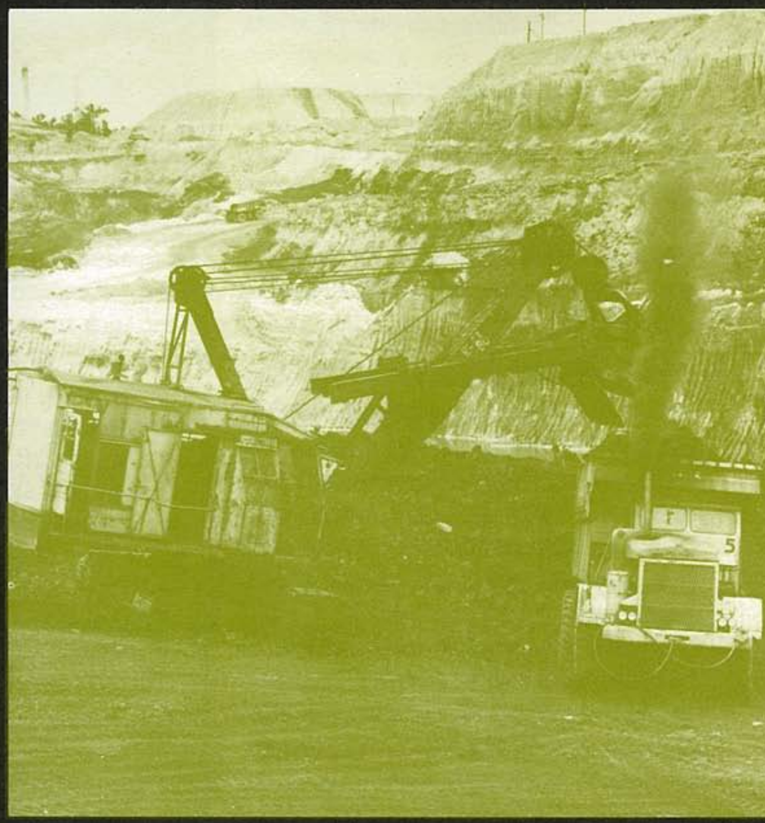


MAKING OIL FROM COAL

A big expansion of coal-mining could cause severe environmental problems.

When will the world's oil-fields run dry? It's impossible to predict; we don't know how much oil remains to be discovered. But although less than a third—perhaps much less—of the world's crude oil has been used, demand seems likely to outstrip supply within decades rather than centuries.

The reason lies in oil's success. Before the 1920s it supplied an insignificant proportion of the world's energy; now it supplies nearly half. The growth rate is so rapid that about five times more oil will be consumed this year than in 1950. Consumption in the year 2000, just 25 years away, will be more than 20 times the 1950 figure if the present rate of increase is maintained.

In Australia, growth in use of the fuel has closely followed the world pattern, and oil took over from coal as the main energy-supplier in the early 1970s. Our known oil reserves are very limited. Although they meet about 60% of the demand now, they will dry up in 10–12 years if consumption continues to grow at current rates and no new finds are made. The Department of Minerals and Energy estimated last year that Australia's total requirement for oil in the next 25 years would amount to four times our known reserves.

Not only is the use of oil growing very rapidly, so is total energy consumption. Throughout the world, about 10 times more energy will be used this year than in 1900, and since 1950 there has been almost a three-fold increase. In Australia, also, energy consumption has trebled since 1950.

Gone forever

How long this sort of growth will continue can't be predicted, but one certainty is that the fossil fuels—oil, natural gas, and coal—once used are gone forever. And the surest way to hasten their departure is to continually increase rates of consumption.

Natural gas supplies seem unlikely to be able to meet world needs much beyond the end of this century, and in Australia the Minerals and Energy Department's estimates suggest that demand up to the year 2000 will account for all of our known reserves.

Coal will be the stayer. It has a much longer history as a fuel than either oil or natural gas, but there's so much of it that only about one-fiftieth of world reserves are likely to have been used by the end of the century. Australia has just 0·2% of the world's coal; the biggest reserves are in Asia, followed by North America and Europe. But we have enough for the Department to be able to predict that by the year 2000 only 2% of our available black and 16% of our available brown coal will have been consumed.

Despite the surge in demand for oil and natural gas in recent decades, use of coal has continued to increase year by year. But it has only doubled in Australia since 1950, compared with the five-fold increase in oil consumption. One obvious drawback to using more coal is the damage mining does to the landscape—it makes a mess.

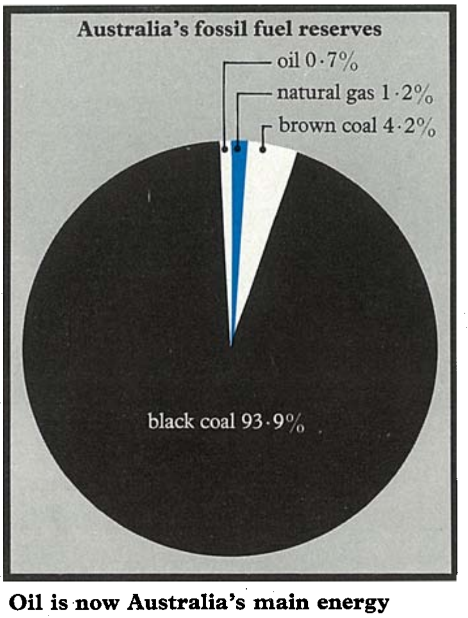
The fossil fuels—once used—are gone forever.

