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Prepared by Sandia Laboratories, Albuquerque, New Mexico 87115
and Livermore, California 94550 for the United States Atomic Energy
Commission under Contract AT (29–1)-789

Printed June 1974

Sandia Laboratories
energy report

This work was supported by the United States Atomic Energy Commission.
Contract Number AT-(29-1)-789

Issued by Sandia Laboratories, operated for the United States
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SAND74-8604
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Printed June 1974

PROSPECTS FOR SOLAR ENERGY UTILIZATION

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Prepared for presentation at the Annual Conference of the California Society of Professional Engineers, June 13-15, 1974, Sahara Tahoe Hotel, Stateline, Nevada.

PROSPECTS FOR SOLAR ENERGY UTILIZATION

Solar energy has often been acclaimed as an almost ideal source of energy. It is widely distributed, nonpolluting, inexhaustible, and free. And yet, in spite of these outstanding attributes, man has extended his direct uses of solar energy only slightly beyond the ancient applications of agriculture and drying. I will try to give a very brief overview of the present status and the prospects for various potential applications, and offer a few general observations regarding the nature and utilization of solar energy.

But first, why isn't solar energy being more widely used today? The main reason is that other sources of energy have simply been so plentiful and inexpensive in this country, relative to the cost of collection of solar energy, that there has been little incentive to develop the resource. Technology has thus far enabled us to exploit our energy resources at a pace equal to our rapidly rising energy demands, and has also managed to keep prices down. Only recently, as impending energy shortages are becoming more evident and as energy prices are escalating, a great deal of renewed interest is developing in the prospects for using solar energy to augment fossile and nuclear energy supplies. Not only are the traditional sources becoming economically less competitive, but it is becoming increasingly apparent that, even with diligent conservation measures, we will probably need to exploit all of our energy alternatives.

There are a variety of methods currently under investigation for harnessing some of the power of the sun. Most of these methods fall into four categories:

1. Photovoltaic
2. Photosynthesis
3. Wind and ocean thermal gradients
4. Solar thermal

I will touch on the first three very briefly in order to dwell a bit more on the last -- the category with which I am the most familiar.

Photovoltaic methods involve direct conversion of solar energy to electricity by means of certain semiconductors. One of the best examples is the solar cell developed and used so successfully in the space program. Unfortunately, efficiency tends to be low and the single crystal solar cell is presently much too expensive, by a factor of about a thousand, for general power applications. Work is underway, however, attempting to lower the cost through the use of alternative materials, less costly fabrication methods, and mass production techniques. There are some promising approaches, but it appears that it will likely be many years before it becomes economically competitive.

Photosynthesis utilizes solar energy in the growing of special crops which can then be used directly as fuel or converted to synthetic fuels. More direct photochemical processes for producing fuels are also being studied. The method suffers from low efficiency and the relatively high costs involved in harvesting and handling. But the economic prospects are sufficiently attractive that a number of studies are continuing.

Wind and ocean thermal gradients are two methods currently under investigation for indirectly tapping solar energy. Windmills have, of course, been around for a long time. But because there has been so little development in the last 20 or 30 years, a fresh look is being taken at wind machines in light of today's technology. It appears likely that they will prove to be practical and economically competitive in selected locations for generating electrical power. The ocean thermal gradients method would use the 30 to 40°F temperature difference between surface water and water near the ocean bottom to drive a heat engine. A Rankine cycle heat engine with an organic working fluid would probably be used. The concept is characterized by very large pipes, heat exchangers, and water flows, and by the very low efficiencies imposed by the small temperature differences. Work is being funded by NSF to investigate the concept further.

The solar thermal category encompasses a number of different applications and at least three different types of collector systems. Solar energy is first converted to thermal energy which is then used to operate a heat engine to produce electricity, to run an absorption air conditioner for cooling, or used directly for industrial process heat, space heating of buildings, or domestic hot water. Some applications are single purpose, such as central electrical power stations. At the other extreme are the cascaded or "total" energy applications in which most of the electrical, heating and cooling needs of a residential or industrial community would be supplied from solar energy.

