DIRECT USE OF THE SUN'S ENERGY

BY FARRINGTON DANIELS

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Foreword

The direct use of sunlight to supply the basic human needs for energy is of primary importance to man's continued survival on earth, for the stored fuels, fossilized or organic, are being consumed at an incredible rate. Only green plants are able to convert the sun's energy into fuel and food for animal needs, but the amounts thus produced, large as they are, cannot keep pace with the requirements after the stored supplies of fossilized fuels—coal, oil, and gas—have been consumed.

This conversion ability of green chlorophyll-bearing plants, as in past ages, to form organic compounds is nature's solution to the problem of capture and storage of energy. It remains for scientists to develop photosynthetic processes suitable for commercial development on an enormous scale—a complex but not insoluble problem.

Another approach is to devise efficient physical equipment to utilize directly the heat energy from the sun's rays on a practical low-cost basis. This field has already received much attention, but the results to date have not been too encouraging. Professor Daniels has given many years to a consideration of all aspects of the problems associated with the direct transfer of solar energy. His studies have involved extensive experimental programs and conferences with scientists all over the world. It is indeed fortunate that his results and conclusions are now made available in this most timely volume of *Trends in Science*—a project of the Yale Chapter of Sigma Xi and the Yale University Press.

GEORGE A. BAITSELL

Winter Park, Florida
February 1964

Preface

The purpose of this book is to interest scientists and engineers in undertaking research on the direct use of the sun's energy. The book is expanded from a Sigma Xi lecture delivered at Yale University in April 1960, and from an earlier Sigma Xi lecture tour in 1951, and it is based in part on the author's research program on solar energy during the past decade.

Research in the field of solar energy use is unique in several respects. First, it cuts across many different sciences and branches of engineering—physics, chemistry, meteorology, astronomy, chemical engineering, mechanical engineering, and electrical engineering. Often an area between different fields of science that has been neglected becomes a fruitful field of research. Solar energy research is an example.

Second, it holds promise of leading rather soon to benefits for human welfare. Scientists formerly took little thought of the social and political impact of their work—but all this has been changed since they developed nuclear energy and made atomic warfare possible.

Third, it can be carried out in small laboratories with inexpensive equipment. Expensive nuclear reactors, atom smashers, and wind tunnels are not required, nor is it necessary to master highly specialized techniques such as the handling of radioactive materials.

The author has visited scientists in many of the nonindustrialized countries where abundant sunshine is available and fuel is expensive, and he has been asked frequently, "What research can we undertake in solar energy which might help our country?" This book is an attempt to answer this question and to point out the array of challenging problems in both pure and applied science that await scientists and engineers in the study of solar energy utilization. In an effort to interest readers who are not specialists in solar energy, many engineering and technical details have been minimized, but an attempt has been made to give a comprehensive bibliography where these details can be found.

Four international symposia on solar energy use have been held recently and it is therefore appropriate at this time to survey the present status of the many different ways in which solar energy can be used directly, to summarize present trends and opportunities in research, and to gather together the latest references so that others can build on the efforts which have gone before.

Until recently solar energy research has not been given much financial support, but now with the need for power in space vehicles the United States government is supporting large efforts in the use of solar energy in outer space; some of it will find application on earth.

The author desires to express his deep appreciation to Dr. Warren Weaver and to the Rockefeller Foundation, which has supported generously the research

program on solar energy utilization for the past nine years at the University of Wisconsin. The grant has made possible the exploration of many of the ideas described here and is designed to emphasize helping the economically less-developed countries. The author is indebted also to the Guggenheim Foundation, which supported his work in its earlier phases. He is pleased to acknowledge the efficient help of Mrs. Irene Frey in typing the manuscript and of Mr. Harry A. Schopler in preparing many of the figures.

F. D.

Madison, Wisconsin
January 1964

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CHAPTER 1

Introduction

All our food and fuel have been made possible by the sun through the photosynthetic combination of water and atmospheric carbon dioxide in growing plants. If the world's supply of fuel were evenly distributed there would be a sufficient amount everywhere for present use. But if the earth's population increases at its present rate and if all people achieve the standard of economic development which the quarter of the world's population now industrialized enjoys, there will not always be an adequate supply. Plans should be made now to develop substitutes for combustion fuels—coal, oil, and gas. These fuels have become so vital to modern civilization that research for new sources of heat and power is long overdue.

All our machines have been developed to operate with heat engines or with electricity generated from heat engines or water power. In large units the power is cheap, but in small units of from 1 kw to 500 kw, operated by Diesel engines in isolated areas, the power is relatively expensive—5¢ to 15¢ per kwhr. The upkeep and repair of the Diesel engines and the high cost of transportation of petroleum fuel over poor roads contribute to these high costs. In large power stations electricity is cheap at the bus bar of the power plant but it becomes expensive after distribution over large rural areas to many small consumers. Because atomic energy is essentially a weightless fuel, the cost of its transportation is negligible, but atomic energy can be produced only in large, expensive units and accordingly there is still a high cost of distribution through power lines.