Oil has become by far the dominant power source for land, sea, and air transport. It rose to prominence with the car and aeroplane, and has now largely replaced coal as the fuel for ships and trains. It has also replaced coal in a lot of industrial uses, including manufacture of the gas (once known as 'coal gas') that is piped to houses in many Australian cities and towns.

Other sources of oil

The run-down in production from the world's oil-fields, when it comes, won't necessarily herald the end of oil-based technology. Other potential sources of vast quantities of the fuel exist, but they are not yet economically competitive.

One such source is oil shale. This type of rock yields oil when it is heated, and it exists in such enormous quantities in North and South America, Europe, and Asia that theoretically it could supply more fuel than all the world's known oil-fields. Australia has some relatively small deposits in Queensland, New South Wales, and Tasmania. But some very large problems, including environmental ones associated with mining the rock or extracting the oil without mining it, will have to be overcome before shale can make significant contributions to the world's oil supplies.



Oil is now Australia's main energy source, but the energy available from our known reserves is much less than that from our coal reserves and considerably less than that from natural gas.

Another source is tar sands. The main deposit explored so far, in Canada, covers thousands of square kilometres and could yield something like half the reserves of the oil-fields. Again big problems remain to be solved, including similar environmental ones, before large-scale production becomes feasible. No tar sand deposits are known in Australia.

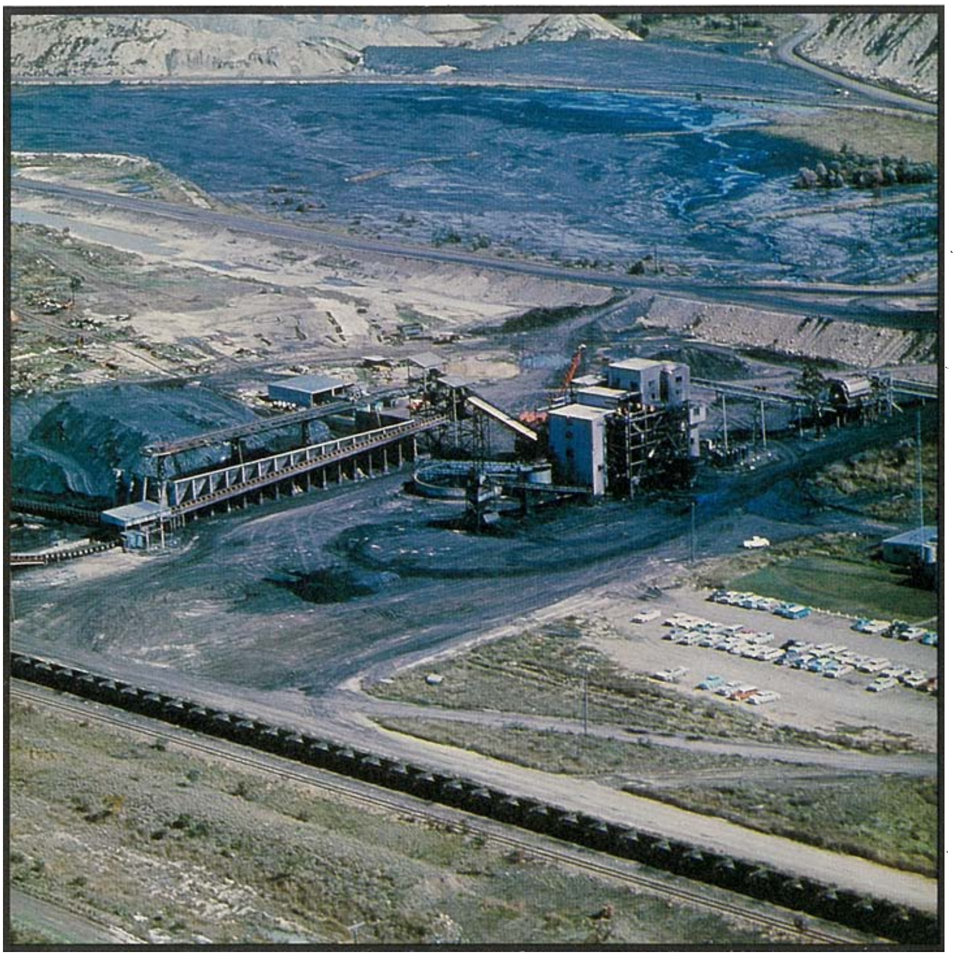
The third alternative is manufacture from coal and, unless new oil-fields are discovered, this seems to be the most likely way for Australia to maintain some self-sufficiency in oil supply after the 1980s. From research extending over more than 20 years, CSIRO has gathered a great deal of information about the composition, and behaviour under a wide range of conditions, of the many different types of coal found in Australia. The broad aim has been to promote effective and efficient use of our coal resources, but much of the knowledge gained is relevant to oil production from coal. This year CSIRO has begun research directed specifically to oil production. Scientists in four Divisions are looking at the prospects for producing fuel oils from Australian coals.

