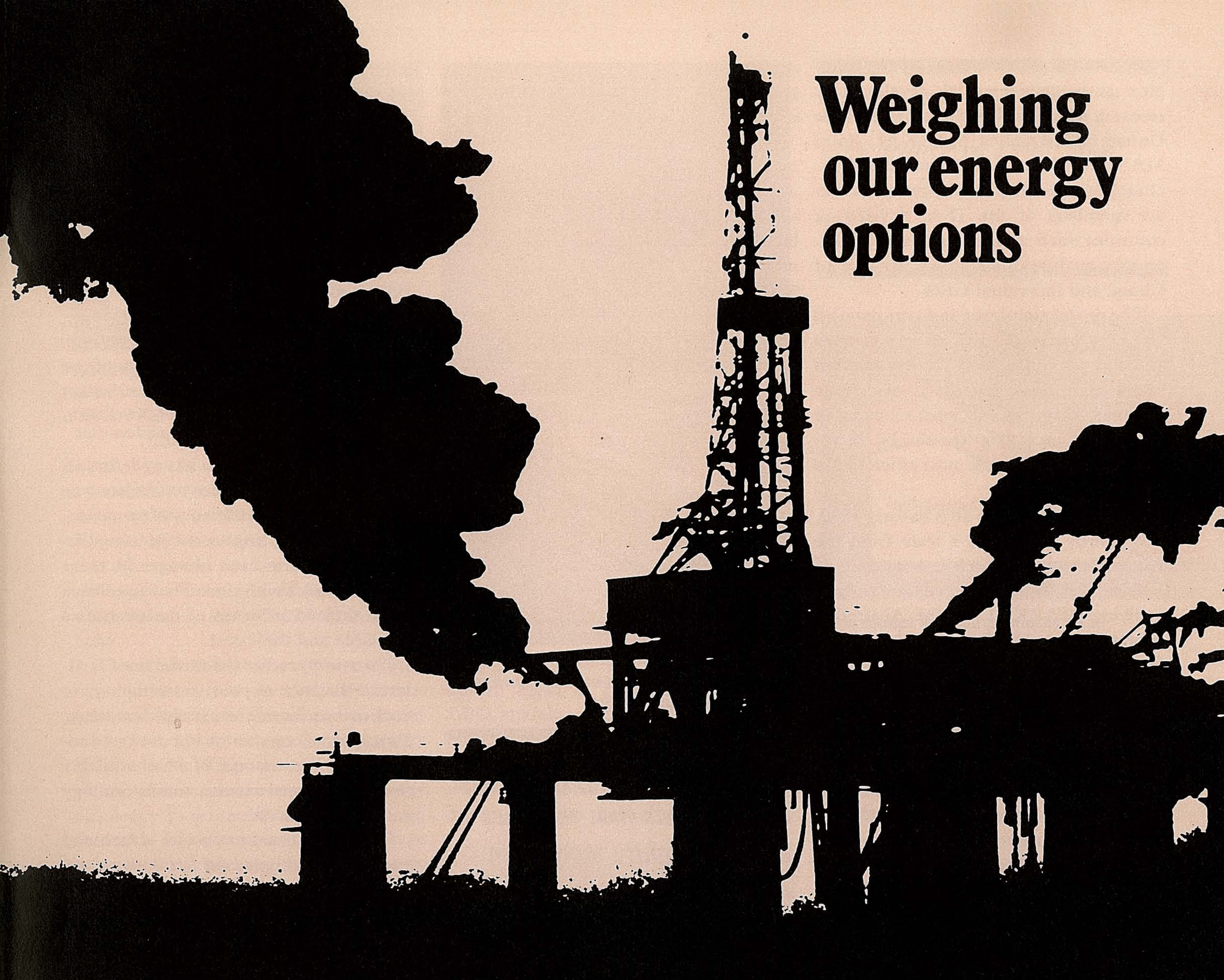
Weighing our energy options



Oil prices have fallen this year, and there is talk of a world glut of the precious liquid. Only a few years ago we appeared to face the prospect of constantly rising prices and a looming shortage. How quickly things change.

And of course they can change again. An end to the world recession would see the demand for oil pick up. No doubt the price would pick up too. Whatever transpires, we cannot escape the fact that oil is a finite resource and won't go on gushing forever.

