AUSTRALIAN NATURAL HISTORY

SPECIAL ISSUE—
ENERGY

JULY-SEPTEMBER 1979 VOLUME 19 NUMBER 11 $1.50*

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COVER: The Sun rising at West Head in NSW. Will this star be one of the answers to our future energy problems? (Photo: Keith Gillett).

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INTRODUCTION

The imperative need to explore and acquire commercially and ecologically viable alternative energy sources sufficient to meet future world demand has for some time been the mainspring behind much global, scientific and social research. In a world which has dramatically increased its dependence on petroleum this century, the approaching energy shortage will affect every area of existence from architecture to transport, from the private to the public sectors of life.

In Australia, as elsewhere, areas of research are influenced by factors such as priority in the type of energy demanded—sixty percent of Australia's energy is required for transportation—by climate variation, availability of funds, the pressures and implications of overseas interests and world trade agreements.

There is increasing Australian Federal and State government concern to encourage both conservation of existing energy sources and the exploration of alternatives. This must be accompanied by greater public awareness, discussion and identification with the many complicated issues involved. For Australia, the multiplicity of energy sources available poses problems. To the world controversy surrounding nuclear energy—generally agreed to be a short-term resource only unless safe, efficient and economic fast breeder reactors are developed—is added a number of indigenous problems: Aboriginal land rights, the degree of foreign investment permissible, and the extent to which overseas military exploitation of uranium can be monitored and controlled. The situation is complicated by the fact that Australia's climate may in the long run make solar energy and plant alcohol fuels far more attractive for domestic use than *any* form of nuclear energy, no matter how safe. Domestic and foreign consumptions may well conflict and priorities have yet to be fought over and established.

Each alternative energy source poses its own problems. Solar energy, the one completely renewable energy source free and available everywhere, is unlikely to play a significant role until the twenty-first century. So far, its intermittent nature renders it cumbersome and uneconomic to harness using present technology, and development will require much more interest, funding and research supported by government and private industry. Solar energy is expected to contribute increasingly however, to the production of heat, electricity and synthetic fuels using crops such as sugar cane and algae. It is not yet known whether these crops can produce fuel in sufficient volume to meet the needs of our transport-oriented society.

Fossil fuels pose other problems. The outlook for natural gas consumption over the next thirty years is highly favourable, and our deposits of black and brown coals are reassuringly extensive. Consequently, however, agreements are currently being made with several overseas countries—the USA, Japan and Germany—to embark on joint research projects involving coal conversion. The fear is that these, as yet harmless agreements, may develop into a commitment to supply highly expensive, huge amounts of coal, stimulating our export industry and domestic job market at the expense of Australia's ecological balance and landscape. The overall significance of coal conversion schemes will depend on the impact of solar and nuclear forms of energy.

Geothermal energy, already used in Iceland, New Zealand, the UK and parts of Europe, may prove useful in Tasmania, Western Australia and South Australia both as a clean, renewable resource in itself, and as an aid to assist the conservation of fossil fuels. An adequate survey of geothermal resources has still to be undertaken in Australia.

Wind energy, using updated versions of the windmill which has served us for centuries, has a limited use but may aid activities like irrigation in conjunction with hydro-electricity in country areas and the generation of electricity in countries like New Zealand where sufficient wind velocities are attained.

Hydrogen energy, though expensive at present, may have the greatest immediate application of all, being easy to produce and to transport. Its unique versatility enables it to be used to transport solar energy produced by giant collecting centres far from city centres. Costs are still unattractive and hydrogen has problems with safe storage. It appears, however, to be the most immediately viable replacement for coal and oil.

Waves, tides, ocean thermal conversion are all possible contributors but are still in the infancy of their development.

This special issue of Australian Natural History has been prepared as a forum to discuss energy conservation and alternatives—the variety of sources and technologies available, the degree of progress so far achieved by current research projects and the short- and long-term prospects each energy source may offer both Australia and the rest of Earth.

TABLE OF MEASURES USED THROUGHOUT THE ENERGY ISSUE

WATT — unit of electrical power

KILOWATT — a thousand watts

MEGAWATT — a million watts

JOULE — unit of electric power; to lift 1 kilogram 0.1m requires approximately 1 joule of energy.

4.18 J = 1 calorie

MEGAJOULE — a million joules

MOLE — unit of mass; equal in grammes to its molecular weight e.g. 55grs of H_2O = 1 mole

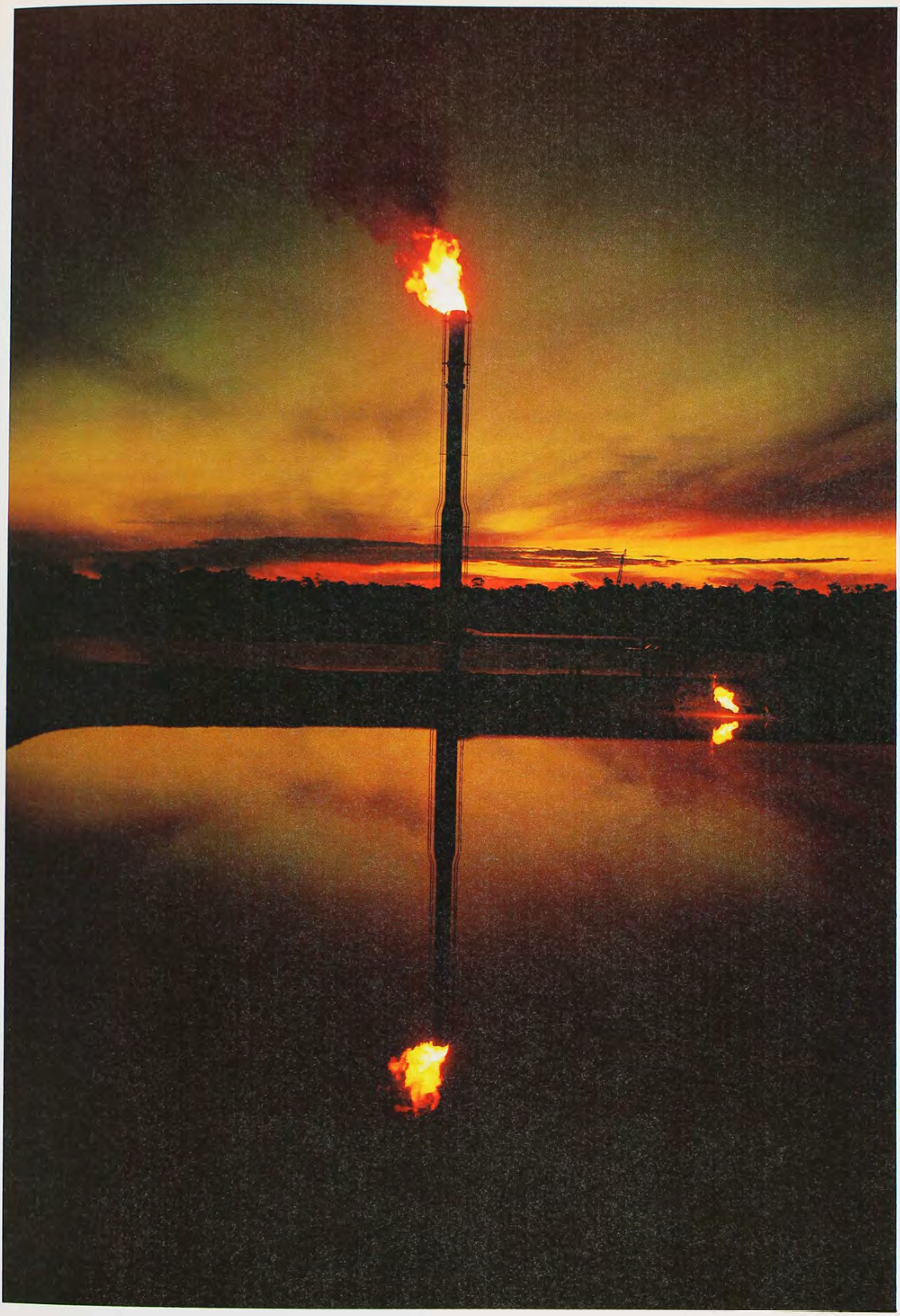
GRAMME — unit of weight (0.035ozs)

KILOGRAM — a thousand grammes (2.2lbs)

10^6 — a million

10^9 — a thousand million

10^{21} — a thousand million million million



Lyn Gee ESSO Australia

FOSSIL FUELS

BY G. D. SERGEANT

Fossil fuels are non-renewable organic resources which can be considered to be concentrations of solar energy laid down tens to hundreds of millions of years ago. They contain carbon which can be burned in air or oxygen to produce heat for almost any purpose. The fuels are characterised by their physical form (solid, liquid or gaseous), by their calorific value, and by a variety of other properties including their combustion characteristics.

The primary fossil fuels are petroleum, natural gas, coal, oil shale and tar sands. These fuels usually undergo some treatment or processing before use. Petroleum crude oil can be used directly as a boiler fuel, but is usually refined to give the wide range of petroleum products with which present day society is familiar and on which it has become very dependent. Natural gas as recovered from a gas well needs to be treated to remove any impurities and some easily liquified hydrocarbons before it can be pressurised for pipeline transmission. Coal used in firing boilers for steam raising and power generation is pulverised to a fine powder and undergoes only physical treatment; when used in large tonnages to make coke however, a more elaborate series of operations including washing, drying, crushing, blending and, in some cases, preheating, is required before charging it into the coke-making ovens. Oil shale and tar sands, which have had only a limited application, require substantial processing to derive the mineral oil from the shale or sand. This operation must then be followed by a series of refining processes.

Fossil fuels are currently dominant in providing the world's energy supplies. Since 1800, when wood fuel was largely replaced by coal, fossil fuels have assumed greater importance, and coal itself has been overtaken by liquid and gaseous hydrocarbons. In the last fifty years, a steadily increasing percentage of primary fossil fuels has been used for electricity generation, and the substitution of electricity for other forms of energy has led to a decline in the use of wind, water and solar power.

Oil

Petroleum has been known for thousands of years, but the first significant oil well in the western world struck oil at 21.4 metres in Pennsylvania, USA in 1859. It has become apparent only in the last thirty years that oil distribution on a global basis is widespread. In Australia, for example, the first producing oil well was discovered as recently as 1961 at Moonie in the Surat Basin in Queensland.

The process of oil formation has sometimes been shown to be of marine origin with evidence of it still occurring in some shallow seas of the world. One reason why Earth does not have larger reserves of oil (and gas) is that it seeps and leaks away. Oil has a lower specific gravity than water so it tends to flow upwards and disperse unless there is a geological trap to retain it. In the search for oil, geologists seek those structures capable of

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Fossil pollens from drill cuttings help determine the age of rock structures and so to estimate the hydrocarbon potential in a search area.

Cyril Cox ESSO Australia

trapping and retaining liquids and gases. Most of the world's continental land masses have been explored for oil and exploration is now shifting into increasingly difficult areas, an example being the major project in the Exmouth Plateau off the north coast of Western Australia, where the first well has been sunk and where future drilling will be in 2000 metres depth of water.

Early research work on the composition of crude oil was undertaken by chemists whose elemental analysis revealed that the material was predominantly composed of carbon and hydrogen in the range: C 83.98–86.8 wt % and H 11.4–14.0 wt %, together with smaller quantities of sulphur and nitrogen: S 0.06–1.75 wt %, N 0.11–1.75 wt %. Further work has shown that the limits for sulphur and nitrogen can be wider.

Physical examination of crude oils reveals quite wide differences. Some oils are solid at room temperature, some are viscous, some are quite mobile liquids, some smell pleasant, others are very sour, some are black, some brownish, red or green, a few are even straw-coloured. None of these observations correlate very well with the elemental analysis approach and other means of classifying oils had to be found.

We now know that crude oils actually consist of many molecules of different molecular weights, therefore giving a range of volatility, and of different homologous series.

Non-hydrocarbon components occur in petroleum to a greater extent than is generally imagined; these are mainly compounds containing sulphur, nitrogen and oxygen and, in smaller amounts, organometallic compounds in solution. These compounds appear throughout the boiling range of crude oils but tend to concentrate in the heavier boiling point and non-volatile fractions. Their importance is out of all proportion to their low concentrations, because they cause problems of catalyst deactivation and corrosion in refineries, and lack of product stability coupled with corrosion and pollution in subsequent use.

Refinery procedures and processes are well established to produce, to standard specifications, the familiar range of poetroleum products to meet the market demand of a particular region from a wide variation of crude oil types.

G. D. Sergeant

Ravensworth No: 2 Open Cut Coal Mine, Bayswater Seam, NSW. Australia is the world's third highest coal exporter after the USA and Poland.

In Australia, crude oil production from the Surat Basin at Moonie in Queensland started in 1964 and reached a peak flow of some 9000 barrels per day; the flow has been in decline since 1969 and is now less than 1000 barrels per day.

The second oldest oilfield is that on Barrow Island off the Western Australia coast which started producing in 1967 and peaked in 1970 at 45,700 barrels per day; in 1977 it averaged nearly 32,000 barrels per day giving 7.4% of the total Australian production.

The most recent and largest area of oil production is the Gippsland Basin which has been making a significant contribution to Australia's oil supply since 1970. This area currently produces ninety-two percent of indigenous oil which represents approximately two-thirds of the total oil consumption in Australia.

The crude oils discovered in Australia give a high yield of gasoline which is appropriate to meet the high demand for this product. Crude oil still has to be imported into Australia, together with finished products to meet the demand for items such as lubricating oils and bitumen. The discovery of natural gas in this country at the same time as indigenous crude oil has enabled much of the fuel oil market to be substituted by natural gas.

As far as consumption areas are concerned, the transport sector alone currently uses fifty-five percent of all oil consumed in the country. High energy density per unit volume, portability, availability and low cost of transport fuels have been prime factors contributing to the high level of personal mobility, particularly in Western industrialised societies. The social consequences of this mobility have been remarkable and any withdrawal or retraction from the present situation is likely to cause severe social dislocation.

Consumption of oil in industry, including agriculture and mining, accounts for thirty-six percent of oil consumed, while the domestic and commercial sector accounts for seven percent. The remaining two percent is consumed in power generation.

Natural Gas

Natural gas is primarily methane (CH_4) but the gases obtained from different gas fields show a variation in the

amount of higher hydrocarbons—ethane, propanes, butanes, pentanes and hexane—and in nitrogen and carbon dioxide content.

In 1969, Brisbane became the first capital city in Australia to be supplied with natural gas. This followed the completion of a gas pipeline from the Roma area in Queensland. Shortly afterward, Adelaide received gas by pipeline from the Gidgealpa and Moomba fields and Melbourne by pipeline from the Gippsland Basin. Perth followed in 1971 with a pipeline from the Dongara field and in December 1976 the gas pipeline from Moomba delivered natural gas to Sydney.

Drilling in search of hydro-carbons and minerals is carried out in many remote areas of Australia.

Cyril Cox ESSO Australia

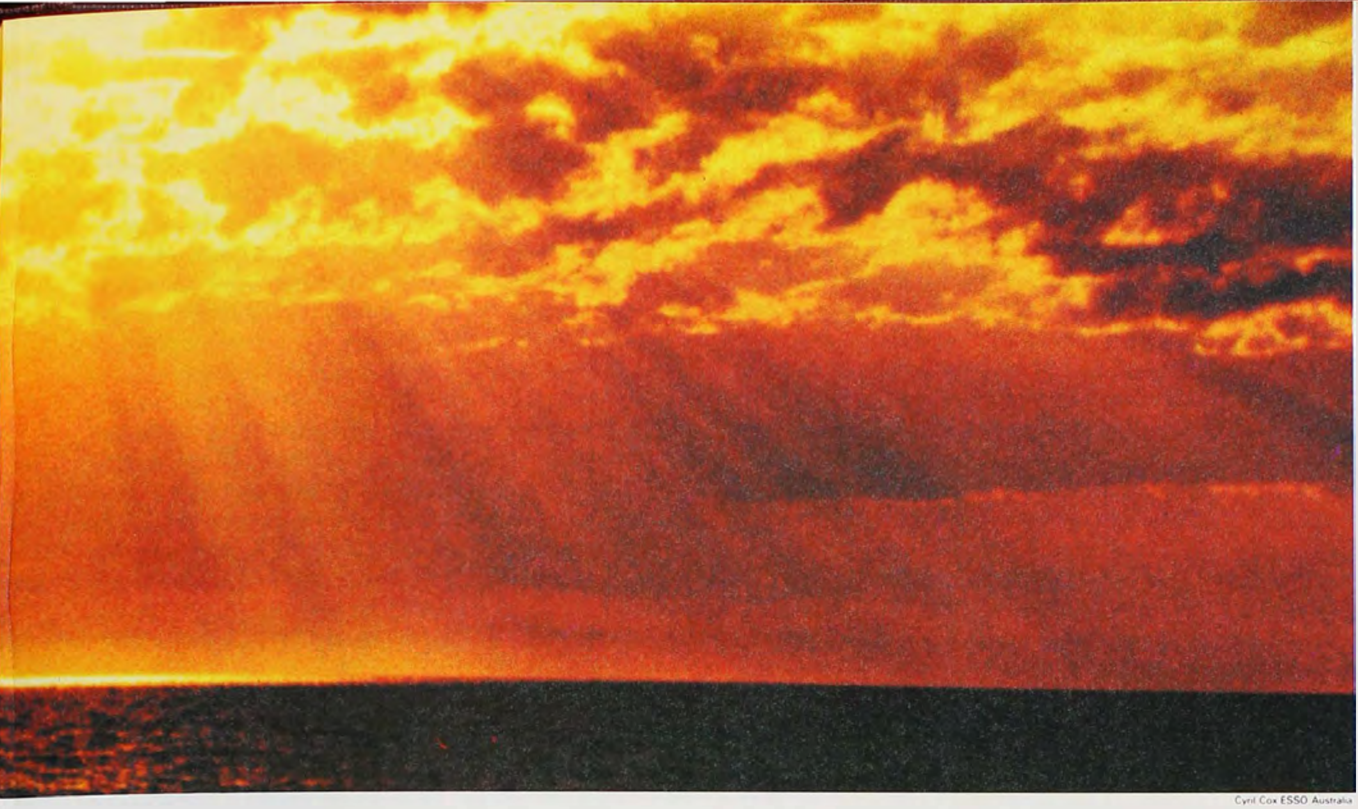
When natural gas became available to the gas manufacturers and distributors in Australia they were faced with a choice to convert all gas-using appliances to burn the newly available fuel, or to change, or reform, natural gas to produce a gas of similar composition to the manufactured 'towns gas' already in use.