A big expansion of coal-mining could cause severe environmental problems, and great care would be needed to avoid these. Open-cut mining can ravage landscapes, and refuse from coal washeries is hard to dispose of acceptably (see *Ecos* 1).

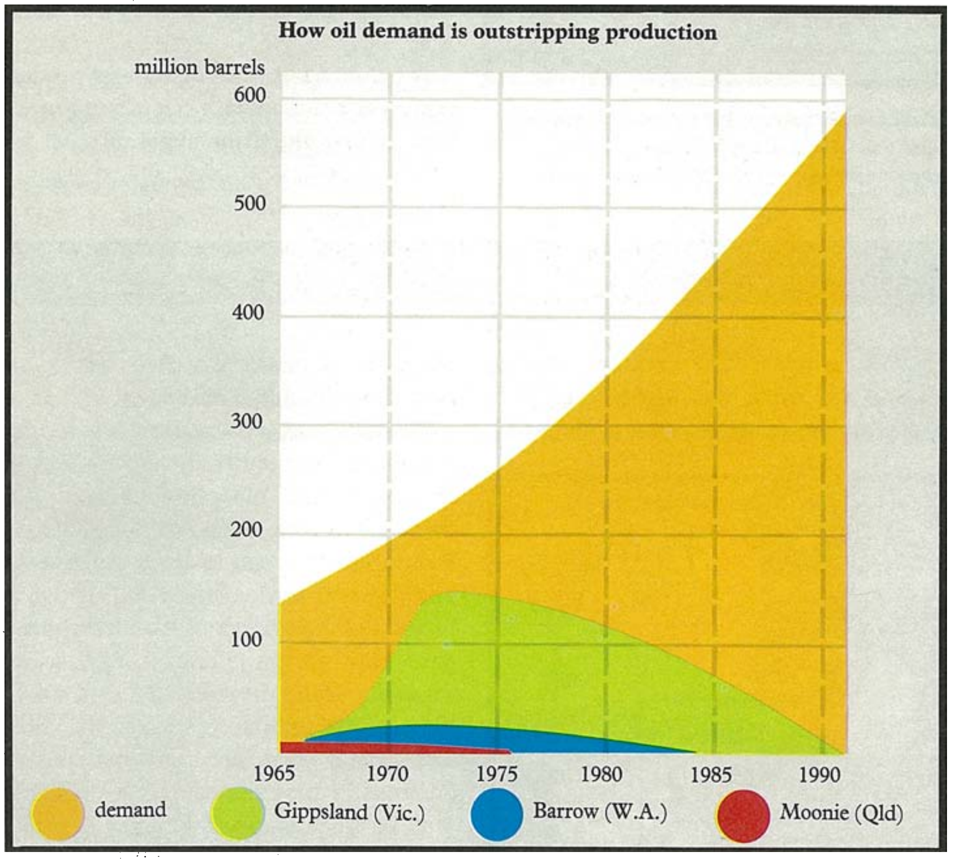
World War II

There's nothing new about making oil from coal. As long ago as 1913 the German chemist Friedrich Bergius found that he could make it by treating coal with hydrogen at high temperatures and pressures. Twelve oil factories based on his discovery produced about 85% of the aviation gasoline used in Germany during World War II and large quantities of petrol and diesel oil. Similar plants were built in the United States, Britain, and Italy during the 1930s.

In 1923 two more German scientists, Franz Fischer and Hans Tropsch, found another way to make oil. First they converted coal to a mixture of carbon monoxide and hydrogen by reaction with steam and oxygen. Then, by reacting the product gases together in the presence of a



Only part of the very extensive coal-mining operation at Moura, Qld.



A rapidly growing gap between Australian demand for oil and production is expected, unless major new oil finds are made.

catalyst and at high pressures and temperatures, the scientists found they could make fuels that ranged, depending on the reaction conditions, from heavy oils to petrol and hydrocarbon gases.

Nine plants using the Fischer-Tropsch process were built in Germany from 1933 onwards, and similar plants were built in France and Japan. The only commercial oil-from-coal plant now operating uses this process. It is run by the South African Coal, Oil, and Gas Corporation (SASOL), near Johannesburg.

The pyrolysis approach

Oils can also be obtained from the tar produced when coal is decomposed by heating in the absence of air. Only a portion of the coal turns into liquids; gas and carbon, in the form of char or coke, are also formed. This is the process normally used to produce town gas and metallurgical coke from coal. Its potential for producing oils is now attracting growing scientific interest.

