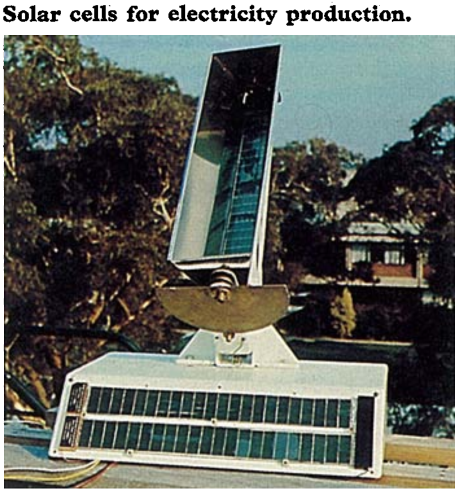
The energy the world needs has always been supplied by the sun. The fossil fuels that industrial society consumes in such great quantities—oil, coal, and natural gas—supply energy from the sun gathered by green plants over millions of years and stored. And, of course, solar energy lights and warms the earth and sustains the vegetation that the rest of life depends on for food.

Harnessing heat from the sun

A house with solar water heating.

Solar cells for electricity production.



We're all well aware of the finite nature of fossil fuel resources, and of the fact that the store is running out at an increasingly rapid rate. The world used 10 times more energy obtained from these fuels last year than in 1900. Vast quantities of coal remain to be mined, but demand for oil and natural gas seems set to outstrip supply early next century.

If the amount of solar energy harvested directly, rather than from the fossil fuel store, could be boosted to meet the world's energy demands, the problems posed by the rundown of reserves would go away. Also, potentially hazardous alternative energy sources such as uranium could be left alone.

The sun produces more than enough energy to satisfy any foreseeable demands, so the need is to find ways to harness much more of it. At present, solar energy can compete economically with fossil fuels in only very limited applications.

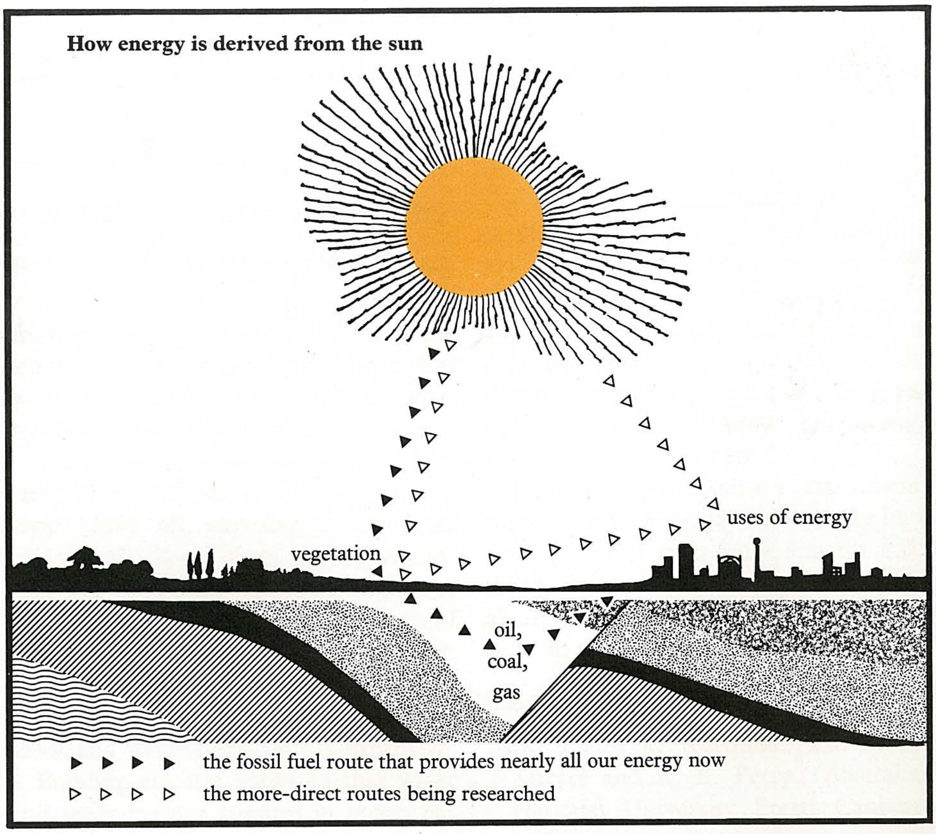
To date, domestic water heating has been the most successful application. Silicon solar cells, which give off small amounts of electricity when the sun shines on them, have found uses in isolated areas and on satellites in space. And ways are known to produce, from trees and crop plants, fuels (such as alcohol and methane) that could do the jobs of oil, coal, and natural gas—offering, in effect, a regular harvest of 'solar fuel'.