All the capital cities other than Sydney embarked on conversion programmes and these were successfully accomplished. Sydney, which had available suitable modern reforming equipment, has embarked on a much slower conversion programme with industrial loads being supplied with natural gas and the bulk of the domestic consumers receiving a processed natural gas.

The industrial applications of natural gas are extensive and include firing steam or hot water boilers, furnaces, ovens, vats, kilns, providing space heating, air conditioning and refrigeration, as well as fuelling stationary internal combustion engines. Natural gas is also used as a chemical feedstock. Natural gas has been used in Australia for one decade only and is rapidly increasing its share of the primary energy supply. It is anticipated that natural gas will supply about ten percent of Australia's demand for primary fuels in 1979, and that this will increase to fifteen percent by 1985.

The development of the North West Shelf is expected to bring gas on shore in the mid-1980s, thus relieving energy supply problems in Western Australia. Offshore fields are expected to produce, in association with natural gas, some eight million barrels a year of condensate (equivalent to a light crude oil) which should provide much-needed additional supplies of transport fuels in Australia.

The reserves of natural gas in the Gippsland Basin will serve Victoria well past the turn of the century and it is



Solar rays highlight an aspect of the current intensive search for fossil fuels. *Kingfish B* oil rig in Bass Strait at sunset.

Cyril Cox ESSO Australia

anticipated that further natural gas reserves will be found in the Cooper Basin area to sustain the NSW and South Australian demand. Recent discoveries in Queensland have allayed fears of running out of natural gas within the next few years.

Liquefied Petroleum Gas L.P.G.

As indicated earlier, liquefied petroleum gas is produced either in association with crude oil or natural gas, or as a by-product in the processes of refining crude oil. Liquefied petroleum gas is composed of propane or butane or a mixture of both and may include some butylene or propylene. These are all gases which are easily liquefied under relatively low pressures at ambient temperatures.

They are therefore readily transportable in small pressurised cylinders ranging in size from those used in cigarette lighters, through the familiar vessels used by campers and caravanners to large vessels for industrial use. Liquefied petroleum gas has a large-scale application in providing domestic gas in many Australian country towns. It is quite extensively used to fuel internal combustion engines in such vehicles as fork-lift trucks, and is increasingly being used in vehicular transport, particularly in fleet vehicles like taxis. Several incentives have been introduced to encourage the use of liquefied petroleum gas in transport both to relieve the demand for gasoline and to minimise pollution. However, it must be realised that if all liquefied petroleum gas produced in Australia were used for motor transport, it would provide only about ten percent of the current demand for gasoline.

Coal

Coal is a very complex material having a variable composition which, despite many years of research, is still not fully understood.

The differences in source material—which may be moss, wood, bark, leaves, pollen grains, or algal remains—lead to the variation in coal 'type' which should not be confused with the term 'rank', the maturity of any type. The rank of coals is represented by the peat to anthracite series.

On an elemental basis, coals consist primarily of carbon, hydrogen, oxygen, nitrogen and sulphur. The range of carbon content is from sixty to ninety-six percent on a

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Ocean Endeavour, One of the most modern machines for offshore drilling. This rig is mobile and can economically be transferred from one exploration site to another. Time and money can also be saved by the semi-submersible feature of this rig, it can safely operate during turbulent conditions avoiding heavy losses in time and labour stand-downs.

dry ash free basis with black coals having a variation of seventy-three to ninety-six percent. It is interesting to compare this variation in carbon content with that of the petroleum products, where the range from gasoline to heavy fuel oil is eighty-four to eighty-eight percent carbon content. The difference between gasoline and heavy fuel oil is obvious, but at first consideration differences between black coals are not as apparent.

Brown coal occurs at an early stage in the transformation of vegetable matter from peat through to black coal. It is formed in horizontal deposits and is covered by layers of sand, silts and clays. Brown coal occurs in several places in South Australia, Victoria and Tasmania, with the significant, large deposits being in the Latrobe Valley, Victoria. These deposits rank among the world's leading brown coal deposits in both extent and quality.

As mined, brown coal has a low heat value and a very high moisture content—up to two-thirds by weight. If mined and stockpiled for more than a few weeks as raw coal, it can ignite spontaneously. The winning of brown coal is therefore confined to large-scale, low-cost mining operations, the principal use currently being electricity production—twenty-seven million tonnes out of a total of thirty million tonnes mined providing eighty-five percent of electricity generated in Victoria. A small quantity, 300,000 tonnes per annum, is used directly by industry and close to three million tonnes goes into the manufacture of brown coal briquettes for industrial and domestic heating, power generation, charcoal production and export.

Black coal was discovered in Australia very early in the settlement of the country, the first reported discovery being in 1797 near Coalcliff, to the south of Sydney, and the second, a few months later, near Newcastle, NSW. The larger, known resources of black coal are located in Queensland and NSW with smaller amounts of generally lower rank coals deposited in South Australia and Western Australia.

Black coal takes a dominant position in Australia's overseas trade—more than thirty-six million tonnes valued at approximately $1400 million dollars were exported in 1977. Australia is the world's third highest coal exporter after the USA and Poland, accounting for seventeen percent of world exports. To maintain a sense of perspective with respect to our black coal exports, it has to be recognised that approximately eight percent of the world's black coal production is exported.

At present, within Australia, black coal has two major uses: combustion for steam raising in thermal power plants and production of metallurgical coke for the steel industry. Other industrial use has declined due to low oil prices and in some cases due to the introduction of natural gas, coupled with the need to meet clean air requirements. Coal as a source of town gas has rapidly declined because of lower cost oil gasification some years ago, followed more recently by liquefied petroleum gas in country areas and natural gas in the cities.

Oil Shale

Oil shale is defined as a sedimentary rock containing solid, combustible organic matter in a mineral matrix. The organic matter, called kerogen, is largely insoluble in petroleum solvents but decomposes to yield an oil when heated. The colours of oil shales range from black to light tan and they can be found on all continents.

The world's organic-rich shale deposits represent a very large store of fossil energy, but large scale commercial production of oil from shale has been considered uneconomic in competition with petroleum oil. However, there have been commercial operations in such countries as Scotland, France, Canada, Brazil, Germany, Estonia and Australia (where spasmodic production took place in NSW from the mid-1860s until 1952). There are known to be modern developments in Manchuria and Estonia where a thick shale oil deposit overlies a rich coal seam, and there is constant evaluation of large scale deposits in the USA. In Queensland, feasibility studies are also being carried out on some deposits. Australia's proven but subeconomic resources of oil from shale oil are of the same magnitude as the proven economic petroleum reserves.

Tar Sands (bituminous sands or oil sands)

Tar sand is a loose sand or semi-consolidated sandstone impregnated with a heavy asphaltic crude oil which is too viscous to be processed by conventional refinery methods. Tar sands are found around the world but the best known are in Alberta, Canada, with the Athabasca Tar Sands deposits reported to be the largest known oil fields in the world. The second of two commecial plants to produce oil from these tar sands, near Fort McMurray, has only recently been completed.

Future of Fossil Fuels

Fossil fuels are the basis of modern industrial society and are essential to our community's agricultural, commercial and transportation activities. They are however, non-renewable resources, so—what lies ahead? Due to various forecasts from industry, government and research institutions that world demand for oil will exceed production rate within the next twenty years, there is increasing discussion in technical literature about 'what will happen when the oil runs out'. Known coal reserves far exceed those of oil and natural gas—it is estimated that in Australia over ninety-five percent of known fossil fuel enegy resources are in the form of coal; and on a global basis, it is inevitable that coal will become an increasingly significant fossil fuel. Its overall significance in supplying energy to society will depend on the impact of other non-fossil energy forms such as nuclear and solar.

Coal conversion offers further possibilities. It is interesting to consider coal, oil and gas in terms of their carbon to hydrogen ratio by weight. The C/H ratio gives values for coal of 15 to 18/1, for petroleum oil and products 6 to 8/1, and for natural gas 3/1; that is, as we go from solid to liquid to gaseous fuel the carbon to hydrogen ratio by weight decreases. It is obvious then that if we want to make liquid or gaseous hydrocarbons from coal we must adjust the C/H ratio and the general ways in which this can be done are known.

Coal can be heated in the absence of air, in a thermal cracking, pyrolysis or carbonisation process. Pyrolysis of coal gives gaseous, liquid and solid fuel products. This is the method by which metallurgical coke is made. The difference is that instead of optimising coal selection for coke properties, the choice has to be based on liquid yield. The solid product of low temperature pyrolysis is called char and its yield is sixty to seventy percent. Its efficient and effective use is essential to the whole process development.

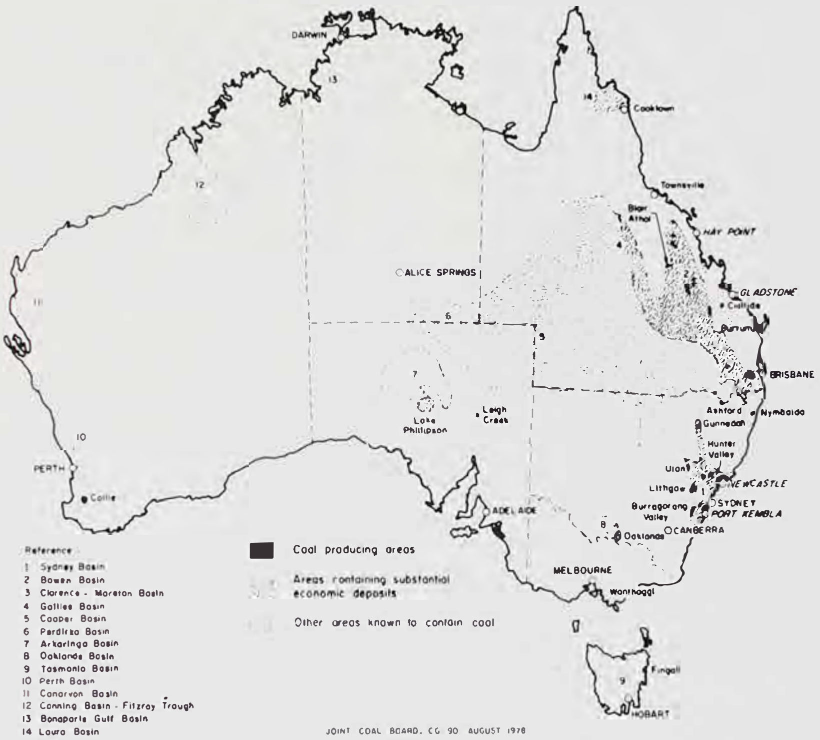
We can 'add' hydrogen to vary C/H ratio in a hydrogeneration process. This is an attractive process thermodynamically for liquid fuel production, but it presents the most difficult technical problems. Coal-oil slurries have to be contacted with hydrogen under elevated temperature and pressure, with or without catalyst. The products then have to be separated from undissolved coal and the mineral matter, both of which are in very fine particulate form. This separation process has been extensively researched without any apparent success. It may be that a novel system of product separation has to be developed.

Coal can be completely gasified, by partial oxidation, to give carbon monoxide and hydrogen. These gases can then be reacted over catalysts to produce hydrocarbons.

Pyrolysis would produce about one barrel of oil per tonne of coal, hydrogeneration about three barrels per tonne and gasification plus synthesis about one and a quarter barrels per tonne. The following table illustrates the amount of coal that would have to be mined to produce Australia's current daily oil consumption of about 650,000 barrels per day!

Yield barrels/tonne coal per year	650,000 barrels/day	100,000 barrels/day
1	237 million	36 million
2	119 million	18 million
3	79 million	12 million

MAP OF AUSTRALIA SHOWING BLACK COAL DEPOSITS



JOINT COAL BOARD, CG 90 AUGUST 1978

These figures can then be compared with a current black coal mining industry that produces 84 million tonnes a year. It is obvious then that the production of oil from coal will require large investment in both processing and mining of coal.

In Australia the fossil fuel situation can be summarised thus: we have extensive coal resources which on a per capita basis represent a very favourable position and which in relation to Australia's current annual consumption give a high reserves-to-use ratio. It is important to keep these resources in context on a world basis and it must be recognised that the massive coal deposits of the Carboniferous period stretch across the Northern Hemisphere through the USA, Europe, USSR and China. Available figures suggest that Australia has from two to four percent of the world's coal resources.

The situation with respect to natural gas is a favourable one for the next twenty-five to thirty years at least. One of the problems here is that many of the demonstrated gas reserves in the northwest region of Australia are remote from population centres and unless large-scale industries move nearer to gas sources it is likely to be viewed as an export trading commodity rather than as an indigenous supply of energy, apart from the Western Australian demand.

The situation regarding crude oil is the one of greatest concern at the moment. Australia has had a relatively short period of significant indigenous oil supply and it certainly came at a fortuitous time in terms of world events in the supply and pricing of crude oil. The crude oil production rate from indigenous sources has now levelled out and each year will see an increasing export bill for crude oil unless we make other very significant discoveries or far fewer demands on its use.

SOLAR ENERGY

BY J. E. GIUTRONICH

The Sun is a gaseous body with layers of different densities. The photosphere, from which radiation appears to be emitted, has a diameter of about 1.4 million kilometres (0.86 million miles), and the extremely small density of one hundred millionth that of water. Beyond the photosphere, the chromosphere and corona extend for very large distances but their densities are extremely low. Earth-Sun distance varies slightly throughout the year as Earth moves in an elliptical orbit around the Sun. Average distance is about 150 million kilometres (93 million miles) so that the Sun subtends an angle of a little over half a degree to an observer on Earth.

The Sun's enormous emission of energy results from the fusion of hydrogen nuclei to form nuclei of a heavier element, helium. The extremely high temperatures and pressures necessary to maintain this fusion reaction exist near the Sun's centre, with temperatures estimated at eight to twenty-four million degrees Celsius. Associated with the fusion of hydrogen nuclei to form helium there is a loss of mass. The helium nucleus has less mass than the sum of the four hydrogen nuclei required for its creation. The missing mass is completely converted to energy, which can be calculated using Einstein's famous equation $E = mc^2$ where m is the mass lost and c is the velocity of light.

Astrophysicists believe that the Sun is an average star about half way through its life cycle. Its estimated age is 3500 million years with a similar period to go before the hydrogen supply is sufficiently depleted to significantly change the size or energy supply of the Sun. During this time, it will continue to radiate to Earth at the rate of $50{,}000 \times 10^{21}$ joules per year. This is just 50,000 times the projected world energy requirement in the year 2000 AD.

These figures can give a false impression of the Sun's potential to solve our energy problems. Major difficulties arise from the very low and intermittent nature of solar radiation. On a clear day the peak insolation (power arriving at Earth's surface) is about one kilowatt per square metre. If allowance is made for cloud cover and a maximum useful collection time limited to eight hours per day, together with low conversion efficiencies, very large areas are required to collect a significant fraction of Earth's energy requirements. For example, at fifteen per

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J. Giutronich

The largest Solar furnace in the world—1000kW capacity—in the French Pyrenees. Used for research and for practical purposes, and to test boilers in large solar electric installators.

cent efficiency, at least twenty square metres of collector, with appropriate energy storage, are required to power a one kilowatt motor or a single bar radiator continuously. Most research now concentrates on producing the most cost-effective collection devices even if they lack the maximum energy conversion efficiency.

