those wishing to review solicitations in all the above categories with the exception of residential solar heating and cooling demonstration projects can be placed on the appropriate mailing list by writing:

Division of Solar Energy
Energy Research and Development Administration
Washington, D. C. 20545

A standard Government procurement procedure known as the Program Opportunity Notice (PON) will be issued for commercial demonstrations (which include publicly and privately owned non-residential buildings, industrial process heat, and agricultural uses).

The Department of Housing and Urban Development (HUD) and ERDA share joint management responsibility for residential demonstration projects. For more information on the residential demonstration program as now structured or for solicitations in this area, please write to:

Division of Energy, Building Technology, and
Standards
Department of Housing and Urban Development
Washington, D. C. 20410

Studies are under way to establish fair and equitable mechanisms by which private individuals can participate in the residential demonstrations. Such mechanisms are not now in force. However, the names of individuals who request an opportunity to participate are being recorded by HUD at the above address, and should be marked "Attention: Individual Participant List".

Federal demonstration project funds are to be spent only for that portion of the costs of heating and cooling systems that goes beyond the expense for more conventional methods.

ERDA's Division of Solar Energy will consider proposals from any source. Unsolicited proposals, submitted in accordance with the ERDA "Guide for the Submission of Research and Development Proposals" will also be accepted. There are two such guides, one for educational institutions and another for individuals and organizations other than educational institutions. Copies are available from:

Division of Procurement
Energy Research and Development Administration
Washington, D. C. 20545

Contracts for proposed research or development projects may be recommended based principally upon whether the work would significantly contribute to solar energy program objectives. In particular, proposers are encouraged to forward a relatively brief (5-10 pages) preliminary proposal in order to obtain an informative reaction from ERDA program managers before submitting a formal proposal. All proposals, preliminary or formal, will be acknowledged as soon as the staff can evaluate them. Proposers will be notified officially of a final decision in each case.

PHOTO CREDITS

Page	
Facing page 1	Lick Observatory
3	Sandia Laboratories
6	Leslie Salt Company
8	Sandia Laboratories
9	*The Washington Post*
14	Dr. George Löf
22	University of Delaware
34	Lawrence Livermore Laboratory

☆U.S. GOVERNMENT PRINTING OFFICE: 1976 - 641-240/7

About the Author

Dr. William W. Eaton, an independent consultant, holds a Ph. D. in physics from Yale University and is a registered Professional Engineer. He has extensive experience in industrial research and development, both in this country and abroad, and has been a Director or Trustee of numerous science-oriented organizations. He was closely involved with early applications of high-speed computers to problems of government and business.

For 3 years he served as Deputy Assistant Secretary for Science and Technology in the U. S Department of Commerce. He has also been prominent in science affairs in Maryland. He headed formal studies on the environmental effects of nuclear power plants, both for the Governor of Maryland and for the Southern Governors' Conference.

Dr. Eaton has prepared patents and articles in a number of technical fields, including several related to various aspects of energy. For ERDA, in addition to this booklet, he has written "Geothermal Energy".

A word about ERDA . . . .

The mission of the Energy Research & Development Administration (ERDA) is to develop all energy sources, to make the Nation basically self-sufficient in energy, and to protect public health and welfare and the environment. ERDA programs are divided into six major categories:

- CONSERVATION OF ENERGY—More efficient use of both existing and new sources of energy in industry, transportation, heating and cooling of buildings, and the generation of electricity, together with more efficient transmission of energy.
- FOSSIL ENERGY—Expansion of coal production and the development of technologies for converting coal to synthetic gas and liquid fuels, improvement of oil drilling methods, and development of techniques for converting shale deposits to usable oil.
- SOLAR, GEOTHERMAL, AND ADVANCED ENERGY SYSTEMS—Application of solar energy to heat and cool buildings and development of solar-electric power, conversion of underground heat sources for electricity and industrial heat, and development of hydrogen fusion for generating electricity.
- ENVIRONMENT AND SAFETY—Investigation of health, safety, and environmental effects of energy technologies and research on managing wastes from energy production.
- NUCLEAR ENERGY—Expansion of medical, industrial and research applications; advancement of reactor technologies for generating electricity, especially the breeder concept; and production of nuclear materials for civilian needs.
- NATIONAL SECURITY—Development, production, and testing of nuclear weapons and attention to such related issues as safeguards and international security matters.

ERDA programs are carried out by contract and cooperation with industry, university communities, and other government agencies. For more information, write to ERDA-Technical Information Center, P.O. Box 62, Oak Ridge, Tennessee 37830.

Energy Research and Development Administration
Office of Public Affairs
Washington, D.C. 20545