There are three general types of collector systems currently under investigation for the various applications: flat plate, linear focus, and point focus. Three of the principal characteristics which distinguish these three types are (1) the amount of solar energy concentration involved; (2) the type of tracking required; and (3) the maximum temperature at which energy can be collected at reasonable efficiency. These and other characteristics are listed for comparison in Table I.

Table I

CHARACTERISTICS OF SOLAR COLLECTOR SYSTEMS

Type	Application	Collection Method	Tracking Requirement
Flat Plate	Low Temperature (Typically <100°C)	Solar energy is absorbed directly on a surface with no concentration. Both the specular and diffuse components of the solar input are collected.	Generally none
Linear Focus	Low to Moderate Temperature (Typically <300°C)	Solar energy is concentrated to a "line" by means of a parabolic trough mirror or a long fresnel lens. Energy is then absorbed on the surface of a pipe and transferred to a fluid flowing within the pipe. Only the specular component of the solar input is collected.	Must track the sun in at least one dimension
Point Focus	Low, Moderate, and High Temperature (up to 1000°C or higher)	A large number of nearly flat mirrors reflect solar energy to a central "point" at the top of a tower. The concentrated flux is then absorbed on a surface and transferred through the walls to a working fluid, or absorbed directly in a working fluid. Only the spectral component of the solar input is collected.	The mirrors must individually track the sun in two dimensions

For applications where high temperature and high efficiency are needed, the amount of concentration is an important means of achieving these goals. The more that solar flux can be concentrated, the smaller will be the area required to absorb it. Heat losses by conduction, convection, and radiation all increase with effective absorber area. Conduction and convection losses are also proportional to the difference between operating and ambient temperature, while radiation loss is a function of the fourth power of temperature. This drop in efficiency with increasing temperature is illustrated qualitatively in Figure 1 for the three collector types.

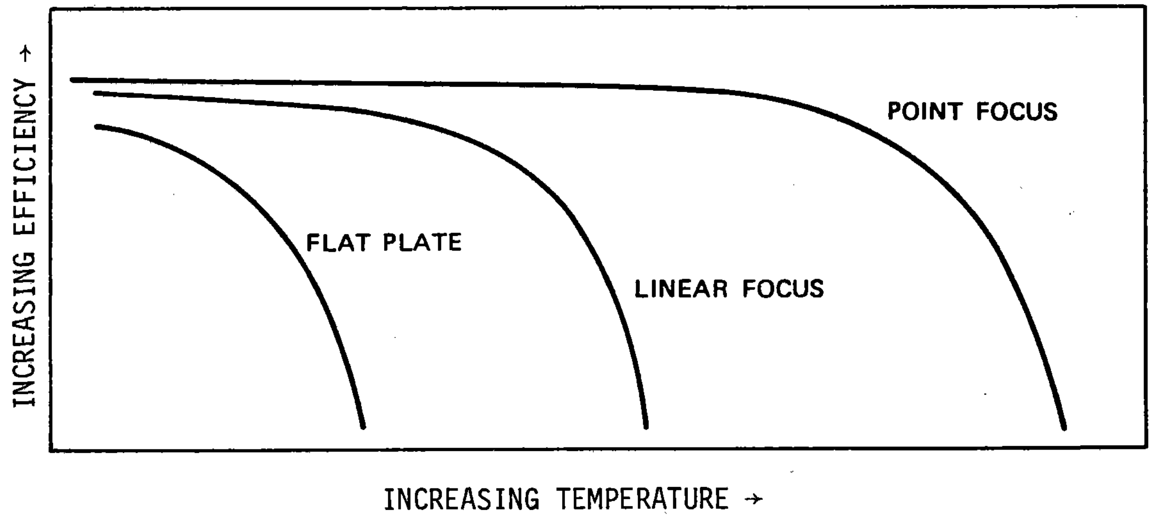

Figure 1. Collection Efficiency as a Function of Temperature for the Three Types of Collector Systems

Flat plate collectors are suitable for low temperature applications such as heating or cooling, but are too inefficient at temperatures above 100°C. They are simpler in that no concentration or tracking is required, although efficiency can be improved somewhat with booster mirrors and roughly 20% more energy can be collected with gross tracking. They have the advantage that both the direct and diffuse components of incident solar radiation can be absorbed. A good deal of work has been done over the years on flat plate collectors and various designs have been widely used for heating domestic water in Australia, Israel, Japan, and Florida. Several homes in the U.S. are being heated with flat plate collectors, and experiments on combined heating and cooling are underway. It also appears that a 50 million dollar heating and cooling demonstration program may soon be initiated by the federal government. The economics are becoming attractive, and I expect we will see a number of different designs being offered by commercial suppliers within the next 12 to 18 months.