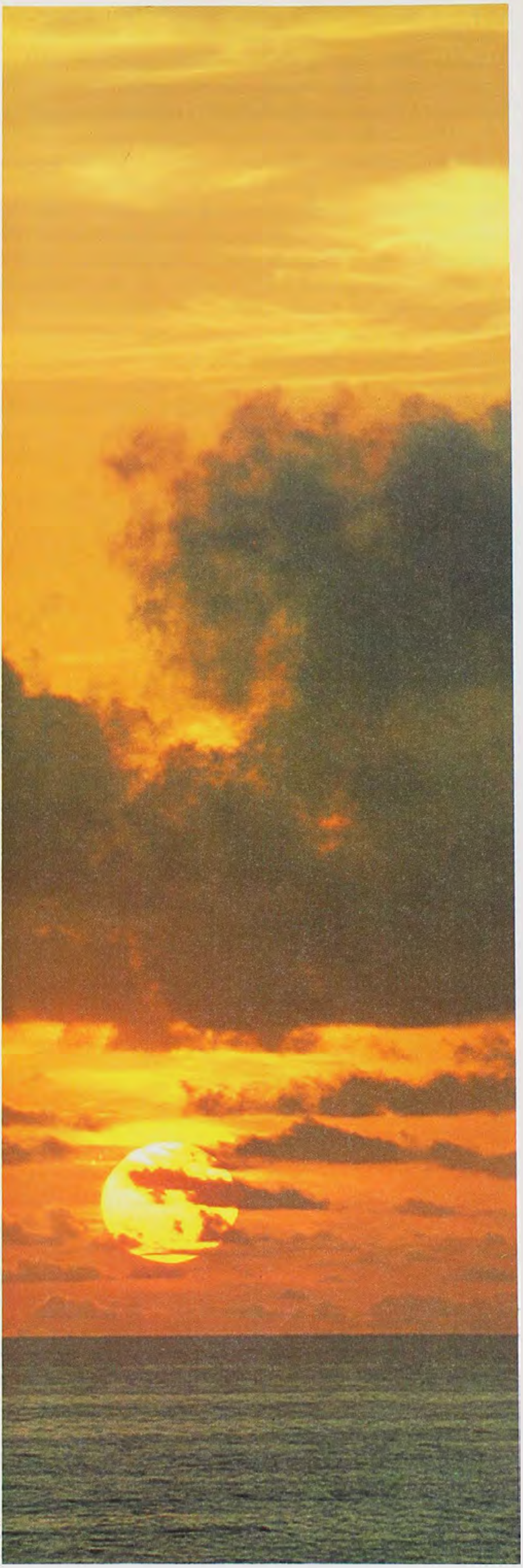
Apart from its dilute nature, solar insolation varies even on a clear day, is non-existent at night, falls off dramatically due to cloud cover and, for a stationary collector, the effective collection area depends on the time of day and time of year. The combination of all these factors renders it a most difficult source to harness economically even though the energy is free and available everywhere. The variable nature of the source makes it necessary to use appropriate storage systems, the cost of which can counterbalance economic viability.

It is estimated that the world energy requirement in the year 2000 AD will be 1.0×10^{21} joules which is, as stated earlier, a very small fraction of the total solar energy intercepted by Earth. Our total energy reserves including fossil fuels and uranium are variously estimated to be from 150 to 700×10^{21} joules. The higher estimates include fuels which are currently considered uneconomical to win. However, the situation is far more critical than these figures indicate, since oil reserves, at the present rate of usage, will be seriously depleted in a few decades.

The following table gives the distribution of the major end uses of energy consumption for the USA.[1]

End Use	*Per Cent of Total*
Transportation	24.9
Space Heating	17.9
Process Steam (industrial)	16.7
Direct Heat (industrial)	11.5
Electric Drive (industrial)	7.9
Feedstocks, raw materials	5.5
Water Heating	4.0
Air Conditioning	2.5
Refrigeration	2.2
Lighting	1.5
Cooking	1.3
Total	95.9

Relative uses in other countries vary widely depending on climate and state of industrial development. As the USA is a major energy consumer, it is taken as an illustration. It should be noted that approximately twenty-five percent of total end usage is for transportation and as such represents the usage of oil. The direct heat require-



Sunrise over the Coral Sea.

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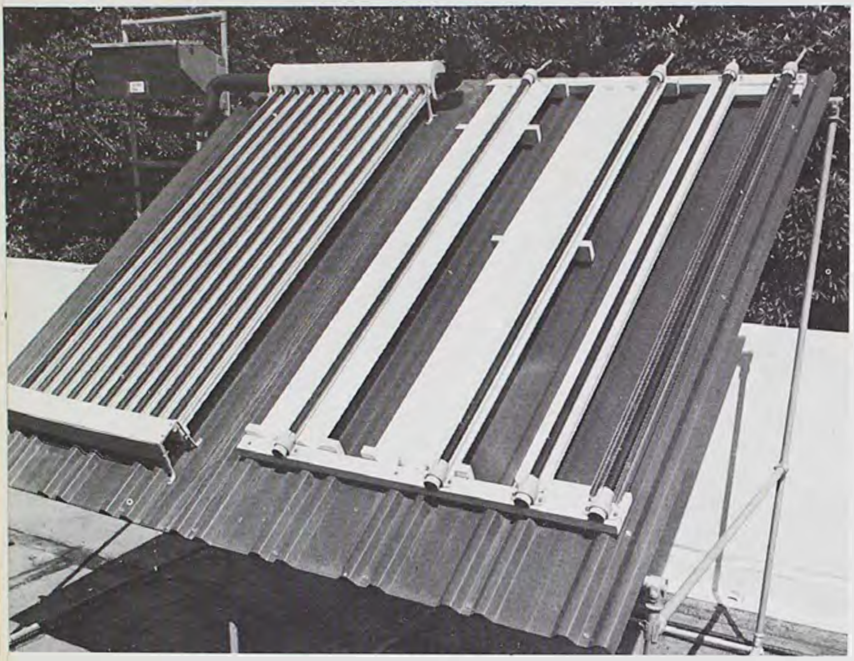
[1] Report to the office of Science and Technology, *Patterns of Energy Consumption in the United States,* Washington, DC, Stanford Research Institute, US GPO, Jan. 1972 p. 7.

ment accounts for fifty per cent which is currently produced mainly from oil, with the remaining twenty-five per cent to cover electric and other end usages.

At present, the prospects are not good for producing alternative liquid fuels over long periods in the quantities required. Possible new discoveries of oil can only delay, perhaps by decades, the day when oil cannot play such an important role in our society. The extra time that such new discoveries might allow must be used to work towards a permanent solution. In his book *Energy: The Solar Hydrogen Alternative,* John Bockris surveys numerous alternatives and presents sound arguments for hydrogen as the alternative liquid fuel. Hydrogen could be produced from water by electrolysis using electricity generated from solar energy. Large, arid, high solar radiation areas throughout the world could be covered with solar collectors to become the future liquid fuel suppliers of the world. The hydrogen is transportable in suitable containers and could solve our future transport problem. The modern motor car can easily be adapted to use hydrogen as fuel instead of oil, but at the moment, the economics of this scheme are most unattractive and there are many problems to be solved.



Some evacuated tubular modules on test at the University of Sydney. On the left is a bank of ten evacuated modules interconnected to form a collector panel. The water passes through each module via the manifold on top. On the right are four individual modules being used with various types of reflectors (Photo: Courtesy Sydney University).

Alternatives such as alcohol from sugar cane, algae or other crops are quite feasible. It is not yet clear whether these could supply the necessary volume of fuel required to meet the needs of our transport-oriented society. Brazil is aiming at being self-sufficient in liquid fuel as a result of its vast programme to extract alcohol from sugar cane. One must remember that Brazil is a large country which is not highly industrialised and the solution for it need not be a world solution. However, it is possible that a useful contribution can be made from crops of various kinds on a world basis.

Where the end usage of energy is in the form of heat at moderate temperatures, which accounts for nearly fifty per cent of the energy used in the USA, it is clearly preferable to convert solar radiation directly to heat energy. At temperatures below 80°C this can be achieved with efficiencies of twenty-five to seventy per cent depending on the temperature required. The higher efficiencies are achieved where the temperature requirements are only a few degrees above ambient as in swimming pool heaters. Domestic hot water systems require about 65°C heat and the current commercially available flat plate collector can usually achieve this. Without excessively large and therefore expensive storage systems, however, the collectors cannot be guaranteed to meet demand during bad weather. It is therefore still necessary to use a manually or automatically controlled electrical heater as a back-up system.

Early research and development of the flat plate collector was carried out by CSIRO and it is mainly their work which earned Australia its reputation as a leader in solar energy research. Solar water heaters are now available across Australia, as well as in many other countries throughout the world. Current research on flat plate collectors in CSIRO is concerned with improving the efficiency of collector designs to enable useful collection at high temperatures.

The flat plate collector can also be used for air conditioning, space heating and low temperature industrial processes. Collectors have been installed on the roof of the Eldridge Medical Centre at Bankstown. The total collector area is 400 square metres and the energy collected contributes significantly towards the operation of an air conditioning plant of fifty tonnes capacity. This work was carried out by industry using consultants from the NSW Institute of Technology.

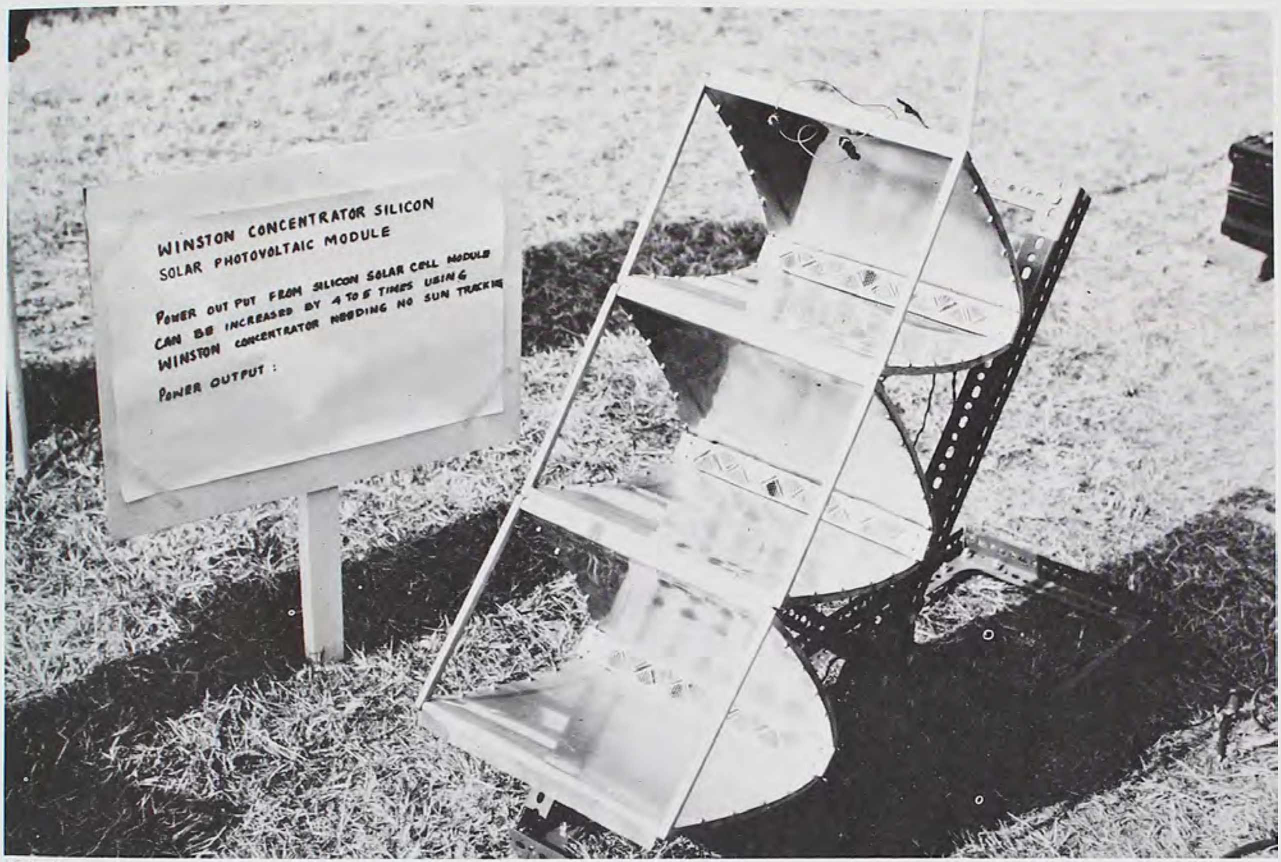
Industrial process heat is also required in large quantities at temperatures up to 250°C. The higher temperatures are beyond the range of the current flat plate collector. They can be achieved by using vacuum insulated systems which also incorporate selective surfaces (see illustration page 360). It is this area that scientists in the School of Physics at the University of Sydney are making a potentially important contribution.

Solar energy may also be converted to thermal energy at high temperatures by using concentrators. Temperatures up to 3000°C can in practice be achieved but at a prohibitive cost. The highest temperatures of practical use are between 500°C–600°C for production of electricity. However, for purely thermal end usage, the required temperatures up to 250°C can be achieved by concentrator tracking systems. At the School of Physics, University of NSW, an eight square metre cylindrical parabolic one-axis tracking concentrator has been built, which can produce temperatures over 300°C and can work with good efficiency at 250°C (see illustrration page 362).

A recent innovation is the stationary concentrator. It will not produce the high concentration factors of tracking systems but used with well-designed absorbers such as the vacuum insulated system mentioned above, may prove cost effective at all temperatures up to 250°C. A group at the University of NSW is working on improved designs of this type of concentrator.

One approach to electricity production from solar radiation involves the production of steam using a concentration system. The steam powers a heat engine which in turn drives an electrical turbine. Such systems working at temperatures of 500°C–600°C have been analysed in the

USA and a ten megawatt pilot plant is currently under construction. A 1974 analysis resulted in a cost estimate of six cents per kilowatt hour before distribution. Whilst this is expensive compared with current Australian electricity prices, it may not be beyond economic viability in the future. The pilot plant consists of a large number of plane or slightly curved mirrors which are distributed over several hectares. The mirrors are mounted so that they can be continuously moved, each to reflect the solar rays to a boiler which is placed near the middle of the field of mirrors. A 200 megawatt power station would occupy an area of about one square mile. Thirty or more such stations placed in suitable locations complete with storage areas would be required to meet the demand in NSW. Solar energy usage on a large scale is enormously capital intensive.



J. Grutronich

Stationary Concentrators are used to direct the sun's rays onto photovoltaic cells. International Solar Energy Society Congress, Delhi, 1978.

A more modest approach which could meet the needs of country homesteads and towns not connected to the electricity grid, involves the use of semi-stationary concentrators with vacuum insulated absorber tubes. These concentrators will give a higher concentration than the stationary designs but require occasional seasonal adjustment of orientation. Steam at a temperature of 200°C–250°C would be available to drive the generators. It is expected that such systems would compete economically with diesel electric power and hence contribute to reducing the demand of the world's dwindling reserves of oil.

Direct conversion of solar energy to electricity can be achieved using photovoltaic devices. These are commonly known as solar cells. The efficiency of conversion to electrical energy is typically twelve to fifteen per cent. The cells were first developed for use on spacecraft to recharge batteries. Initially the cost was extremely high and therefore not practical for large-scale electricity production. Over the last decade the cost has been reduced by a factor of 100. Even so, the current cost is about $1200 per square metre, resulting in a peak output of 100 watts under perfect solar conditions. This is equivalent to a cost of $12 per peak watt. Due to recent advances made by scientists in the School of Electrical Engineering at the University of NSW and intensive work in the USA, it has been forecast that the cost may drop to $1 or less per peak watt in the near future. At this price the cost of electricity from solar energy would compete economically with the cost of electricity from diesel power.

A semi-stationary or stationary refracting, total internal reflecting concentrator has been developed in the School of Physics at the University of NSW for use with solar cells. This device can increase the output per cell by a factor of five. Since the cost of the concentrator is very small compared with that of the cells, the use of the concentrator should reduce the current cost of solar-electric power by a factor of four or five. The device is currently ready for industrial development and commercialisation. The further expected reduction in cost of the cells together with the use of the concentrator might render the cost of solar electricity an economically viable alternative not only for off-grid generation but even for generation to feed into the electricity grid.

At a recent conference, 'Solar Energy Today' held in Melbourne and sponsored by the Victorian Solar Energy Research Committee, no less than forty-seven exhibitors displayed products associated with solar energy. This was indeed an indication of the growing interest by industry in the future of solar energy appliances. However, the rate of growth of industrial involvement must increase dramatically if solar energy is to play a significant role in our energy future. Further, more intensive research and development must take place in our research establishments.

The Melbourne conference was attended by over 300 delegates from all states of Australia and from overseas. Speakers from the USA, Japan, France, Brazil, Canada and Germany reported on developments in their countries. The Australian contribution to the conference was significant and belies their meagre solar budget which jumped to $6,000,000 this year. This budget is insignificant when compared to a number of other countries—the USA for example spends over $200,000,000 annually on solar research.

Solar energy research is being carried out by groups in almost every university and institute in Australia, and at other tertiary education establishments. Many projects are at least partially supported by a government agency. The range of projects includes: solar home architecture, swimming pool heaters, domestic water heaters, industrial heat (up to 250°C), photovoltaic conversion, photoelectrochemical conversion, space heating, air conditioning, desalination, hydrogen from solar, solar thermal production of electricity, and energy storage of various kinds.

