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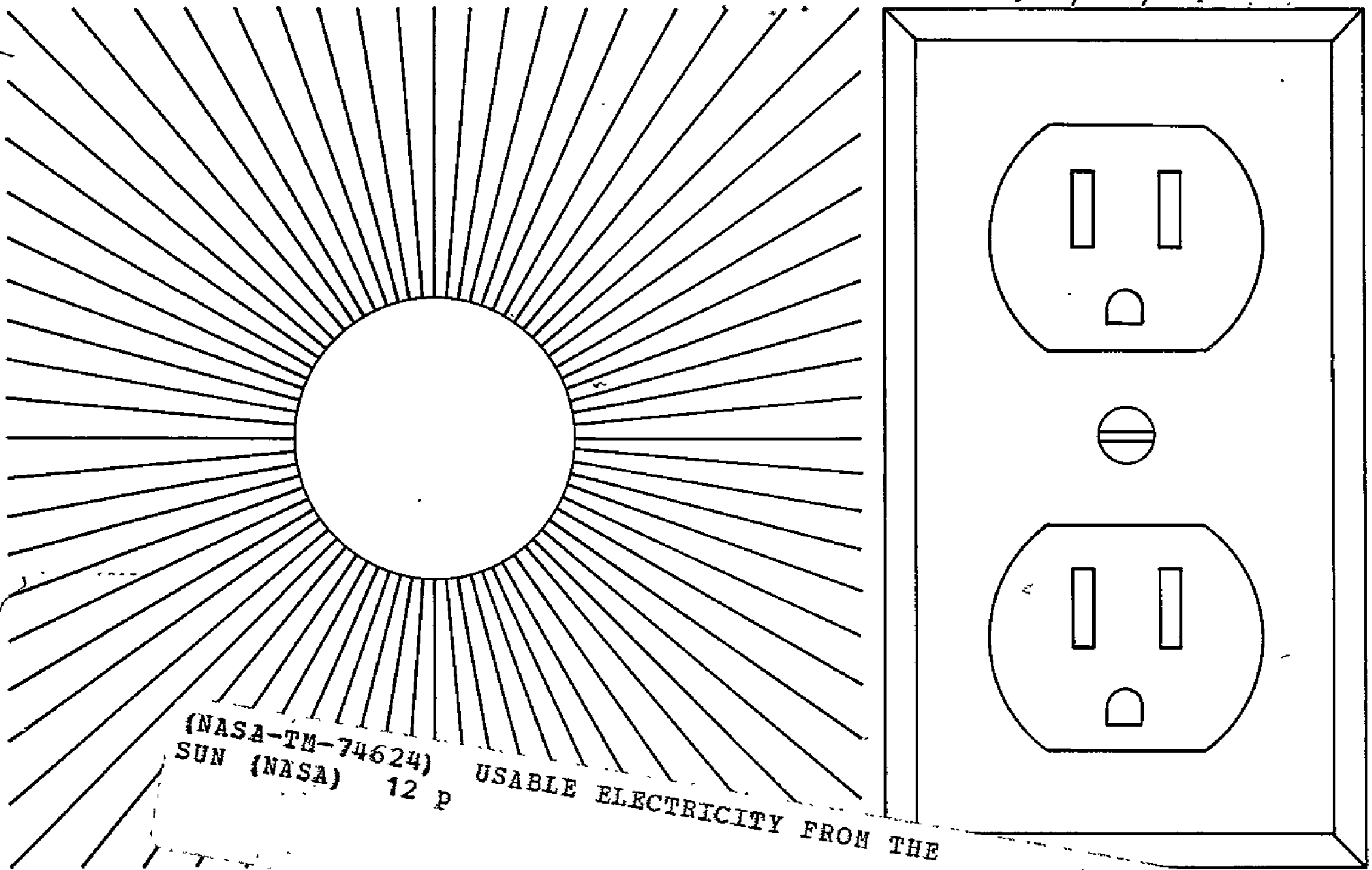

(NASA-TM-74624) USABLE ELECTRICITY FROM THE SUN (NASA) 12 p N77-81939

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USABLE ELECTRICITY FROM THE SUN

Solar Electric: A Better Source

A solar electric (photovoltaic) system converts visible sunlight directly into electrical energy suitably conditioned to meet the requirements of the electrical load. This brochure deals entirely with electricity produced directly by solar cells and the necessary systems to control it. We will list many of the current applications of these systems and will evaluate the economics involved. We will not be considering any indirect solar energy systems, such as wind energy generators (considering wind an effect of the sun); solar thermal, where heat is collected by fluid in pipes and used to drive turbine generators; or ocean thermal, where small differences between warm surface waters and cool deep waters can be utilized to drive turbines.

In many ways electricity generated by solar cells directly from the sun is a gift compared to other sources of energy. The sun is ideal because it is a non-depletable source available everywhere. There is never any need for fuel resupply. There are no moving parts in the system, so maintenance requirements are extremely low. (In fact, normal rainwater even cleans the solar cell surfaces for you.) Solar cells are non-polluting. They produce no noise, no heat, no fumes and no waste products or toxins.

Finally, because of their rugged solid-state construction, solar electric power systems have a very high potential for reliability and a long operational life.

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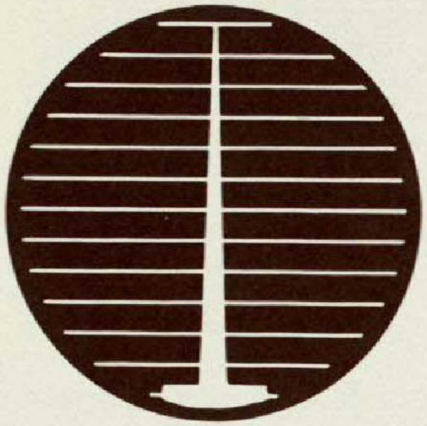
Solar Cells: Simple and Direct

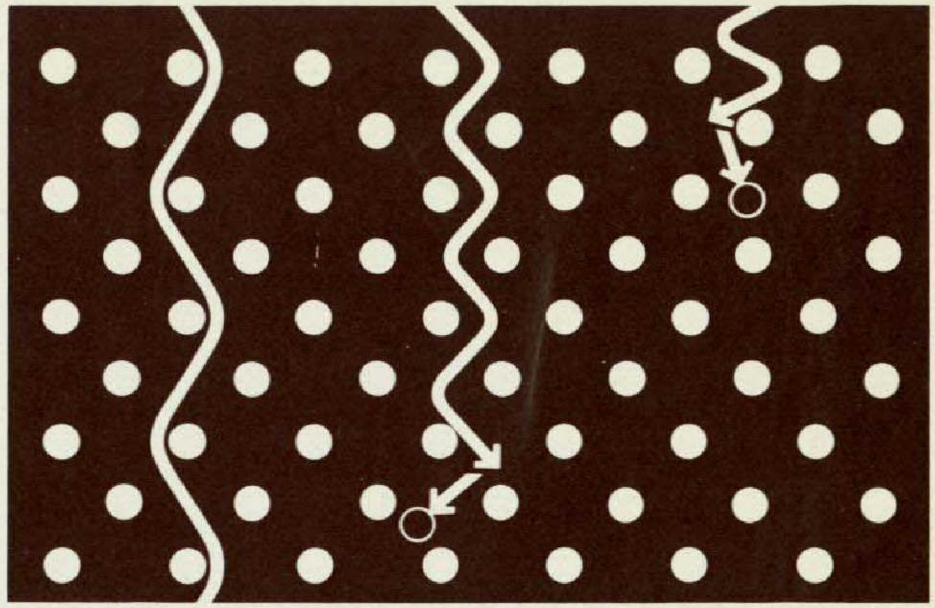


Solar cells are the basic unit of a solar power system. They are made of semi-conductor materials such as silicon (Si), or cadmium sulfide (CdS).