In 1976, when oil prices seemed set on a continuing upward course, the International Energy Agency (IEA) initiated a project aimed at helping member countries set priorities for research. At that time it looked as if shale oil, oil from coal, and other alternatives to oil from the ground would become economically competitive quite soon. The question that interested Agency members was: how would the best mix of energy sources change over the next 40 or so years, and where should energy research funds go in consequence?

Although the need to develop new energy technologies seems less urgent now than it did a few years ago, the importance of working out the best future energy options remains. Australia is one of about 20 countries that have joined in the IEA Energy Technology Systems Analysis Project.

At the centre of the exercise is a complex mathematical model, developed by research teams in West Germany and the United States, called MARKAL (from MARKet ALlocation). Its users now include most of the developed countries that are members of the IEA, developing countries such as Indonesia and Brazil, regions such as the Canton province of China, and individual cities.

The model simulates, in a very detailed way, the interactions of energy sources and end uses. Based on the information and assumptions fed in, it can show whether, when, and to what extent new energy technologies should be introduced, if the goal is the most efficient use of resources.

Australia joined the IEA in early 1979, and shortly afterwards a team from the Lucas Heights Research Laboratories in Sydney, led by Mr Peter Essam, began applying MARKAL to the Australian energy scene. Mr Essam and his colleagues — originally members of the Australian Atomic Energy Commission and now with the CSIRO Division of Energy Technology — have recently published the results of a study that looked at possible developments up to the year 2020.

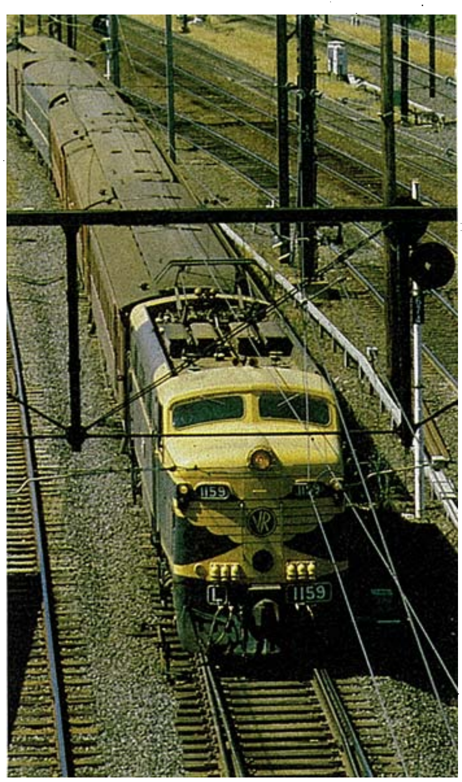
Among the assumptions they adopted was that the price of oil (the real price, adjusted for inflation) will rise by about 2% a year, which means that it will slightly more than double by 2020. They assumed that there will be no restrictions on the amount of oil that can be imported. And they assumed that Australia's population will reach 19·5 million by the year 2000 and 25·4 million by 2020.

One result from the model was that total consumption of primary energy (that is, the energy in the coal, oil, and so on used for all purposes, including production of secondary energy sources such as electricity) would increase from about 3000 PJ (petajoules, or 10^{15} joules) per year to 6740 PJ per year by 2020. This implies an increase of about 30% in energy use per Australian. The model concluded that electricity use would grow by 3·8% per year to the year 2000 and then by 1·6% per year to 2020.

The team fed a wide range of alternative energy technologies, along with cost estimates for each, into the model's data base. Looking for the most efficient way to supply projected energy needs, the model introduced methanol-from-natural-gas plants in 1990 and a plant for producing synthetic oil products from brown coal in 1995. Technologies that the model largely rejected included the production of oil from shale and of liquid fuels from vegetation.

The Moomba gas field in South Australia. Natural gas consumption may well increase markedly.

Among the assumptions they adopted was that the price of oil will slightly more than double by 2020.



Electrification of railway lines that carry big freight traffic looks desirable.

The MARKAL model

How does MARKAL work? It applies the mathematical technique of 'Linear programming' to allocate possible energy sources to all the specified uses. It makes the choices that will achieve an overriding goal, the obvious example being to minimize total costs.

