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SOLAR HEATING AS A MAJOR SOURCE OF ENERGY FOR AUSTRALIA

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SOLAR HEATING AS A MAJOR SOURCE OF ENERGY FOR AUSTRALIA

L'ENERGIE SOLAIRE COMME SOURCE MAJEURE D'ENERGIE POUR L'AUSTRALIE

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1. INTRODUCTION

In 1974/75, the primary energy input to the Australian economy comprised oil 48%, coal 40%, natural gas 7%, miscellaneous 5% (2% hydro-electric, 2% bagasse, 1% wood). The end use of this energy can conveniently be divided into three groups, viz., heat used at various temperatures, energy for all forms of transportation, and energy used as electricity.

This is illustrated in Figure 1 which classifies as heat, that electrical energy used for low and medium temperature applications such as house and water heating, giving end use energy as heat 50%, transport 40% and electricity 10%.

Primary energy for the generation of electricity is coal 81%, oil 7%, natural gas 6% and hydro-electric 6%. There is little doubt that the percentage due to oil will decline, and there is active debate at present as to the wisdom of using a premium product like natural gas for the generation of electricity. Since about half the country's hydro-electric potential has been developed, its percentage contribution will also decline. There are no nuclear power stations at present, nor are any currently being planned. It is clear that the generation of electricity will continue to be predominantly coal based. Australian coal reserves are so large that the primary energy needed for electric power generation can be considered secure for as far ahead as can be seen, so there will therefore be no need to contemplate large-scale solar or nuclear electricity generation for the foreseeable future.

Oil reserves, however, are being depleted rapidly, and increasing quantities will have to be imported. As it accounts for nearly half the country's total primary energy, it is clearly as a replacement for oil that solar energy could make its most effective contribution. Oil supplies almost the entire transportation needs, and a large percentage of the heat requirements, but the extent to which solar energy can contribute to the replacement of oil depends on the actual application. The technology is available now for solar heat generation up to temperatures of about 80°C, and it can be forecast with reasonable confidence that within the next decade this will be extended to about 150°C.

It is also possible to produce renewable liquid fuels from solar energy, but this is more speculative because it will be very dependent on the level of research and development which can be mounted in this area and the degree of success which is achieved. One proposal is the use of forests to convert solar energy into cellulose by means of photosynthesis followed by the conversion of the cellulose into ethanol in chemical processing plants [1]. This is one of several possibilities for the production of renewable liquid fuels suitable for transportation.

A scenario for the year 2000 incorporating these possibilities and assuming no natural oil, is shown in Figure 2. It has been proposed [2] as a basis for research and development so that future governments could have the option of making Australia self-sufficient in energy in due course. If this is compared with Figure 1, it shows a 4.5% p.a. growth in the total consumption of primary energy, and for a predicted population of 18 million at the end of the century, represents a per capita energy consumption of 439 GJ/a (cf 174 for 1972). This can be compared with the United States figure for 1972 of 329 GJ/a and a prediction by the U.S. Department of Commerce for 2000 of 643 GJ/a. The energy usage pattern is significantly different from the 1972 percentages and reflects a more efficient use of energy for transportation and a greater use of electric power because of its convenience and versatility. It also assumes much the same percentage of the end usage in the form of heat.

It is clearly in the form of heat that solar energy can make its greatest impact, and it is also clear that this will lead to the establishment of a major new industry to design, construct and install the solar heat generating systems. The size of this industry can be forecast since we know the area of collector which would be required to generate 1 EJ/a of heat and the cost per square metre of collector. Assuming an average collector efficiency of 35%, insolation of 17 MJ/m^2 d and installed system cost for large-scale production of $100 per square metre of collector, the total installed value of solar heat generating systems to produce 1 EJ/a will be $46 000 million.

If this investment in equipment requires replacement at the rate of 5% p.a. it will represent an annual production of $2 300 million to maintain it, which would be an industry comparable in size with the present automobile industry in Australia.

Large-scale production of liquid fuels such as solar ethanol could also lead to a major new industry, but this is further away and will depend on the level of R & D that can be supported.

The situation which emerges is that the most immediately practicable way in which solar energy can make a major contribution to Australia's primary energy is as heat for industry, commerce and homes.

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[1] Morse, R.N. & Siemon, J.R. Solar Energy for Australia. The Role of Biological Conversion. The Institution of Engineers, Australia 1976 Engineering Conference, Townsville, 11th-14th May, 1976.

[2] Australia. Senate. Hansard, 17th June, 1976. Submission to the Australian Senate Standing Committee on National Resources. Enquiry into Solar Energy, by CSIRO Solar Energy Studies.

2. SOLAR RADIATION

The performance of systems which utilize solar energy depends on the radiation incident on the collectors, and the design of such systems requires a detailed knowledge of this radiation at the locality in question. Most countries have radiation measuring networks, and in Australia there are 20 stations which measure insolation continuously. This is recorded in the form of half-hourly integrated totals throughout the day, and some daily

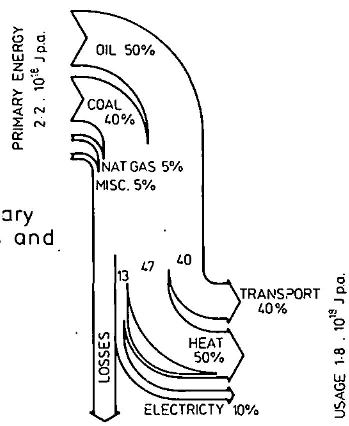

Fig. 1.
Australian Primary Energy Sources and Usage 1972

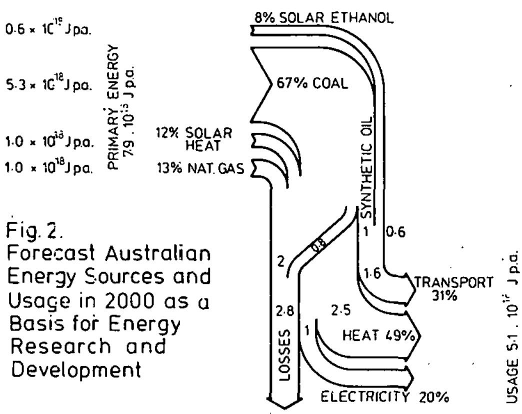

Fig. 2.
Forecast Australian Energy Sources and Usage in 2000 as a Basis for Energy Research and Development

averages are given in Table I. The most useful information is the total global radiation on a horizontal surface and the diffuse radiation on a horizontal surface recorded hourly for some years. From these two measurements it is possible to separate the direct component of radiation from the total global radiation on the surface and apply standard trigonometrical formulae to calculate the radiation that would be received on a surface inclined at any angle and oriented in any direction. There have been several methods proposed for this, but a problem arises when diffuse radiation is not measured and the only figures available are those for total global radiation on a horizontal surface.