Silicon is receiving primary emphasis as a solar cell material in the United States. Silicon technology is already highly advanced due to the electronics industry and the space program. Silicon is the second most abundant element on earth and is used in many manufacturing processes.

The basic principle of solar electric cells is very simple. Light hitting silicon dislodges electrons (Figure 1). In a typical silicon solar cell there exists a junction between p-type silicon and n-type silicon called a pn junction (Figure 2). The p-type is made by replacing a few silicon atoms in the crystal with boron atoms. The n-type substitutes phosphorus atoms for silicon atoms. An electric current results from the flow of dislodged electrons which are driven across this pn junction.

Some electrical performance characteristics of the solar cell can be seen in a typical current-voltage curve (Figure 3). Note that even though changes in light level affect the amount of current produced, the maximum voltage remains approximately 0.45 volts. The cell delivers maximum power at the operating points indicated on the curves.



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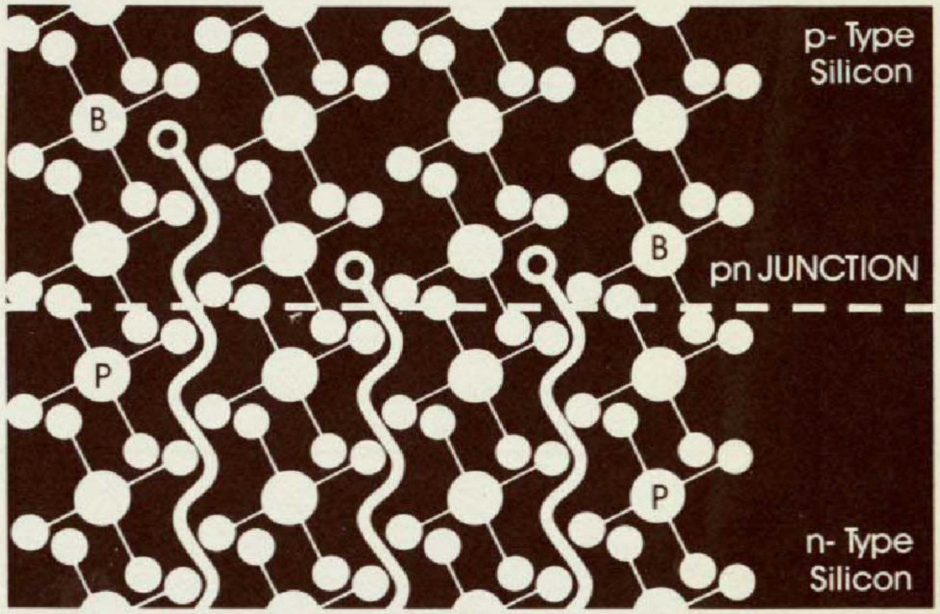

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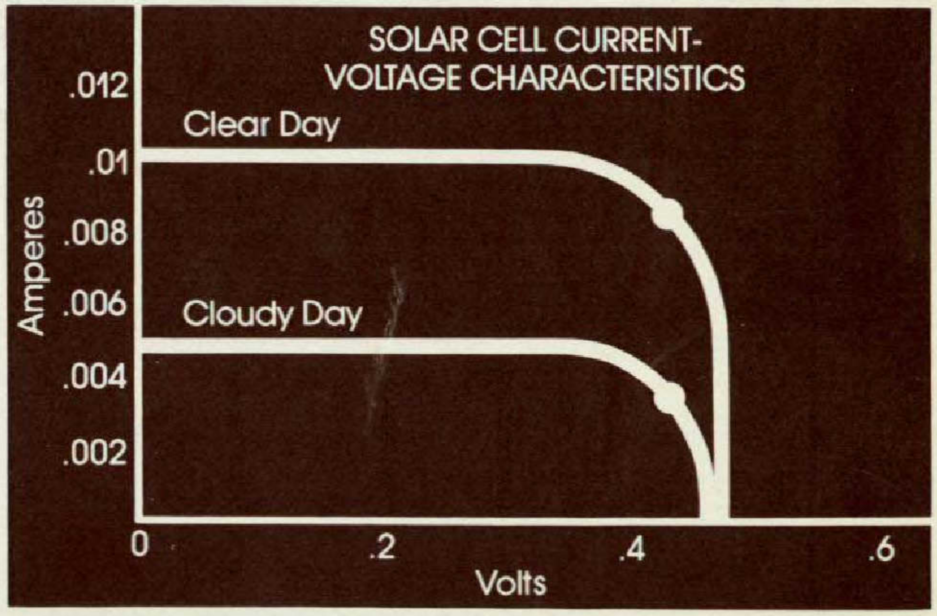

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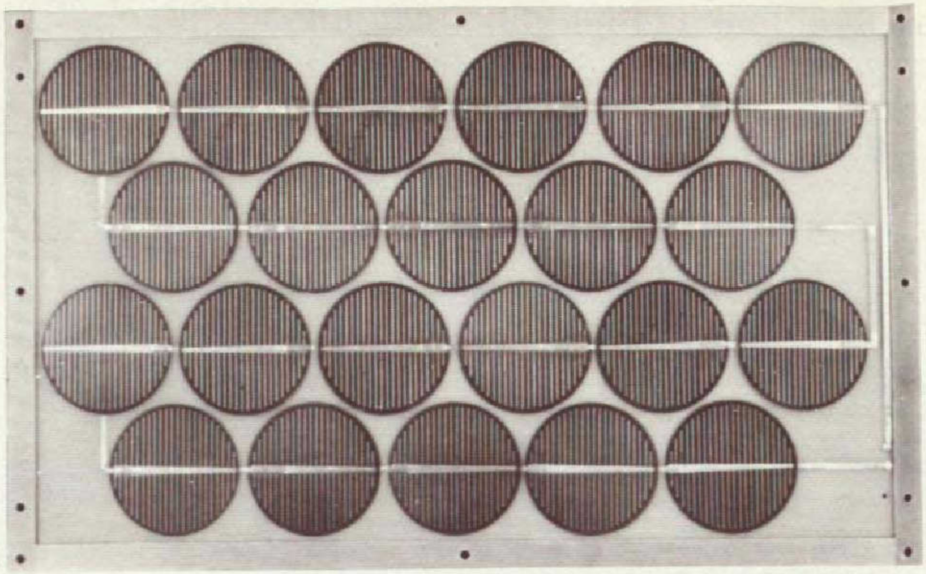
Solar Modules: Building Blocks

Solar modules are the basic building blocks of solar electric power systems designed to produce a certain voltage at a certain current. These primary modules are assembled in series-parallel combinations to deliver power at a desired voltage. It takes 40 cells connected in a series, for example, to charge one 12-volt lead-acid battery. When cells are connected in series, the total voltage equals the sum of the cell voltages, while the current remains the same. When connected in parallel, the total current equals the sum of the cell currents, while the voltage remains the same.