That sounds quite simple, but when you get down to detail the complexity of the model becomes apparent, as does the fact that a very large amount of information is needed to run it successfully.

For example, the user has to define all the energy technologies considered in terms of fuel type, efficiency of operation, capital and operating costs, operating lifetime, limitations, and changes in these characteristics with time. Fuel types have to be defined in terms of the quantities available and their cost.

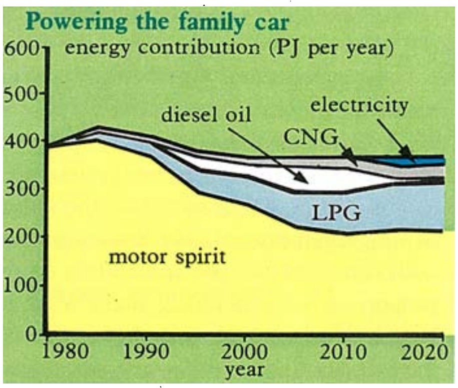
Essentially, what the model does is allocate the least expensive technology to each use until some 'constraint' is reached. Examples of constraints imposed are limitations on the amount of a fuel available and on the rate at which a new technology can be introduced.

The model bases its choices of fuels and energy technologies on 'shadow prices' that it determines. These take account of all the constraints, and hence can produce an economically more rational picture than straightforward reliance on fuel-extraction costs or import prices. Where no constraints limit the availability of a fuel, its shadow price is the assumed cost of extracting or importing it. But when limits are imposed, the shadow price becomes the cost of the next best alternative; thus, the shadow price of indigenous oil equals the cost of imported crude.

Fact-gathering

The Australian MARKAL team assembled data from all over the place before running the model. For example, projections of energy demand and supply were based on material supplied by the then Department of National Development and Energy (now the Department of Resources and Energy); and population projections came from the Australian Bureau of Statistics. Technical details and costings for alternative energy sources came from the most up-to-date Australian and overseas studies.

New technologies considered in the study included six methods for producing liquid fuel from coal, the conversion of



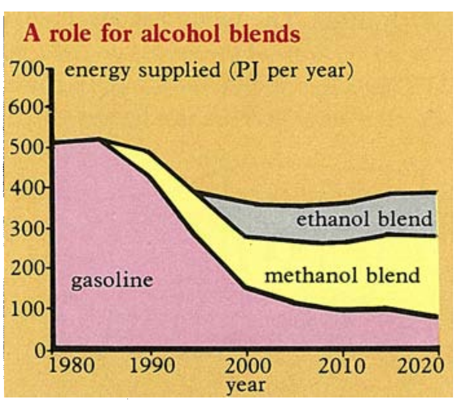
Although alternative energy sources will grow in importance, the study sees motor spirit remaining the main fuel for private automobiles.

natural gas to methanol with the further option of converting the methanol to gasoline, and the production of oil from shale. Recent CSIRO studies provided much of the information used on the production of diesel fuel from oilseeds, methanol from crop residues, and ethanol from sugar-cane.

The team collected estimates of fuel demand under four headings — industrial, transport, residential and commercial, and chemical and non-energy requirements. They adopted projections of significant improvements in energy efficiency in a number of areas. Among these was an assumption that the average private automobile would halve its energy consumption per kilometre by 2020.

Demand

And how did it all work out? In the transport field, alternatives to oil, predictably, gained increasing prominence in the model's output. At sea, coal became a major fuel of bulk carriers. However, train buffs will be sorry to hear that coal-fired steam trains did not make an appearance, because of their low efficiency and high maintenance costs. The model preferred electrification of railway lines heavily used for freight traffic.



Blended motor spirit — petrol with 15% by volume methanol or ethanol — will become increasingly competitive, according to the model.

Because change inevitably takes time, the researchers limited fuels competing with motor spirit to a maximum of 10% of the private automobile market by 1990. The limitation was then progressively removed. As the graph on this page shows, liquid petroleum gas (LPG) and, to a lesser extent, compressed natural gas (CNG) and electricity gained a substantial proportion of this market by 2020, although motor spirit remained the main fuel. But motor spirit was no longer purely petrol.