TABLE I

TABLEAU I

SOLAR RADIATION FOR SOME AUSTRALIAN TOWNS

IRRADIATION SOLAIRE POUR QUELQUES VILLES AUSTRALIENNES

Daily Average Total Global Insolation on Horizontal Surface

		MJ/m^2			MJ/m^2
Albany	=	15.6	Macquarie Island	=	9.3
Alice Springs	=	21.9	Melbourne	=	14.3
Casey (Antarctica)	=	8.6	Mildura	=	18.2
Darwin	=	20.9	Oodnadatta	=	21.3
Forrest	=	19.6	Perth	=	19.2
Geraldton	=	20.6	Port Hedland	=	23.3
Halls Creek	=	22.4	Rockhampton	=	18.9
Hobart	=	13.5	Wagga Wagga	=	17.6
Laverton	=	15.4	Williamtown (near Sydney)	=	17.0
Longreach	=	21.7	Woomera	=	20.1

A useful method of estimating the hour by hour values of diffuse radiation in these circumstances has been proposed by Bugler [3] who compares the measured value of total global radiation on a horizontal surface with the predicted direct radiation in the absence of cloud, and so builds up an atmospheric model from which the diffuse radiation for that period can be estimated. This has now been developed in the form of a computer program known as PRERAD, which takes measured values of hourly total global insolation on a horizontal surface for a number of years at a particular location and predicts the incident radiation hour by hour over the same period of time on a surface inclined at any angle and oriented in any direction.

Program PRERAD is now being used to predict hourly or monthly values of insolation falling on a particular factory roof, for use as input data for the design of solar heat generating systems. The Program will also print out values of diffuse radiation, hours of sunshine, and direct beam radiation which is needed for focusing collectors. (Note that meteorological literature generally uses the term "direct radiation" to refer to direct beam radiation, that is the energy received by a sun tracking instrument with an acceptance angle of 10°).

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[3] Bugler, J.W. The Determination of Hourly Solar Radiation Incident upon an Inclined Plane from Hourly Measured Global Horizontal Insolation. CSIRO Solar Energy Studies Report No. 75/4. July 1975.

3. COLLECTORS

All collectors in commercial use in Australia at the present time use water as the energy transfer fluid, although air heaters have been developed and used in experimental installations for the drying of timber and for building heating. Air heaters are being manufactured and used for house heating in the United States. For industrial process heating, the energy transfer loops normally use either water or steam, and can be adapted to be integrated with solar collectors for temperatures up to about 80°C. No cost effective steam generators have yet been demonstrated.

The fixed flat plate collector is the most widely used device in the world today for solar heat generation systems. It has been developed to the point where durable, cost-effective collectors are in quantity production using special selective surface treatment on the absorber plate to reduce the re-radiation losses and increase the efficiency of collection. The flat plate collector can accept both direct and diffuse components of radiation, and is capable of operating at relatively high efficiencies.

The instantaneous collection efficiency is given by the equation

$$\eta = \eta_0 - (a + c\ V)\ \frac{\Delta T}{G} - b\ \frac{\Delta T^2}{G} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where η = steady state efficiency of the collector

η_0 = efficiency when $\Delta T = 0$

ΔT = difference between mean water temperature in the collector and the equivalent temperature of the surroundings °C

G = radiation on the collector W/m^2

V = wind velocity in m/s

a, b, c, and η_0 are parameters which can be measured on an appropriate test rig and represent the thermal properties of the particular collector in question.

From equation (1) it follows that the heat output Q in watts per square metre of the collector is

$$Q = \eta_0\ G - (a + c\ V)\ \Delta T - b\ \Delta T^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Experimental procedures for measuring the properties of collectors have been described by Cooper [4] and Symons [5]. They enable the thermal characteristic of a particular collector to be measured and expressed in graphical form, in which η is plotted against $\frac{\Delta T}{G}$, for a particular wind velocity. The effect of wind and hence the value of the co-efficient c in equation (1) can be allowed for, and heat tables for a particular collector are computed using programs developed by Proctor, Salt and White [6,7]. These heat tables

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[4] Cooper, P.I. The Testing of Flat-Plate Solar Collectors. The Institution of Engineers, Australia 1976 Engineering Conference, Townsville, 11th-14th May, 1976.

[5] Symons, J.G. The Direct Measurement of Heat Loss from Flat-Plate Solar Collectors on an Indoor Testing Facility. CSIRO Division of Mechanical Engineering Technical Report No. TR 7, 1976.

[6] Proctor, D. Program SOLARHT. CSIRO Solar Energy Studies Report No. 75/2. July 1975.

[7] Salt, H. & White, R.F. Calculation of Heat Tables using Program SOCOFI. CSIRO Solar Energy Studies Technical Note 1. October 1976.