Many different sizes and shapes of solar cell modules are now available from over a dozen companies who are manufacturing solar electric products. (A far cry from the 1950's when the first cells were produced.) Some typical examples of current products can be seen in Figures 4, 5 and 6 at the right.

In 1975, U.S. manufacturers produced enough silicon solar cell modules to generate about 100 kilowatts of electric power. The fabrication of solar cells today is largely a handcrafting process. However, new techniques and automation of manufacturing processes will dramatically increase solar cell module production in the near future. This, in turn, will make the cost even more attractive, particularly when conventional energy sources such as primary batteries, natural gas, propane and fuel oils are becoming more scarce or more expensive.



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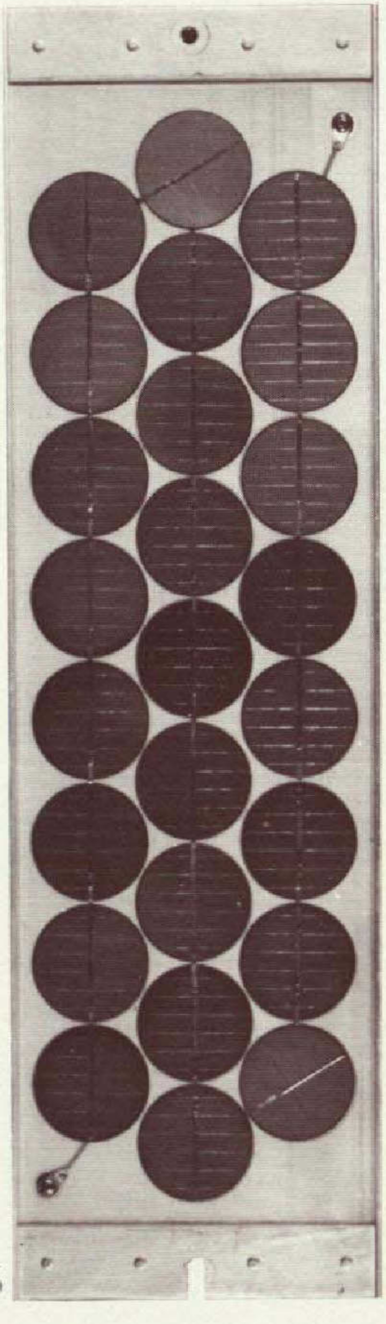

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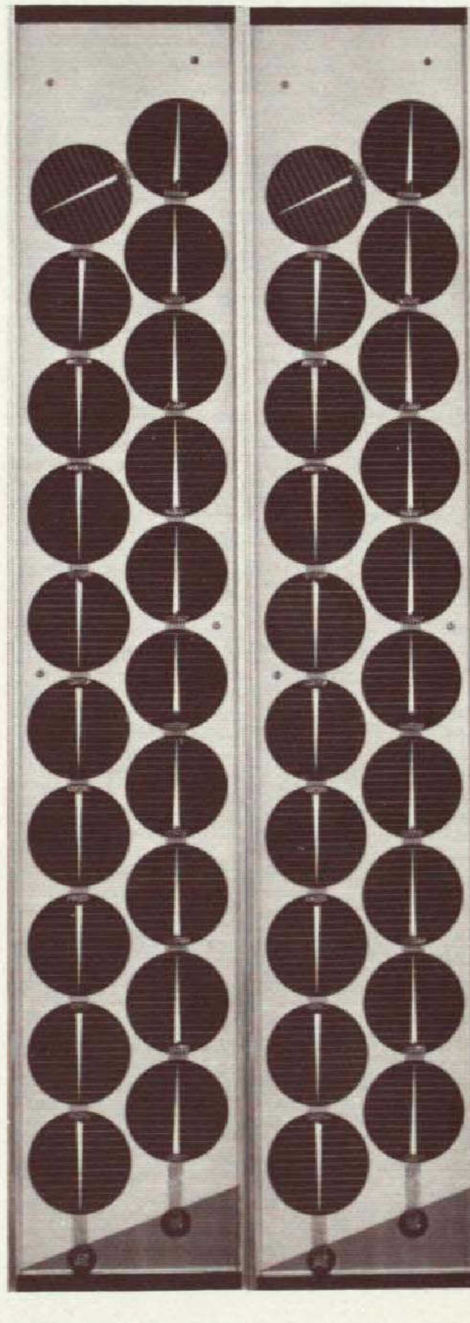

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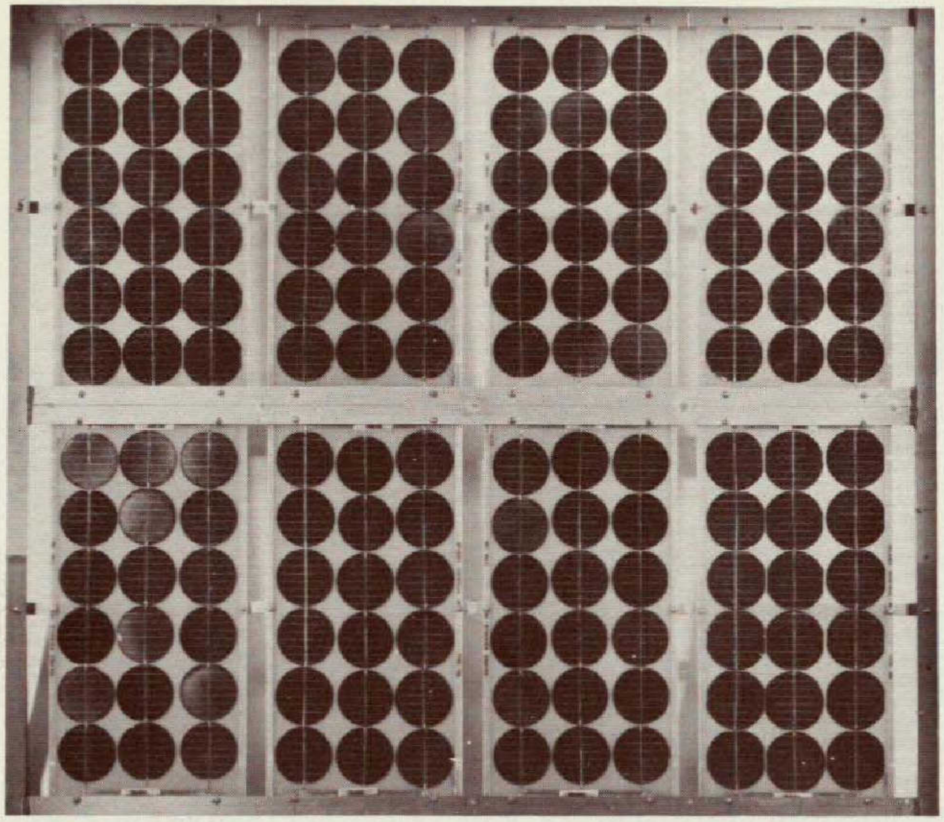