The model assessed demand for three types of motor spirit — straight gasoline, a gasoline blend containing 15% methanol by volume, and a 15% ethanol blend. Methanol made its appearance in the model's output in 1990, and ethanol from sugar-cane appeared in 1995. By 2020, as the graph shows, the methanol blend had the biggest market share, followed by the ethanol blend and then straight gasoline.

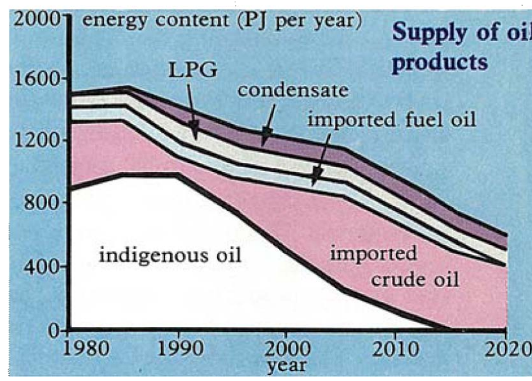
Almost all commercial vehicles and light trucks ran on motor spirit in 1980, the starting point of the study, and they did so again in 2020. Light distillate, LPG, straight methanol, and CNG gained market shares in the 1990s, but the model saw all except CNG disappear again by the end of the study. Most heavy trucks ran on distillate throughout the period.

Black coal remains the main fuel for power stations.

The model saw large and rapid changes take place in the way we heat houses and work-places. Electric radiators and oil and kerosene heaters, which now meet about half the demand, were out — radiators because of their much lower efficiency than electric heat pumps and the others because of their high fuel costs. All disappeared by 1995. Heaters running on natural gas and reverse-cycle electric heat pumps then had the market to themselves.

For water heating, the model initially favoured off-peak electricity, but natural gas gained the upper hand by 1990. Then after 1995 solar water heating with gas back-up became increasingly competitive. Solar heaters with instantaneous electric back-up did not find favour. However, in a separate study, the team checked out solar heaters using off-peak electricity as the back-up energy source, and found these did even better than solar heaters backed by gas.

Methanol made its appearance in 1990, and ethanol from sugar-cane in 1995.



The model sees oil products as a declining energy source, and Australian oil production ending about 30 years from now. The relatively small quantities of oil imported for lubricating purposes are not shown in the graph.

For industrial heating, oil and natural gas rapidly disappeared from the model's solution, to be entirely replaced by black coal and products derived from brown coal by the end of the study.

Supply

So much for energy uses; what about the sources of energy? The graph shows how the model sees the supply of oil products changing. It envisages local oil production peaking about 1990 and then falling to nothing by 2015. Oil imports decline substantially then grow rapidly before falling back again by 2020 to levels comparable with today's. Total oil use falls by more than half over the study period, to be replaced mainly by use of synthetic equivalents and methanol.

Consumption of natural gas, on the other hand, shoots up. The study dealt separately with gas from the conveniently situated Bass Strait field and gas from other sources, most of them remote from centres of population and industry. The Bass Strait gas is cheaper to distribute, but more limited in quantity.

After 1990, the model sees substantial quantities of natural gas going into the production of methanol. But as the year 2020 approaches, residential and commercial uses (heating, cooking, etc.) are the main consumers of the Bass Strait gas. Between 1985 and 2005, the model sees the manufacture of liquefied natural gas (LNG) for export as the biggest single user of natural gas, but it assumes this will end by 2010.

According to the model, total use of Bass Strait gas increases steadily over the study period, reaching double the 1980 figure by 2020. Use of natural gas from other sources undergoes nearly a fivefold increase by 1995, and then falls back slightly.

Consumption of black coal more than doubles over the study period, according to the model. Electricity generation and industry are the dominant users. No black coal goes to liquid fuel production, because brown coal and natural gas do the job more cheaply.

Brown coal emerged from the study as the boom fuel, with demand increasing between 1980 and 2020 by a factor of more than seven. By the end of the study period, about two-thirds of it is slated for the manufacture of liquid fuel. Most of this will be synthetic crude oil produced by a coal-hydrogenation process. Two other oil-from-coal processes make smaller appearances in the model's output, and some methanol could be produced from brown coal.

