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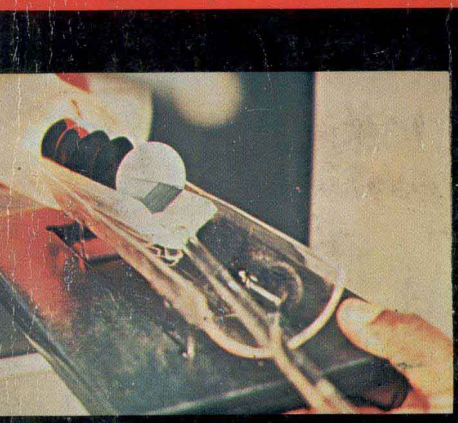
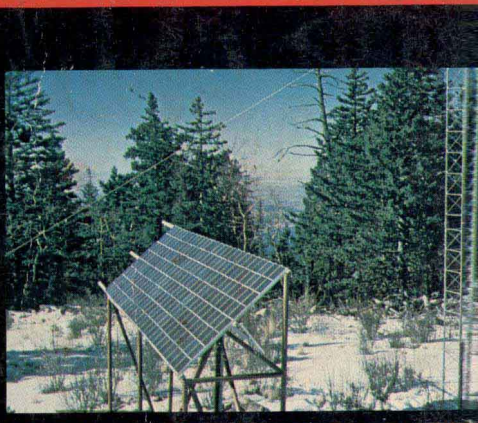
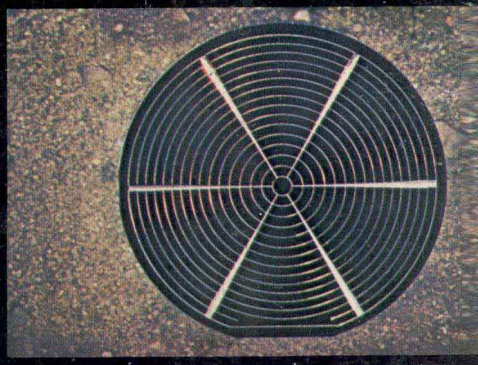
HOW TO MAKE YOUR OWN SOLAR ELECTRICITY

A complete guide on how to convert sunlight into electricity.







BY JOHN W. STEWART

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"Since the dawn of man, we have sought to take advantage of the resources around us. We have captured the wind in our sails. We have harnessed the seas. We need only now to harness the sun."

Author Unknown

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Since his early existence on this planet earth, man has always sought simplier and better ways of accomplishing that which he needed done. It seems man has been keenly interested in energy throughout all the centuries of time, but has become extremely dependent on it in the last few hundred years. At first he employed his own muscle power and sometimes that of his friends. History tells how man has at various times used slaves to do much of his work.

Man learned to use and harness the great energy released by burning wood. Wood was used as one of his early fuels to keep him warm and cook his food. When Marco Polo went to China, he found the Chinese burning a strange black rock which he later introduced to Europe as coal. After many years, coal began to replace wood as man's prime fuel source; then, with the invention of the steam engine in the mid-1800's, the Industrial Revolution was born. The birth of the Industrial Revolution began the greatest exploitation of energy sources in the history of mankind, a practice which has continued at an ever-increasing rate until the present time.

With little concern for the future, we have used the richly-stored energy sources of the earth. We have extracted the earth's natural resources at such an alarming rate we are now faced with complete exhaustion of our presently used sources of energy. It seems that man has no appreciation of what he enjoys until it is no longer available to him. In 1972, this was brought to the public mind with the Arab oil embargo, when people were lined up for miles to purchase gasoline for their cars. The average person was stunned by

the realization of our growing dependence on other nations for energy. Faced with this dilemma, man is once more seeking new ways to solve his energy needs.

The logical place to look for relief is to the sun, the source of endless energy. With renewed determination, man has gone to work to develop practical and useful solar devices. He has made ovens to cook his food and heaters to heat water and homes. He has even developed air conditioners run by the sun! In his attempt to solve his energy needs, man has once again discovered the extraordinary power of the sun.