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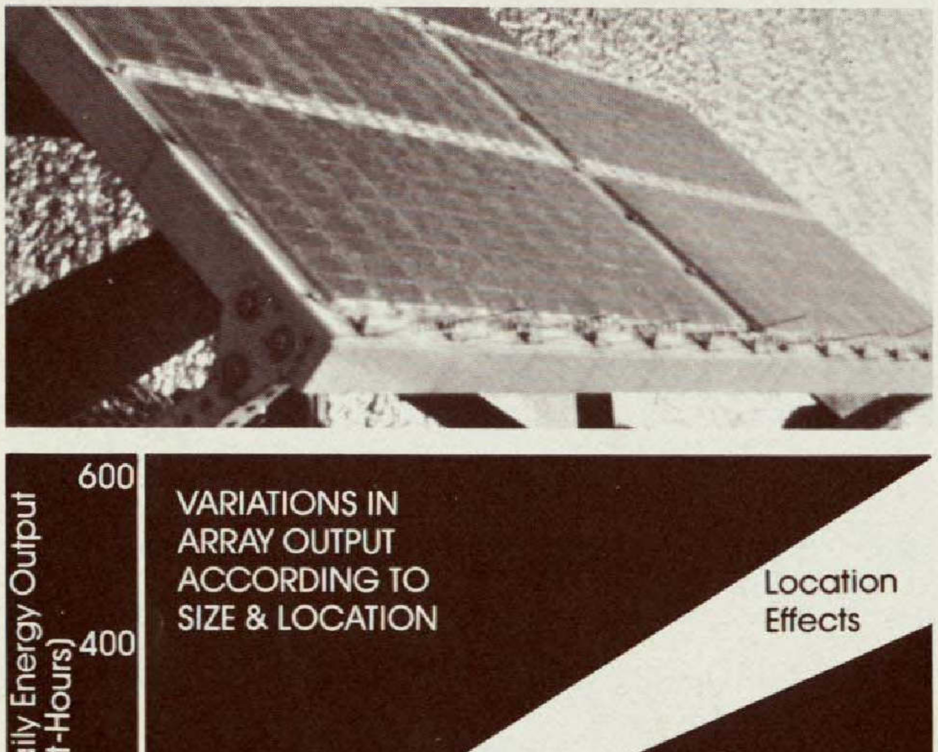

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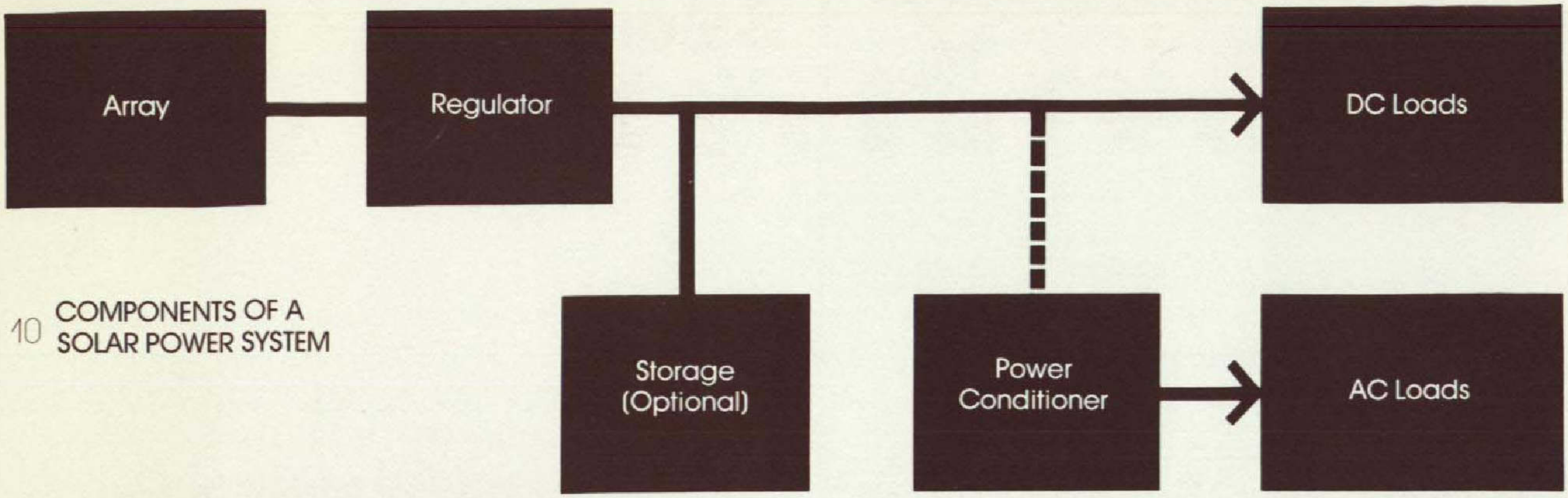
Solar Arrays: More Power

The solar array is the total assembly of all the solar cell modules needed for a particular power application. Virtually any power or voltage requirement can be met.

A typical array is shown at the left in Figure 7. An installed array is shown in Figure 8 providing power for a reef light off Key Largo, Florida. There are many factors which the designer must consider in order to provide a reliable solar power system. Geographical latitude must be taken into consideration. For one given location the total number of hours of sun, as well as seasonal changes in the sun's angle, can be determined. Also the average weather conditions and local terrain must be considered. Mountains and lakes will affect cloud cover which in turn affects the percentage of direct and indirect sunlight reaching the array.

The chart shown in Figure 9 graphically demonstrates these considerations. Note the total energy output (watt-hours) that can be expected per square foot of solar array. There is a significant variation between the most favorable locations and the least favorable locations. The important point here, however, is that a solar array will work at virtually any location within the continental United States. In the poorer locations you may need a larger array to deliver the desired energy output. A solar array is rated in peak power which is the wattage it delivers at noon on a clear day.