For applications involving thermodynamic conversions, such as electrical power generation, or other applications which require or benefit from high temperatures, reasonably high overall efficiency can only be attained through the use of concentrating systems such as linear or point focus collectors. In the explosion of writings on the subject of energy in the last couple of years, solar energy has occasionally been characterized as a low quality energy source. The writer is generally alluding either to the low power density of the solar flux at the earth's surface or to the interruptions caused regularly by the earth's rotation or not so regularly by cloud cover. In a thermodynamic sense, however, solar is one of the highest quality energy resources available to us. Direct solar radiation can be and has been concentrated so as to produce temperatures in excess of 3000°C -- far in excess of the temperatures normally attainable by combustion of fossile fuels. Thus, solar energy is dilute, and it is interruptible; but because it can be concentrated, it is also of extremely high quality.

In linear or parabolic trough collectors, incident solar energy is concentrated by a factor of about 10 to 50 and absorbed on a pipe through which a heat transfer fluid is circulated. The collectors must track the sun in at least one dimension. Heat losses and the pumping energy associated with the distributed piping network are two factors which can significantly degrade performance. They are reasonably efficient up to temperatures of about 300°C. Systems utilizing a large number of such collectors are under investigation for electrical power generation and for total energy systems. Solar total energy systems are those in which the collected energy is cascaded through two or more uses of decreasing temperature to meet most of the integrated energy needs of residential or industrial communities. Energy is first routed to a turbine generator to produce electricity. The by-product heat, which is normally dumped to the environment at the lowest practical temperature, is instead exited at a sufficiently high temperature that it can then be used for domestic hot water heating, process heat, or space heating or cooling. In this application the goal is not necessarily to produce electricity at the highest possible efficiency. The goal is rather to balance supply and demand by adjusting the ratio of output electricity to output heat so that the integrated energy needs of the community are met.

In point focus systems, incident solar energy is reflected by an array of individually steered mirrors to a receiver mounted atop a central tower where it is absorbed and converted to thermal energy in a heat transfer fluid. Each mirror must track in two dimensions and the movement of each is slightly different from adjacent mirrors. Solar concentrations in the range of one to a few thousand are typical, and high temperatures can readily be achieved. Because of the relatively small absorber area and the shorter heat transfer loops involved, heat and pumping losses are much smaller than for distributed collector systems, and the collection efficiency tends to be high even at high temperatures. Central receiver systems appear to be good candidates for electrical power generation and other applications, such as thermochemical hydrogen production, which need or can benefit from high temperatures. Conversion temperatures up to 800°C or higher are under consideration, but most of the current effort is aimed at about 540°C for electrical power generation.

The common goal for all of the different types of systems is low delivered energy cost. This equates to low initial capital cost since operating costs should be minor in comparison. Total system cost is usually dominated by the cost of the collectors, but efficiency of collection and efficiency of use are also important because they affect the total collector area required. If System A is twice as efficient as System B, for example, only half the collector area will be required to produce the same energy output, and collectors could cost up to twice as much per unit area before the total cost would be as high as System B.

An aggressive federal solar research and development program is now being outlined by the National Science Foundation. Several bills aimed at accelerating the exploitation of solar energy are presently under consideration in Congress. Passage of legislation creating the Energy Research and

Development Agency (ERDA) appears imminent. The broad research and technology capabilities of the AEC and other government laboratories will be utilized, and participation by industry, utilities, builders, and others to be involved in utilization will be emphasized. The funding levels being proposed for solar energy over the next five years will support a great deal of the research, development, and demonstration activities needed to accelerate the movement of solar energy systems into the marketplace. Because of this support, and because of the rising cost of other forms of energy, it appears that the age-old dream of harnessing solar energy is an idea whose time has finally come.

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