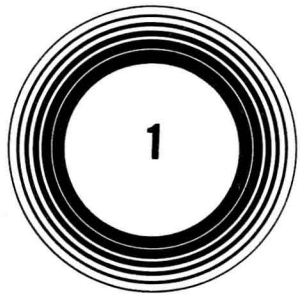
In recent years, we have become dependent on electrical power as a convenient form of energy. Great interest is being exhibited in areas where solar energy could be used to produce electricity for use in our homes and businesses. Research in this field has brought to light many ways in which this could be accomplished. Some enthusiasts have proposed using large tracking mirrors to direct the sun's heat on a given point; this would make steam to drive a conventional electric generating system. This requires complicated equipment which is expensive and costly to maintain. One of the most intriguing concepts being developed is a method of direct conversion of the sun's energy into electricity. This process, known as *photovoltaics*, requires no machinery with moving parts to wear out, and if protected, the cells should last indefinitely. The cells can harvest the sun efficiently with no noise or pollution. Photovoltaic cells have been used very successfully in the space program and in many small remote applications on earth.

It is to this subject, its development, uses, and future that this book is directed. Some interesting facts about the sun and man's attempt to harness its energy will be presented, after which the discovery and development of the solar cell will be discussed. We will explain how the cells are made and why they work. Uses of the solar cells now and in the future will be examined. Solar electric generators from simple cells to complete systems will be covered.

It is hoped that through this book, the reader might learn more about the solar cell, how it converts sunlight into electricity, and how it may be used in solving many of our energy needs.

John W. Stewart

The Sun is Up



Probably nothing in our universe has aroused man's curiosity more than the sun. He has studied it, used it and looked to it as the giver of heat, light and even life itself. Without the sun, all life as we know it would cease. Our earth revolves around the sun, the center of our solar system. The sun has always been a scientific curiosity to mankind. He has looked to the sun with great awe and mystery. Seeing it, yet not understanding it, he has long been the recipient of its benefits.

The sun has provided us with light, warmth, food and clothing through endless centuries. It causes the winds to blow, creating a comfortable climate for life. It has purified our water through an evaporative process which has made the rain fall, refreshing the earth.

The very food we eat grew because of nourishment from the sun. Even our own bodies, if shut in without the healthful rays of sunlight, would soon become diseased. The absence of the sun's energy would cause the very earth to become barren and unproductive. Energy from the sun interacts with oxygen in the earth's atmosphere to create a layer of ozone that protects us from lethal doses of the sun's radiation. These are only a few of the ways we directly benefit from the sun's energy.

We also benefit indirectly from the sun, receiving its energy "secondhand." Nearly all of the energy available to us is or was created by the sun. From the sun we receive almost all other forms of power currently available for man's use. The electricity generated

by a windmill, for example, is the sun's energy once removed; uneven heating of our atmosphere by the sun causes the wind to blow, thus driving windmills and other useful machines. Hydroelectric generation would not be possible if the sun did not evaporate moisture to replenish our water supplies. The sun's heat evaporates water, causing rain to fall at higher elevations. Water power is created as it rushes down to the ocean. Coal, oil and natural gas were made from plants that required the sun's energy to grow. Energy absorbed by plants and trees provide man and animals with food and energy.

When we contemplate how dependent we are upon the sun, it is little wonder that ancient man at various times worshipped this mysterious object in the sky. The power of the sun and its influence in his daily life made it a natural object for early man to revere. Recorded history cites examples of people who worshipped the sun as their god or one of their gods. Centuries ago, men made temples to their sungod at Stonehenge, England. The sun god Ra is pictured in many of the Egyptian pyramids. From the source of this homage, Sunday, the day so many spend in religious worship, received its name.

SOURCE OF ALL ENERGY

The sun, called by scientists an *orange dwarf*, is 864,000 miles in diameter and weighs as much as 330,000 times the weight of the earth. This fiery ball of gas is composed largely of hydrogen, which is continually being converted into helium by a fusion process. The surface of the sun is called the *photosphere*, a name made from the Greek words meaning light and ball. At the surface, the temperature is 10,000 degrees Fahrenheit, while the inside temperature may reach as high as 300 million degrees Fahrenheit.