10 COMPONENTS OF A SOLAR POWER SYSTEM

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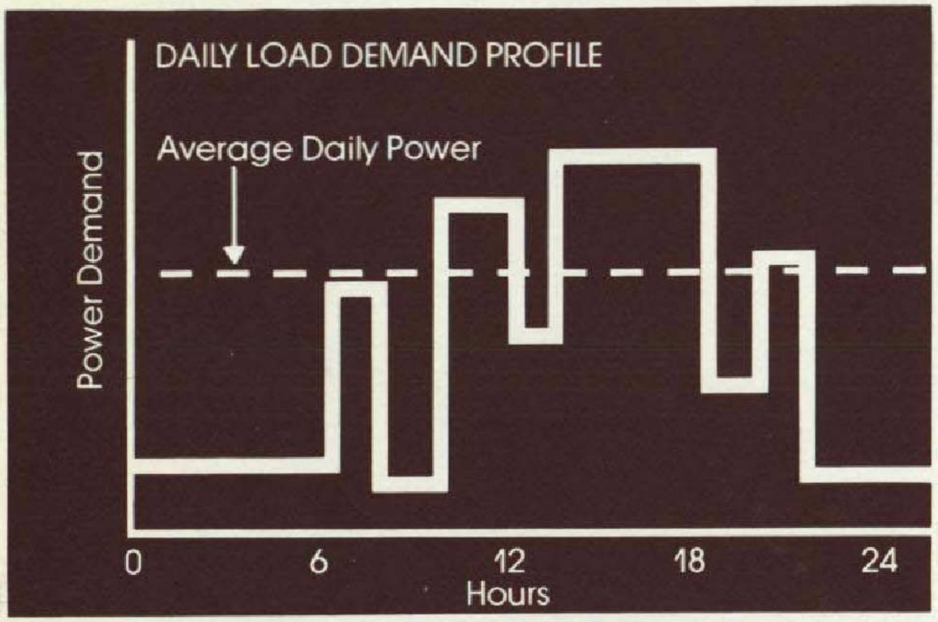

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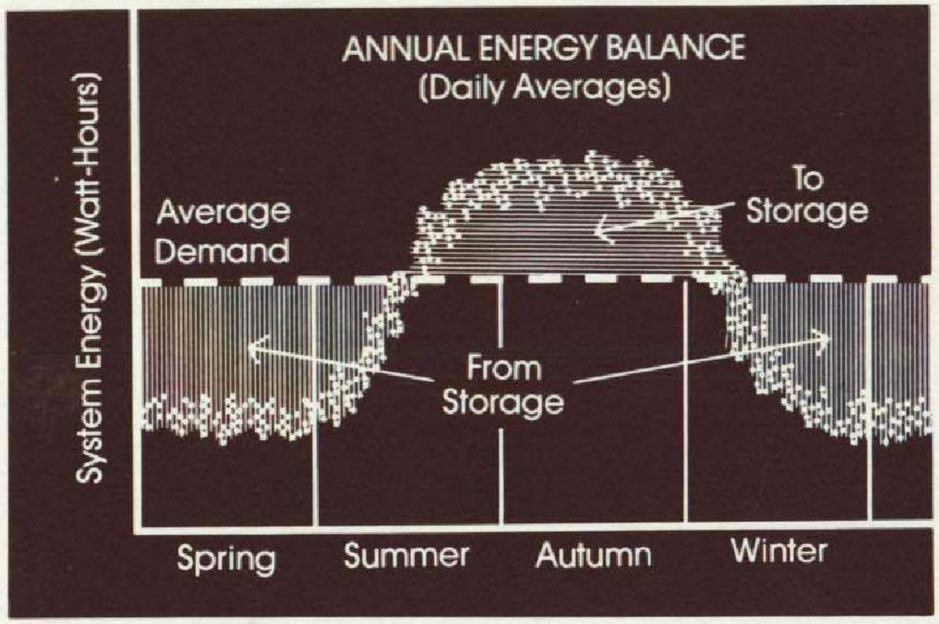

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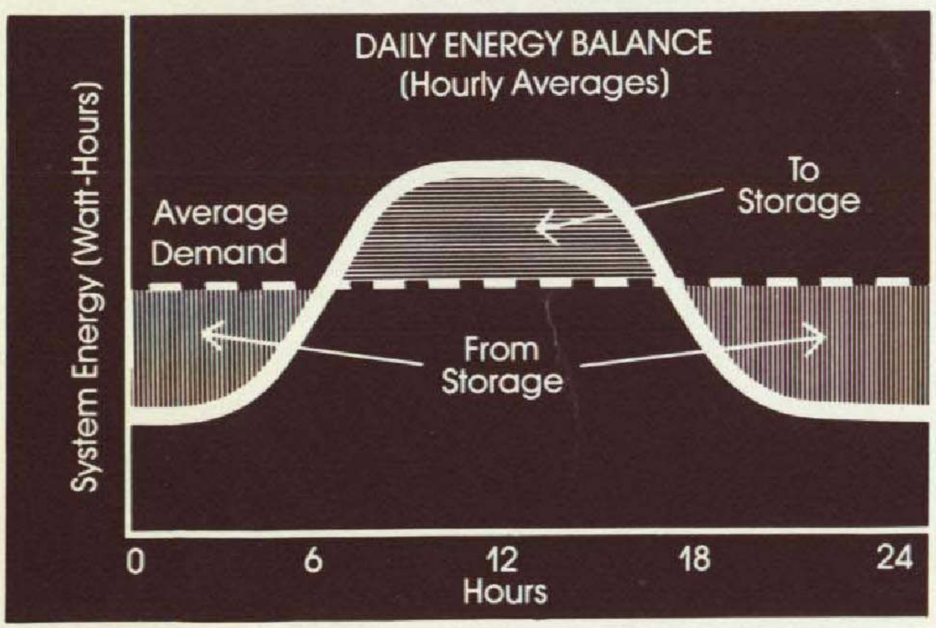