Money is made available from the federal government via the Australian Research Grants Committee (ARGC), the National Energy Research Development and Demonstration Council (NERRDC) and the Industrial Research and Development Incentives scheme. NERRDC is a recently established funding body exclusively concerned with energy matters. It was formed following the National Energy Advisory Committee Report No. 3. Their recommendations stated that solar energy might be able to contribute in Australia as heat, in the production of electricity and in the production of synthetic fuels for transport, and that research should therefore be supported by governments, industry and universities in the following areas:

(1) The heating of water up to 200°C. In the range 90°C–200°C Australia consumes about one-quarter of its primary energy; this is the temperature range where research during the next one to ten years could produce the greatest dividends, particularly in saving oil. Applications include the generation of process steam, heating and cooling of buildings, refrigeration, drying processes, food processing, mineral processing, and desalination. It should also be noted that there will be need to carry out research on the associated thermal problems of heat storage using water, oil, rock or eutectics. NEAC believes this higher temperature application of solar energy to be the most important one.

(2) The use of solar energy for specialised remote area applications generally involving small amounts of elec-

An experimental cylindrical parabolic one-axis tracking concentrator at the University of New South Wales. It is 4m x 2m and can collect up to 4kW thermal power.

trical energy. Here both photovoltaics and thermoelectric systems are already being employed throughout the world, including Australia. Thermal conversion systems operating up to 200°C could be economic in some remote areas.

(3) The production of liquid and gaseous fuels from plant materials. This can be achieved by the process of fermentation, chemical reduction or pyrolysis. A significant fraction of Australia's liquid and gaseous fuel requirements could be provided by the use of agricultural and timber wastes, and by growing trees and other plants for fuels.

(4) There are also longer range programs to make hydrogen by thermochemical and photochemical processes. The Japanese have already claimed an efficiency of about 5 per cent for a photochemical process. Improvements in fuel cells as hydrogen to energy converters have been quite dramatic during the past few years.

The Western Australian Government through their Solar Energy Institute of Western Australia (SERIWA) are very active in promoting the use of solar energy for electric and heating purposes particularly in remote areas. Other states have similar committees through which funding is available. This is a vast improvement on the situation a few years ago. However, not even the most optimistic analyst can foresee solar energy as a source which can be developed quickly enough to have a dominant role in Earth's energy needs by 2000 AD.

Solar energy and energy from fusion are the only two sources which can be considered inexhaustible and the society of the twenty-first century will depend heavily on developments in these two areas. Solar energy includes many of its forms apart from the immediate utilisation of the incident radiation. Wind, tides, geothermal energy, ocean thermal gradients, ocean waves as well as crop growing may all make useful contributions. Energy from fusion is not an easy task. It is beset with many technological difficulties and the possibility of an early solution is indeed remote.

Twentieth century man in a few decades has been responsible for the drastic depletion of Earth's energy reserves which took thousands of millions of years to accumulate. It is our responsibility to make amends to future generations by progressing as far as possible towards providing them with viable energy sources.

FURTHER READING

Anderson, Bruce. "The Solar Home Book", Cheshire Books, 1977.

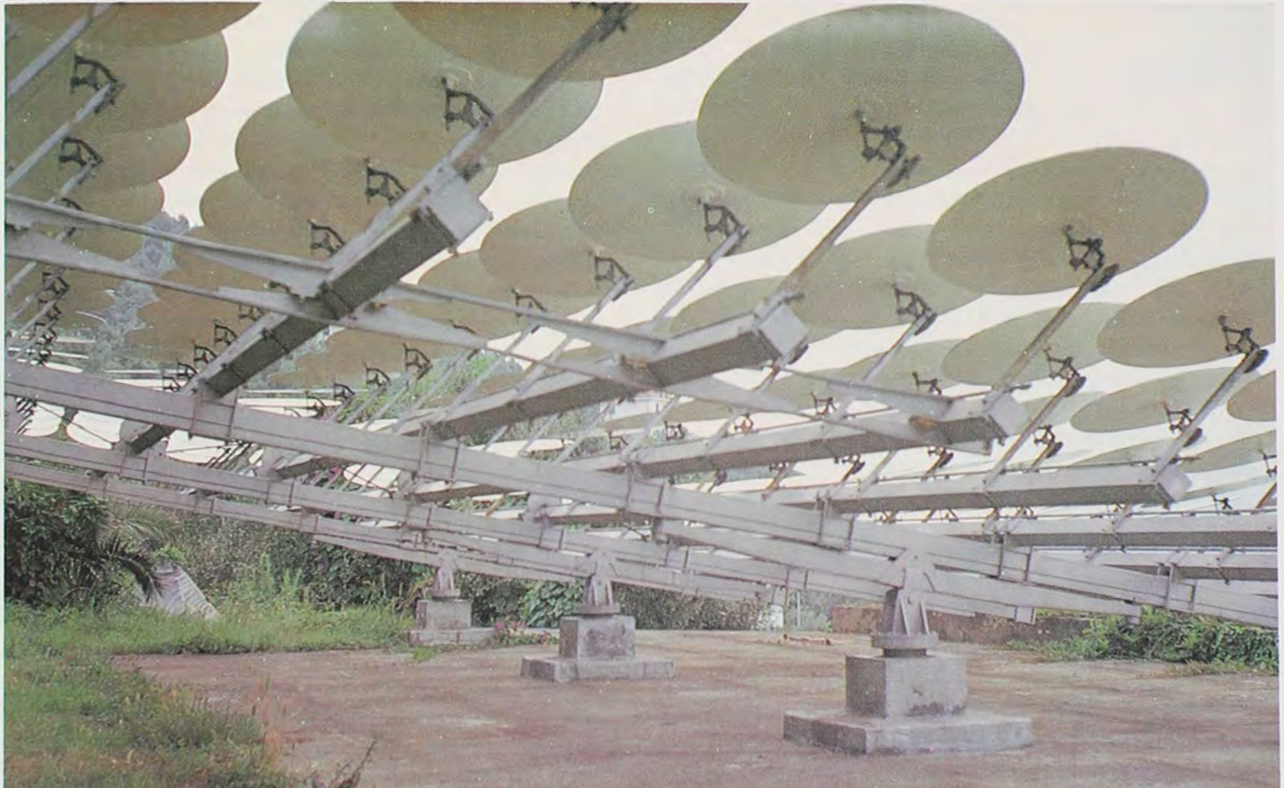
Bockris, J.O'M. "Energy: The Solar-Hydrogen Alternative", Australia and New Zealand Book Company, Sydney, 1977.

Franta, Gregory E. and Kenneth R. Olson. "Solar Architecture", Ann Arbor Science Publishers Inc., 1977.

Meador, Roy. "Future Energy Alternatives", Ann Arbor Science Publishers Inc., 1978.

Williams, J. Richard. "Solar Energy, Technology and Applications". Ann Arbor Science Publishers Inc., 1977.

J. Giutronich



An array of curved tracking centres built by Professor Francia in Genoa, Italy. Mirrors reflect solar rays to an overhead boiler.

ENERGY CONSERVATION

BY RICHARD TEMPLE

Few people understand the term 'exponential growth' or its implications, since most people tend to think of growth in linear terms. A boy growing at a constant rate of 2.5 centimetres a year is growing linearly. An exponential growth on the other hand is one where the quantity concerned increases each year by a certain percentage of its value in the preceding year, that is the growth accelerates and the rate of growth increases with time. The characteristic of exponential growth is that after a seemingly slow start it begins to generate large numbers very rapidly. What may have seemed tolerable or even desirable may eventually threaten to overwhelm.

It is impossible to understand the controversial predicted 'gap' between future demand and supply of energy, unless we understand the implications of sustained exponential growth. This is a concept most politicians, businessmen and economists fail to grasp. Our economic troubles are usually attributed to a 'stagnant-economy' and it is often implied that all will be well if we can once more achieve an annual product growth rate of five per cent. It seems to me however, that humanity is attempting the impossible. Part of it lives in a very resource-and-energy-greedy way while a much larger part can hardly survive but is striving to catch up with the others. Since it is impossible to persuade the affluent to forego any of their consumption to give to the needy, the only possible course considered is to increase the size of the global cake so the poor can have a few more crumbs without incommoding the rich. We have thus arrived at a state of affairs where six per cent of the world's population consumes thirty to thirty-five per cent of the world's total output of energy and raw materials. So far from being satisfied with this, economic experts demand still more growth. E.F. Schumacher quotes a former economic adviser to the US President as saying "We need expansion to fulfil our nation's aspirations. In a fully-employed, high-growth economy you have a better chance to free public and private resources to fight the battle of land, water and noise pollution than in a low-growth economy. . .I cannot conceive a successful economy without growth". As Schumacher commented "If a high-growth economy is needed to fight the battle against pollution, which itself appears to be the result of high growth, what hope is there of ever breaking out of this extraordinary circle?" Schumacher also says, "If the US economy cannot conceivably be successful without further rapid growth and if that growth depends on being able to draw ever-increasing resources from the rest of the world, what about the other ninety-four per cent of mankind who are so far 'behind'?"

As a result of such thoughtless patterns of living, some of us continue to waste energy and raw materials on a vast scale while thousands of millions live in utter want and the exhaustion of many vital raw materials is now becoming apparent.

Most politicians, economists and businessmen vehemently deny this. An Australian Treasury white paper has told us that past scares of such shortages invariably resulted in exploration and discovery of new supplies. Therefore, it must be merely a question of searching harder and exploiting a lower-grade of supply.

Not many scientists believe this. The growing exhaustion of valuable minerals can be exemplified by the fact that the average copper content of North American copper ores has dropped from 2.5 per cent to 0.2 per cent in seventy-five years. It is now necessary to mine, treat and dispose of more than ten times as much rock to obtain a tonne of copper in the USA today as was needed at the beginning of the century. As richer ores have been worked out, it has even been profitable to rework the refuse dumps of former mines.

All this is possible only by an increased consumption of energy. Temporarily, technical improvements may offset increased costs of mining and treating larger and larger volumes of rock to get the same amount of product. Eventually, however, more energy per tonne of extract is required. Thus, recovery of 1kg of copper from one per cent ore in the 1940s required the input of 54 megajoules of energy, whereas today equivalent extraction from 0.3 per cent ore requires 98 megajoules or not quite twice as much. Energy costs per kilogram must rise inexorably as ores become scarcer and waste-disposal problems more intractable.

The discovery and exploitation of fresh supplies are invalidated as a solution, by the mathematics of long-term exponential growth. The following table may demonstrate this. It gives the life of a stock of 1000, 10,000 and 1,000,000 years' supply (calculated at today's rate of use) if consumption rises by one, two, three, five or seven per cent per year. (The last figure was the approximate figure

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for the increase in oil consumption before 1973; even now during a prolonged world trade recession it has still risen by about four to five per cent per year.) It is evident that even 'a million years' supply' would be exhausted in less than two hundred years at a yearly increase of seven per cent in its use. How much we have used already, makes very little difference to the life of our resource if the doubling time is short. The only way we can make significant increases to the life of the commodity is by lowering the annual growth rate considerably.

Effect of Exponential Growth on the life of a Stock with an annual growth rate of:

Initial Stock*	1%	2%	3%	5%	7%
1000 years	240	150	120	80	65 years
10,000 years	460	270	190	120	95 years
1,000,000 years	920	500	350	220	165 years

* Expressed as a number of years' supply at this year's rate of usage.

For many raw materials we can, theoretically, move to a lower grade of supply if we can afford to use more energy in the extraction processes. Energy supplies are, therefore, crucial as the key to everything else we need. However, there is an essential difference between the raw materials for energy industries and for other commodities. It takes energy to make other energy available. In the UK, thirty per cent of all energy used is used by the energy-producing industries—coal mining, oil refineries, electricity generation. There is, therefore, a lower limit to the grade of raw material which the energy industries can use.

In a discussion of this sort, it is necessary to distinguish between 'reserves' and 'resources'. Reserves are deposits of minerals etc, that can be recovered at a profit using existing technology; resources include deposits which are known to exist but which cannot yet be recovered at a profit. The lower limit to the grade of possible energy resources comes when it takes one unit of energy from the proven reserves to make available one unit of energy from the resources. Beyond this, the process becomes a net-consumer instead of a net-producer of energy, but the economics involved would break down long before this point was reached.

In the developed world, the fuel most immediately threatened is oil. As a result of prolonged exponential growth in its use, it now looks as though, *even allowing for future discoveries,* all recoverable liquid oil will be consumed in as little as fifty years—a very short time for our cumbersome technological society to adapt to its disappearance.

Even if the world could turn to entirely new supplies of energy, exponential growth would defeat our efforts. Much has been said about the importance of nuclear fission in the world energy scheme. Yet A.B. Louins has calculated that if energy usage continues to expand by five per cent per annum for the next twenty years, even if it were possible to build one new 1000 MW (megawatt) nuclear power station *every day* from now on, fifty per cent of all primary energy output in 2000 AD would still have to come from fossil fuels, which would then be consumed at twice the rate they are today.

Mesarovic and Pestel in *Mankind at the Turning Point* examine the question of how many fast breeder reactors would be needed in 100 years' time if all the world's energy were to be nuclear by then. They concluded that if energy requirements were to continue to grow at five per cent per year and if the world's population increases four times in the next 100 years, we would need to build four breeder reactors a week for the next 100 years, each reactor being five times as big as the largest thermal reactor that has yet been built. (Remember, it was estimated that the UK's first commercial-sized fast breeder reactor would cost at least $2000 million at 1974 prices.)

Clearly no scheme can provide enough energy to cope with exponential growth for much longer. It is also likely that continual release of increasing amounts of heat into the biosphere, whether from combustion or fission or fusion reactions, will heat the world to such an extent that within less than 200 years a large part of the globe now inhabited may well become unfit for habitation.

Nothing short of a revolution in modern man's behaviour is required to end exponential growth as soon as possible. World population growth must be reduced to zero, and energy use restricted to renewable resources, fossil fuels being kept for stocks of chemical raw materials.

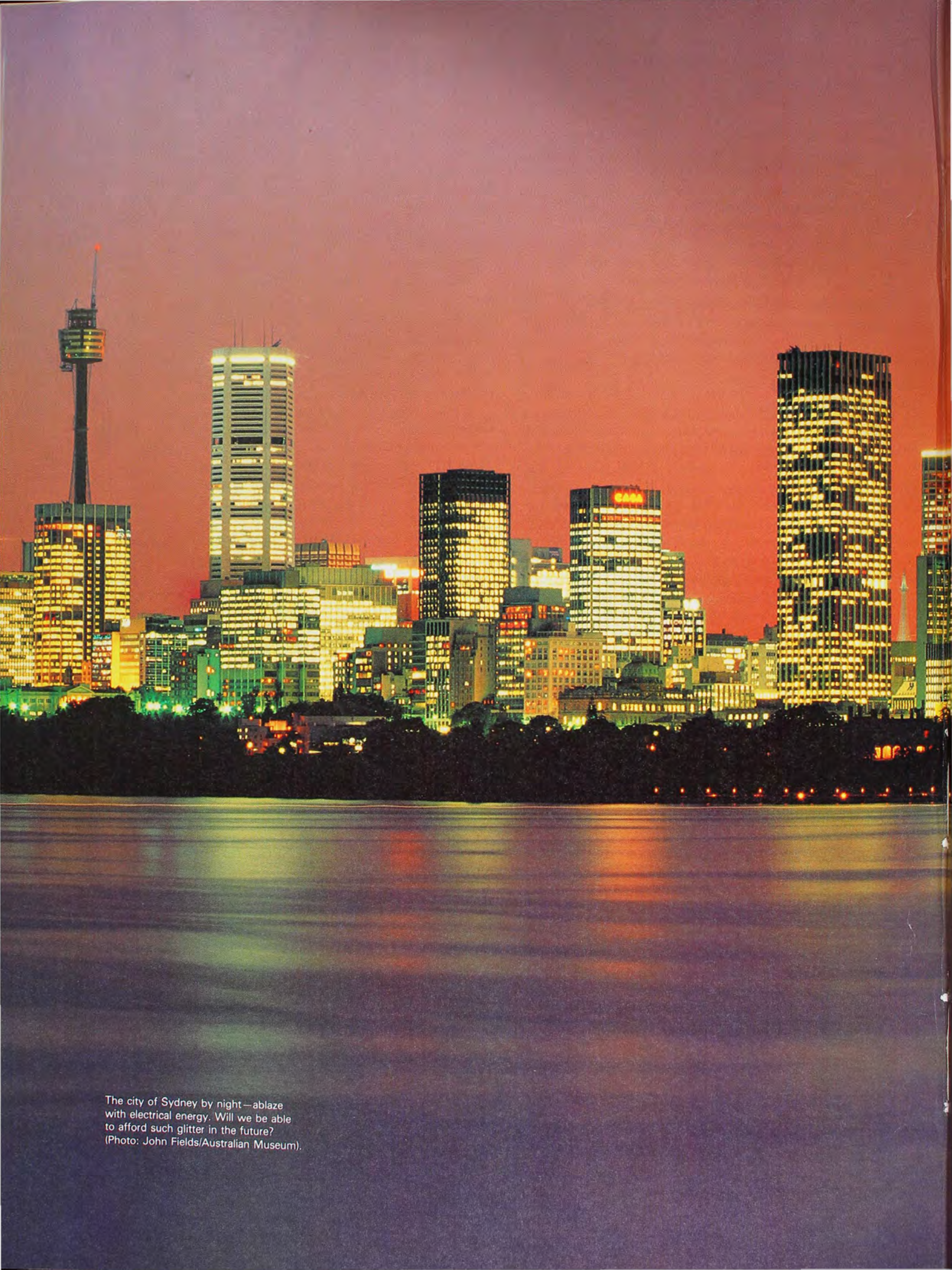
The most effective thing any of us can do about energy is to conserve it. Many of our present practices are extraordinarily wasteful and only of marginal benefit to more than a few people. For example, an average house can be lit for a whole evening by the electricity needed to make one throw-away aluminium drink can. In 1974, the American Institute of Architects showed that by thorough insulation of new and existing buildings, energy saved in fifteen years would equal the output of 500 large nuclear plants that would cost altogether at least $500 × 1,000,000,000 ($500 × 10^9) to construct, even supposing enough uranium could be found to fuel them.