In 1973 a committee of the Australian Academy of Science looked into the prospects for using more solar energy and into the most effective ways of expanding the research effort. It suggested that Australia should aim at satisfying from solar energy more than one-third of its heat generation needs and about half its liquid and gas fuel needs for transport by the year 2000. The committee said a very substantial research effort would be needed to achieve those goals. It did not suggest a goal for solar electric power production, and said Australian needs for electrical energy could continue to be met mainly from coal-fired stations for several more decades.

Solar energy research is expanding rapidly overseas. In Australia, by far the bulk of the relatively small research effort is on heating applications. Projects are going ahead in CSIRO, Australian and State government departments, private companies, and universities and colleges of advanced education.

The Australian pioneer in this area, with research going back to the early 1950s, is the CSIRO Division of Mechanical Engineering at Highett, Melbourne. This article will deal mainly with the

Division's research on water heating, led until 1973 by Mr Roger Morse and now by Mr Wal Read. This work has given rise to an industry that is now producing domestic hot-water systems in all Australian States. Later issues of *Ecos* will describe other areas of solar energy research.

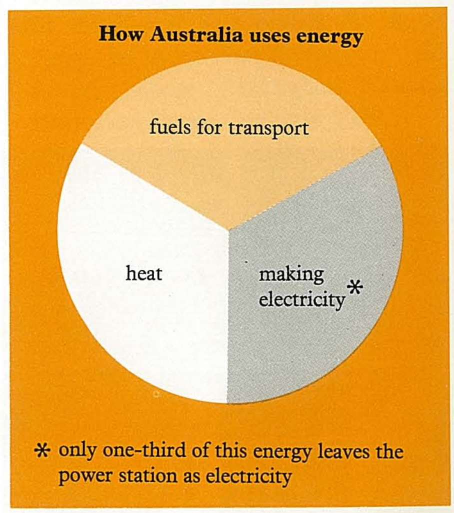


Water heaters

Something like 30 000 houses throughout Australia now have solar water heaters, and demand is growing so rapidly that production has increased five-fold since the middle of last year. Larger systems have been installed in hotels, hostels, and boarding schools.

Export markets for complete systems or components have been found in nine countries, including the United States and Japan. One Australian manufacturer has licensed companies in New Zealand, Japan, and South Africa to produce water heaters it has developed from CSIRO designs. Developments by the industry in Australia include the design of systems operating at mains pressure, improved methods of installation, and solar swimming-pool heaters.

Production of solar water heaters has increased five-fold since the middle of last year.



The heart of a solar hot-water system is its panel of energy collectors, usually installed on a sloping roof. Water heats up as it flows through these, and is stored in a tank for later use. This tank usually contains a thermostatically controlled electric element, which provides additional heat when the collectors fail to supply all that is needed. Tests with installations in different parts of Australia show that 60–80% of a year's heating is done by the solar collectors.

The collectors developed by CSIRO and produced commercially in Australia are insulated rectangular boxes ranging in base area from 0·75 to 3 sq m. Energy from the sun is absorbed by a plate made up of narrow copper tubing soldered to a sheet of copper. Above this plate is a glass cover, and below it a layer of insulating material.

Where the energy comes from

use	main sources now	possible solar sources
fuels for transport	oil	fermentation of plant material to produce methane, hydrogen, ethyl alcohol, or methyl alcohol destructive distillation of plant material to produce hydrocarbon fuels
heat	oil, coal, natural gas	solar heat collectors furnaces burning plant wastes and fuels from plants
making electricity	coal	silicon solar cells similar carbon-based cells generators fired by fuel from plants

Black plate

The surface of the copper plate is blackened to make it a good absorber of radiation. The most efficient process now used is one developed at the Highett laboratories in the early 1960s by Dr Don Close and Mr Bob Dunkle. It involves dipping the copper in a mixture of sodium hydroxide and sodium chlorite. The blue-black surface that results is not only a good absorber; it is also a poor radiator of energy. This 'selective' property of the treated surface is important in reducing energy losses.