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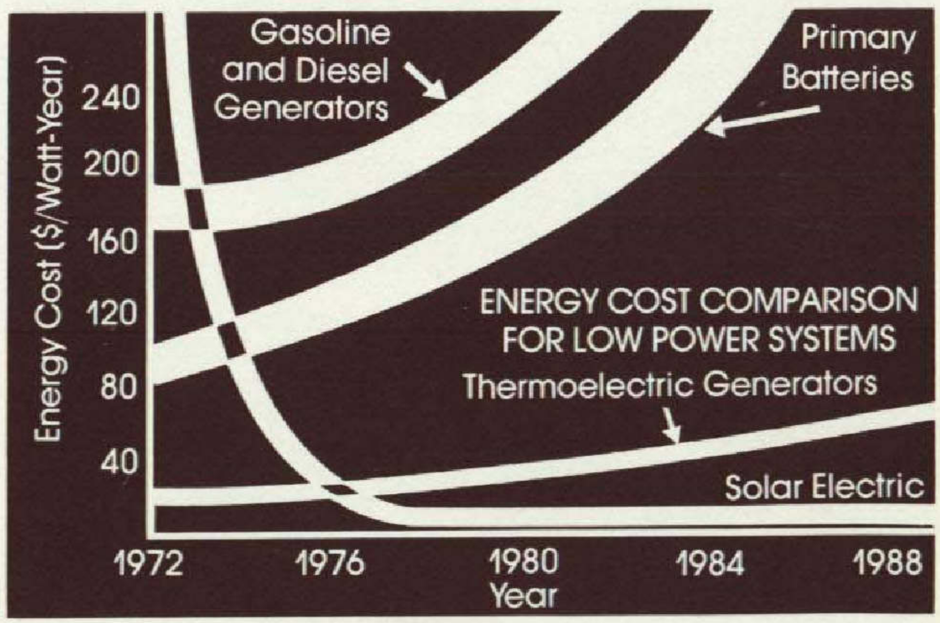


Solar Electric Power Systems

In addition to array technology, designers will need to consider system design data such as array size, energy storage, power transfer and power control. The basic components of solar electric power systems are shown schematically in Figure 10.

The solar array converts solar energy directly into DC electrical energy. The voltage regulator controls array voltage, and can control the flow of current to an optional battery. The battery can provide DC power during periods of darkness or when the load demands exceed the array output. Finally, a power-conditioner is necessary if you want to convert the DC power to AC power.

The primary system considerations are location and sizing. Location factors, in addition to latitude and amount of sunshine, include temperature variations and humidity. Array size depends on the total energy requirement plus expected losses in batteries, regulators, power-conditioners and any other sub-system components.

Figure 11 shows an application power profile with expected load demands during the course of a single day and the computed average power. This average power can be compared to the daily (Figure 12) and annual energy cycles (Figure 13) to determine storage size needed to provide power during the periods when array output is insufficient.

Solar Economics

The solar cell is presently the single most costly component in a solar electric power system. Until recently, only space-quality solar cells were available at a cost of about $80 per peak watt.

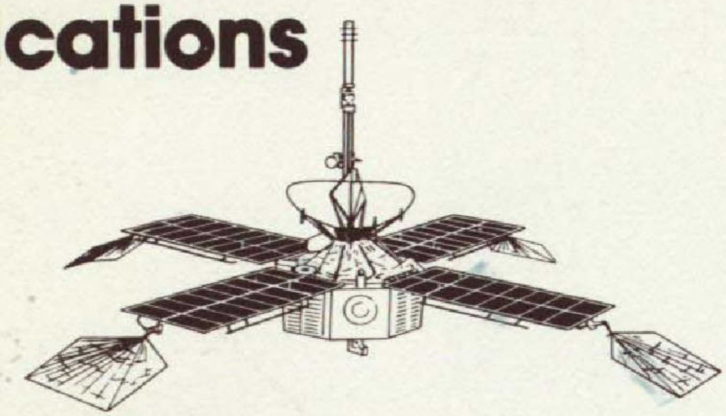
Now there is a national program to reduce these costs for terrestrial applications. In 1975 terrestrial-quality solar cell modules were available at a cost near $20 per peak watt. The Energy Research and Development Administration (ERDA) plans to achieve further reductions in the near future so that by the mid 1980's solar cells will be as low as 50¢ per peak watt.

At current solar module prices, the cost of solar electric systems is already competitive for many applications. These systems presently being marketed for remote applications (10 to 100 watts) are priced from $30 to $70 per peak watt including array, storage batteries and power-conditioning equipment.

For remote applications requiring 200 watts or less, Figure 14 illustrates a cost by year comparison between a solar electric system and other electric systems. The chart shows a projected continual decline in the dollar cost per watt-year of delivered energy for solar systems.

The cost of all other systems such as primary batteries, thermoelectric, and gasoline or diesel generators is expected to increase. It is important to note the "cross-over" point of economic feasibility for each system shown. The first cost of solar energy may appear to be high compared to other systems. However, when you compare the total system cost plus maintenance and operational cost, the picture rapidly improves.

Successful Applications



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Past and Present

Many applications of solar electric power systems are cost effective now or will be in the near future, particularly when dealing with modest power demands. In some remote areas, potential savings can be realized by converting existing installations to solar power. Also, in some existing systems which are power limited, solar systems can provide additional power more economically.

Solar systems have provided electrical power for the majority of unmanned space missions conducted by the National Aeronautics and Space Administration. Mariner IV (Figure 15) took and returned to earth the first photos of Mars. The spacecraft was powered by a 320-watt solar cell array.

There are many examples of successful terrestrial applications as well. Solar arrays provide 50 watts of power for navigational aids such as this United States Coast Guard buoy (Figure 16) in Long Island Sound. Private and commercial boat owners are using similar arrays to keep batteries charged and to power lights and other marine equipment. A solar array also powers this railroad semaphore signal (Figure 17) at a grade crossing in Rex, Georgia.

A solar array operates this Satellite Instructional Television Experiment (SITE) receiving system (Figure 18) consisting of an antenna, an RF converter and a TV monitor in Cleveland, Ohio. In Africa, the French National Broadcasting Authority is using a similar system with 33-watt TV sets in remote schools.

Early uses for solar arrays included powering remote weather and radio equipment. The U.S. Weather Service operates this Remote Automatic Meteorological Observation Station (RAMOS) atop 11,000-foot Mammoth Mountain, California (Figure 19). A 16-watt array powers this Voice-Radio Repeater atop 14,200-foot White Mountain in California for the U.S. Forest Service (Figure 20).

A 1.7-watt solar cell power supply operates this backpack-mounted portable two-way radio (Figure 21) for U.S. Forest Service backcountry guards patrolling mountain trails in Inyo National Forest. A 3-watt array provides power for a commercial stream-gaging telemetry system in California (Figure 22). A small solar panel powers this remote highway emergency call box in a National Park (Figure 23).

In addition, solar systems supply power for cathodic protection on fuel transmission pipelines and on well casings. Without protection, corrosion can destroy steel pipe in 5 years or less. With cathodic protection, the useful life of these pipes can be extended up to 25 years.

Some additional possible applications for solar electric systems include powering environmental monitoring devices (air or water pollution sensors); water pumps; water purifiers; security systems (perimeter protection, surveillance, intrusion sensors, alarms); and portable equipment (for use in construction, agriculture, food processing and oil drilling).