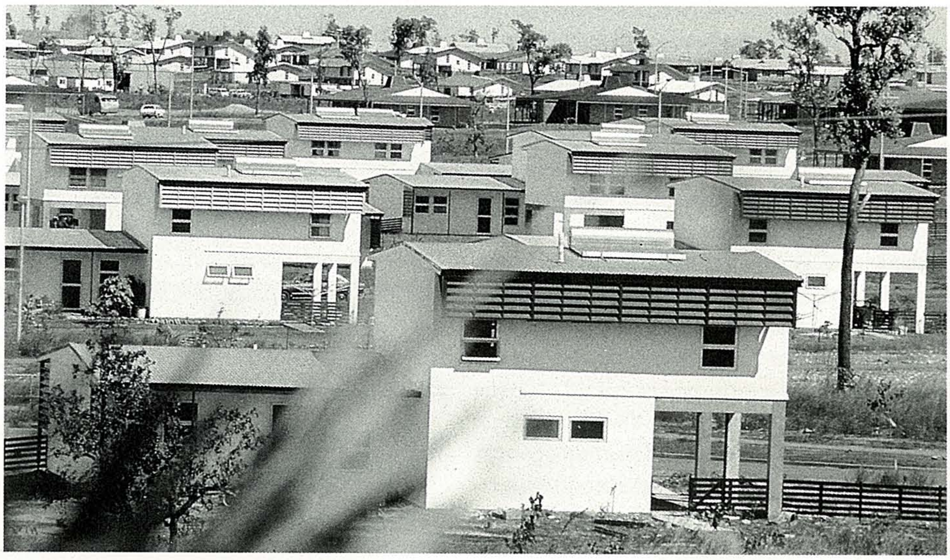
The study team assumed that brown coal would be available in effectively unlimited quantities up to 2020 and that real extraction costs would approximately double by then. However, in the light of the very large demand for it indicated by the model, they suggest that these assumptions may need to be looked at again more closely.

In dealing with electricity generation, the model divides the year into three seasons — winter, intermediate (spring and autumn), and summer — and the day into two portions — day and night. Other features aimed at mimicking what happens in the real world include representation of shutdowns of generating plant — for maintenance and due to breakdowns. The model makes sure that sufficient generating capacity is always available to meet peak demand with some reserve capacity left over.

However, Australia's electricity supply system has one important feature that MARKAL cannot simulate — the separate electricity grids in each State. To account as best they could for the effects of this arrangement, Mr Essam and his colleagues introduced constraints on the proportion of generating plant used for base-load electricity production and on the contributions of different types of base-load plant.

The model projected nearly a trebling in electricity production between 1980 and

Solar water heating should become increasingly competitive.