To measure probable energy supply against projected 'demand' it is helpful to recall Gerald Foley. Foley points out that 'demand' is not the same as 'desire'. Many people would like an original impressionist picture on their wall, but at a million dollars apiece there is little 'demand' because few can afford it. If each painting cost only $10 there would be a very considerable 'demand' for them. Future demands for energy will similarly depend on whether people can afford to pay for it. As energy becomes harder to obtain, its price will rise and consequently the rate of growth in demand might well fall. Predictions of an energy crisis must be seen in this light. While, on current consumption patterns, life styles and attitudes, Americans can seriously imagine themselves in a state of energy crisis by 1985; with a revolution in attitude, behaviour and expectation, the world may survive. After all, the Indian peasant needs only enough cow dung to cook a handful of rice a day.

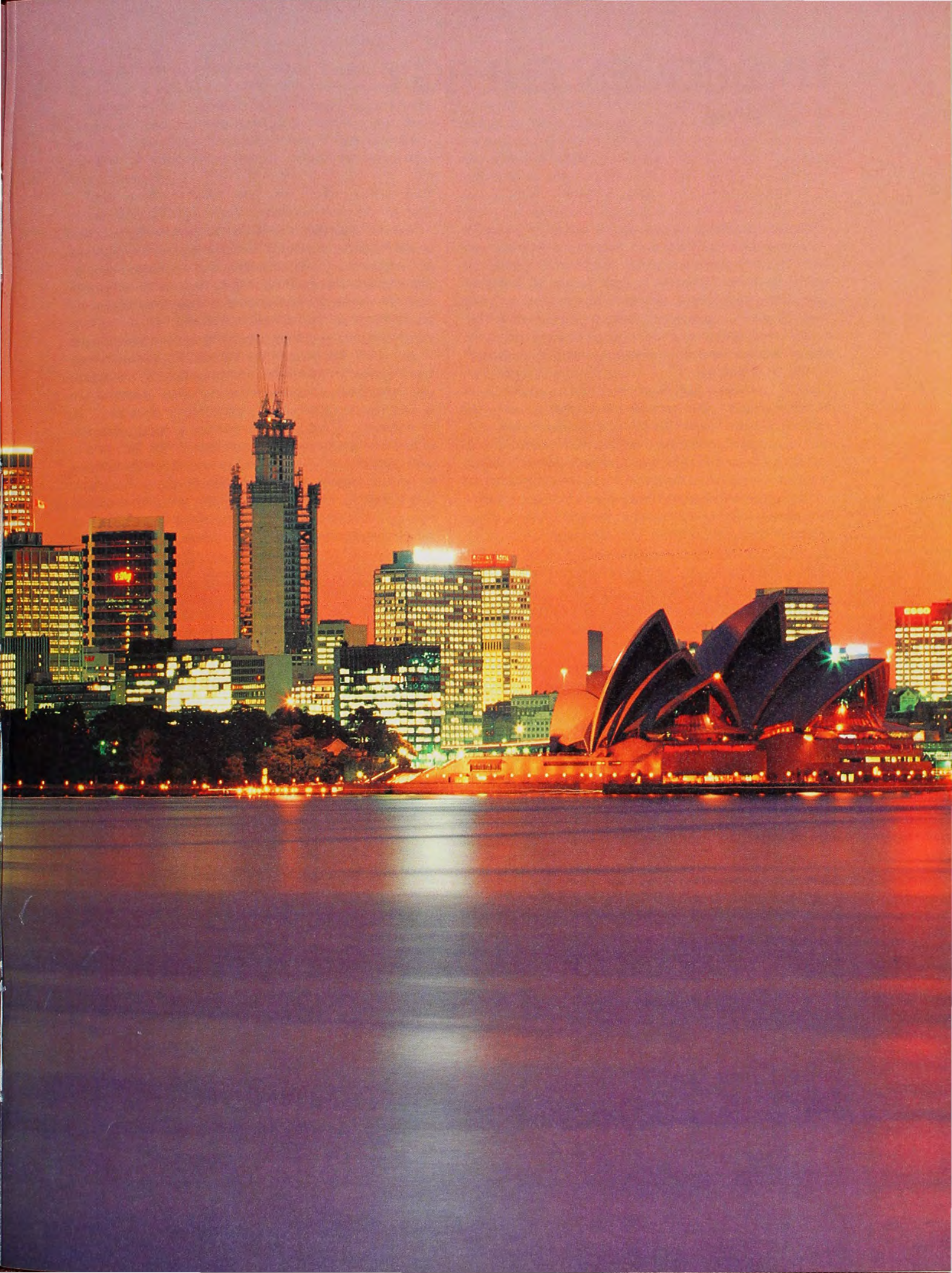
FURTHER READING

Heilbroner, R. *Rescuing the Future: an Enquiry into the Human Prospect,* Norton, New York, 1975.

Mesarovic, M.D. and E. Pestle *Mankind at the Turning Point: the Second Report to the Club of Rome,* Button, New York, 1974.



The city of Sydney by night—ablaze with electrical energy. Will we be able to afford such glitter in the future? (Photo: John Fields/Australian Museum).



HYDROGEN ENERGY

BY KEN TAYLOR

The gas called hydrogen is the most common element in the Universe. Although Earth's atmosphere contains very little of it, one of our most widely distributed materials, water, consists of two atoms of hydrogen chemically combined with one atom of oxygen. If we produce water, a great deal of energy is released. For example when 1cc of water/sec is produced, the energy released is equivalent to a power production of approximately 20 kilowatts.

Since hydrogen gas does not exist naturally, the hydrogen used in the reaction above must be prepared first, by breaking apart the water molecules into hydrogen and oxygen before they can be recombined. This is readily achieved by electrolysis systems, and the operational efficiencies are very high. However, to obtain one kilowatt from a hydrogen-oxygen reaction, it is necessary to invest at least one kilowatt in making the two gases to start with.

So why, one might justifiably ask, is anyone concerned about the possibility of future energy economies based on hydrogen, and why do some enlightened governments direct enormous funding to research and development in this area? The answer is that hydrogen, once you have it is, by its nature, portable. Of all the fuel types one can envisage (excluding oil and natural gas) those which will most affect our current life style when the shortage finally comes, are those used in transportation. Naturally we can return to the fossil fuelled steam engine for any form of land transport—messy, slow, inconvenient and not pollution free but at least reliable. It is hard, however, to envisage a steam-driven 747, as it is also hard to conceive the engineering demands which a sun-driven car, tram, boat or aeroplane would impose.

Is hydrogen, then, just a convenience fuel? No: anyone who has looked seriously at the alternatives which must be developed to take over today's fossil-fuel-based

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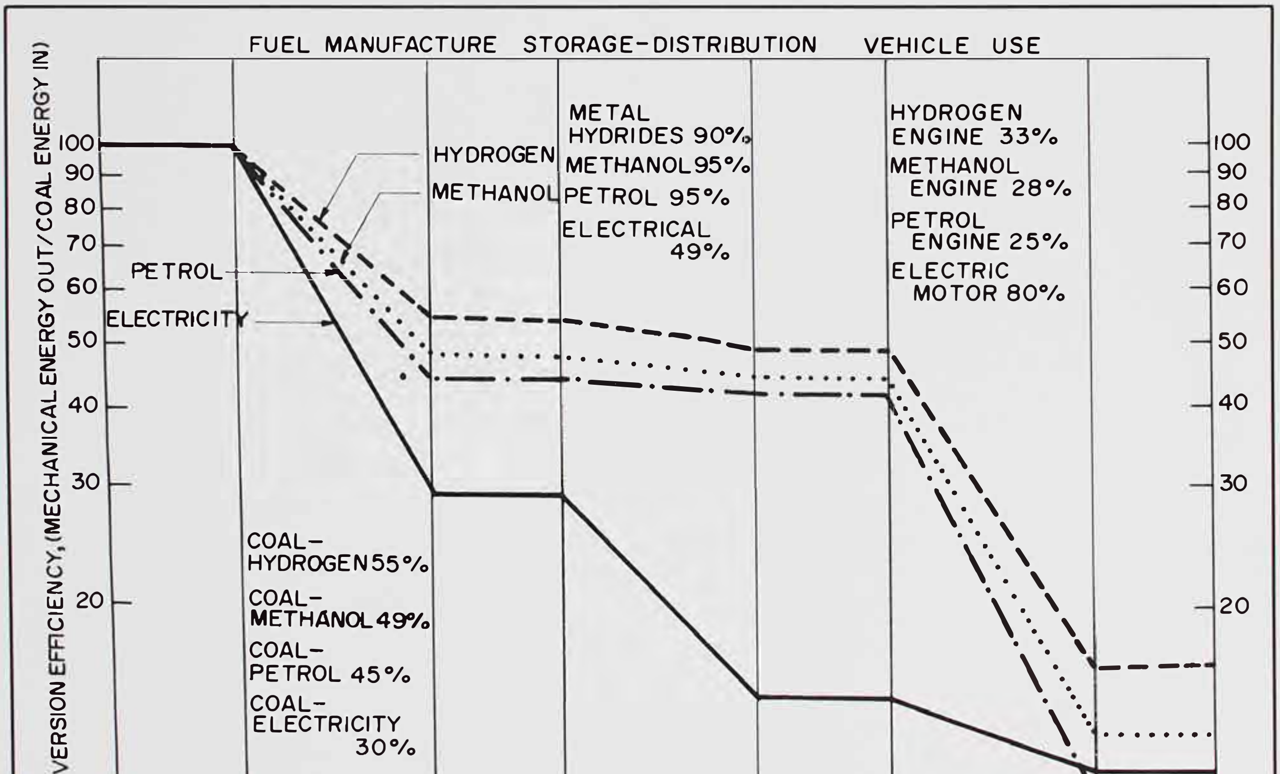
KEN TAYLOR is Professor and Head of School of Physics at the University of New South Wales. He has been involved in research into the effects of hydrogen on metals and on projects relating to a Hydrogen Economy since 1973. At present the work of his group includes the development of a hydrogen production and storage system using solar energy concentrators coupled to solar cells to provide the power required in the electrolysis units. Such systems could find immediate application in either outback stations or solar energy 'farms'.

Comparison of efficiencies of various fuels used for vehicle propulsion, showing the various stages of fuel production, storage, distribution and use. All fuels are derived from coal. The roduction of hydrogen by electrolysis has a nuch higher efficiency, and using that value the final efficiency for hydrogen is just greater than 20%.



economies will point to the unique versatility of this material. Not only is it possible with current technology to satisfy domestic and industrial energy requirements using hydrogen, but also research in Australia and overseas has shown that the development of hydrogen burning internal combustion engines should be reasonably straightforward.

There is also a further attraction, in the area of solar energy. The 'cottage industry' concept of a roof-mounted water heater on every house is very appealing but inadequate as a general solution to the total energy problem. This for a city such as Sydney, automatically puts the energy collectors and convertors in areas remote from the city. Transport problems of solar-produced energy might be solved if hydrogen were made electrolytically at the solar collection station and, using conventional gas pipelines, were transported to the city. For distances in excess of only a few hundred kilometres, the installation and operation costs of such a system have been shown to be less than the equivalent electrical distribution system.

While the universal economic attraction of hydrogen is clearly evident, pubic attitudes towards it remain ambivalent. The 'Hindenberg Complex' still exerts a major psychological influence. Hydrogen in a compressed gas or liquid form is undeniably explosive. Like petrol, petrol vapour or natural gas, it needs careful handling and in a severe accident the consequences are unpredictable. However, hydrogen gas can be stored in a different form to these other portable fuels. An increasing number of metals are known which can absorb hydrogen atoms into their bulk in enormous quantities. The hydrogen fills in the holes which exist between the metal atoms. Each such 'interstitial site', as they are called, can accept one hydrogen atom, and there are so many of these sites in a solid that the density of hydrogen atoms stored in the metal can be as high as three to four times the density of hydrogen atoms in liquid hydrogen. Examples of alloys which can achieve this high storage are titanium-iron, thorium-iron and lanthanum-nickel mixtures. A fuel 'tank' of hydrogen formed in this way contains significantly more available energy than the same volume tank of petrol. In its stored form hydrogen is relatively safe as stored fuels go. Release of the gas is achieved by heating the metal to 20°C–30°C, depending upon the gas pressure which is needed. Such release is readily achieved in automobiles using controlled exhaust heat. To refill the exhausted tank, the metal is returned to room temperature and gas is supplied at a slight excess pressure, say from a storage tank at the 'gas' station. The ability to desorb gas at controllable excess pressures by heating the storage matrix is also significant in the proposed system for energy transport from solar collectors to city using gas pipelines, since the same metallic storage hosts may be used as pumps. The only input energy to these pumps would be low grade heat which can adequately be catered for by solar hot water during both day and night.

Hydrogen could replace significantly more of our current energy usage tomorrow than any current alternative and its versatility is such that it must be high on the list of contenders for the fuel to replace coal and oil.

Unfortunately the National Energy Advisory Committee of the Australian Federal Government in its Report No. 3, 'A Research and Development Program for Energy', saw hydrogen as being of relevance only in the twenty-first century. Consequently little NERDDC funding has been directed for energy research into hydrogen use. Other advanced technological countries of the western world however, are investing considerable research funds in this area, and when hydrogen is accepted into their future energy economies we will hopefully be able to continue our present way of life by importing their technology.

FURTHER READING

Bockris, J.O'M., Energy: the Solar-Hydrogen Alternative. Halsted Press, 1977.

Veziroglu, T.M., Hydrogen Energy. Prenum Press, 1974.

Proceedings of the 1st and 2nd World Hydrogen Energy Conferences.

FUEL COSTS

	1980	*1985*	*1990*
Petrol	$3.32	$3.43	$3.43
Hydrogen	$2.32	$2.53	$2.53
(With efficiency correction)	($1.53)	($1.69)	($1.69)

Recent U.S. forecasts of the comparative fuel price costs and annual expenses for operating a fleet of 100 buses travelling 480km per day.

ANNUAL OPERATIONAL EXPENSES

FUEL COST

Petrol	$580,000
Hydrogen	$170,000
Difference	$410,000

ANNUAL SAVINGS

Incremental fuel cost	$410,000
Credit for engine overhaul	5,000
Annual savings	$405,000
Initial conversion cost	$400,000

WIND ENERGY

BY GRAHAM BOWDEN

In the year 1800, there were an estimated 8000 windmills in Holland and a similar number in Britain, performing various functions such as pumping water and milling flour. In Australia, early prints of Sydney show windmills on the skyline and it is possible to date the prints by simply counting the number of windmills. Following the discovery of cheap oil sources and the internal combustion engine, most windmills were dismantled and relegated to the Museum of Industrial Progress. Nevertheless, it is still possible to see multi-bladed Southern Cross windmills in the countryside, continuously pumping water for irrigation purposes.

Following the oil crisis of the early 1970s, there has been an upsurge in wind energy research. Most of this work is taking place in the USA and to a lesser extent in Canada and New Zealand. Several new wind turbine designs have appeared recently and wind energy enthusiasts now talk of Darrieus vertical axis rotors, the Lebost turbine, Yen's vortex generator, and others. Illustrations of these devices give details of the maximum power so far achieved by these machines. Of these, one of the more interesting wind turbines is the Darrieus vertical axis rotor, patented in 1931 and rediscovered, independently, by the National Research Council of Canada (NRC), in the early 1970s. The two symmetrical aerofoil blades rotate about a vertical axis, in the shape taken up by a spinning rope. It is an omnidirectional device and can use winds coming from any direction. It is also relatively cheap to construct, as it requires only guy ropes to keep it erect. This particular windmill is currently the subject of much research both by the NRC and ERDA, the Energy Research and Development Administration of the USA. ERDA is currently testing a 17 metre diameter Darrieus turbine rated at 60 kilowatts, whereas the NRC machine is 24 metres in diameter and rated at 200 kilowatts. Smaller 3 kilowatt and 6 kilowatt machines are already marketed by Dominion Aluminium Ltd of Ontario.