MEAN MONTHLY VALUES OF DAILY HEAT PRODUCTION, IN MJ/SQ.M., OVER THE 6 YEARS

T	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVE
(a) SINGLE GLASS COLLECTOR AREA 0.74 m^2 SELECTIVE SURFACE $Q = 0.69\ G-(2.9 + 0.42\ V)\ \Delta T-0.18\ \Delta T^2$													
25	13,05	12,99	12,46	11,19	8,58	6,48	7,88	8,82	9,53	11,04	12,07	13,47	10,63
35	11,14	11,17	10,78	9,57	7,09	5,23	6,37	7,17	7,80	9,27	10,17	11,57	8,95
45	9,40	9.47	9,16	7,91	5,73	4,09	5,02	5,69	6,24	7,60	8,42	9,86	7,38
55	7,69	7,80	7,53	6,42	4,47	3,03	3,71	4,28	4,86	6,10	6,79	8,11	5,90
65	6,08	6,22	6,08	5,08	3,33	2,10	2,56	3,04	3,55	4,70	5,29	6,49	4,54
75	4,68	4,81	4,74	3,78	2,35	1,30	1,58	2,01	2,43	3,46	3,94	5,02	3,34
85	3,39	3,56	3,45	2,66	1,53	,72	,81	1,17	1,50	2,35	2,76	3,71	2,30
95	2,29	2,47	2,40	1,72	,89	,32	,35	,59	,84	1,45	1,78	2,53	1,47
(b) SINGLE GLASS COLLECTOR AREA 2.72 m^2 NON-SELECTIVE $Q = 0.73\ G-(4.6 + 0.64\ V)\ \Delta T-0.02\ \Delta T^2$													
25	13.22	13,14	12,53	11,04	8.13	5,96	7,23	8,19	9,06	10,79	11,85	13,56	10,39
35	10.52	10,57	10,12	8,69	6.16	4,33	5,26	6,05	6,75	8,34	9,27	10,97	8,08
45	8.13	8,22	7,09	6,60	4,43	2,90	3,52	4,14	4,85	6,24	6,97	8,53	6,03
55	5.96	6,12	5,94	4,82	3,00	1,72	2,09	2,62	3,17	4,41	4,99	6,37	4,27
65	4.18	4,34	4,21	3,23	1,85	,89	1,02	1,45	1,85	2,88	3,33	4,50	2,81
75	2.67	2,55	2,77	1,93	1,21	,38	,40	,68	,96	1,66	2,00	2,93	1,69
85	1.45	1.72	1.65	1,08	,45	,11	,11	,29	,42	,82	1,00	1,67	,90
95	.65	,91	,85	,47	,18	,01	,02	,07	,15	,34	,41	,81	,41
(c) DOUBLE GLASS INDUSTRIAL COLLECTOR AREA 1.48 m^2 SELECTIVE $Q = 0.67-(2.0 + 0.1\ V)\ \Delta T-0.01\ \Delta T^2$													
25	13,11	13,04	12,60	11,49	9,22	7,24	8,77	9,66	10,18	11,56	12,51	13,62	11,08
35	12,07	12,01	11,62	10,58	8,30	6,38	7,87	8,71	9,25	10,49	11,43	12,44	10,10
45	11,01	10,97	10,66	9,64	7,40	5,65	6,98	7,75	8,27	9,52	10,36	11,44	9,14
55	10,02	9,99	9,69	8,64	6,54	4,92	6,16	6,83	7,27	8,52	9,35	10,47	8,20
65	9,01	8,98	8,69	7,62	5,75	4,24	5,35	5,96	6,34	7,52	8,33	9,44	7,27
75	7,97	7,95	7,69	6,70	4,96	3,56	4,53	5,09	5,50	6,58	7,30	8,36	6,35
85	6,92	6,95	6,73	5,85	4,15	2,87	3,72	4,20	4,67	5,69	6,36	7,29	5,45
95	5,98	5,96	5,83	4,99	3,38	2,25	2,97	3,37	3,81	4,85	5,43	6,29	4,59

FIG. 3 HEAT TABLES FOR THREE AUSTRALIAN COLLECTORS. INCLINATION 33°, FACING NORTH, WILLIAMTOWN (NEAR SYDNEY) DATA FOR 6 YEARS. VALUES ARE FOR DAILY HEAT GENERATION MJ/m^2 WHEN WATER AT TEMPERATURE T IS SUPPLIED TO THE COLLECTOR.

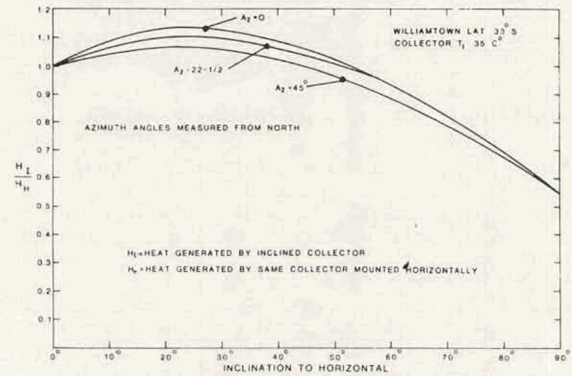

FIG. 4 EFFECT OF ANGLE OF INCLINATION AND AZIMUTH ON ANNUAL HEAT GENERATION OF A COLLECTOR.

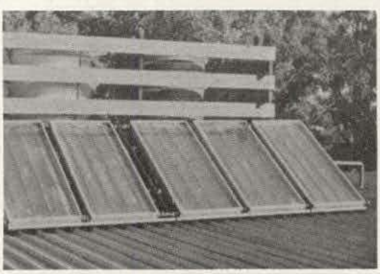

FIG. 5 ROOF MOUNTED SOLAR WATER HEATER SHOWING HOT WATER STORAGE ARRANGED FOR THERMO-SIPHON FLOW (BUILDING COLD WATER TANK INCLUDED IN SAME ENCLOSURE).

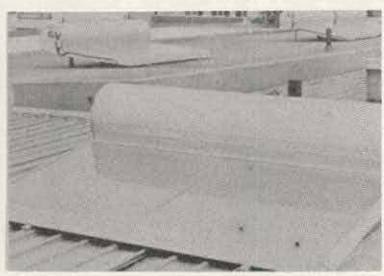

FIG. 7 SOLAR WATER HEATERS IN DARWIN SHOWING INTEGRAL ARRANGEMENT OF STORAGE AND COLLECTOR.

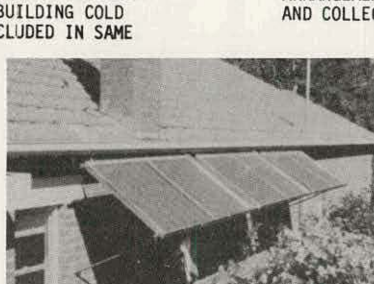

FIG. 6 AWNING MOUNTED SOLAR WATER HEATER IN MELBOURNE. COLLECTOR AREA 5 m^2. STORAGE 450ℓ CONCEALED IN ROOF SPACE.

give the heat generated by the collector in a particular locality when supplied with water at a constant temperature and a controlled flow rate. They require meteorological records, preferably for several years, giving simultaneous hourly values of solar radiation, ambient temperature and wind velocity.

The following steps are involved in predicting the heat output for a solar collector in a particular location:

1. Measure experimentally the thermal collector characteristic, η as a function of $\frac{\Delta T}{G}$.
2. Assemble the meteorological characteristics of the particular location in question so that solar radiation, ambient temperature and wind velocity at hourly intervals can be stored on magnetic tape and accessed by suitable computer programs.
3. Compute by means of programs such as PRERAD the hourly values of solar radiation on the plane inclined at the particular angle and oriented in the particular direction for which the heat table is required.
4. Compute by means of programs such as SOCOFI the hour by hour heat generation and printout average daily values in the form of heat tables.

The programs which produce this information, using meteorological records which might typically cover six years of data, are very fast and relatively inexpensive, the total cost in computer time being typically $15 for a heat table, such as illustrated in Figure 3. This shows the heat generation for three commercially available Australian collectors, two of which are single glazed with a single glass cover, one having a selective surface absorber, and the other a flat black painted surface. Figure 3(c) covers a recently introduced double-glazed collector intended for industrial process heating applications. Although its thermal performance is superior, it is more expensive to manufacture, but the value of these heat tables is that it is now possible, knowing the price of the collectors, to calculate the heat output per dollar investment, which is a critical consideration for the cost effectiveness of complete installations.