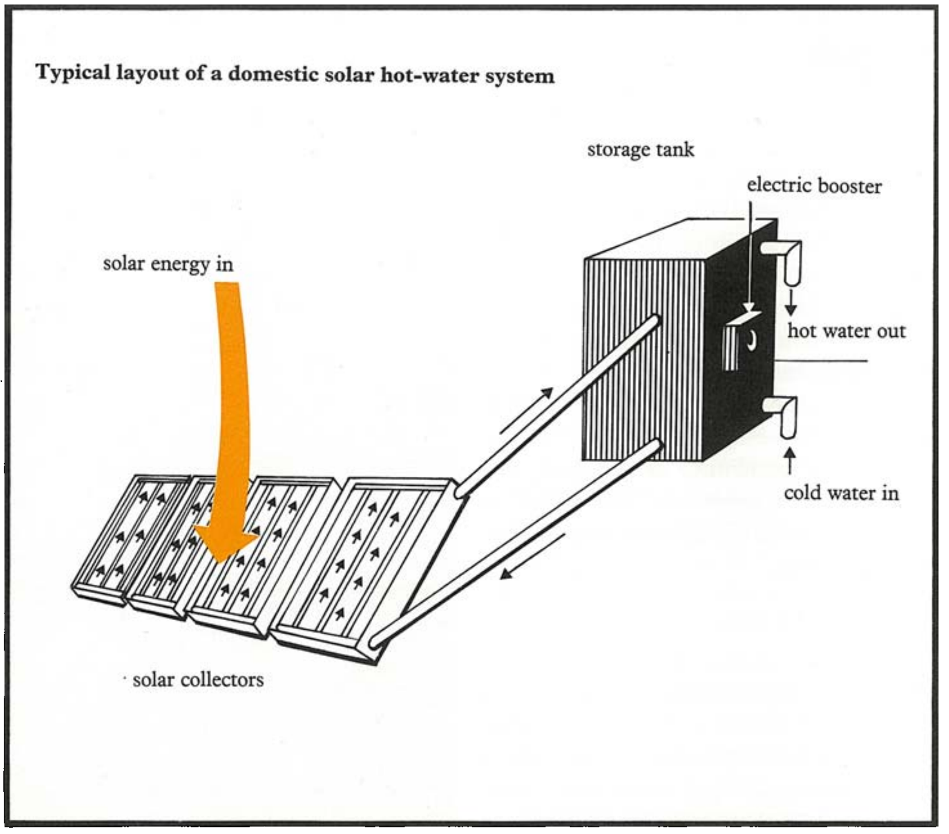
Also important for reducing losses is the glass cover, because it prevents air heated in the collector from moving away and being replaced by cooler air. The collectors have high efficiency; when they are used for heating water to about 55°C —a typical figure for domestic hot-water systems—they transfer 40–50% of the solar energy reaching them to the water flowing through. When losses from the other parts of a house's water heating system are included, the efficiency comes down only to an average of about 40%. The collectors are much more efficient harnessers of solar energy than vegetation; plants take up only about 0·5% of the energy falling on them.

Solar water heaters are more expensive to build and instal than their non-solar competitors, but their running costs are lower because they use much less fuel. They are most competitive where electricity prices are highest and sunshine is most plentiful. Their economic attractiveness in any area depends on the time it takes the operating cost of conventional systems to mount up to the additional capital cost of the solar heaters plus the solar heaters' fuel bills.

Calculations by Mr Tad Czarnecki and Mr Ted Davey, of the Division of Mechanical Engineering, suggest that this takes only about 3 years in Darwin—making solar models very attractive there. In Perth the figure is probably about 4 years, which is also attractive as the systems should have a life of at least 20 years.

In other Australian cities, the figure rises to something like 10 years. Of course if fuel prices increase in coming years, as they seem certain to do, the competitive position of solar water heaters may improve.

However, if Australia is to use solar energy to make a big dent in its demand for non-renewable fuels, Australians will have to do much more than wash themselves, their clothes, and their dishes in solar-heated water. About 7% of Australia's energy consumption is in houses and flats, and that figure takes in the energy used for cooking, house heating, and all other domestic activities as well as water heating. So it is obvious that domestic water heating accounts for only a small proportion of our total energy use.