Yields of liquid vary with the conditions under which coal is heated. In gasworks

About 10 times more energy will be used this year than in 1900.

and coke ovens, lumps of coal are heated for perhaps 24 or 48 hours, and the extended heating time encourages the liquids that form to break down into solids and gas. The outcome is lower yields of tar than can be obtained with more rapid heating. The process CSIRO is studying is flash pyrolysis, which involves extremely rapid heating. Coal pulverized so that particles are no longer than 0·1 mm is heated to temperatures up to 700°C in less than half a second.

The initial aim of the CSIRO flash pyrolysis studies is to investigate the potential for producing heavy fuel oil. Most now used in Australia is imported—very little is available from local crude oil—and its price here is rising rapidly. The increase last year was from about $15 to $50 a tonne. Other oil products could be obtained with further processing of the tar.

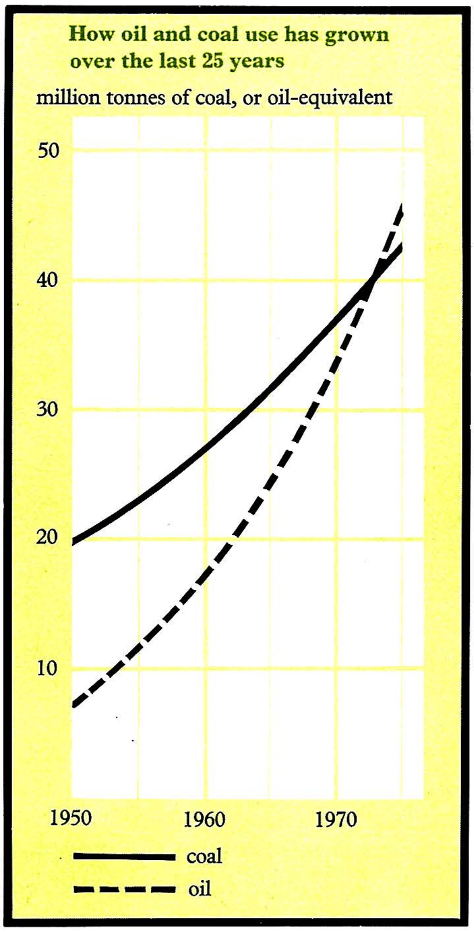
One attraction of the pyrolysis approach over other oil-from-coal routes is its simplicity; this should increase the chances of developing an economically attractive process reasonably quickly. High pressures are not required, and neither are catalysts, which can be troublesome and expensive. Also, it should be quite easy to adapt existing technologies for handling the coal and its products to an oil-production process.

With power production

But coal pyrolysis inevitably produces large amounts of carbon and gas, which must be put to use. Because of this, the scientists suggest that oil production by flash pyrolysis could be integrated with electricity production. The char and gas would go to power-station boilers, and the liquid would be collected. Preliminary calculations indicate that an oil plant coupled with a 2000-megawatt power station—the size of Australia's biggest so far, at Liddell in the Hunter Valley, N.S.W.—could significantly reduce our requirement for imported fuel oil. They also indicate that the cost of the fuel produced should be appreciably below the current cost of fuel oil.

However, it's early days yet; the research is just beginning. At the Sydney laboratories of the Division of Mineral Chemistry, Mr Ian Smith is looking at the effects of different processing conditions on the yield and characteristics of the tar. His early results are promising. With some black coals, more than one-fifth of the input has come out as liquid. This is a much higher proportion than is obtained with slow heating, and indications are that it can be further increased. In tests with brown coal about one-eighth of the material has been converted to liquid.

The tars obtained have been sent to the Division of Applied Organic Chemistry in Melbourne, where Dr Peter Wailes and Dr Tom Mole are analysing them and assessing their potential as fuels. Tars from future tests will also be sent to them for assessment. The scientists will look for links between different processing conditions and fuel characteristics, with the aim of finding out how to obtain the best possible yield of the best possible product. Their analyses should also show whether the liquids will need further processing before use as fuel oil.



This graph shows the massive increase in Australia's use of oil and coal—especially oil—over the past 25 years.

Finding the best coals

In Sydney, Dr Bob Durie of the Division of Mineral Chemistry and Dr Michi Shibaoka of the Division of Mineralogy are drawing on CSIRO's accumulated knowledge of the characteristics of Australian coals to select the most promising candidates for flash pyrolysis. In Melbourne, at the Division of Chemical Engineering, Dr Otto Sitnai is working on designs for flash pyrolysis reactors and the plumbing needed for separating the solid and liquid products.

Mr Ralph Tyler of the Mineral Chemistry Division in Sydney is examining the char produced to see how it would be likely to perform in power-plant boilers. In the same laboratories, Mr Jim Edwards is reviewing the present state of the art of hydrogen production. Hydrogen can be produced from coal or char, and will be needed for any upgrading of the liquid product of flash pyrolysis.

At the Melbourne laboratories of the Division of Mineral Chemistry, Mr David Roney is coordinating the project—setting target dates and so on. In 2–3 years, the scientists hope to have all the information needed for a pilot plant to be designed, assuming that all goes well in the meantime.