The most convenient place for mounting collectors is usually on the roofs of buildings which, as a general rule, are not sited with a view to solar energy collection. It is important, therefore, to be able to predict what penalties, if any, are incurred by placing the collectors directly on the roof without resorting to unsightly or expensive additional supports.

The effect of angle of inclination and azimuth on the radiation incident on a plane can be computed and it can be shown that within certain limits there is not much variation in the total annual insolation received. In terms of the heat generated annually by collectors, the position is rather more complicated. The inclination and orientation to give maximum annual energy collection depends on the monthly load pattern throughout the year, the temperature at which the heat is required and the capacity of the thermal store. General solutions which allow for all these variables are not available, although it is possible by means of the heat tables described above, to produce curves for specific applications and situations which may illustrate general trends. The effect of the angle of inclination and azimuth on the annual heat generation of an Australian commercial collector in Sydney, latitude 33° south, used in a domestic water heating application, is shown in Figure 4. It will be seen that maximum collection occurs at an inclination of about 25° to the horizontal, that is about threequarters of latitude angle, and that it is not sensitive to angle changes from about 15° to 35°.

Also a change in azimuth from zero, that is due north, to 45°, only reduces the annual heat collection by about 6%. For azimuth angles much exceeding 45° it is better to mount the collectors horizontal and accept about a 14% loss, compared with the maximum output attainable. As a broad generalization, it is likely that it would be more economical to increase the area of collectors mounted directly on a roof rather than build special structures to support them at a more favourable angle.

It should be emphasized that the effect of angle of inclination and azimuth on annual heat generation becomes more pronounced as the latitude is increased, and at this stage the use of the curves shown in Figure 4 for locations other than Sydney should be handled with caution. However, a study currently being undertaken has shown that the values for Melbourne, latitude 38° south, differ from the Sydney curves by only a few percent.

4. THERMAL STORAGE

Where the product itself can be stored, e.g. hot water, it is merely a question of providing an adequate sized insulated storage tank. Off-peak electrically heated hot water services have for many years used this principle, and such systems are readily available commercially. It is a simple matter, therefore, to incorporate such a storage into a solar water heating system, it being only necessary to increase the size of the tank to provide one and a half to two days' supply and perhaps increase the amount of insulation provided.

For industrial process heating and other applications where heat rather than hot water is required, storage presents a greater problem in that the tanks become rather bulky when only the sensible heat of water changing in temperature by a few degrees centigrade is available. Nevertheless, large insulated tanks are being used satisfactorily for this purpose. Concrete, steel and copper tanks have been used without any of these emerging as being clearly superior.

For use with air heaters, rock storages have been used experimentally and, although satisfactory, they are bulky and somewhat expensive.

5. HEAT GENERATING SYSTEMS

The systems most commonly used today are solar water heaters for residential and commercial purposes. These have been commercially available for many years and are now being exported to a number of countries. Australian manufacture of solar water heaters has grown rapidly, the production figures in terms of collector area being: 1973, 8 400 m^2; 1974, 11 600 m^2; 1975, 25 330 m^2.

The reason for this is that there are many places where electric power for water heating costs between 2 and 4 cents per kW.h which makes a solar water heater an attractive proposition. There is also a growing interest in the solar heating of swimming pools, mostly for private homes, but also in larger installations for public and institutional pools.

Industrial applications, on the other hand, are inhibited by the current low energy prices in Australia, which in some cases are around 0.13¢/MJ (.47¢/kW.h). Despite the fact that at current energy prices, large solar heat generating systems do not provide the return on investment that is considered satisfactory, there is a widespread recognition that the technology should be developed as quickly as possible. CSIRO has commenced a programme of demonstration installations in industrial plants, which will have the dual objective of demonstrating the technology which is now available, and at the same time obtain actual operating performance and costs on an industrial scale.

5.1 Residential Hot Water Services

Domestic installations use 3 to 5 m^2 of collector connected to an insulated storage tank of 200-450 litres, fitted with an electric heater element and thermostat. If the storage tank can be located close to and above the collectors, water circulation through the system can be by thermosiphon flow, which avoids the use of any pumps or valves in the energy transfer loop between the collector and the tank. This is shown in Figure 5, which also illustrates the problem of concealing the tank. This can be overcome by mounting it in the roof space above the ceiling, as shown in Figure 6, or if this is not possible, pump circulation is used so that the tank may be mounted in any convenient position.

In an optimized system, the collector area is chosen so that it will supply all the heat required in the best month, relying on electric or fuel supplementary heating to make up any deficit in other months. In this way, no solar energy is wasted, and over the year typically 70% of the total heat required would be provided by the collectors, in a locality such as Sydney, assuming the same daily consumption throughout the year.

Storage capacity of twice the average daily consumption is needed to allow for the combined effect of variations in insolation from day to day, and the wide fluctuations which occur in the daily consumption pattern.

A unit which is extensively used for small installations comprises a collector and a horizontally mounted tank which are close coupled to form a single unit which can be completely factory assembled (Figure 7). This has both advantages and disadvantages. A trained two-man crew can erect two such units in a day in favourable situations, which makes it an attractive commercial proposition and one which is widely used at the present time. On the other hand, it is difficult and expensive to provide two days' storage with such a design, particularly if built to operate at mains pressure.

Australian built solar water heaters have developed a reputation for durability and reliability. The thermosiphon system is inherently simple and there are many installations which have been operating for 15 years or more with little or no attention except for occasional cleaning of the glass. Except in very dusty situations, even this is often unnecessary since rain keeps the collectors clean in most situations.

A common type of hot water system extensively used in Australian homes is a low pressure (50 kPa) insulated hot water storage tank mounted above the ceiling, electrically heated at night-time at a cheap off-peak electric power tariff. Such a system can readily be adapted to be connected to a solar collector by means of a small circulating pump and a special three-way adapter which is fitted to the existing cold water inlet. This does suffer from the disadvantage that normally the tank is too small, but this can be corrected by connecting another tank in series with it to provide two days' supply in the storage system.

When selecting the size of a solar water heater for domestic application, the important considerations are the area of collector and the volume of the tank. *The tank volume should be twice the average daily demand*, which is usually taken to be 45 litres per person. The collector area depends on the location and the actual siting of the collector, and can be calculated by making certain assumptions and using heat tables. The method can be seen from the following example:

Example

Determine the area of collector needed for a solar water heater located in Sydney delivering 200 litres per day of hot water at 55°C using the collector referred to in Figure 3 (a) inclined at latitude angle facing north in a thermosiphon system with an electrically boosted 400 litre insulated storage tank.