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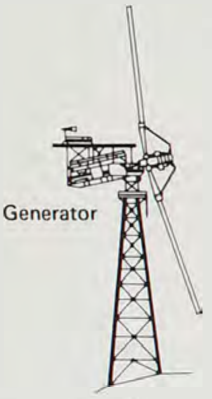
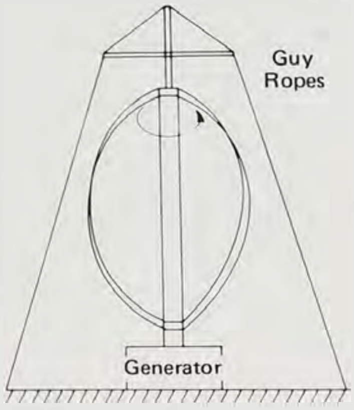
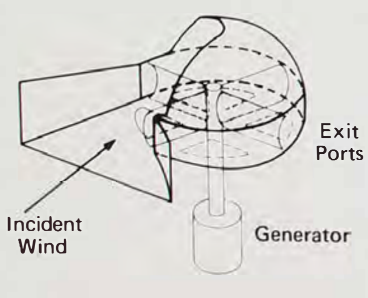


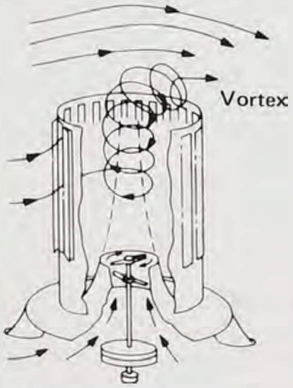
Smith/Putnam
Wind Turbine
Power rating 1.25 MW



Vertical Axis Darrieus Rotor
Power rating estimated 200 kW (NRC)



Lebost Wind Turbine
Power rating – no figures available



Yen's Vortex Generator
Power rating 1.10 MW (Yen 1976)

The biggest and most powerful windmill ever constructed, prior to 1978, was the Smith-Putnam wind turbine, at Grandpa's Knob, Vermont, USA. This two-bladed propeller system produced 1.25 megawatts in wind speeds of 15.4 metres per second. The Smith-Putnam machine was tested during the period October, 1941 to March, 1945 for a total of 1100 hours, until one of the rotor blades broke off, at an overstressed blade root. In fact, every two or three bladed propeller windmill, with power ratings in excess of 100 kilowatts, has suffered the same fate. Because of this, the Danish Ministry has slapped a speed-limit on the recently constructed 2 megawatt three-bladed windmill, at Tvind in Denmark. In the United States ERDA research workers are currently working on a 100 kilowatt three-bladed machine, in an attempt to overcome stress problems, with the aid of modern technology.

The Lebost windmill is the latest in wind turbine designs. It was patented by Lebost in 1977 and tested by Hoffert and co-workers in 1978 using small plastic models placed in a wind tunnel. The preliminary results are encouraging, but it is likely that the wind-flow focusing and shrouding required by this device will render this machine more expensive than its omnidirectional Darrieus or propeller competitors.

Still more exciting is the Yen vortex turbine. In this machine, a vortex is established within a large cylindrical tower, by opening vanes on the windward side of the cylinder. This vortex sucks in air through turbines, which are located in the tower base. Yen has speculated that it should be possible to build a 10 megawatt wind turbine using this method. So far, however, no results which would support this claim are available on the small scaled models.

It is not yet possible to say precisely to what all this research will lead. There are, however, several clear signposts. It is unlikely that single, *reliable,* windmills producing electric power in excess of one megawatt, will ever be built. The bigger the diameter of either the propeller or Darrieus wind turbine, the more serious the stress problem. If windmills are ever to produce the power output of, for example, a single nuclear power plant of 1000 megawatts, then it will be necessary to have windmill farms containing between 1000 and 10,000 individual wind turbines. Because such large numbers are envisaged, wind energy enthusiasts have suggested using shallow off-shore sites, where the wind speeds are high and shipping is not a problem. One such area would be the Coorang National Park, South Australia.

From an Australian viewpoint, there are several embryonic wind research programmes at Sydney University, The University of New South Wales, the Australian National University at Canberra, and Flinders University, S.A. Notable among these is Sydney University's scheme, due to B. Roberts and C. Fletcher, for extracting energy from the jetstream 35,000′ above the ground, and D.J. McCann's planned wind survey of New South Wales. In New Zealand, however, a region of high wind energy density, a wind evaluation programme has been established under the auspices of the New Zealand Energy Research and Development Committee (NZERDC). Wind monitoring stations have been established all over the country about fifty of which are located in the Canterbury and Otago provinces of the South Island. The New Zealand Government has not yet committed itself to a Wind Energy-Electricity conversion programme. But with the cost of imported oil ever increasing, and with their desire to remain non-nuclear, there is a real prospect that New Zealand may adopt such a programme in the near future.

FURTHER READING

Golding, E.W. *The Generation of Electricity by Wind Power,* E. & F.N. Spon Ltd., London, 1955.

Simmons, D.M. *Wind Power,* Noyes Data Corporation, USA, 1975.

Blackwell, B.F., W.N. Sullivan, R.C. Reuter and J.F. Banas Engineering Development Status of the Darrieus Wind Turbine. *J. Energy* 1:50-64, 1977.

Hoffert, M.I., G.L. Matloft and B.A. Rugg The Lebost Wind Turbine: Laboratory Tests and Data Analysis. *J. Energy* 2: 175-181, 1978.

Yen, J.T. Tornado-type wind energy system: basic considerations. *Proceedings of the International Conference on Wind Energy Systems,* BHRA Fluid Engineering, Cranfield, Bedford, England, 1976.

BIOLOGICAL SOURCES OF ENERGY

BY P. L. ROGERS

Many of our traditional energy materials are biological in origin. Oil, natural gas, coal and timber are all products of biological processes. The difference between these and the new biological forms of energy is that the latter are renewable and can be regenerated in relatively brief periods. Crops of sugar cane, wheat or cassava can be harvested at least once a year to provide raw materials for alcohol fermentation. Animal and vegetable processing wastes are available continuously for methane generation. Besides being rapidly renewable, a further advantage of the new biological forms of energy is that the plants and micro-organisms are capable of adaptation and can be manipulated genetically to yield better strains. This latter advantage should give rise to more economic processes in the future. In this brief review some of the recent developments in biological energy sources are discussed.

The Alcohol Story

The possibility of using ethanol as a liquid fuel supplement has attracted wide publicity. This has been stimulated by the increasing price of oil and the implementation of programs such as that in Brazil for the large scale fermentation of ethanol from sugar cane and cassava.

In 1975, Brazil initiated a National Alcohol Program which committed over $1,000m to the establishment of 120 new distilleries by 1980 for fermentation ethanol production. With further capital expenditure, it was estimated that by 1985 20% of the country's liquid fuel needs would be met by ethanol, and that Brazil might even become a net ethanol exporter.

Fermentation to produce ethanol from sugar and starch-based raw materials is a well established process, and was used during the Second World War to provide supplementary liquid fuel. Four additional fermentation plants were constructed in Australia during this period. The technology depends on yeasts, usually strains of *Saccharomyces cerevisiae* or *Saccharomyces carlsbergensis,* to ferment sugars to 6-9% weight/volume ethanol with yields of 70-90% of a theoretical value. The ethanol can be recovered to 95%w/v by steam distillation and further purified to absolute alcohol by an azeotropic distillation.

With renewed interest in fermentation ethanol, research groups in a number of countries have begun to reassess the process. Powerful new techniques ranging from computer control of fermentation to the genetic manipulation of micro-organisms are now available. Research into alcohol fermentation is being actively pursued by groups at the Universities of NSW, Sydney and Queensland and by several Australian companies.

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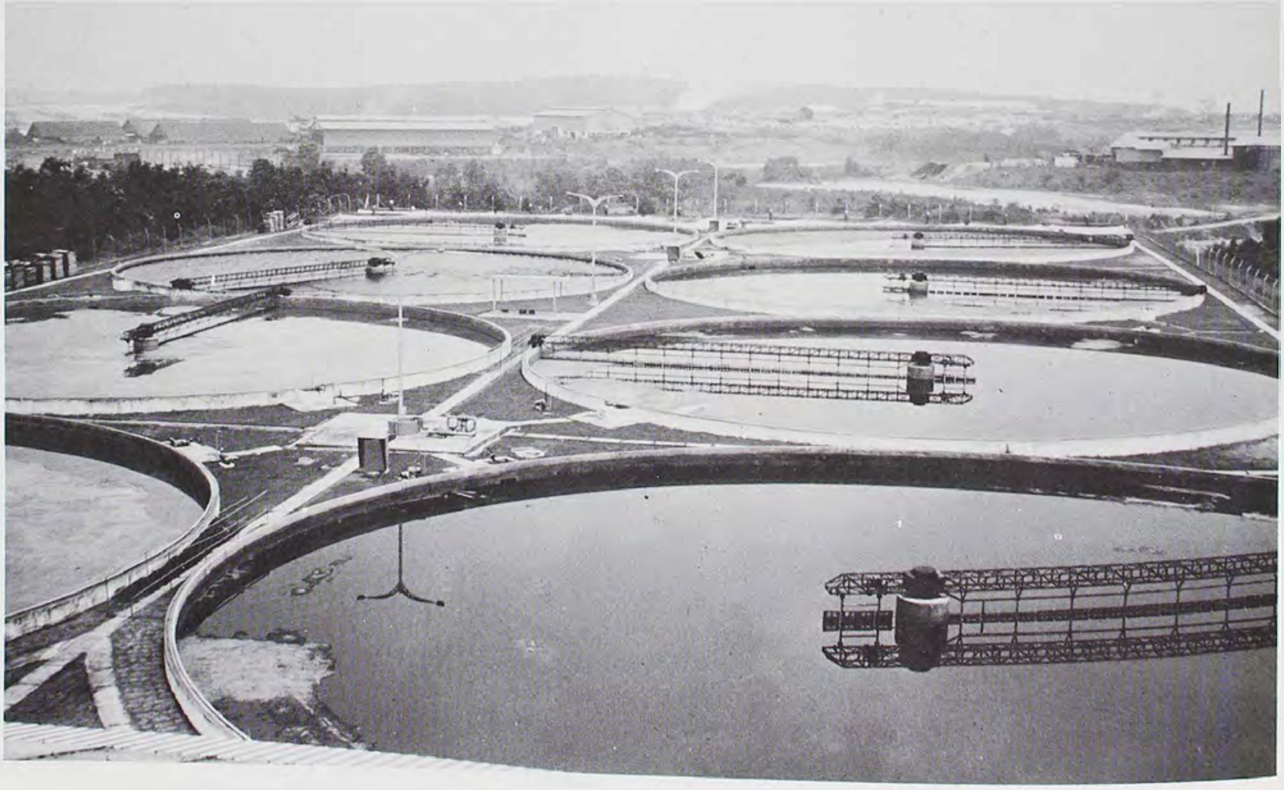


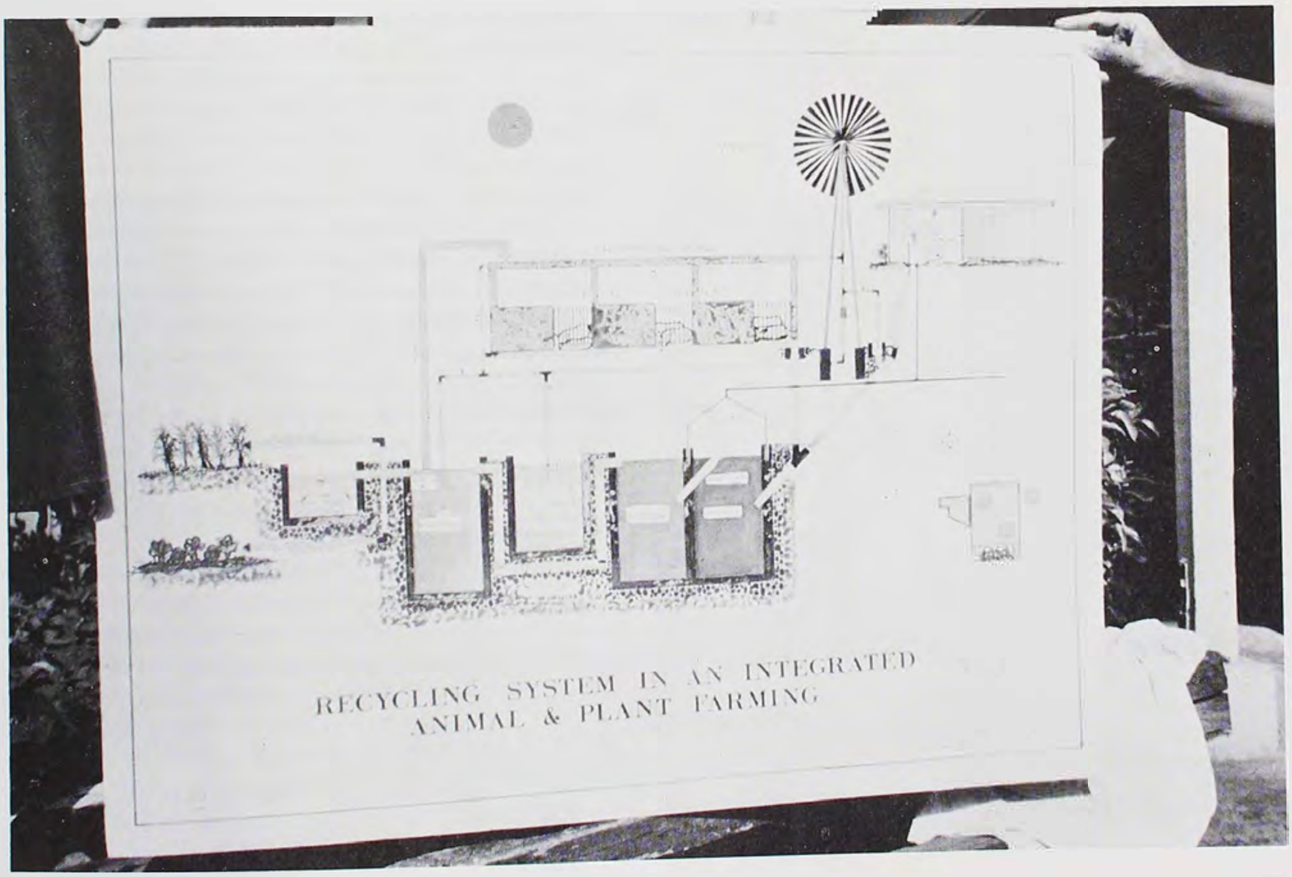
Large-scale cultivation of algae for biomass production at Johore Bahru, Malaysia.

Major research is being focused on the following areas:

- The choice of suitable raw materials (substrates) for the fermentation. Sugar-based substrates have been used traditionally (eg: sugar cane, molasses, sugarbeet). However the potential of using starch-based substrates (cassava, cereal grains) or cellulosic raw materials (bagasse, straw, packaging wastes) to minimise costs, is under active investigation.
- The selection of micro-organisms with desirable properties. The isolation of yeasts and bacteria (eg: *Zymomonas spp*) which have fast rates of alcohol production, are tolerant to high alcohol and sugar levels and can ferment at elevated temperatures, is advantageous.
- The design and operation of the fermentation process itself. In the past, batch processing has been practised using conventional agitated vessels as fermentors. Continuous fermentation has many advantages particularly when coupled with cell recycling to achieve high cell concentrations. New types of fermentors have been designed, some of which may be applicable to low technology situations (eg: tower fermentors). Other strategies such as the use of vacuum fermentation and computer control offer the potential for very high productivity fermentations.

Fermentation ethanol has not been more widely used in the past as a liquid fuel supplement owing to the relatively high cost of the alcohol produced. In Brazil, already committed to a large-scale program, its justification is based on the additional grounds of a decreased vulnerability to further rises in the price of imported oil, that it stimulated investment in the agricultural sector and that it encouraged decentralisation.

Estimates of the cost of producing fermentation ethanol vary. From a paper at a recent United Nations (UNIDO) Workshop in Vienna *'Fermentation Alcohol for use as a Fuel and Chemical Feedstock for Developing Countries'* it can be concluded that a price in the range 25-35 cents/litre might be appropriate for Australia. The major expense lies in the cost of raw materials (up to 70%). It has been estimated by the Colonial Sugar Refining Co. Ltd. that it would be necessary to double the size of the existing sugar cane industry at a cost of some $2,000m to produce sufficient ethanol to meet 20% of Australia's future liquid fuel needs. To put this figure of capital expenditure in perspective it should be noted that a similar estimate applies for a coal to oil conversion process or for an industry in Australia to extract oil from shale. The great advantage of fermentation ethanol is that it would involve the use of a renewable resource and not be dependent solely on depleting reserves of coal, oil-bearing shale or natural gas.



Integrated farming project in the Philippines for recycli animal wastes and for methane generation and single cell protein

Courtesy of James L. Ruhle & Associates

Above: A gobar gas generation plant such as this will produce methane for heating and lighting an Indian village of 150-200 people. Below: The lowly cow-pat may soon become the source of home-heating in many cities in the United States. Cow power is being investigated in many countries including Australia and India. Research and practice in these countries indicate the anaerobic digestion of wastes to produce methane is economically viable. The cattle feed lot in Colorado, US, (pictured below) could provide heating for 12,000 homes.