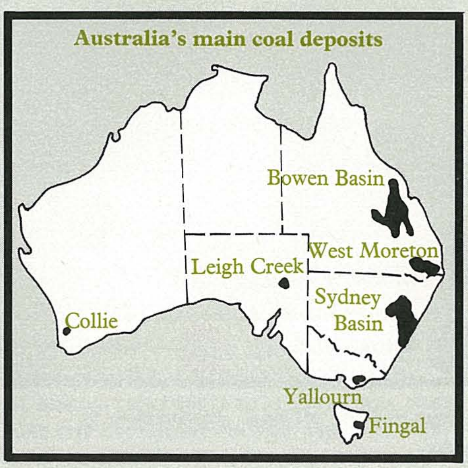
A reason for proposing fuel-oil production in association with electricity generation is that the same types of coal are

continued on page 8

Oil and coal are very old

The world's oil appears to have been formed from decaying plants and animals. About half of it is contained in rocks formed in the Tertiary age, which began about 68 million years ago and ended just $2\frac{1}{2}$ million years ago. (If that sounds recent, it's worth remembering that Man has been around only about half a million years.) The Tertiary was the period when modern mammals and plants evolved. The rest of the oil is contained in older rocks, some dating back as far as the Carboniferous age, which began about 345 million years ago.

That was when coal formation began on a massive scale. It was also the time when primitive reptiles, which later gave rise to the dinosaurs and huge flying reptiles, evolved. The average temperature of the earth was higher than it is today, and luxuriant vegetation flourished.



Imprints of giant tree-fern leaves are sometimes found on coal faces.

At that time, vast masses of decaying vegetation accumulated, and peat bogs formed. Later, inorganic material that turned into rock settled on top. Pressure built up on the peat, its temperature rose, and slowly it turned into coal.

Most of Australia's black coal deposits date back to the Permian age, which extended from the end of the Carboniferous 280 million years ago to about 225 million years ago. This coal is predominantly bituminous or hard black in rank or stage of development. Victoria's brown coal was laid down much later—in the Tertiary, the main age of oil accumulation.

Some non-fossil alternatives

The great thing about oil is that it is liquid. It is easy to pump, carry, and store—a very convenient fuel. This is a major reason for its success in competition with other energy sources, such as coal.

Transport accounts for about one-third of Australia's direct energy use, and oil is the dominant fuel. Another third goes to the production of the secondary energy source, electricity. Oil is one of the fuels used, and of course some of the electricity powers trains and other forms of transport. The rest of the energy goes to low-grade heat production (up to 120°C) for home and office heating and a variety of industrial uses. Again oil is an important fuel.

Many sources in addition to the fossil fuels can yield large amounts of energy. The most significant, in terms of their long-term possibilities rather than their contributions now, are solar, nuclear, and geothermal energy. Others, including the use of running water, tides, and wind for electricity generation, can make smaller contributions.

Nuclear power

By the middle of last year, 148 nuclear power stations were operating in 19 countries and generating a total of about 56 600 megawatts of electricity. The United States was the biggest nuclear power producer, with 47 stations operating. Britain was next, with 29, followed by the U.S.S.R., France, and Japan.

Another 300 or so plants, with a total capacity of about 280 000 megawatts, were being built or were committed at that time. Australia has no nuclear power stations and no plans, at the moment, to build any.

Existing plants and those being built and planned now convert only 1–2% of the energy content of natural uranium to electricity, but the 'breeder' reactors now being developed should raise this proportion to 60–70%. The Australian Atomic Energy Commission expects that, if present research progress in Europe and America continues and operating experience is satisfactory, construction of commercial 'breeder' stations with capacities of more than 1000 megawatts may begin in the late 1980s.

Drawbacks of the existing plants and 'breeders' include the hazards posed by by-products that will remain radioactive for thousands of years. Plants based on nuclear fusion rather than the fission reactions used in conventional and 'breeder' reactors may turn out to be less hazardous and are potentially capable of producing vast amounts of electricity. But many research and development problems remain to be solved.

The sun

The main application of solar energy now is in low-grade heat production, particularly for water heating. Scientists at the CSIRO Division of Mechanical Engineering have played an important role in the development of effective solar water heaters, and are researching other applications of low-grade heat from the sun. Possibilities include heating and cooling for houses, factories, and offices, food processing, and desalination of water.

Solar energy can also contribute to the supply of liquid and gaseous fuels. This is indirect use of solar energy—the production of fuels such as alcohol, methane, and hydrogen from plant material that needed the sun's energy to grow. The material could include agricultural and timber wastes and trees and plants grown for fuel production. Whether a significant proportion of fuel needs could be met this way is not yet certain.