With the tank placed slightly above the collectors, water moves up and out of the collectors as the sun heats it, and is replaced by cold water from the tank. A pump is needed only if the tank is below the collectors.

Heat for factories

Industrial applications of heat, however, are major energy users. Mr Morse, now CSIRO's Director of Solar Energy Studies, calculates from the available statistics that about half of Australia's final use of energy is in the form of heat. The other half is divided in about a 4:1 ratio between transport and uses of electricity. (Of course some overlap between the categories does occur, but it is not great.) So there is much more room for supplying energy from the sun as heat and liquid or gaseous fuels for land, sea, and air transport than as electricity.

But most electricity is produced by burning coal, oil, or gas, and about three times more energy is used to produce it than is available from the electricity. So solar electricity production also could considerably reduce the demand for fossil fuels.

Heating is the largest of the energy-use categories, but before possible solar contributions can be worked out it is necessary to know the heating requirements of industries. The Solar Energy Studies Unit, set up in 1973 under Mr Morse to advise on research priorities, has begun a project to gather information on these requirements—how much heat industries use, what temperatures various processes operate at, and so on.

In the first stage of the project, Dr David Proctor and Mr Flynn White looked at 25 Australian food-processing factories. They obtained information about these plants, which account for 2·7% of the energy used in the Australian food, beverage, and tobacco industry, through interviews with technical staff and questionnaires.

They found that nearly nine-tenths of the energy used in the 25 factories was in the form of heat, all of which was produced by burning oil, coal, or gas. Just six processes—bottle-washing, pasteurization, sterilization, cooking, product separation, and water heating—accounted for all but 4% of the heat used.

They also found that most of the heat was needed at temperatures above those that the solar collectors available now can consistently supply, but 14% was needed below 50°C, putting it within the range of these collectors. Half of it was needed between 60 and 100°C, and most of the rest below 150°C.

The researchers calculated that if half the heat needed by these 25 factories in the 60–100°C range came from solar energy, the area of collectors required would take 20 years to produce at Australia's rate of production in the middle of last year. The potential demand for a collector producing steam at 120°C would be not much less. These figures refer to just a small fraction of Australian industry, so it is clear that if solar heating is to penetrate into industry in a significant way the manufacture of collectors will have to expand enormously.

Whether this penetration will take place depends, in the up-to-50°C area, on the competitive economics of the solar and conventional alternatives. Above 50°C it depends also on developments in collector technology.

If solar heating is to penetrate into industry in a significant way, the manufacture of collectors will have to expand enormously.

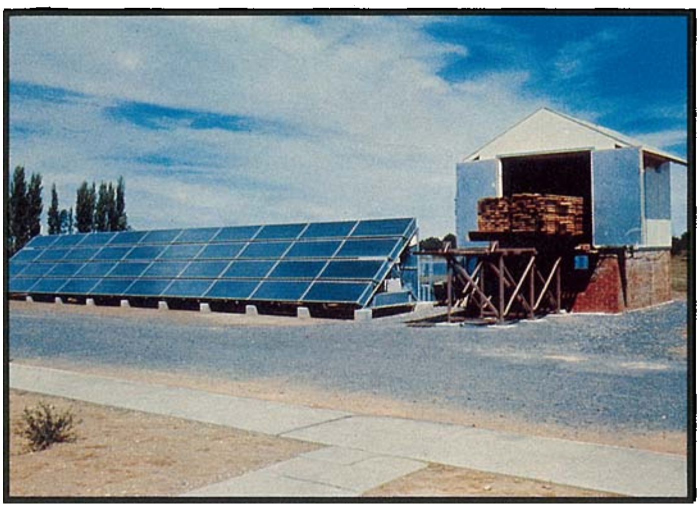
Reflection losses

The collectors for sale now are flat; therefore they don't concentrate the sun's energy, but collect it evenly over their surfaces. Obviously collectors that reflect the radiation striking them onto small areas can heat these areas to temperatures higher than those reached by flat collectors exposed to the same sunlight. However, much of the energy available from the sun is lost in the process of concentration.

The flat collectors now available rapidly lose efficiency with increasing temperature when they are used to heat water above about 60° C.