Assume (1) hot water draw-off from the system is the same each day for 365 days a year.

(2) the temperature of the cold water entering the system is the mean ambient temperature for the month in question.

(3) the temperature of the water entering the collector is the average of the mean ambient temperature and the nominal hot water discharge temperature (55°C in this case).

(4) system losses are 15% of the total heat required, and all solar heat collected is used either to heat the water or to supply losses.

(5) supplementary heating occurs outside sunlight hours and not more than one day's supply is heated electrically.

Use heat tables published for the collector for Williamtown (nearest available data to Sydney).

Best month is December for which mean ambient temperature is 21.9°C.
Annual mean ambient temperature is 16.6°C.

Collector Area

Daily heat required = $200\ (55-21.9) \times 4.2 \times 10^{-3} + 15\% = 31.9$ MJ.
(for best month (December))

Collector inlet temperature = $\frac{55 + 21.9}{2} = 38.5$°C.

From heat tables for December for $T_{in} = 38.5$°C, Heat production = 11.0MJ/m^2 d.

Area of collector required for best month = $\frac{31.9}{11.1} = 2.90$ m^2.

The collector selected has a collection area of 0.74 m^2. Therefore choose 4 units total area 2.96 m^2.

Annual solar contribution

Mean annual inlet temperature to collector = $\frac{55 + 16.6}{2} = 35.8$°C.

From Tables for $T_{in} = 35.8$°C *Heat production* = 8.90 MJ/m^2 d.

For 2.96 m^2 Annual heat production = $8.90 \times 2.96 \times 365 = 9620$ MJ/a.

Annual heat required = $200(55-16.6) \times 4.19 \times 10^{-3} \times 365 + 15\% = 13500$ MJ/a.

Percentage solar contribution = $\frac{9620}{13500} = 71\%$.

Annual supplementary heat = 13500-9620 = 3880 MJ

A system such as the above would typically have an electric heating element located in the tank such that one day's supply of water was above it. It would be controlled by a time switch to ensure it was not energized during the day and a thermostat set for 55°C.

Sydney, the location chosen, is roughly typical of the Australian continent in that there are some better and some worse locations, as can be seen from Table I. If the roof does not face north or the angle of inclination is less favourable than latitude angle, the appropriate heat tables should be used which would result in a somewhat larger collector area. If the collector area installed is greater than that indicated in this example, the annual solar contribution will be increased, but there will be occasions when some of the heat collected, is wasted.

5.2 Large Water Heating Systems

Large systems use forced circulation instead of thermosiphon flow through the collector, the circulating pump being energized by a differential control which ensures that it operates only when heat is being added to the system. The choice of collector area and volume of storage tank can be determined in the same way as that outlined for domestic systems, except that it is usually necessary to do a month by month calculation based on the monthly load which generally varies throughout the year. This applies particularly to industrial systems, which will be covered in the next section.

The circulating pump and the connecting piping between the storage tank and the collector array need to be carefully chosen to minimize pumping power, since if this is excessive, it will affect the overall energetic efficiency of the system. The flow must be adequate to avoid excessive temperature rise in the collectors under maximum insolation, since this would reduce the efficiency of collection. The temperature rise from collector inlet to collector outlet should not exceed 20°C for 1200 W/m^2 insolation and a flow of 0.01 ℓ/s m^2 will usually achieve this. It is not difficult to ensure that the pumping power is kept to less than 5% of the total annual energy collected by the system.

5.3 System Performance

Although commercial manufacture of solar water heaters began in Australia over 15 years ago, the performance of very few installations has been reported. However, several systems have now been instrumented and a preliminary report on three of these is now available [8].

The three applications are very different, and the water usage pattern in each case varies substantially throughout the year. The oldest is a laboratory building in Canberra with 30 m^2 of collector and 1800 ℓ storage tank. It was installed in 1962, and the solar input is 66% of the total, the remaining 34% being supplied by electric boosting.

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[8] Salt, H. Progress Report on the Performance of Three Australian Solar Hot Water Systems. CSIRO Solar Energy Studies Report No. 8. September, 1976.

The second system supplies hot water for showers in a residential school in Adelaide. It has 60 m^2 collectors and 4100ℓ storage, and was installed in 1966. The solar contribution is 46%, and the supplementary heating is from an oil fired boiler.

The other system described was installed in 1974 to supply hot water for a sailing club near Melbourne, using 10 m^2 collector and 1050ℓ storage with electric boosting. The annual solar contribution is 74%, which is due to the combined effect of adequate storage and the fact that the demand tends to match the solar radiation pattern throughout the year.

Maintenance on all systems has been minimal, and present indications are that a life of at least 20 years should be achieved.

5.4 Industrial Applications

Industry is Australia's largest consumer of primary energy, amounting to 40% of the total. By comparison, only 4% of primary energy is used in homes (not including energy used as electricity or the primary energy to generate it). See Table II.

Clearly, the way that solar energy can make a major contribution to Australian primary energy is in industry. Since industrial applications represent the greatest potential for solar energy, it is worth examining in some detail how they can be encouraged. A study in 1974 of the food processing industry which uses about 3% of Australia's total primary energy [9] found that 70% of the heat used is at temperatures below 100°C and that there is very little usage above 150°C. The study covered meat processing, milk products, fruit and vegetable canning, and beer and soft drink production. It found six processes accounted for 96% of the heat used, these in order of importance being: Product cooking 25%, Pasteurization 18%, Product separation 18%, Bottle washing 14%, Water heating 13%, Sterilization 8%.

Most of the heat, 84%, was required for processes which operated at a constant temperature, the balance being used over a range of temperatures such as heating of water from one temperature to another.

Constant temperature processes require heat inputs at temperatures above the process temperature, but it was found that about 40% of the total was required in the 60-80°C range. Collectors are now available which can operate at 80°C with a year-round efficiency of 35%. They use the improved selective surface now becoming available for domestic collectors but incorporate more insulation to reduce losses, and are double glazed. When low iron glass becomes available to replace the existing window glass, the collection efficiency will be increased.

Thermal storage is provided in the form of large insulated tanks of hot water which is circulated to and from the process either directly or through heat exchangers. The collectors can be mounted on the roof of the building close to the thermal store and the process, to minimize the length of the two energy transfer loops - collector to store and store to process.

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[9] Proctor, D. & Morse, R.N. Solar Energy for the Australian Food Processing Industry. 1975 International Solar Energy Congress, University of California, Los Angeles, California, U.S.A. 28th July-1st August, 1975.