The earth, 93 million miles from the sun, is so small and far away that it receives less than one thousandth of one millionth part of the sun's total energy. Even so, this small amount of radiation is equal to 85 trillion kilowatts of energy falling upon the earth constantly.

Every day the sun showers the earth with several thousand times as much electrical energy as we consume. Of this energy, thirty percent is reflected back into space by our atmosphere. Even though only a fraction of the sun's energy reaches the earth, it provides us with all the energy we can possibly use. The amount of sunlight striking the earth every fifteen minutes could be enough to satisfy our total energy requirements for an entire year. The solar energy reaching the earth three days is greater than the estimated

total energy of all the fossil fuels on earth. The amount of solar energy received each year by the United States alone is equal to 1150 billion tons of coal. In fact, the average solar energy striking the roof of a typical residence is 10 times as great as its annual heat demand.

Why are we not making use of this tremendous source of energy provided by the sun? The answer, of course, is that we have been using it for some time. However, instead of using the sun's power directly, we have been using stored or indirect solar energy in the form of fossil fuels. These were created by the sun and trapped in the earth eons ago, and only recently reclaimed by drilling and mining. But we must now begin using this power directly from the sun. It is estimated that the sun will be shining brightly for at least another five billion years, so solar power is considered inexhaustible. This ever-present, furnace-like sun offers man his only free, universally available source of power which continues to fall on the earth, waiting only for man to reach out and utilize it. Because of the tremendous potential of energy both for the present and future, we must look to the sun to provide our future energy needs. Consequently, solar energy could be providing substantial levels to fill the public's need within the next 10 years.

THE FORGOTTEN SUN

From the dawn of time, man has found sources of energy to help him do his work. He used wood for many years to warm his home and cook his food. The discovery of coal made it possible to use this rock to satisfy his needs. And with coal, he began to develop even greater power sources to work for him. With the widespread use of coal and the invention of the steam engine, the Industrial Revolution was born. The steam engine made the railroads possible. Men like Tesla and Edison soon developed electrical generating plants to be driven by steam. The internal combustion engine was developed along with the advent of gas and oil. The automobile industry soon adapted this engine to such an extent that all others seemed to disappear. Fossil fuels provided power for all these new inventions. Because industrial development was dependent on fossil fuels, the costs associated with using stored solar energy became significantly less than the cost of developing means to collect and utilize energy received directly from the sun.

History is full of examples of man's trying to harness the power of the sun. A Greek scientist, Hero, made wind- and sun-powered devices. In 212 B.C., Archimedes set fire to Roman ships at Syracuse using polished shields. Water wheels and windmills were soon

capturing an indirect solar power. For centuries, sundials were used as a way of telling time. Sailing ships made it possible for man to discover the far away lands of the earth. The clipper ship *Sovereign of the Seas* traveled 485 miles in a single day. Between the 14th and 17th centuries A.D., many solar devices were invented. The solar engine invented by Salomon de Caus of France used sun-heated air to run a water pump.

In the 18th century, a solar furnace designed by a French scientist, Antoine Lavoisier attained temperatures of 1750° C or 3182° F. In the 19th century, the famous Stirling engine was developed, which can operate by the sun. This engine ran everything from printing presses to water pumps. Up to this time, most of the work with the sun was with devices that focused the sun's rays on a single point. In the late 19th century, a new device appeared on the solar horizon: the flat-plate collector. A flat-plate collector uses the sun as it falls upon its surface without concentrating the rays. This procedure proved to be a less expensive way to harness the sun. The next 50 years brought many different devices of this kind into play, all using the sun to work for man.

With the discovery of coal and later oil, however, solar-powered gadgets made way for these less expensive forms of readily obtainable energy. The vast reserves of stored energy were now being used to supply energy to man. Because these fuels were already in a form that could be easily obtained, transported and stored, and required no elaborate method of collecting, fossil fuels were preferred to the sun. However, as world fossil fuel demand has increased and conventional fuel supplies have decreased, the direct use of the sun's energy has emerged as a powerful alternative to man's increasing energy and environmental problems. The advantages of solar energy are already becoming readily apparent. Areas such as cooking, heating, refrigeration and light temperature steam generation are already successfully used and developed. Additionally, using the sun to desalinate sea water could solve some of our world's water shortages.