Solar energy requires neither transportation of fuel nor distribution of electricity because it can be produced in small electrical converters wherever the electricity is to be used. For heating and cooling also the direct use of the sun eliminates the need for transporting fuel and conveying power over long distances. These advantages tend to offset in part the present high cost of any device that will convert the sun's energy into electricity and the serious handicap in the storage of power required by the intermittency of sunlight. In some cases, then, it is practical to consider the use of solar devices even though they are more expensive than those that consume fuel.

One of the important characteristics of our present civilization is that we are concerned for the welfare of others—for our descendants and our neighbors. We are aware as never before of the living conditions in other parts of the world, and the industrialized countries are eager to help the nonindustrialized countries become more productive and achieve a higher economic level. More mechanical or electrical power would be a very effective means of help. Though the industrialized countries do not seriously need more fuel now as the nonindustrialized countries do, they are in a good position to give important practical help through research and development of means for using solar energy. Fortunately even the smaller countries with little experience in scientific research and engineering and with small financial resources can undertake both basic and applied research in the use of solar energy.

The rapidly developing countries are eagerly looking for new sources of industrial power. Some are expecting too much too soon, and it is important to emphasize that education and research and the spirit of public service are more important than kilowatts. If however it is a question of "water or no water" or "power or no power," no price is too high to pay. Solar energy is a hopeful source, especially in sunny, rural areas, though it cannot compete with conventional sources of energy where these are abundant, or in cloudy climates, or in large cities where the amount of available sunlight is too small to supply the power needs.

The question may properly be asked: "Will the need for solar-generated power be only temporary?" Conventional fuel-powered electric generating systems with their transmission lines and power grids are expanding rapidly and will eventually cover the earth. But there are now 2 billion people in the world without electricity and it will be a long time before they can be served. Moreover, in communities of small rural users widely distributed the cost of distribution of conventional electric power will continue to be so great that solar energy may perhaps be competitive.

Already there is a specific case that might be considered. Twenty thousand wells are needed for pumping water in Pakistan to rinse salt deposits out of irrigated lands which have become agriculturally unproductive because of waterlogging and excessive accumulated salinity. It would be natural to turn to electric pumps with large, efficient electric power plants and a network of transmission lines. But if practical solar pumps can be developed soon enough, they might well be considered, in spite of the considerably greater cost of power production, because they would eliminate the long, expensive power lines.

The immediate urgency for research in solar energy is for use in the economically less developed countries. The long-range need for research in solar energy is in the highly industrialized countries, because the fossil fuels will not last indefinitely and will certainly increase in cost. There is now a temporary excess of petroleum production, but within five years the domestic supply of petroleum in the United States is expected to continue to rise, pass its peak, and begin to decline. More petroleum will have to be imported. The present rate of petroleum production in the world is about 7 billion barrels per year, and the world's proven reserves are about 300 billion barrels, which would last less than half a century at the present rate of consumption. But since the rate of consumption is bound to increase rapidly, particularly in those large areas of the world seeking to industrialize as fast as possible, shortages may be expected within a half century. New reserves, far beyond the 300 billion barrels, will continue to be found in the future as they have in the past, but eventually fuel will become so expensive to recover that new sources of energy must be found to supply a world which will have become ever more dependent on abundant fuel.

Solar energy research has been neglected. In the industrialized countries fossil fuel is abundant (or they would not be industrialized), and there is little private incentive for solar research. Neither has there been need for government support. In the nonindustrialized countries in sunny areas there have been few resources in funds and technical manpower and little knowledge of the potentialities of solar energy. If a small fraction of the resources and efforts now directed toward atomic energy and space science were directed toward use of solar energy, a great deal of progress could be made. There is no gamble in solar energy use; it is sure to work. It has been demonstrated that solar energy will heat, cool, convert salt water into fresh water, and generate power and electricity. The problem is to do these things cheaply enough to compete with the present methods based on fuel, electricity, animal power, or manpower in any given locality. The competition is difficult because of the low intensity of radiant energy in sunlight and the interruptions of night and cloudy weather. It is hoped that intensive work by many scientists and engineers in many countries will solve the problems and make solar energy useful in some areas of the world now and in many areas in the future.

The direct use of the sun's radiation is not new, but we have new materials to work with, such as inexpensive transparent sun-resistant plastics and semiconductors of high purity. We have new ideas in science, accumulated experience in engineering, and a broader knowledge of world-wide opportunities and needs. Thus it is important to re-examine all the ways in which science and technology can help to make direct use of the sun practical.

General Bibliography

The scientist or engineer who desires to look over the field in search of an interesting or useful project may study the following general bibliography, which is largely based on the international symposia of the past decade. (Specific references will be given in later chapters when the research opportunities in the several different solar energy applications are discussed.)

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