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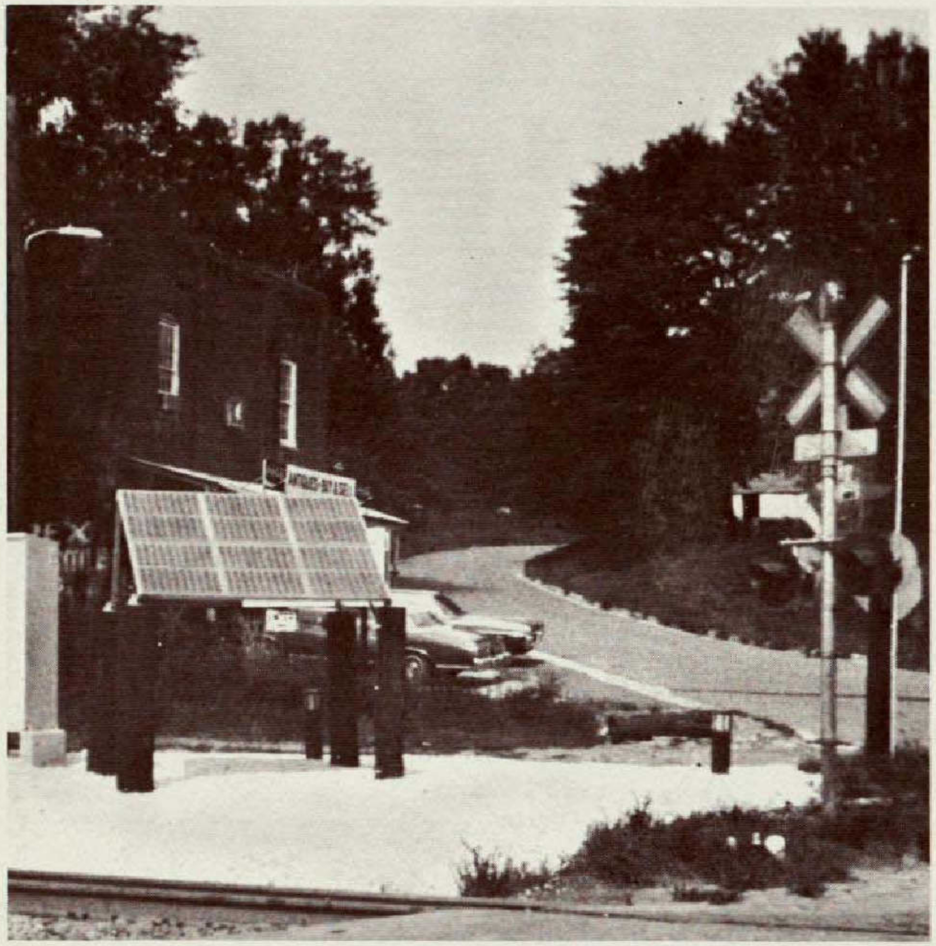
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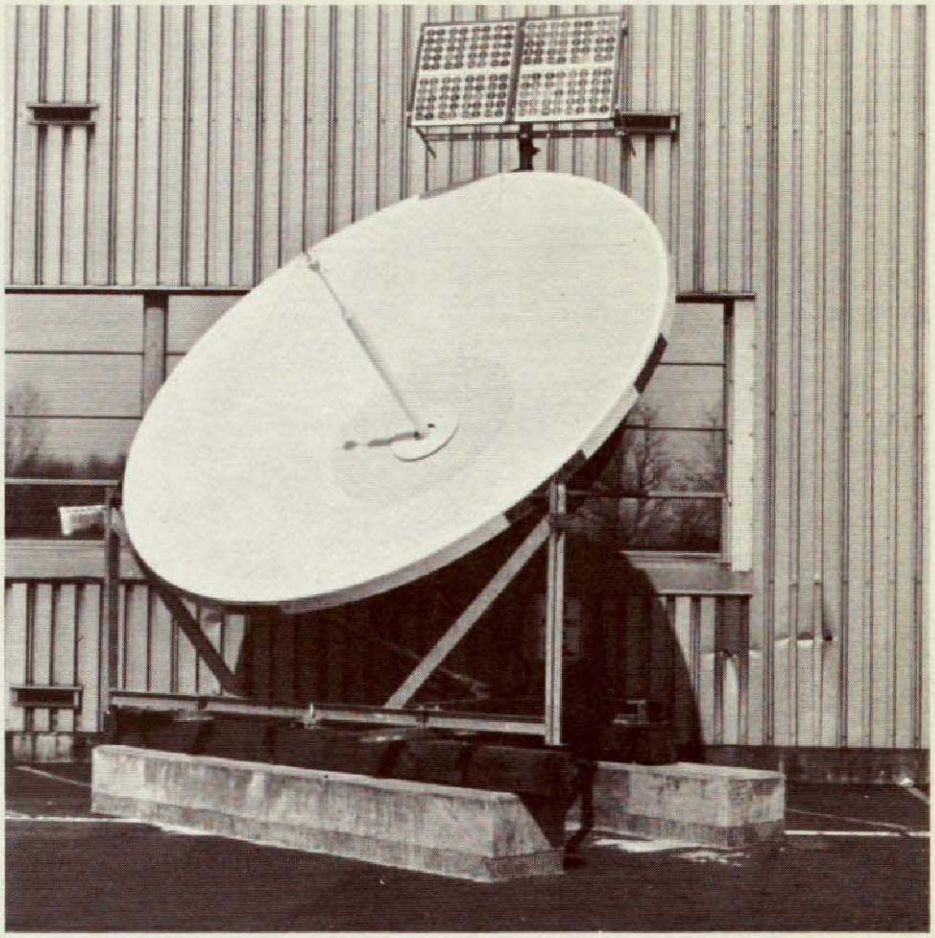
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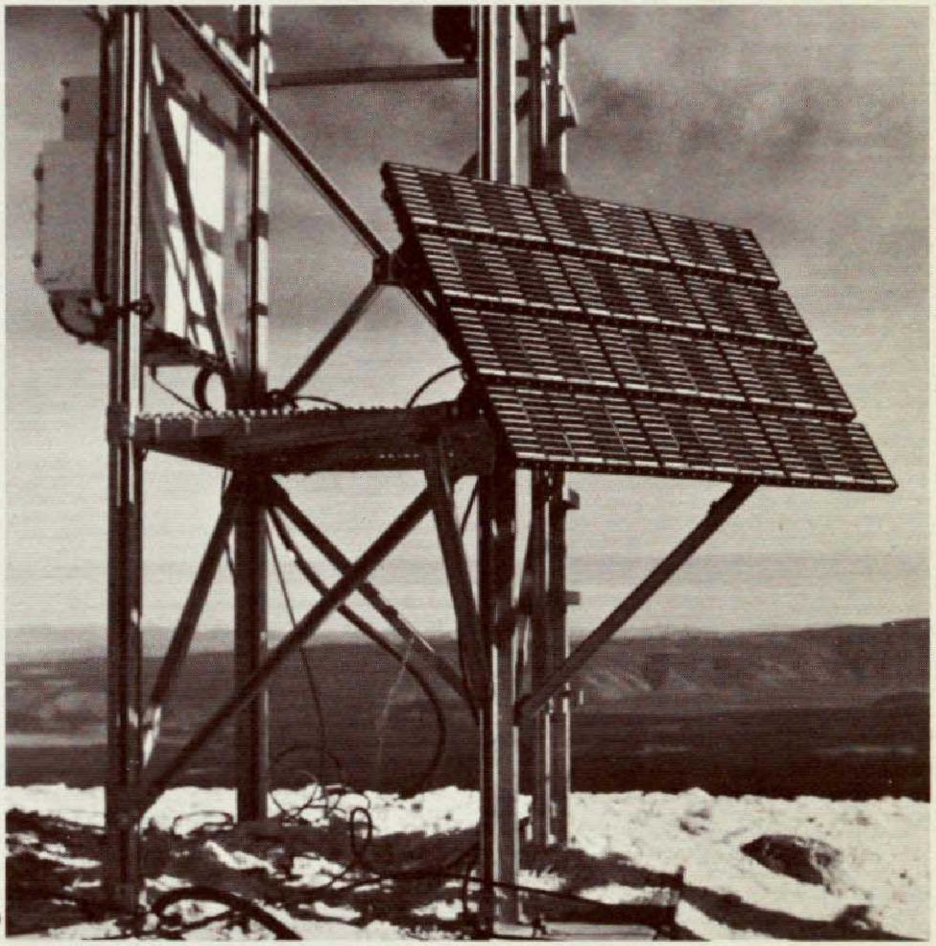
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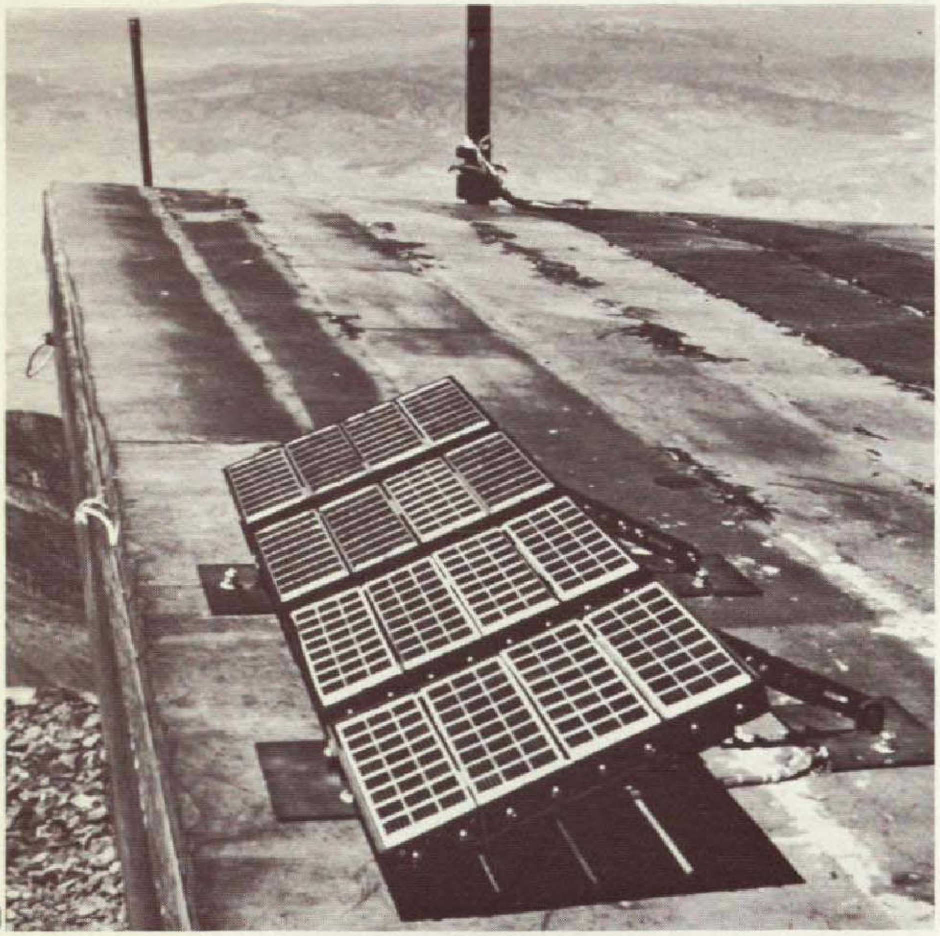
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Solar Electric Now