PRESENT-DAY ENERGY DEMANDS

Of all the energy used in the world today, over 96 percent is from fossil fuels. Because there has been an abundance of fuel, such as nature's wood, coal, oil and gas, people have long viewed these resources as their birthright. These sources of energy have powered our automobiles, heated our homes, and fueled our industries. Where these fuels were once abundant and low-priced, they are now becoming scarce and expensive.

Due to the ease of electrical distribution, the demand for its convenience, and its use in lessening pollution, electrical production will require the highest future increase. The total energy used in the United States for electrical power generation will increase from 25 percent in 1970 to 36 percent by 1985. From 1950 to 1970, electric consumption increased annually at the rate of 7.5 percent. This increase in consumption is expected to remain relatively constant through 1985.

Most of the electricity used in the United States comes from changing water into steam that in turn drives some type of turbine. Coal, oil or some other type of fossil fuel is used to produce the steam for these generating plants. To see how we consume our energy, let's look at the sources that now supply our electricity.

Hydroelectric power contributes only 4.1 percent of America's energy and has been used to its maximum. At the present time, we have used practically all of the hydroelectric sites that are available in the United States and other parts of the world. Few locations for dams remain which could be used to produce electrical power, and a number of those will probably be eliminated after environmental impact studies are made.

Nuclear power produces only 1 percent of our nation's electrical power. Because the use of nuclear reactors is relatively new and has produced problems in waste disposal, it has met with poor public acceptance. But even nuclear power has a limited source of fuel available. Because of these problems, it doesn't appear that the use of nuclear power will have a substantial impact on our current and future energy needs.

Coal, now providing approximately 20 percent of our energy, is being revived as a major source, but this, too, is finite. If we shift too heavily in this direction, our coal reserves will soon be depleted.

Natural gas, providing 32 precent of our total energy needs, is becoming difficult to obtain. In many states, new natural gas hookups are no longer available due to shortages.

Oil, which we are now using more than any other source, supplies 44 percent of our current energy requirements. If we continue to use oil at this high rate of consumption, it, too, will soon dwindle. Today we are so reliant on oil and natural gas to heat our homes and factories that we would be in serious difficulty if we could no longer get these precious commodities.

It appears that only through the jolt of the Arab oil embargo were we awakened to the realization of our growing dependence on fossil fuels. We had been going merrily on our way, spending the money from our energy bank as though it would last forever. Sud-

denly we received our overdraft notice. We then had to borrow from someone else to cover our deficit. Because of this, we are now getting almost 30 percent of our energy from foreign sources, and this figure increases daily.

Instead of using and developing other sources of energy, Americans have practically exhausted our known sources of oil and natural gas. Our domestic supplies are dwindling, forcing us to import more fuel at higher prices. In 1972, the United States produced about 87 percent of its energy requirements. With the increase in energy usage and our dwindling supply, our dependence on foreign sources of fuel is expected to increase dramatically. Although it has only 6 percent of the world's population, the United States consumes almost one-third of the total energy in the world each year.

In his attempt to keep warm and find energy to do his work, man has indiscriminately used fossil fuels to such an extent that they are fast disappearing. Predictions are that in less than 100 years, fossil fuels will be depleted. Besides the fact that we have used up our sun-created oil reserves at an astronomical rate, we have also played havoc with our environment. We begin to see the pollution we have created through our indiscriminate use of our natural energy resources. Exhaust from burning fossil fuels from our cars, homes and factories has polluted our environment to such an extent that we can hardly breathe or see the world around us. Our eyes burn from the smog in the skies, the fish die in our polluted rivers and lakes, and we are being poisoned by the food we eat and the water we drink. The elimination of wastes has destroyed and polluted our surroundings. The strip mining of coal has ravished the landscape. The wastes from nuclear power plants threaten our very existence. Many of the once-beautiful beaches are now covered with oil.

It seems to be the nature of men that when we find something which performs well for us, we begin to exploit it. We have abused the earth for our own gain. In a short 50 to 60 years, we have used up most of these abundant reserves of energy. Only now do we realize that these unreplenishable sun-created stored sources of energy cannot last forever. We have started a trend which will not easily be reversed. Yes, in a brief space of time, we have turned our world upside down, only to realize we have destroyed the beauty and tranquility of our once uncomplicated existence.