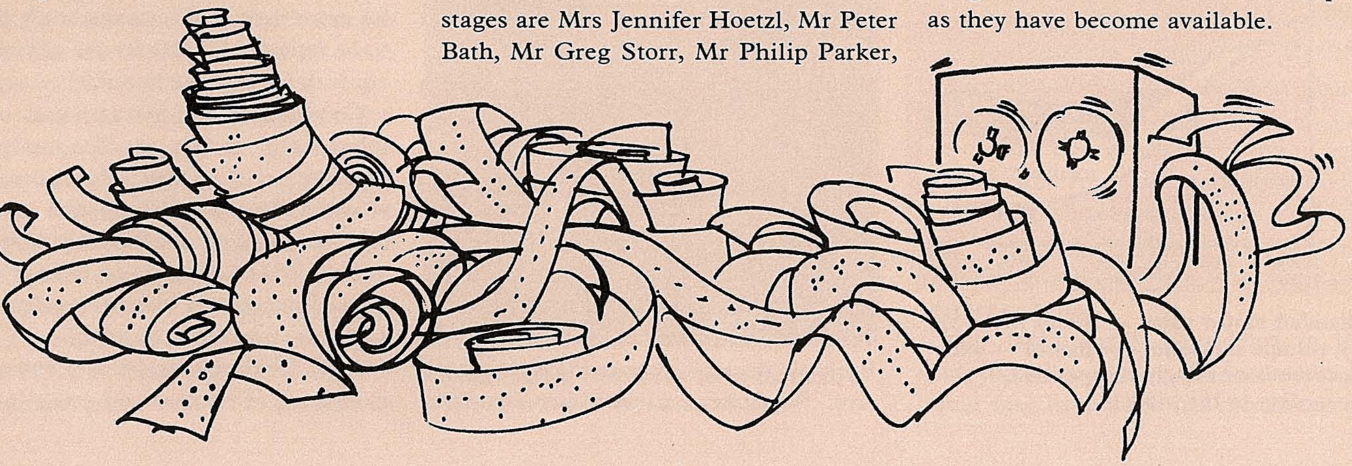


The Australian end of MARKAL

Australia's participation in the IEA Energy Systems Analysis Project was supported by a grant under the National Energy Research, Development and Demonstration Program. It was managed by a steering group chaired by the National Energy Office of the Department of National Development and Energy. The Department, and the Australian Bureau of Statistics, were heavily involved in assembling the data fed into the model.

The Energy Systems Analysis Group, which performed the study reported in the main article, moved from the Australian Atomic Energy Commission to the CSIRO Division of Energy Technology in April 1982. Mr Peter Essam is its leader and Dr Kenneth Maher his deputy. Present members of the group are Mr Anthony Musgrove, Dr Kenneth Stocks, Mr Dung Le, and Mrs Janice Faulkner. Former members who were involved at various stages are Mrs Jennifer Hoetzl, Mr Peter Bath, Mr Greg Storr, Mr Philip Parker, Mr Fawsey Soliman, and Miss Yvonne Hargreaves.

Group members contributed to the development of the MARKAL model while seconded to the West German institute, Kernforschungsanlage, where most of the work on it has been done. The first version of MARKAL became available in early 1981. The group has installed updated versions of the model on the Lucas Heights Research Laboratories computer as they have become available.



2020. Plants fuelled by black coal produce about half the total output throughout the study period. Brown coal, natural gas, and hydro sources remain important contributors. And nuclear power, in the form of light water reactors, puts in an appearance after the year 2000 and by 2020 accounts for just over 10% of electricity production.

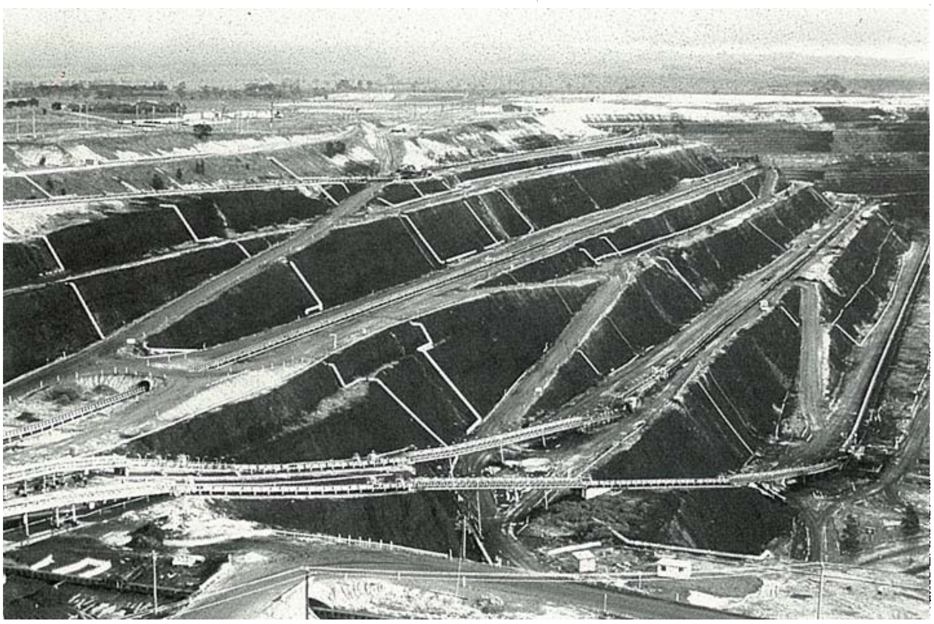
Changing assumptions

When they had finished their study, the researchers used the model to see how the energy picture would change if they varied some of their assumptions. For example, what happens if you change the 'discount rate' — a factor that has to be incorporated in studies like this to account for the fact that money spent at different times has different values, even after adjustment for inflation? In the study, all costs were discounted to the starting year at 6% a year, somewhat less than the rate at present recommended by Treasury.