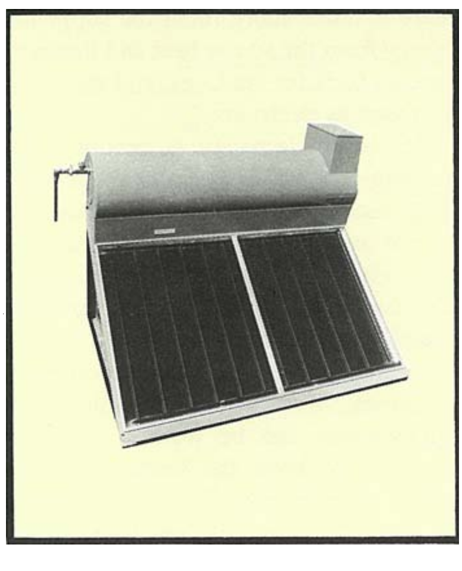
The reason is that a big part of the radiation reaching a collector doesn't come straight from the sun, but is scattered on the way by clouds and dust. This diffuse radiation usually makes up 20–40% of the total reaching the ground, and nearly all of it when clouds block the sun. Because diffuse radiation comes from all directions, concentrating collectors can't focus it and therefore can't make use of it. Flat collectors, on the other hand, are unconcerned by the direction of the radiation striking them, so they absorb energy from both the direct and the diffuse components.

The flat collectors now available, however, rapidly lose efficiency with increasing temperature when they are used to heat water above about 60°C. Heat losses mount until, at boiling point, they almost equal the energy input. These losses can be reduced by using two or even three sheets of glass for the collector face, but each sheet also reduces the amount of energy reaching the copper surface. Better insulation also can reduce losses. But each addition increases the collector's cost.



An experimental sun-powered timber kiln at Griffith, N.S.W.

This array of collectors heats a school's water.



A recent development in water heater design—one-piece collector and tank.

Inside a solar collector factory.

Factories are much bigger potential users of solar energy than houses.

An effective, although much more expensive, solution to the heat-loss problem may be to make collectors with a vacuum between the glass and copper; there would be no air to carry heat away from the copper, by convection. Possibly concentrating collectors, despite their inherent inefficiency and the need to keep them pointing at the sun, will prove to be the most favourable solution at the higher temperatures.

At the Highett laboratories, Dr Peter Cooper, Dr Jeff Symons, Mr Paul Pott, and Mr John Sheridan are looking for ways to increase the efficiency of solar water heating above 60°C while at the same time keeping costs down.

Better dip

One possibility is to give the glass face of each flat collector a coating that will reduce the amount of radiation reflected from it, allowing more to come through to the copper plate. Another is to develop coatings for the copper that will increase its energy absorption while keeping losses low.

Dr Alan Reid of the Division of Mineral Chemistry in Melbourne came up with such a coating a few months ago, and it will soon be available on commercial collectors. The new dip is a development of the one devised earlier at Highett. Measurements by Mr Eric Christie at the Division of Mechanical Engineering show that it gives significantly improved performance.

Another possibility is to use some material other than copper. Collectors have been made in America using steel, aluminium, and plastic plates, but the metals are liable to corrosion and plastic to degradation by sunlight.

It seems inevitable that the complexity and cost of the collectors required will continue to rise with the temperature water is to be heated to. One method the scientists are looking at to minimize this drawback is heating the water by stages, in a series of collectors designed for different temperature ranges.

At Highett, a large array of collectors is now being installed. Members of the solar energy group will see how it performs various industrial heating tasks.

Much of the research being done by the Division of Mechanical Engineering team is aimed at gaining a detailed understanding of how solar collectors perform. The scientists are finding out, for example, exactly how much heat is lost, and where; this information should improve the chances of reducing losses without making costly additions to collectors. Another of their aims is to establish standard techniques for testing the performance of collectors. These will enable objective comparisons to be made between different collectors offered for sale.

Judging performance

Also, people will need this detailed information of they are to make accurate predictions of how solar water-heating systems will work in any situation. Mathematical models are used to predict performance and to help in the design of the most cost-effective systems for particular jobs. A computer program developed recently by Dr Cooper and scientists at the University of Wisconsin, U.S.A., can be used for modelling any solar water-heating system. But the output from the computer can only be as accurate as the performance data fed in.