Courtesy of James L. Ruhle & Associates

Energy From Waste (Anaerobic Digestion)

A recent article titled 'the power behind humble cow pats' outlined a process whereby cows in Oklahoma will soon be providing heat for homes in Chicago. Cow power is being exploited by a company which turns manure into methane gas, livestock feed and liquid fertiliser. Up to 500 tonnes of manure per day will be processed and it is estimated that the plant at full production will supply gas for 3,500 homes per day.

The process, otherwise known as anaerobic digestion, has been used widely on a smaller scale to provide supplemental energy at sewerage plants and sometimes on farms. It depends on a complex mixed culture of micro-organisms to convert organic matter (mostly cellulose) into methane, carbon dioxide and ammonia. Three different types of micro-organisms have been identified in the process, viz. fermentative, acetogenic and methanogenic bacteria. Although such an anaerobic digestion would normally function at the prevailing temperature it has been shown that better operation will occur at 55-60°C. Elevated temperatures are likely to give faster rates of gas production, less sludge and lower concentrations of pathogenic micro-organisms in the overflow, although some of the gas produced will need to be used to provide the heating.

From the viewpoint of economic viability, the anaerobic digestion of wastes to produce methane would seem to be applicable in certain specific applications. In Australia for example, investigations at the CSIRO Division of Food Research have established that citrus and fruit processing wastes can be converted readily to methane. A pilot plant is under construction.

In a country such as India with low labour costs, the Government has initiated a widespread 'gobar gas' program at village level. Capital costs for a small-scale process are \$200-\$250 (subsidised by the Government), and it has been estimated for a village of 150-200 people with a similar number of head of cattle, that a 'gobar gas' process could produce sufficient energy for heating and lighting.

Within the ASEAN region and particularly in Singapore, Thailand and the Philippines, considerable research has been directed towards 'integrated' processes for treating animal wastes (eg: piggery effluents). Methane is used for heating and lighting, while the liquor from anaerobic digestion supports growth of yeast and algae. This reduces the pollution load of the liquor and provides a source of single cell protein (SCP) for refeeding. Overflow liquor can also be used for irrigation and aquaculture.

Unconventional Possibilities

The most interesting micro-organism for hydrocarbon production is the alga, *Botryococcus braunii,* which has been reported to contain hydrocarbons up to 76% dry mass under certain growth conditions. In Australia occurrence of *B. braunii* had originally been noted as Coorongite—a naturally occurring material found on the shoreline of dried-up lakes in a number of widely-separated locations (eg: Coorong Region, SA; near Albury, WA). The material was described as being "black in colour but yellow in thin sections under transmitted light. It is flexible when in thin pieces, not unlike crude natural rubber or bitumen for which it is frequently mistaken". From the original research data collected in 1969, it was considered that the growth of the alga could be separated into three phases:

- A green 'exponential' state in which the colonies are actively dividing. In this state the oil content may account for up to 17% of the algal dry mass. The oil consists of linear unsaturated hydrocarbons.
- An orange 'resting' state. At this stage the oil content may be as high as 76%, the major component being botryococcene, $C_{34}H_{58}$.
- A large green form. Obtained by culturing the resting state material under nutrient starved conditions, and reportedly low in hydrocarbons.

In a Defence Department Report (1976), Hillen and Warren discussed the potential of this micro-organism for hydrocarbon production and concluded that further research effort was required. The need for more accurate scientific observation on which to base economic feasibility analyses was also pointed out by the National Energy Advisory Committee in their Report (1978) 'A Research and Development Program for Energy'.

It would seem even at this early stage that a number of problems need to be addressed. The critical factors affecting the growth and hydrocarbon production of *B. braunii* are not understood. The hydrocarbon is produced as botryococcene, $C_{34}H_{58}$ and would require extensive catalytic 'cracking' to be useful as a liquid fuel and finally the feasibility of large-scale cultivation of the alga in the Australian context (with limitations of suitable cultivation area and water supply) needs to be assessed. The feasibility of large scale growth of *B. braunii* and other algal species, with the carbon nutrient supplied by the waste CO_2 from blast furnaces or coal power stations, is under investigation by the CSIRO Division of Chemical Technology.

Apart from micro-organisms, another interesting possibility involves the use of green plants to produce hydrocarbons or hydrocarbon-like material. Through the mechanism of the photosynthetic carbon cycle, the green plant captures carbon dioxide from the atmosphere and reduces it to various carbohydrates. Some plant species are known which can further reduce the carbohydrates to hydrocarbons. Various plants having this characteristic are currently under study eg: the *Hevea* rubber tree which produces latex and a species of the family *Euphorbiaeceae* which has a hydrocarbon content of 8% of the dry weight of the plant.

Three other possibilities are worth mentioning, although still in a very early stage of research. They are—production of volatile fatty acids by anaerobic digestion, (subject of research at the CSIRO Division of Chemical Technology); production of hydrogen from micro-organisms (still very much at the laboratory stage); and microbial oil recovery, (a group at the Baas-Becking Geobiological Laboratories in Canberra has already initiated research in this area).

Conclusion

The two most promising new biological energy sources in the short term are fermentation ethanol from various carbohydrates and methane ('biogas') from relatively large scale quantities of organic wastes. Fermentation ethanol is being used already as a liquid fuel supplement (10-20% in petrol) in Brazil and in the United States, and is under active consideration in Australia.

In the longer term there are several fascinating possibilities which one day may provide unique energy-rich materials. Hydrocarbons from algae, plastics from organic acids, the use of plants or 'synthetic chloroplasts' to produce hydrogen, and enhanced oil production through microbial action are all possibilities. As a recent study by the Battelle Institute of Future U.S. Energy Requirements points out "the solution to the world's future energy problems would seem to require many small contributions, and not what might be described as a 'single technological fix'".

FURTHER READING

Alcohol Fuels Conference Proceedings. Institution of Chemical Engineers, NSW Group. August 9-11, 1978.

Hillen, L.W. and D.R. Warren. "Hydrocarbon Fuels from Solar Energy via the Alga *Botryococcus Braunii*. Department of Defence Report, 1976.

Lane, A.G. "Methane from anaerobic digestion of fruit and vegetable processing wastes". Food Technology in Australia. 31(5): 201-207. 1979.

Lane, A.G., M.S. Oxenburgh, T. Duxbury and K.C. Marshall (Eds.), Microbial Energy Conversion. A Policy Paper of the Australian Society for Microbiology, Inc., 1979.

McCann, D.J. and H.D.W. Saddler. "A Cassava Based Agro-Industrial Complex—A New Industry for Australia?" *Process and Chemical Engineering.* 28(4): 23-27 and 28(5): 37-40. 1976.

Rogers, P.L., Kye Joon Lee and D.E. Tribe. "Kinetics of Alcohol Production by *Zymomonas Mobilis* at High Sugar Concentrations *Biotechnology Letters.* 1(4): 165-170. 1979.

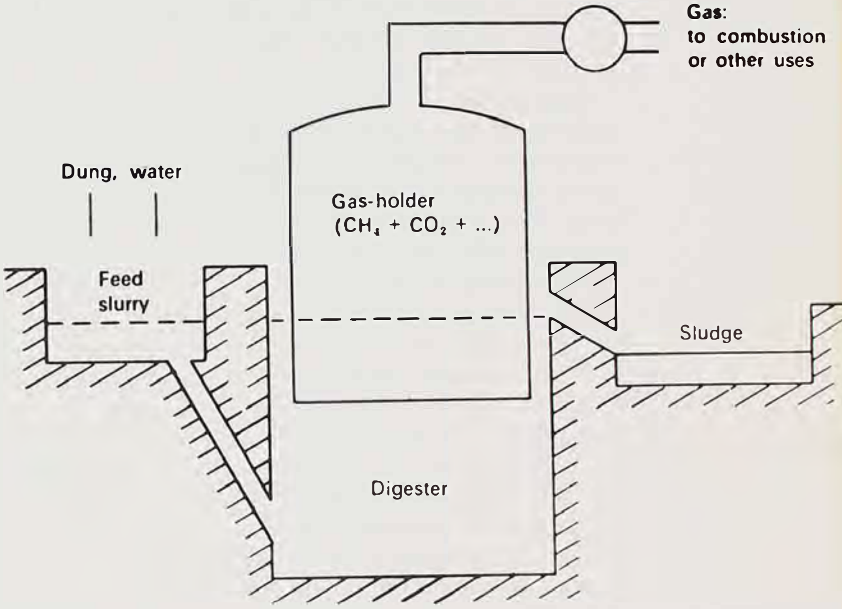


Diagram of *gobar-gas* plant used to obtain methane from dung by anaerobic fermentation (after C. Prasad, N. Prasad and A. Reddy, 'Bio-gas Plants: Prospects, Problems and Tasks', *Economic and Political Weekly,* Vol. 9, 1974, p. 1347.

GEOTHERMAL ENERGY

BY JAMES CULL

Vast quantities of heat are contained within rocks close to Earth's surface. In volcanic regions, high temperatures are clearly demonstrated by lava flows, geysers, fumaroles (gas/steam vents), and hot water springs. In some of these areas, geothermal energy has long been exploited by native peoples for cooking, heating, and bathing. Even in more stable, non-volcanic areas, crustal temperatures usually increase with depth. The rate of increase is generally about 30°C per kilometre, giving temperatures of 100°C at depths of about three kilometres. With current drilling technology, these depths are readily accessible, and geothermal energy may therefore be exploited in many areas remote from active volcanism.

The aim in most recent geothermal energy programmes has been to produce electric power for distribution to existing grid systems. The Larderello and Geyser steam fields in Italy and the USA respectively, are particularly suited to this type of exploitation. In both places dry steam (i.e. no excess water during production) is directly available at the surface and conventional turbine generators are used with only minor modifications. Such systems require an intense source of heat, for example recently intruded magma at depths of less than ten kilometres, highly permeable aquifers (rocks containing large volumes of water) close to the source, an impermeable cap rock, and low recharge pressures. These geological conditions in combination are rare.

Much more common are systems which contain hot water rather than steam—Wairakei in New Zealand is a well-known example. The geological conditions are similar to those in steam fields but the rate of heating is lower. Temperatures at depth may, however, still be in excess of 200°C and consequently, if pressures are sufficiently reduced at the well head, flash steam can be obtained. Residual water must be separated from the steam in a centrifuge, otherwise standard techniques can be used in subsequent generating stages. The effective running cost in such a system depends primarily on the number of bores which must be drilled to achieve adequate flow rates, but in most instances, geothermal power can be obtained at highly competitive prices.

Much of the geothermal energy currently available is wasted in generating electricity because of low conversion efficiencies. There is, therefore, growing interest in more direct methods of exploiting geothermal resources, particularly where water can be obtained in the temperature range between 80°C and 140°C. Heat energy of this type is required directly in a variety of industrial and agricultural processes including wood pulping, fish farming, sugar refining, and greenhouse horticulture. Commercial viability has been demonstrated for several such schemes, but the single most important use so far has been in domestic space heating. Extensive heating grids have evolved in Iceland and are now being developed for use in Hungary, France, Germany, and the UK. Reverse cycle air-conditioning can also be included in such projects and, for a system installed in a hotel at Rotorua, NZ, the running costs are estimated to be only five percent of normal cost with conventional compression units.

In Australia, there are few surface expressions of geothermal energy and there has therefore been little impetus for detailed exploration. However, some major prospects can be readily identified. Although there are no active volcanoes, eruptions did occur as recently as 4500 years ago in western Victoria and in South Australia at Mount Gambier. Furthermore, earlier Quaternary and Tertiary volcanism occurred in central Queensland and the eastern highlands of New South Wales. In view of the low cooling rate in rocks, it is probable that large amounts of heat still remain in these systems. Hot springs have been observed in volcanic rock at Talaroo and Innot in Queensland, and artesian water in western Victoria and Queensland must be cooled before it is distributed for domestic use. Proposals have been made to extract some of this geothermal energy for space heating in a Portland hospital in Victoria but the project has not been pursued because of excessive costs in establishing hot water circulation for only one consumer.

Prospective areas are perhaps most readily identified in surveys of surface geology. However, because of the low thermal conductivity in rocks, high temperatures in the crust need not affect conditions at the surface. In these circumstances, deep sounding geophysical techniques are required so that major sources of heat can be located by secondary effects, which may include electrical and magnetic disturbances, rather than changes in rock type.

Borehole surveys indicate that in eastern Australia, temperatures at the base of Earth's crust, thirty to forty kilometres deep, may exceed the melting point of rock and these conditions may favour the generation and transfer of steam close to the surface. The best geother-

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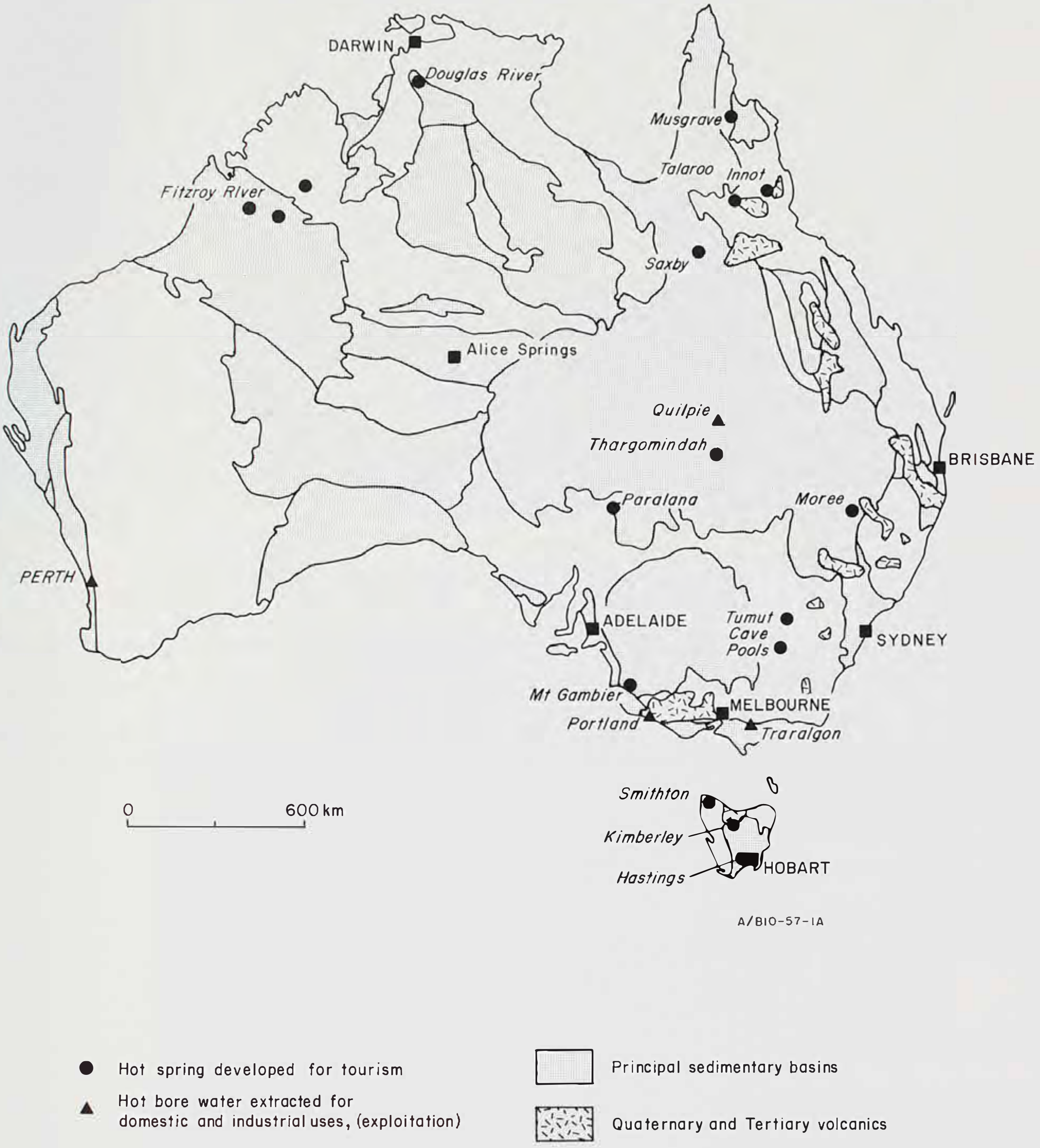
MANIFESTATION OF GEOTHERMAL ENERGY IN AUSTRALIA



Geothermal gradients are generally close to 30°C/km. Boiling water is obtained in numerous bores and mound springs within the Great Artesian Basin.

mal energy prospects appear to be in Tasmania, western Victoria, and South Australia. Although melting in lower crustal rocks is considered unlikely, in Western Australia, near-surface temperature gradients may be much greater in sedimentary basins than in basement rocks, and exploration for geothermal resources therefore need not be confined to eastern regions.

The most extensive and well-documented measurements of subsurface temperatures in Australia have been made in boreholes within the Great Artesian Basin. Water temperatures of 110°C have been recorded at depths of 1700 metres in bores with flow rates in excess of four million litres per day. In some of these bores it may be possible to obtain flash steam for generating electric power. However, most bores penetrate to depths of less than 1000 metres and water temperatures do not exceed 100°C. Near Darwin, Perth, Hobart, Tumut and Moree, hot water is obtained from bores and springs for spa bathing, but no commercial uses are known.