The team tried out discount rates ranging between 3% and 13%. Generally, as the discount rate increases the cost of capital increases relative to fuel costs, so capital-intensive technologies tend to become less economic.

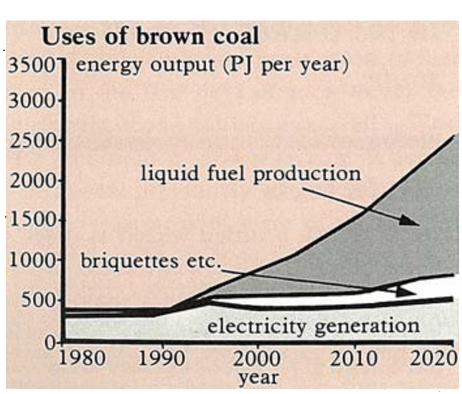
Changing the discount rate had few dramatic effects. As expected, the lower rate favoured the introduction of alternative fuels for transport. However, the use of methanol–gasoline blends remained viable at the 13% rate. Total production of synthetic fuels fell by about 10% in 2020 when the discount rate was increased from 10% to 13%.

One technology that proved extremely sensitive to the discount rate was solar water heating with gas back-up. At the 3% discount rate it captured almost 70% of the market by 2020, while at 13% ordinary gas water heaters were always better value.



Victorian brown coal — in strong demand.

Brown coal emerged from the study as the boom fuel.

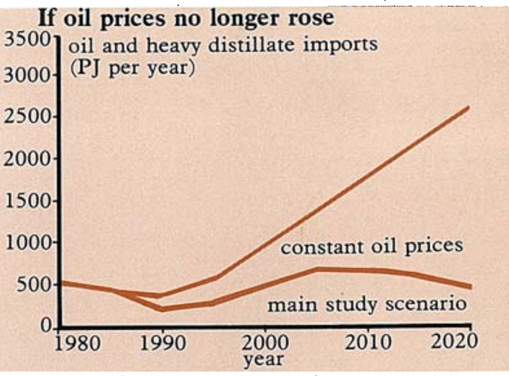


The study envisages liquid fuel production becoming the main consumer of brown coal.

The team tested another assumption that looks much closer to reality now than it did when the MARKAL study began. This was that oil prices will remain constant through the study period.

Not surprisingly, this scenario results in the demise of all synthetic fuel projects except the production of a small amount of methanol to blend with gasoline. By 2020 oil imports increase to five times their present level. The researchers make the point that the rapid increase in oil imports that the model envisages after the year 2000 would presumably be matched in other countries and is therefore not consistent with the assumption of constant oil prices much beyond that year.

The team looked at a number of other scenarios, including the results of imposing various excise duties on petrol and diesel fuels. One of the main virtues of the model is its ability to show how changes in one portion of the energy picture will affect other sections.



A constant oil prices scenario saw much-increased oil imports by the end of the study period.

Detail and drawbacks

The level of detail that MARKAL operates at is impressive; in the Australian study it handled data on 15 types of electricity-generating plant, 50 other energy-conversion processes, and more than 60 energy-use technologies. Nevertheless, the team acknowledges that many real world considerations have to be overlooked.

For example, large oil-from-coal plants could have adverse environmental impacts. They would certainly be large water-consumers. Also they would be very expensive to build; how would their requirement for capital affect other parts of the economy? And, of course, the model cannot take account of political influences on choices of energy sources, or of the fact that people may sometimes prefer energy options that are not the most economic.

Despite these limitations, MARKAL will undoubtedly help Australia's energy planners. The Australian researchers are continually refining the data they feed it. Recently, they made improvements to the model that allow a much better representation of our independent electricity grids. Currently, they are linking MARKAL to an economic model that studies the level of demand for different forms of energy in the light of general economic activity.

Robert Lehane

More about the topic

Exploring some Australian energy alternatives using MARKAL. A.R. de L. Musgrove, K.J. Stocks, P. Essam, D. Le, and J.V. Hoetzl. *CSIRO Division of Energy Technology Technical Report* No. TR2, 1983.