An important part of any design job is deciding how much of a year's heating should be done by the non-solar booster in a system. This is essentially a question of economics. The sun supplies more energy in summer than winter and much more on sunny days than cloudy days. If a solar system is designed to supply all the

Variations in solar input

Australia's deserts are sometimes proposed as good places to gather solar energy, and they certainly have the advantage of seldom being covered by cloud. But the amount of energy reaching them in a year is not vastly greater than that reaching greyer areas, and it is hard to envisage circumstances where the extra energy available would exceed the losses involved in taking it to potential users. A square metre of Simpson Desert sand, for example, receives only about 40% more solar energy than a square metre of solar collector on a Melbourne roof.

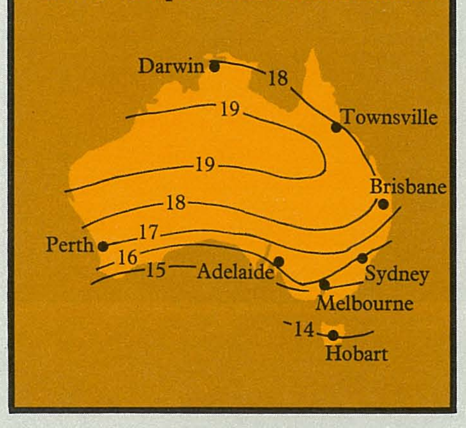
Places near the equator, however, have a considerable advantage over those further away, because the variation with seasons in the amount of radiation reaching them is significantly less. The difference in energy received between the best and worst months is only 40% in Darwin, compared with 120% in Melbourne.

Clouds have a big effect on the amount of energy reaching the ground; a cloud passing overhead can cause an immediate 80% reduction. And, of course, no solar energy comes in at night. For heating applications, storage and non-solar boosting is nearly always necessary to cope with all the fluctuations.

The scientists at Highett have found that north-facing solar collectors give the maximum output, averaged over a year, if mounted at an angle approximately equal to the angle of latitude. This output is only slightly greater than that of collectors installed in a horizontal position, but varies considerably less with season.

Mr John Bugler, of the Capricornia Institute of Advanced Education at Rockhampton, recently devised a method for calculating the amount of solar radiation available to collectors inclined at any angle and pointing in any direction. The calculations are made from the amount of radiation striking a horizontal surface—information that is available for many locations throughout Australia. Mr Bugler's work, done at the Solar Energy Studies Unit, should make possible improved predictions of the heat output of collector installations.

How solar input varies across Australia



Average daily solar radiation varies from about 14 megajoules per square metre per day at Hobart to nearly 20 in the north-western desert.

People designing solar systems for an area need to know how much radiation reaches the area and how it varies. With this information, and temperature and wind velocity data, they can predict the energy output of collectors installed there.

Dr Proctor from Highett and Dr Harry Salt of the Solar Energy Studies Unit recently developed computer programs that should assist in these predictions. The first programs, developed by Dr Proctor, give print-outs showing the maximum, minimum, and average heat outputs that can be expected from collectors installed in Melbourne for each month of the year. They also show how the output will vary with the temperature a heating system operates at. Dr Salt has drawn on these programs and on Mr Bugler's work to develop programs that give similar heat-output predictions for any area where the necessary records of radiation, temperature, and wind exist.

These have been measured regularly in parts of Australia for many years, but the Academy of Science committee recommended an upgrading of the measuring network. The Solar Energy Studies Unit has begun a project to store all available measurements in accessible form in a computerized data bank.

wanted heat in periods when little energy is available from the sun, it will need to have a collector area much greater than that required at other times. There would be few situations where this could be economically justified.

Experience suggests that a solar contribution ranging from 60 to 90% is best for domestic water heaters. Mr Morse believes industries may aim initially for a much lower percentage for some processes —perhaps 25%—and gradually increase it as fuel costs rise. Solar heating will not eliminate the need for fuels to heat water, although it has the potential to greatly reduce that need. If research on the production of fuels from plants proceeds successfully, however, that form of solar energy may eventually be able to supply the extra heat.

This article has dealt with only one area of solar energy research—one with great potential for reducing use of non-renewable fuels. The question of how future energy demands can be met—and whether it is possible or desirable to meet these demands if they keep doubling every 20 years or so, as they have done this century—is enormously important and complicated. *Ecos* 5 looked at the prospects for making oil from coal, and at the likely time scales for depletion of the world's oil, natural gas, and coal.

It is still much too early to predict whether solar energy will eventually be able to meet the world's energy demands, or how far it will be able to go towards that goal. But clearly much more research will be needed if the goal is to be approached.

More about the topic

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