With the sun shining brightly overhead, we are now experiencing an energy crisis. Faced with the problems of an environment polluted through by-products of our technological society, and with the rapidly-dwindling supplies of presently used sources of energy,

we are now looking at alternative ways to fill our energy needs. The need for economically attractive, nonpolluting alternative energy sources of power other than those presently being used if our future activities continue at their ever-increasing rate.

ALTERNATIVE NATURAL ENERGY

For years, man has used *wind power*, which has served him well. Sailors have used the wind for ages to power their ships. Man has used the wind to grind his wheat, pump his water, and is now considering it an an alternate source of electricity. Perhaps giant windmills will someday be able to provide electrical power for cities. The major difficulties with using the wind to generate electricity are that the wind doesn't blow all the time and that practical storage systems still need to be developed.

For centuries, *wood* has supplied us with heat for our homes and with fuel for cooking. It was one of the earliest forms of energy used by man. Wood is in such high demand today that many are concerned about whether we will have enough to last in the years to come. Because of the shortage of wood, some people are growing trees on farms to provide wood for paper and fuel. Wood has served us well as one of the major building materials for our homes and is now being reexamined as an alternate energy source to heat our homes. Here also, we must be careful not to overuse this precious natural resource or it, too, will soon be gone.

Men are now working with ways of harnessing the power of the *ocean waves*. By trapping the water at high tides and allowing it to run through a generator as it flows back to the ocean level, considerable power could be provided. The problem here is finding a way to harness ocean power economically and to distribute it from where it is obtained to where it is needed. The up and down movement of the waves could also offer a great source of power.

Many are looking to *geothermal* energy, the hot water and steam deep inside the earth, to generate electrical power. Scientists believe that the center of the earth is made of a molten mass. In some areas, this mass is close to the surface, evidenced by volcanos, geysers and hot springs. If this heat could be trapped and used to generate electricity, it could supply much of our electrical need without polluting the atmosphere. The problem is that there are only a limited number of places where the energy can be tapped because generally it is too far from the earth's surface. Considerable time and expense would be required to recover the heat. It is not expected that geothermal power will have a significant impact on the total energy picture before the year 2000.

The percentage of help from *hydroelectric* power is expected to decrease in the future instead of increase. There may be some effort to use off-peak electrical power to pump water back up to the storage pond to be reused during peak electrical requirements.

Much attention has been given to the process of controlled *nuclear* fusion, but perfection of this process is still many years away because of technological and research difficulties.

The conversion of waste heat into electricity, commonly termed *thermal electrics*, could be a viable source if harnessed properly. The problem is in collecting the waste materials to be burned in an economically feasible manner.

It is possible to make a burnable gas, methane, by heating decaying waste products in an oxygen-free environment. Many of the wastes that could be used in this process are now polluting our surroundings. The difficulty with this process is also in gathering waste into a processing plant.

Among the many energy alternatives being examined, *solar* energy ranks high as a consideration. Of all the alternate sources of energy, the sun has the greatest potential as a universal form of power (see Fig. 1-1).

Harnessing the sun's power is considered an attractive alternative because it is a renewable resource which causes no pollution. In contrast to conventional fuels, its use eliminates the need for refining, transporting and conveying fuel and power over long distances. The use of solar energy for heating and cooling promises a more rapid payoff than other energy alternatives because the basic technology already exists and needs only minor refinements. Considerable research, development and demonstration activities have been initiated in the public and private sectors to facilitate the widespread utilization of solar energy.

Although solar energy is available and free, its capture and utilization is not. There are some very difficult technical, social, and economic problems which must be resolved in order to change the existing patterns of energy conversion and consumption. The problem now is to economically convert the sun's energy into a useful product which can be consumed by man.

Through the wise use of solar energy in our homes and industries we may begin to retard the trend of using up our supplies of oil and gas. The widespread use of solar energy could reduce our rapidly-growing dependence on these forms of energy, which are polluting our surroundings and daily rising in cost.

Solar energy is not centralized but is available to all. It can be collected by each person at his own home, thus reducing distribution