TABLE II

TABLEAU II

ESTIMATED AUSTRALIAN PRIMARY ENERGY USAGE 1974-5

UTILISATION ESTIMEE D'ENERGIE PRIMAIRE EN AUSTRALIE 1974-5

	$J \times 10^{15}$	%	
Agriculture, forestry and fishing	58	2.1	Total "manufacturing" 40%
Mining	74	2.6	
Food, beverages and tobacco	95	3.4	
Paper	29	1.0	
Chemicals	34	1.2	
Petroleum refining	135	4.8	
Non-metallic minerals	102	3.6	
Iron-steel	387	13.7	
Non-ferrous metal	147	5.2	
Manufactured goods	47	1.7	
Construction	20	.7	
Wholesale-retail	37	1.3	
Domestic	103	3.7	
Transport and storage	702	24.9	
Electricity (including hydro 46)	795	28.3	
Gas distribution	37	1.3	
Others	13	0.5	
	2815	100	

Source: Department of Minerals and Energy

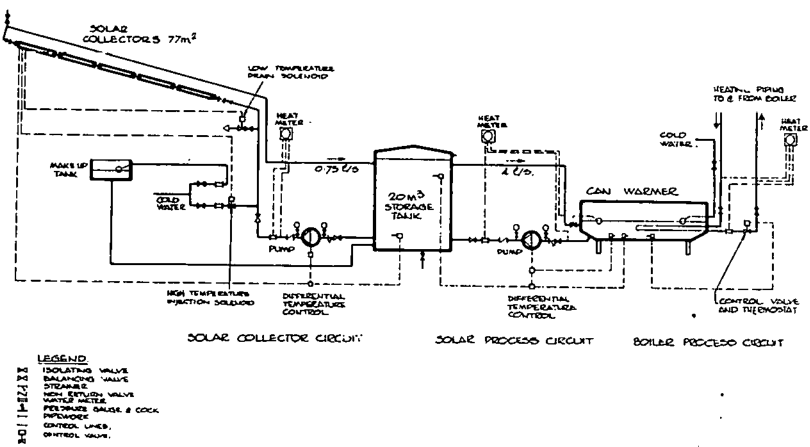

FIG. 8 SOLAR INDUSTRIAL PROCESS HEATING SYSTEM - QUEANBEYAN.
SCHEMATIC DIAGRAM.

FIG. 9 SOLAR INDUSTRIAL PROCESS HEATING SYSTEM - QUEANBEYAN. ROOF MOUNTED COLLECTORS.

FIG. 11 SOLAR SWIMMING POOL HEATER, MELBOURNE.

FIG. 12 SOLAR HEATED COUNCIL SWIMMING POOL, CRIB POINT - VICTORIA.

FIG. 10 SOLAR INDUSTRIAL PROCESS HEATING SYSTEM - QUEANBEYAN INSULATED THERMAL STORE.

The technology for solar heat generation on an industrial scale could be rapidly developed, but has not been used for a number of reasons. In the first instance, the installation and operating costs have not been established. Secondly, the design and construction skills have been confined to research organizations and are not generally available within the engineering profession. Finally, the relatively low energy prices in Australia generally make it difficult to produce savings which are great enough to justify the large capital expenditure involved in solar installations.

In order to obtain hard data on capital and running costs, and at the same time build up professional design and construction skills in this area, demonstration installations are being planned, the first of which was recently installed in a soft drink plant at Queanbeyan near Canberra. This has recently been described [10]. The solar heat generating system is designed to supply heat to the can warmer which forms one of the final stages of the production line. It runs in parallel with the existing heat input to the machine from an oil-fired boiler which delivers heating water at 80°C to a heat exchanger in the sump of the can warmer. When the input from the solar heat generating system is high enough, the boiler heat input is automatically cut off, but when necessary the boiler will take over some or all of the load. The system is shown schematically in Figure 8 and the collector array and thermal storage are shown in Figures 9 and 10.

Some of the features of the design will be discussed briefly.

Collectors

The factory premises comprise a single storey conventional portal-framed steel structure with corrugated asbestos cement roof pitched at 15°, oriented 60° west of north, on which 49 collectors, each 1.58 m^2 in area were mounted directly, the total area being 77 m^2. These collectors are a recently developed type whose thermal properties are given in the heat tables shown in Figure 3 (c), which however do not cover this roof orientation. Heat tables computed for 15° inclination and -60° azimuth were used to calculate the area needed in the collector array, allowing for the fact that the process operates at different temperatures throughout the year, and the load varies from month to month.

It was found that in order to meet the full monthly load, only 54 m^2 would be required in March as against 100 m^2 in December. If, however, 100 m^2 were installed, more heat would be collected than could be used during the other 11 months of the year. The choice of 77 m^2 gives a significantly increased annual heat generation over 54 m^2 without excessive losses.

Thermal Store

The plant operates five days a week and the system should have sufficient capacity to store the heat collected over the weekend, for use when the plant starts up again.

The thermal store consists of a 20 m^3 concrete tank insulated with 125 mm of polyurethane foam, the internal dimensions of the tank being 3350 mm diameter by 2450 mm high.

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[10] Simpson, I.C. A Solar Industrial Process Heating Application. International Solar Energy Society Australian and New Zealand Section Technical Meeting, Industrial Applications of Solar Energy. Melbourne, November 1976.

The thickness of insulation was estimated on the basis that it is increased until the cost of an increment in thickness becomes greater per unit of heat saved than the amount needed to be invested in collectors to generate the same annual production of heat.

In this particular case, the estimated annual heat loss from the store was 19.2 GJ/a for 100 mm, 15.4 GJ/a for 125 mm, 12.9 GJ/a for 150 mm insulation thickness.

Each 25 mm of insulation thickness costs $100 and 1 GJ/a generated by collectors requires an investment of $40. Since the increment from 125 to 150 mm of insulation costs $40 per GJ saved, the choice of insulation thickness was taken at 125 mm.

Energy Transfer Loops

The flow in the collector store loop was chosen to limit the temperature rise through the collectors to 20°C under extreme insolation of 1150 W/m^2 for ΔT = 30°C and V = 0. From equation 2 we get G = 703 W/m^2. Flow for 20°C rise through the collector equals $\frac{703}{20 \times 4.19 \times 1000}$ = 0.0084 ℓ/s m^2. For 77 m^2 this is 0.65 ℓ/s.

For the store to can warmer loop, it is clearly desirable to have the lowest temperature rise that is practicable and 6°C was selected, as this could meet the load conditions with a flow of 4 ℓ/s, which did not put excessive demands on the power input to the pumping system. This is an important consideration since the annual energy consumed in pumping should not be more than about 5% of the total solar heat energy generated. This is based on the consideration that the primary energy necessary to generate this electrical energy is about 4 times the electrical output, which in this case would equal about 20% of the solar heat generated annually.