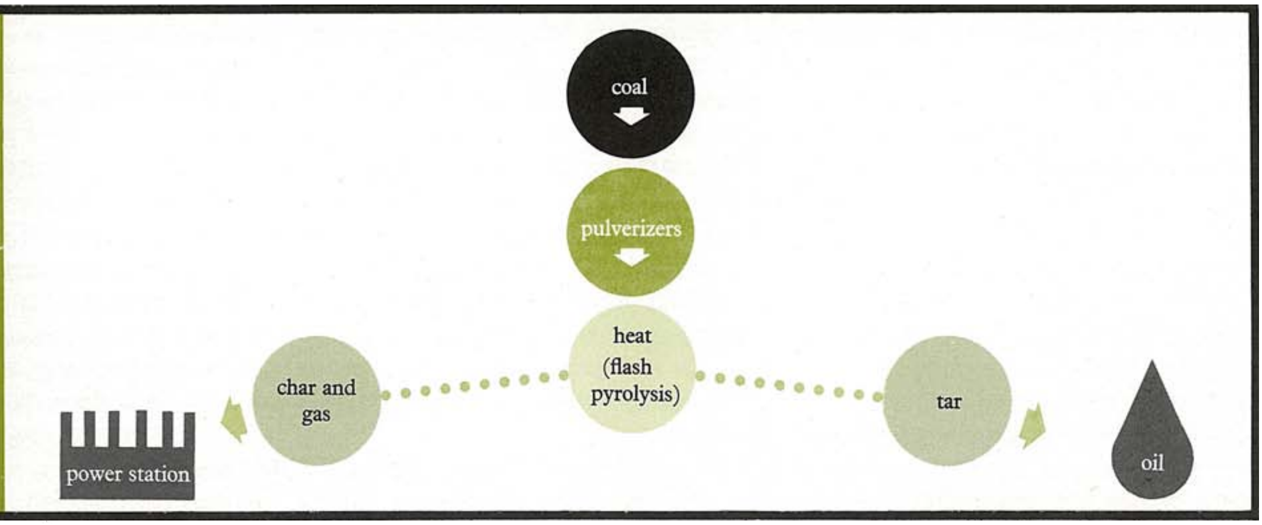
Energy from the sun can also be employed to produce electricity, but so far only in small quantities and expensively. However, vast amounts of energy are potentially available from the sun, and much research is going ahead around the world on ways to utilize it. CSIRO has set up a Solar Energy Studies Unit to advise on research priorities.

Geothermal energy

This is produced by the decay of radioactive materials deep within the earth's interior. An enormous amount of heat is available there, if it can be tapped. In some parts of the world, including New Zealand, America, and Japan, geothermal energy is now being used to produce electricity. Underground water comes into contact with hot rock, producing geysers and hot springs, and the steam or water thrown up drives power generators.

Only relatively small amounts of electricity are available from these sources, however, and the future importance of geothermal energy will depend on the success of efforts to tap more of it. Schemes have been proposed in America for pumping water down into zones of hot rock and using the steam produced to generate electricity.

A scheme for making both oil and power



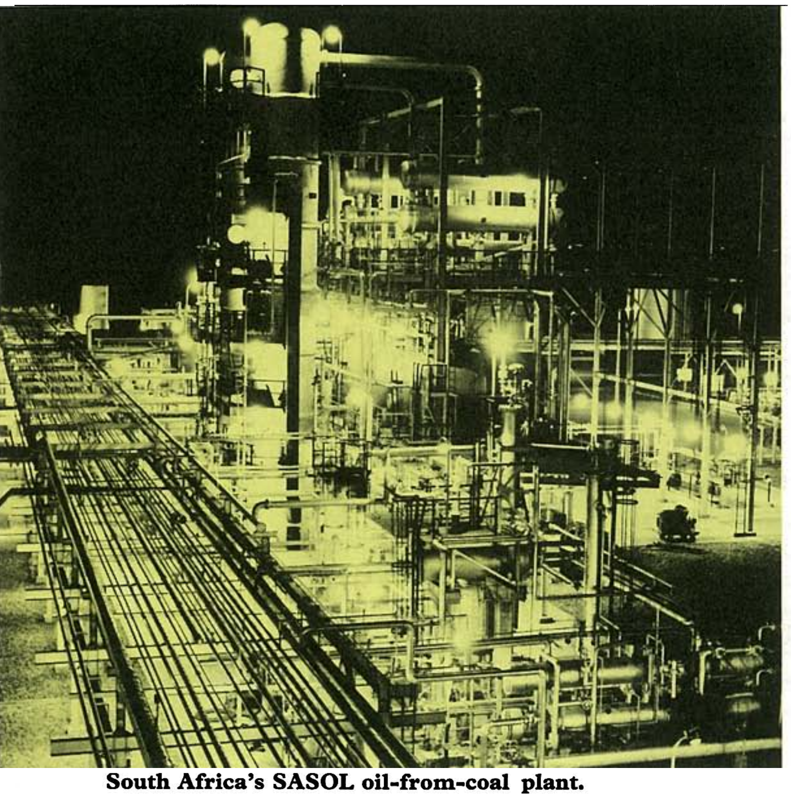
suitable for both uses. Coals that produce the coke used in iron-ore processing are not as suitable for flash pyrolysis, so there should be no conflict of interests between makers of oil and steel.