If new and viable geothermal resources are to be located in Australia, their successful development will depend on detailed knowledge of underground reservoir capacities and flow patterns, together with regional and local data concerning surface heat flow from which thermal gradients may be extrapolated. Maximum rates of heat extraction can then be defined so that the aquifers remain near their original temperatures and are not cooled by relatively rapid and continuous introductions of recharge water. In one typical bore near Portland, flow rates of forty litres per second can be maintained with water at temperatures near 50°C. Each such bore could in theory yield 6 megawatts (thermal) of geothermal energy. This energy is available only as low-grade heat. No steam is produced, and heat exchangers must be used if electricity is required.

Freon vapour generators are available which can make use of water at 65°C, but conversion efficiencies of less than ten percent would favour more direct industrial processes involving consumption of large volumes of hot water. Major electricity schemes are likely to proceed only if near-surface not-rock systems can be developed, involving forced circulation of surface water through deeply fractured hot volcanic rocks.

In view of environmental arguments against the growth of conventional and nuclear power plants, the necessary exploration for geothermal fields should be encouraged, particularly since some other 'clean' energy sources (solar, wind and tidal systems) are non-continuous. Furthermore, the dominant source of heat in rocks is known to be trace-element radioactivity and consequently geothermal energy can be considered at least partly renewable. However, the rate of renewal depends on the time constants of isotope decay and on mechanisms of concentration involving, for example, mass movements of magma.

Regional studies of the temperature field are now included in programmes conducted by the Australian Bureau of Mineral Resources, Geology and Geophysics. Heat flow data are usually obtained in boreholes used for mineral exploration, but special-purpose holes are also drilled occasionally to investigate likely geothermal energy prospects. In addition to heat flow measurements, it is proposed to make a comprehensive inventory of all geothermal manifestations. Primarily, this will be an index of hot spring locations detailing the fluid temperature, chemistry, and flow rate. With programmes such as this, it should be possible in a few years to identify all geothermal resources in Australia, suitable for rapid exploitation and to assist the preservation of existing high grade fossil fuels.

FURTHER READING

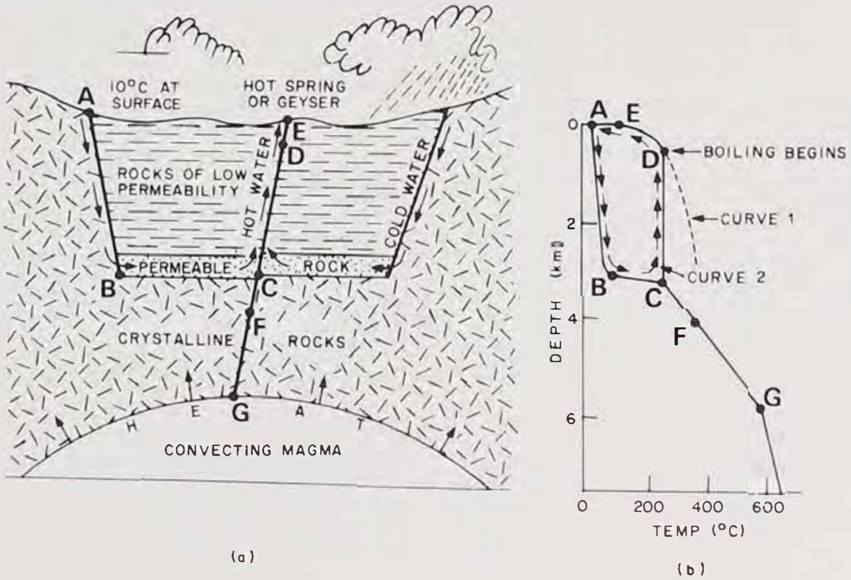
Armstead, H.C.H. (Ed.) *Geothermal Energy: Review of Research and Development,* UNESCO Press, Paris, 1973.

Kruger, P., and C. Otte (Eds.) *Geothermal Energy: Resources, Production, Stimulation,* Stanford University Press, California, 1973.

Cull, J.P. "Geothermal energy prospects in Australia", *Search,* 8: 117-121, 1977.

Cull, J.P., and D. Denham "Regional variations in Australian heat flow;" *BMR J. Aust. Geol. Geophys.,* 4: 1-13, 1979.

Schematic representation of a geothermal system with temperature distributions corresponding to the path of water circulation (White 1973).



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Left: High pressure steam issuing from a shallow bore, Rotorua, New Zealand.

J. Cull

J. Cull

Right: Geothermal energy used in a New Zealand soft drink factory. Note the miniature geyser in foreground.

NUCLEAR ENERGY

BY CHARLES KERR

The age of nuclear power can be said to have commenced on 17 October 1956, when Queen Elizabeth switched electricity generated from the Calder Hall nuclear reactor, into Britain's National Grid. In those early days the future of nuclear energy seemed assured. Here was a bountiful source of energy produced by a technology developed from experience with military reactors. Most people welcomed this exploitation of 'the peaceful use of the atom'. It was widely believed that nuclear power stations would prove to be more efficient, safer and more economical than the fossil-fuelled facilities they would gradually replace.

Twenty-three years later the outlook has changed. Nuclear power remains entrenched in the energy programmes of many countries; 211 reactors contribute to the electricity requirements of the world, of which 181 supply western industrialised nations and thirty operate in centrally-controlled countries of the eastern bloc. But the future is much less clear. Since the late 1960s an international debate has been raging about whether the risks, real or assumed, outweigh the benefits of producing electricity by nuclear methods.

Those in favour of nuclear power are led by politicians and officials of committed governments, and by scientists and technologists in the nuclear industry. Their view is that nuclear reactors are a safe, efficient, non-polluting and economical way to generate electricity. They believe that residual radioactive wastes can be satisfactorily managed and isolated in a permanently safe manner and that the risk of nuclear materials being diverted for weapon production can be minimised by safeguards negotiated on international and national levels.

Those who oppose nuclear power reject the above assertions and regard the industry as dangerous to our health, ecologically harmful, incapable of isolating radioactive wastes and an important contributor to the proliferation of nuclear weapons. Conservationist and environmentalist groups tend to act as a focus for those who oppose the industry.

Nuclear energy has two features which distinguish it from all other sources—its potential for creating material which could be used for atomic weapons and its potential for creating a radiological hazard with adverse consequences for health. Weapons-grade material can be obtained by continuing the uranium enrichment process used in manufacturing reactor fuel until a very high concentration of the isotope U_{235} is achieved, by using spent fuel from a reactor (yielding an inefficient and unpredictable weapon) and by extracting plutonium from reactor fuel. It is this weapon-producing potential for which safeguards are required.

The extent of health risks associated with a nuclear power industry remains uncertain and the subject of continued controversy. There is no satisfactory theoretical basis on which to relate a given level of radiation to harmful effects in humans. In the absence of precise knowledge, a linear relationship is assumed between the radiation dose and its consequences—the larger the dose, the greater its effect. It is also assumed that any radiation added to the environment, which already contains a background level from cosmic, terrestrial and artificial 'largely medical', sources, will be harmful. That is, no threshold dose level exists below which additional radiation can be considered safe.

After fifty years of radiobiological research and analyses of extreme events—high level radiation exposure caused by atomic bomb explosions, medical practices or the working environment in radioactive occupations—a system of radiation protection has been evolved. Based on the principle of reducing additional burdens of radiation to a mimimum the system includes a 'risk-benefit' concept. The latter means that in industries where workers are subject to radiation exposure, standards are set at levels higher than those laid down for the general public. Standards for radiation protection are maintained by national authorities from guidelines established by the International Commission on Radiological Protection (ICRP). The ICRP and other international agencies review at intervals existing standards and modify them accordingly. Despite its uncertain scientific foundations, radiation protection research continues as an evolving process and in the absence of any more precise alternative is accepted by those who work with radioactive substances. Yet in view of persisting uncertainties, controversies flourish.

At high levels radiation associated with a nuclear explosion or an uncontrolled release from the core of a nuclear reactor, normally cause death. Survivors of high doses and those exposed to lower non-fatal levels of radiation, which can be accumulated as the sum of small doses over a period of years, face the delayed effects of cancer and genetic mutation. Extrapolating from direct observations on exposed humans, an estimate of the increased load of premature deaths from cancer can be derived. Estimates of genetic damage are derived in a

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less direct fashion because no such effect has been measured unequivocally in man and has to be calculated from the results of animal experimentation. In an attempt to estimate harmful consequences, two nuclear health workers from the United Kingdom's Central Electricity Generating Board attempted to calculate the health consequences of radiation exposure, involved in supplying the annual electricity needs of one million people by an 1100 megawatt electrical (MWe) nuclear power station. On the basis of ICRP standards, they concluded that the cost of one year's electricity would include one additional death from cancer and, assuming the exposed population were of reproductive age, two cases of serious genetic disease induced over all generations of their descendants.

Contemporary nuclear reactors operate on the fission principle, utilizing energy released from a carefully controlled atomic chain reaction to generate heat. Steam is produced via a heat-exchanging mechanism to drive turbines. The current class of commercial reactors are sometimes collectively termed 'thermal reactors' due to the physical properties of slow 'thermal' neutrons which induce fission within their cores. Reactor fuel contains the fissile uranium isotope U_{235}. A few models are designed to run on natural uranium but most require U_{235} concentrated by a process of enriching the low concentrations of isotope found in the original uranium ore. At present, Australian policy is to participate only in the initial stages: mining, milling and chemical treatment of uranium ore which results in the mixture of uranium oxides known as yellowcake. The yellowcake is packed in steel drums for transport to plants in other countries which manufacture reactor fuel. The Australian Government is, however, investigating the feasibility of enriching uranium ore beyond the yellowcake stage to enriched uranium hexafluoride.

Uranium deposits already surveyed in the Northern Territory and Western Australia can be mined by the open-cut method. This reduces the most serious radiological hazard to uranium miners, the inhalation of radon gas. Radon, a radioactive decay product of radium, is short-lived and in turn breaks down to daughter isotopes which are potent emitters of alpha particles. The result is a greatly increased risk of lung cancer, noted for centuries in radioactive mines but only incriminated casually in the 1950s. Radiation protection is more difficult to maintain in underground mines and involves elaborate ventilation systems. With effective application of codes for protecting workers in Australian uranium mines and mills, the risk of radiobiological damage should be negligible.

The specific environmental hazard of yellowcake production is the creation of stocks of tailings—the finely-milled residue containing most of the radioactivity that was present in the original ore. Nuclear decay with emission of radioactive particles persists in tailings for many centuries and can have a cumulatively harmful effect on an exposed population. Accordingly, tailings are now required to be properly stabilised to avoid environmental contamination or irresponsible use as filling for construction purposes.

Industrial processes which fabricate fuel rods pose only slight radiation hazards. Once the reactor is in operation the core, the fuel and its surrounding structures become intensely radioactive. Elaborate cooling systems are vital for removing heat; robust containment of the reactor core is merely one facet of an engineering strategy designed to reduce operating risks to an absolute minimum.

A nuclear reactor cannot undergo an atomic explosion —its core contains insufficient fissile material for a violent and uncontrolled chain reaction. During normal operations, radioactive gases and volatile isotopes migrate out of the core and into the cooling circuit. A proportion of these effluents are released into the atmosphere in quantities thought not to cause a significant hazard. Nevertheless, there are current moves to reduce such emissions to smaller proportions.

There is much public concern about the potential consequences of reactor accidents. Fears centre around a catastrophic failure of a cooling mechanism, so that the core melts through intense heat and ruptures the surrounding containment, thus releasing dangerous levels of radioactive material into the environment. The matter was examined in the US Reactor Safety Study, which reached the conclusion that "the likelihood of being killed in any one year in a reactor accident is one chance in 300,000,000".

This, combined with the safety record of the commercial nuclear power industry up until now, has been emphasised to allay public fears. Opponents however reject the reassurances and point to several well-documented near-accidents. Moreover, the Reactor Safety Study has been endlessly criticised, largely because predictions concerning the genesis of an accident in such a complicated system as a nuclear reactor remain speculative. In fact, it is now widely believed that the Reactor Safety Study set the probabilities of a serious accident too low.

The recent reactor accident near Harrisburg in Pennsylvania, was the most serious emergency yet faced by the US nuclear power industry. An unpredicted variety of technical failure gave rise to fears of a core melt-down.

Although danger was averted and radioactive contamination of the surrounding population appeared minimal, the ensuing public and political reaction has gravely damaged the image of safe nuclear power.

When reactor fuel has ceased to function effectively it is recovered for temporary storage under water. Decay of short-lived isotopes reduces the spent fuel's intense radioactivity so that after a few months the fuel becomes manageable. There are then three possible ways of using it. The fuel may be reprocessed to salvage unburnt U_{235} and plutonium; it may be processed for permanent disposal; or, as is normally the case, the fuel may be liquefied and stored in specially-constructed tanks pending a final decision on its outcome. Whichever option is adopted, there is a transport sequence between facilities. Ultimately a residue of waste remains for which no further use can be found. Still dangerously radioactive, and likely to remain hazardous for several thousand years, this waste must be immobilised and disposed of safely. Immobilisation has been achieved by incorporating the waste into glass blocks (vitrification). Although this technique is preferred in countries with accumulations of radioactive wastes, A.E. Ringwood of the Australian National University has raised doubts about the long-term stability of vitrified waste; he favours incorporation of waste into a synthetic rock, Synroc.

The final engineered solution for high-level waste isolation has not yet been achieved. Several sites have been considered including the ocean bed, polar ice-caps and extra-terrestrial destinations. The favoured method is burial several hundred metres deep in a stable formation of rock or salt which is free from water, at low risk to earthquakes and beyond human interference.

Consideration of the nuclear fuel cycle *in toto* allows comparisons of safety and health hazards to be made with the fuel cycles of other energy sources. Numerous comparisons have been made between nuclear power and its nearest competitor, fossil fuels. Whatever the consequences for health—immediate or delayed fatalities, episodes of sickness or man-hours lost from work—and considering equivalent electricity generation from each source, nuclear power is found to be less harmful than fossil fuel power, both for industrial workers and the general public. There are relatively greater risks involved in coal mining, oil drilling, transporting fossil fuels and from atmospheric pollutions when these fuels are burnt in power stations.

A recent Canadian study has extended the comparison to cover all conventional or developing energy fuel-cycles including solar energy, hydroelectric power and the use of methane. In this analysis, a unit of electricity generated by a nuclear system was found to result in less harm than all other sources with the exception of natural gas. It was shown, for example, that the manufacture of materials required to construct a solar system of equivalent energy output incorporated a number of hazardous industrial procedures. Taken all together, the risks to health accumulated to a greater degree for the solar system than for an equivalent output from nuclear sources. Needless to say, this Canadian study is already under strong attack by those who oppose nuclear power.

Demonstration of lesser hazards for the nuclear fuel cycle as currently operated would appear to be a logical reason for supporting nuclear power as a relatively safe source of energy. However, this line of argument is rejected by opponents of nuclear power. Apart from disbelieving the assumptions on which such comparisons are made, opponents are more concerned about potential hazards than with those based on over two decades of experience with nuclear power. They see radiation risks as being involuntarily imposed on the public. In short, they believe nuclear power to be an evil whose presence is not justified by the existence of greater evils. This gulf between those who regard relative-risk comparisons of different energy sources as valid and those who hold the opposite opinion, is one of the widest in the controversy about nuclear power.

In many countries, plans for increasing the contribution of nuclear power to their electricity generating programmes have proved over-ambitious. In 1970, the International Atomic Energy Agency predicted that by 1985 western industrialised countries would be generating 555,000 MWe from nuclear reactors. By 1978, the 1985 forecast was reduced to around 200,000 MWe. The US Atomic Energy Agency in 1973 predicted that by 1981 the USA would be generating about 160,000 MWe from nuclear sources. In 1979 it seems that only about half that output will be achieved by 1981. One reason for over-estimating future electricity requirements was too strong a faith in exponential growth curves for western industrial societies. These curves faltered in the 1970s when industrialised output declined in a world-wide economic slump. Planned development of the nuclear power industry was also slowed by rising inflation, the increased cost of obtaining capital and, in several countries, by political action. Nevertheless, those nations with an energy policy incorporating nuclear power have, with certain exceptions, maintained a plan of nuclear expansion.

The nuclear power industry, alone among energy sources, is involved in a world-wide movement to prevent its materials from being made into weapons. In the western world, it is generally accepted that existing national and international safeguards are inadequate; accordingly there is much activity to strengthen existing arrangements. There are essentially two sets of issues: how to protect weapons-grade material at fixed sites or in transit against theft by criminals or terrorists; and more importantly how to prevent nations from diverting materials from their civilian industries for the purpose of making bombs and thus contributing to nuclear proliferation.

The objective of current international safeguards is to maintain all nuclear materials for civilian use, from which weapons-grade material could be derived, within defined channels so that any transfer of significant quantities to outside the specified boundaries can be promptly detected by an international safeguarding inspectorate. At best, this system can only detect diversions; it is not designed to prevent such occurrences.

The main international instrument is the Nuclear Non-Proliferation Treaty (NPT) which states, in effect, that signatory nations should co-operate in promoting the peaceful uses of nuclear power and refrain from using civilian resources for making weapons. NPT nations are required to maintain inventories of nuclear materials and