The project is a joint venture between CSIRO and Diverse Industries who own the plant, with CSIRO meeting most of the cost. It was commissioned in December 1976, and will be operated on an experimental basis for 2 years.

5.5 Swimming Pool Heating

Swimming pool heating can be expected to increase as living standards rise, and as people become aware of the advantages of heated pools, particularly those with low operating costs. This applies equally to private and public pools in all parts of Australia. Solar heating will extend the swimming season significantly, but there is little published information on the subject. A typical solar heated pool is shown in Figure 11.

There are several current projects aimed at measuring the effect of covers and various types of collector on the temperature of outdoor pools. At this stage, the tentative findings are that a cover over the pool at night to reduce evaporation losses is the first priority, since the solar heating of an uncovered pool is not very effective.

Relatively cheap collectors ($35.00 per square metre) consisting of an uncovered metal or plastic absorber plate, with or without rear insulation, are not as effective in the spring and autumn as the more conventional collectors with a glass cover. This situation cannot be corrected by installing a greater area of the cheaper collector, since the collection efficiency is strongly influenced by ambient temperature and wind velocity, often becoming zero in the cooler months.

One of the public pools whose performance is being measured has collectors mounted on supports to provide shade for the users (Figure 12). This system is backed by a gas-fired heater which has only been needed occasionally in the December-January period to maintain the pool temperature between 27 and 32°C provided it is regularly covered each night.

Although the use of solar heating for public pools is still in the experimental stage, the results so far are very encouraging.

6. COST EFFECTIVENESS

The cost effectiveness of a solar heat generating system is measured by the annual value of the fuel or energy it saves in relation to the cost of the solar installation. When this is expressed as a percentage, it represents the gross annual return on the solar investment which is the starting point for cost effectiveness calculations and for comparisons between different systems. The most important single influence on cost effectiveness is the price of the conventional energy source at the particular location, as was demonstrated in a recent submission to the Australian Senate Standing Committee on National Resources, currently enquiring into solar energy. (Reference 2)

The annual value of the heat collected depends partly on the climate, partly on the temperature at which the heat is required, but much more on the cost of the fuel it is replacing. A well designed solar water heater in Sydney, for example, heating water up to 55°C, after allowing for losses, would generate about 2.76 GJ/a for every square metre of collector installed, and would be worth $9.90 if used with an off-peak electric system for which the electricity charge was 1.3 ¢/kW.h or $3.60/GJ. The cost of this system might be $125/m^2 including storage tank and installation, so the gross return in this case would be about 8% p.a.

This would be a marginally attractive position, but if the electricity costs were 4¢/kW.h, the return would be $31 p.a., or 25% gross, which of course is very attractive. The places where solar water heaters are being extensively installed have climates equivalent, or even better than, Sydney's from a solar point of view, and in some cases much higher installation costs can be justified.

For industrial process heating, frequently much higher temperatures are required than the 35°C average inlet temperature to a water heater in Sydney. A process, for example, operating at 75°C in Sydney, would probably use a double-glazed collector with a selective surface costing perhaps $150/m^2 for the completely installed system and generating only 1.68 GJ/a m^2. If the factory was using oil costing $100 per tonne and burning it in a boiler of 75% efficiency, the cost of the heat produced from the boiler would be $3/GJ and the value of the output/m^2 a would be $5.10. This is only a 3.4% p.a. gross return on investment, and it should be remembered that the installation costs quoted are the anticipated values for large-scale installations when production costs of collectors have stabilized. Present costs are considerably higher. If the installation were in Melbourne instead of Sydney, the amount of heat collected per square metre of collector would be only 1.18 GJ/a worth $3.60, and the annual return drops to 2.4%. These are quite unacceptable for industrial enterprises.

This situation has been tabulated in Reference 2, which shows how very low priced natural gas at $1.33/GJ would reduce the gross annual return to

1-1½% p.a. The range of energy prices is about 8 to 1 compared with the range of heat outputs from collectors of less than 3 to 1, showing that the price of conventional fuel or energy has a greater influence on the cost effectiveness of solar heat generating systems than either climate or the temperature at which the process operates, at least up to 75°C.

There is some indication that eventually the price of fuel oil could rise significantly above $3/GJ and if natural gas and electricity prices increased correspondingly, there would be sufficient financial incentive to encourage the widespread use of solar heat generating systems. In the meantime, other incentives will be necessary, such as more generous investment allowances for taxation purposes, and/or loans based on the capitalized value of the annual heat generated from the solar installation.

It is difficult to generalize on the cost effectiveness of solar heat generating systems because of the interaction between climatic factors, energy prices and the temperature at which the heat is required.

Where all the conditions combine in an unfavourable manner such as for a solar/gas 75°C industrial process in Melbourne, a substantial incentive would be needed to make the proposition attractive. On the other hand, a solar/electric domestic water heating installation in a climate similar to Sydney where the electricity tariff is 4¢/kW.h is very attractive and needs no additional incentive. This explains why solar water heaters are popular in Perth, where the system cost for individual small installations can be as high as $250/m^2 and electric power costs 3.8¢/kW.h.

7. EXPERIMENTAL SYSTEMS

The CSIRO Division of Mechanical Engineering operates a number of experimental installations at Highett, Victoria, and also field stations at Griffith, New South Wales, a hot dry location, and at Townsville, Queensland, a hot moist situation. These are connected with building heating and cooling, the development of air heaters and rock thermal storages, evaporative cooling, the commercial drying of timber, and solar distillation for producing fresh water from salt or brackish supplies.

Some Australian universities also have solar research programmes supported by the Australian Research Grants Committee. A report on the Status of Solar Energy Utilization in Australia as at July 1974 has been published [11] which summarizes experimental applications which have not yet reached the commercial stage.

8. RESEARCH AND DEVELOPMENT

Australian research and development in the solar energy utilization field commenced over 20 years ago and has an impressive record of achievement, but it has not progressed in recent years in the same way that it has in countries such as the United States, Japan and Europe. Resources allocated by the Australian Government for the current year, 1976/77, total $1.4 million including $0.13 million from ARGC for university research. These figures

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[11] Morse, R.N., Cooper, P.I. & Proctor, D. The Status of Solar Energy Utilization in Australia for Industrial Commercial and Domestic Purposes. CSIRO Solar Energy Studies Report No. 74/1, Melbourne. July 1974.

have not changed significantly in the last two years, which in real terms represents a decrease, due to the affects of inflation. This situation has been brought to the notice of the Senate Committee enquiring into solar energy from a number of separate sources who have urged a higher priority for solar energy research and development in the allocation of government funds. Typical of the programs being proposed are an emphasis on solar heat generation, particularly with a view to saving oil, and the development of renewable fuels, particularly liquid fuels, for transportation. Proposals have been outlined in some detail [12] pointing out the need for work on collectors capable of operating up to 150°C which are suitable for large-scale industrial operation, together with thermal storages suitable for at least three days, and preferably a week's output from the collector array.