Some give more tar

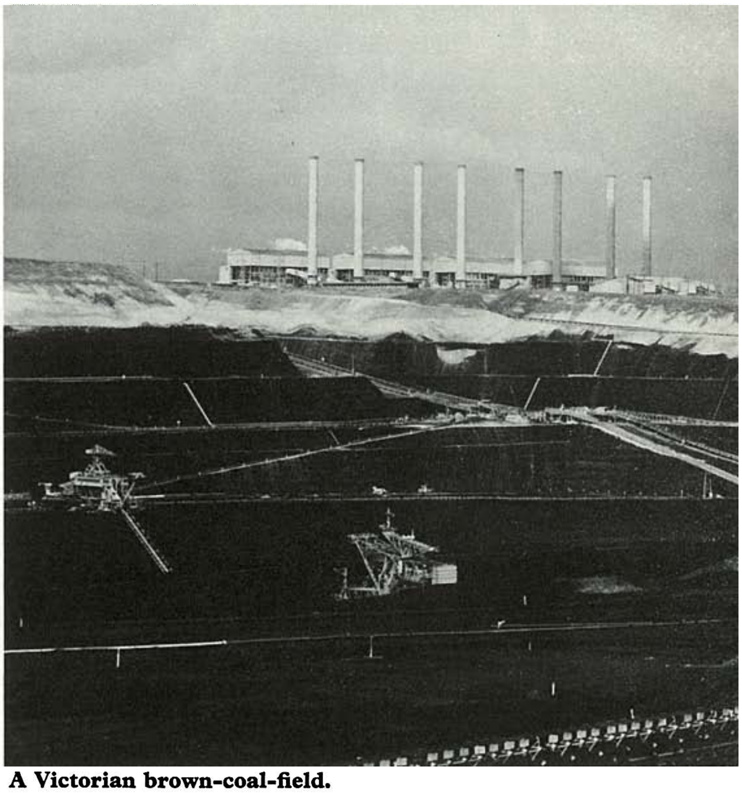
Coals vary greatly, and some types will give much greater liquid yields than others when decomposed by pyrolysis. One important characteristic is rank—the measure of how far a deposit has gone in the progression from vegetable matter to hard coal. Steps up the scale of rank include peat, brown coal, and black coal. The CSIRO research on Australian coals shows that, other things being equal, black coals usually yield more liquids than brown coals, and the lower the rank of the black coal the bigger is the useful liquid yield.

Another important characteristic is the relative abundance of three groups of coal constituents known as exinite, vitrinite, and inertinite. Exinite is the biggest yielder of liquids, but there is very little of it in many Australian coals. Vitrinite is next best, so a high vitrinite : inertinite ratio is desirable. Also desirable is a low content of ash-forming impurities.

Study of the composition of Australian coals is one aspect of CSIRO's investigations over the years that is obviously very relevant to oil-from-coal research, and further work should increase understanding of the effects of various coal properties on coal conversion processes. Also relevant to the flash pyrolysis project is the large amount of work done on various methods of coal pyrolysis. The effects of different coal types, reaction temperatures, and additives on the yields and properties of the solid, liquid, and gas products have been studied. Ways of treating tars to yield things such as simpler hydrocarbon liquids, gases, pitch products, and electrode carbon have been examined. These treatments could be



South Africa's SASOL oil-from-coal plant.



A Victorian brown-coal-field.

SASOL

South Africa's oil-from-coal plant—the only one in the world now operating on a commercial scale—began production in 1955. Run by the South African Coal, Oil, and Gas Corporation (SASOL), it converts about 6600 tonnes of coal a day to petrol and about 70 other products ranging from tar to gases.

The plant is near the inland city of Johannesburg, which is 650 km from Durban, the nearest major port for oil supplies. An industrial town known as Sasolburg has grown up around it. The coal comes from the extensive low-grade deposits in the area. The large amounts of water needed are drawn from the Vaal River.

Efficiency in terms of resource conservation is not one of the features of the plant; only about 12% of the carbon fed into it in coal comes out in saleable products. The energy content of the products is about 30% of that of the coal fed in—a conversion efficiency similar to that of coal-fired electricity plants.

SASOL uses the Fischer–Tropsch oil-making process, in which coal is turned into gas and then the gases react in the presence of catalysts to form the liquid products.

Oxygen and steam react with coal in the gas-making step, producing carbon monoxide and hydrogen. Two types of catalyst are used in the second stage. One, a pelletized iron catalyst, encourages the gases to form mainly waxes, diesel and furnace oil, and a low yield of petrol. The other, a powdered iron catalyst, encourages production of lighter products—mainly petrol, alcohols, and liquid petroleum gas.

The SASOL plant produces about 5% of the petrol used in South Africa, and it feeds a large petrochemical industry. It operates profitably under local circumstances, but there is little doubt that Fischer–Tropsch production of liquid hydrocarbons from coal would not be commercially viable in most situations.

applied to the liquid products of flash pyrolysis.