In 1975, there was a turnaround in which the production of terrestrial solar cells exceeded the production of space-quality solar cells for the first time. Many successful systems are already in service. Solar electric (photovoltaic) technology is now ready to be used to fill some of your energy needs. In many applications, solar electric power systems are already competitive with alternate power systems in cost

ERDA's Role

As noted earlier, ERDA is pursuing a national Photovoltaic Conversion Program directed toward development of economically viable solar cell power systems capable of providing a significant portion of the nation's energy needs by the year 2000

The major objectives of ERDA's program are: to increase annual production of silicon solar cell modules from current levels of 100 peak kilowatts per year to 500,000 peak kilowatts per year by the mid 1980's; to reduce the cost of solar cell modules from about $20 per peak watt in 1975 to 50¢ per peak watt by the mid 1980's, to identify potentially attractive applications of solar electric systems related to current and future needs, to assess economic factors and market impact of each application; to determine operating characteristics for applications with significant potential, and to confirm by test and demonstration that photovoltaic conversion systems will work for these applications.

Looking Ahead

By the early 1980's, engineers will be considering plans for solar cell power stations Such stations will allow us to reduce our dependence upon fossil fuels. By the mid 1980's we should see solar power systems in the 1-to-10 megawatt range and by the late 1980's, systems for communities and large industrial plants capable of generating more than 10 megawatts. By 1990, U.S. industry will be turning out solar arrays capable of producing 5,000 megawatts. Also there will be power stations and power networks in the 100 megawatt range Production of solar arrays should reach 10,000 megawatts by 1995 and 50,000 megawatts by the year 2000. It is estimated that the nation's total electric power need will be 1600 million kilowatts at the turn of the century. Solar electric power systems should be able to supply 3% of this total at that time. By the year 2020, 25% of the nation's power need could be supplied from solar systems.

For More Information

If you want to discuss solar electric power systems, either to retrofit an existing installation or to power a new application, we invite you to contact us.

Call the Lewis Research Center at 216-433-4000, extension 6945, or write us at the following address Photovoltaic Project Office, MS 302-1, Lewis Research Center, 21000 Brookpark Road, Cleveland, Ohio 44135.

Or, if you want more information on the total ERDA Photovoltaic Conversion Program, contact ERDA Technical Information Center, P.O. Box 62, Oak Ridge, Tennessee 37830.

Division of Solar Energy
Energy Research and Development Administration

Photovoltaic Energy Conversion Program
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