Thermal storage is probably the most neglected area at the present time in all solar energy R & D programmes. Effective long-term storage of heat in the range 60-150°C could make a dramatic change in the cost effectiveness of solar systems which require heat inputs in the winter when insolation values are low. The problem with solar house heating is that energy collected during the summer months is wasted, and expensive capital investment is poorly utilized over the year.

There is an urgent need for demonstration installations to be built throughout the country similar to that described earlier, to obtain operating experience in a wide variety of industries and spread across the continent to develop professional expertise in the design construction and operation of these plants. There is also a big need for research contracts in which industry, universities and colleges of advanced education would participate, to develop those applications which research has already shown to be worthwhile. These procedures have been well developed in some countries, but in Australia their importance has not yet been recognized.

<u>Note</u>: 1 EJ = 1 Exajoule = 10^{18} Joules

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[12] Morse, R.N. A Strategy for Solar Energy Research in Australia. International Solar Energy Society Australian and New Zealand Section Symposium on <u>Solar Energy Resources; Applications and Perspectives</u>. Australian National University, Canberra. November 1975.

SUMMARY

Solar energy can make its most effective contribution to Australian primary energy in the form of heat for industrial applications. About 50% of all end use energy is required as heat and it is estimated that 40% of this amounting to 1 EJ/a by 2000 could be supplied by solar heat generating systems. This would be 12% of estimated primary energy requirements by that time, and could help reduce the country's increasing dependence on imported oil. Energy self-sufficiency for Australia is possible, based on coal, solar energy and natural gas as primary energy sources.

Solar energy research and development over a period of 20 years has been very successful, and there is an established industry which supplies equipment, both locally and for export. Existing production, which is expanding rapidly, supplies solar water heaters for homes, schools and institutions.

The reason for the present orientation towards residential solar water heaters is that there are many places where electric power for water heating costs between 2 and 4 cents per kW.h which makes a solar water heater an attractive proposition. There is also a growing interest in the solar heating of swimming pools, mostly for private homes but also in larger installations for public and institutional pools. Industrial applications, on the other hand, are inhibited by the current low energy prices in Australia, which in some cases are around 0.13¢/MJ (.47¢/kW.h).

Industry, however, uses 40% of Australian primary energy, and represents by far the greatest potential for solar heat generating systems. Current R & D is therefore being directed towards industrial applications. Demonstration plants are being planned to obtain data on capital and running costs, and at the same time build up professional design and constructional skills in this area.

The first demonstration solar industrial process heating system was commissioned in December 1976 and supplies portion of the heat requirements of a soft drink plant in conjunction with the existing oil fired boiler. Integrated solar/oil fired systems of this sort ensure continuous operation of the plant and over a year can result in significant oil savings.

Existing collectors are satisfactory up to temperatures of about 80°C and it is known that there are many important applications in this range. In order to reach the target of 1 EJ/a, collectors capable of operating up to about 150°C will be required, and there are indications that these will be available in the near future. Solar heat generation on such a scale will be critically dependent on government policy initiatives to encourage their use and also on a substantial increase in the level of research and development support.

RESUME

C'est sous la forme de chaleur pour les applications industrielles que l'énergie solaire peut apporter la contribution la plus efficace aux ressources énergetiques australiennes. La chaleur represente à peu pres 50% de toute l'énergie d'application finale, et on estime qu'il serait possible de fournir avant l'an 2000, au moyen de systèmes générateurs de chaleur à opération solaire, 40% de ce montant, ce qui s'élèverait à 1 EJ/a. Cela équivaudrait à 12% des besoins en énergie estimés à cette époque-là et pourrait contribuer à la diminution de la dépendance toujours croissante du pays du mazout importé. Il est possible que l'Australie soit indépendante en ce qui concerne l'énergie, si l'on se base sur l'énergie solaire et le gaz naturel comme sources primaires d'énergie.

Depuis une vingtaine d'années la recherche et le développement en matière d'énergie solaire ont beaucoup de succès, et il existe une industrie établie qui produit des appareils pour le marché national ainsi que pour l'exportation. La production existante, qui est en train de s'augmenter rapidement, fournit des réchauffeurs d'eau à operation solaire pour l'emploi dans les maisons, les écoles et les institutions.

La raison de l'orientation actuelle vers les réchauffeurs d'eau solaires pour les habitations, c'est qu'il y a bien des localités où le coût de l'électricité pour le réchauffage de l'eau est de 2-4 cents/kWh, ce qui rend intéressant un réchauffeur d'eau à opération solaire. On s'intéresse de plus aussi au réchauffage solaire des piscines, surtout de celles des habitations privées, mais aussi aux plus grandes installations pour les piscines publiques et celles des institutions. Par contre, les applications industrielles sont inhibées par les tarifs d'énergie australiens, actuellement très bas, qui ne s'élèvent dans certains cas qu'à 0.13 cents/MJ environ (0.47 cents/kWh).

Pourtant, l'industrie utilise 40% de l'énergie primaire de l'Australie et représente le plus grand potentiel pour les systèmes solaires générateurs de chaleur. L'activité actuelle de recherche et de développement vise donc aux applications industrielles. On construit des installations de demonstration pour obtenir des données à l'égard de l'investissement et des coûts d'opération et afin de développer en même temps des habiletés professionnelles en ce qui concerne la présentation et la construction dans ce domaine.

Le premier système réchauffeur solaire de démonstration fut mis en oeuvre en décembre 1976 et fournit, conjointement avec la chaudière au mazout existante, une proportion de la chaleur nécessaire à une installation pour la fabrication de boissons non alcooliques. Les systèmes intégrés de chauffage solaires/ au mazout de cette sorte assurent une opération continue de l'installation et peuvent amener au cours de l'année des économies considérables en mazout.

Les collecteurs existants fonctionnent d'une manière satisfaisante jusqu'à une température de 80°C environ, et l'on sait qu'il existe beaucoup d'applications importantes dans cette gamme de températures. Pour atteindre le but de 1 EJ/a, il y aura besoin de collecteurs capables de fonctionner jusqu'à 150°C environ, et il y a raison de supposer que ceux-ci seront disponibles dans un avenir bien proche. La génération de chaleur par voie solaire à une telle échelle dépendra d'une façon critique des mesures qui seront prises par les gouvernements pour encourager l'emploi des générateurs solaires, ainsi que d'une augmentation de l'appui des efforts de recherche et de développement