Adding hydrogen

Also relevant to oil-from-coal research is work done on ways of adding hydrogen to coal by dispersing the coal in hot liquids that give off hydrogen. An essential step in producing oil from coal is increasing the hydrogen : carbon ratio; coal has 0·4–0·8 hydrogen atoms for every carbon atom, while crude oil has 1·5–1·8. In the flash pyrolysis process the extra hydrogen comes from the portion of coal that ends up as char. But if further increases in the liquid's hydrogen content are wanted, this work may help researchers choose the best ways to achieve them. Also, the information gathered would be very relevant if research began here on total conversion of coal to oil by direct addition of hydrogen—the route pioneered by Friedrich Bergius.

The CSIRO scientists have done a lot of work on making gas from coal, and much of this is relevant to the liquid-fuels research. For example, between 1965 and 1968 Dr Peter Waters and Dr Keith Bowling, of the Division of Mineral Chemistry in Sydney, developed a simple and effective method of producing hydrogen and carbon monoxide from coal. These gases are the starting point for the Fischer–Tropsch oil-making system, and a source of large amounts of hydrogen is needed to operate the Bergius system.

The process developed by Dr Waters and Dr Bowling has the advantages of being able to operate continuously, using air rather than pure oxygen, and working at atmospheric pressure. It uses fluidized-bed reactors; strong updraughts of air or steam keep the solid reacting material suspended so that it behaves like a fluid. Coal burns in air in one reactor to produce the heat needed in the other, where steam and hot carbon particles react to give hydrogen and carbon monoxide. The scientists have recently begun investigating use of chars instead of coal in the process.

A natural gas substitute

The gas mixture produced could be used for industrial heating and metal processing, or for liquid fuel production by the Fischer–Tropsch route. The hydrogen component could also be used in the production of methane from coal, as a substitute for natural gas, which is mainly methane.

One obvious drawback to using more coal is the damage mining does to the landscape—it makes a mess.

In the 1950s and early 1960s, before natural gas became available in Australia, Mr Richard Urie and Mr John Birch, at the Division of Chemical Engineering, made a detailed examination of the prospects for producing methane from brown and black coals. The process involves reacting hydrogen with coal at very high temperatures and pressures. Work stopped with the coming of natural gas, but a great deal of valuable information was obtained on the chemical processes involved. Interest in this research may revive when natural gas supplies begin to show signs of running down.

Australia is far from alone in taking an interest in oil-from-coal technology; a rapidly expanding research effort is under way in many countries. In the United States, which is probably putting more money and manpower into the work than any other country, the main emphasis is on direct addition of hydrogen—the Bergius route. Experimental plants are operating, but many problems remain to be solved before large-scale, economically competitive oil production becomes possible.

Research overseas

The pyrolysis route also is being studied in America. Plants are operating on an experimental scale, but again it seems likely to be years before a major scaling-up becomes feasible. The CSIRO team is keeping in touch with relevant research overseas, especially in America, Japan, and Europe.

The economics of oil production from coal should improve with increasing plant size, and 100 000 barrels (16 million litres) a day is seen in America as a reasonable commercial production rate. A plant of that capacity would have a very large appetite for coal. If the process was direct addition of hydrogen, which converts most of the coal to oil, about 30 000 tonnes of coal would be needed each day. A 100 000-barrels-a-day pyrolysis plant, where most of the coal would end up as char and gas, could demand up to 100 000 tonnes a day.

Dr Durie has calculated that if all the liquid fuel now used in Australia was made from coal, our coal consumption would rise to five times its present level; this is based on the input and output figures for South Africa's SASOL operation. The figure gives an idea of the scale of the increase in demand for coal that will result if oil-from-coal becomes a major element in the energy scene.

Much more coal

Preliminary calculations by the CSIRO team suggest that a 2000-megawatts power station coupled to a flash pyrolysis unit would require about 30 000 tonnes of coal a day, compared with about 20 000 tonnes a day on its own. They suggest that production of liquid fuels should be about 40 000 barrels a day, which is approximately one-third of our current fuel oil consumption.

However, accelerated mining would hasten the depletion of coal reserves. Clearly the development of efficient oil-from-coal technology isn't a long-term answer to the energy problem that the world has suddenly found itself facing. But it could help tide us over while ways are found to reduce and finally end the world's dependence on oil-fired technology.

More about the topic

Production of gaseous and liquid fuels from coal. R. A. Durie and I. W. Smith. *Proceedings, Australian Institute of Mining and Metallurgy (Illawarra Branch) Symposium: Australian Black Coal—Occurrence, Preparation and Use, Wollongong, 1975* (in press).

Australian reaction to changing technology: What would Cyril Kent have done? I. E. Newnham. *Kent Memorial Lecture. Proceedings, Institute of Fuel Conference: Changing Technology of Fuel, Adelaide, 1974* (in press).

'Minerals Research in CSIRO' 6. (CSIRO Minerals Research Laboratories: Sydney 1974.)

'Coal Research in CSIRO' 45. (CSIRO Minerals Research Laboratories: Sydney 1971.)