Growing fuel ~ a future option?

What will the world do when it really does run short of oil? At present we can do little more than gaze at the crystal ball. There really are too many imponderables. Will fusion power at last have been harnessed, or will we have lost our inhibitions about uranium?

One suggestion is that we should use the energy trapped from the sun by plants during photosynthesis. Use of this renewable resource, instead of adding more carbon dioxide to the earth's life system, would just recycle it.

This sounds an attractive proposition. After all, 20 000 times more solar energy reaches the earth's outer atmosphere each year than the human race uses from all sources combined. But how much of this can be trapped by plants and used?

Many scientists have pondered this question in the last few years. Recently, Dr Keith Boardman, who is now a member of the CSIRO Executive, worked out an answer, which (like some others) doesn't give great scope for optimism.

He points out that only 40% of that energy actually arrives at the earth's surface (which still leaves 7000 times the energy we use), and two-thirds of that fall on the, as-yet, not very usable oceans.

Plants use only a fraction of the energy reaching them. Dr Boardman states that on average those in the sea use 0·08% of that reaching the oceans, and those on land use 0·3% of that reaching the land. Consequently, the total solar energy that photosynthesis converts each year — on land and in the sea — amounts to only about ten times Man's present consumption. What's more, if extrapolations of our energy consumption to the year 2000 prove correct, then in that year photosynthesis will trap only three times as much energy as the human race consumes.

Since, obviously, the human race can only hope to use a very small part of all the energy stored by photosynthesis, this renewable resource isn't the answer. Others will have to be found.

The Brazilian exception

But be that as it may, one country, Brazil, is embarking on a massive program to replace imported petrol with ethanol made from home-grown crops of sugar and cassava. In this way it hopes to produce all its liquid fuel requirements from its own land by 1985.

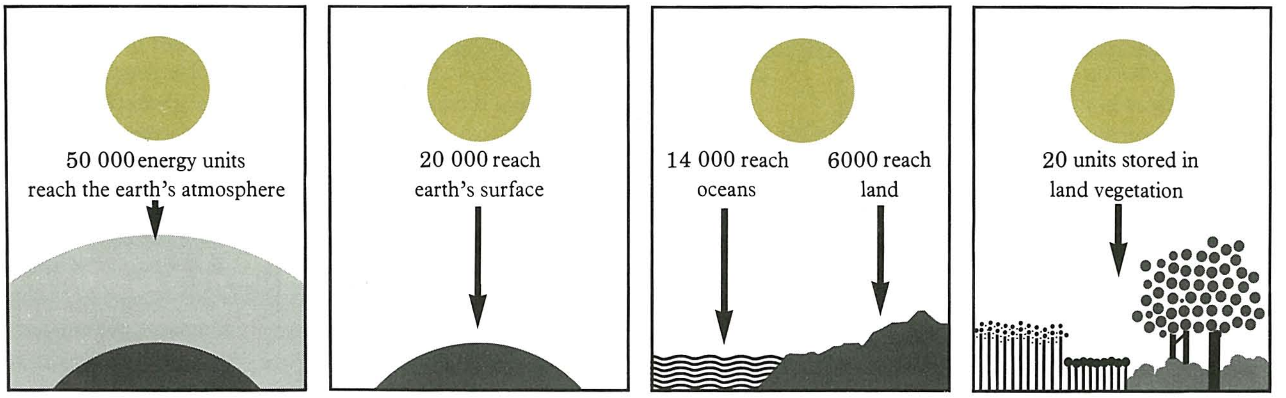
How can Brazil apparently buck the world's energy balance? The phenomenon is local. The country is vast (slightly larger than Australia), with huge amounts of unused land available that is both well watered and suitable for growing high-yielding crops. Energy needs are still relatively small compared with the productivity the land may achieve.

At its conference last July, the Institution of Engineers grappled with the problem of finding the best energy policy for Australia. At this meeting the 12 working parties of the Institution's Task Force on Energy presented their reports.

These reports showed that Australia's energy reserves, rich though they may be, are by no means all in a form that we can effectively use. By 1985 we will, like Brazil, be particularly dependent on imported oil for our supply of liquid fuel. Currently, crude oil supplies about half of the energy we consume. At present, local oil supplies, mainly from the Bass Strait, meet more than 60% of our needs. But, unless much more oil is found, this supply will start to decline quite seriously from 1980. By 1985 it will meet only 30% of our needs, and by the year 2000 existing reserves will be exhausted. Can we, as in Brazil, convert home-grown plants to liquid fuel such as ethanol to help fill this gap?

Like Brazil, Australia is a very large country, and compared with our conti-

One estimate of the way the sun's energy is dissipated



(each unit = 10^{20} joules per year)

Photosynthesis in land vegetation stores only a tiny fraction of the solar energy reaching the earth's surface. If we denuded the earth of all vegetation, the energy harvested would amount to only seven times Man's present usage.

Laying a natural gas pipeline in southern Australia. This gas currently supplies about 8% of our energy needs. Reserves should last beyond the year 2000.

nent's size our energy requirements are not that large either. One hundred million relatively poor Brazilians consume only about twice as much crude oil as we do.

But Australia differs from Brazil. In spite of its size, it lacks the huge expanses of well-watered country needed for growing high-yielding crops. Also, we have to use energy-intensive ways of growing our crops. (Brazil will use its large number of unemployed people in rural areas.) So the problem here in Australia is this: even if we can grow enough crops, can we harvest and convert them into a useful form of energy without burning so much in the process that the effort becomes pointless?

Here is a riddle with which scientists in our universities and in CSIRO have been wrestling for some years. Although they don't yet know the solution, it does already seem that Australia should be able to obtain at least a useful fraction of its energy needs by using solar energy trapped in plants.

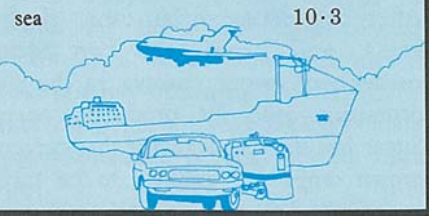
This article will not attempt to suggest what that fraction may be. A working party within CSIRO is currently trying to come up with an answer, and its conclusions will be the subject of a future article. Here we will merely look at some of the implications of growing fuel.

Australian energy usage

To begin with, some crude figures. Australians currently consume about 3 trillion joules of energy each year (that's 300×10^{16} to those with a penchant for figures). This amount is increasing by about 5·5% each year. Dr Roger Gifford of the CSIRO Division of Plant Industry has calculated that all our food crops plus the residue left behind after harvesting and processing would have an energy value as fuel of about 0·8 trillion (80×10^{16}) joules. So we already consume twice as much energy in the form of oil as is stored in our agricultural crops.

How liquid fuel was used by Australian transport in 1974–75

	energy used ($\times 10^{16}$ joules)
air	7·0
road	50·9
rail	4·0
sea	10·3



Ethanol may be used as a substitute for motor spirit, or be blended with distillate for use in diesel engines. Alcohol could therefore make a major contribution to road transport — the largest user of liquid fuel.

Oil rig in Bass Strait. By the year 2000 there will be no more Bass Strait oil.

In practice, converting these crops into ethanol — the best-understood way of converting plant material into a usable liquid fuel — will yield somewhere between one-half and one-fifth of the energy originally stored in the plants — the proportion depends on what the crop is. To this loss must be added those from growing and harvesting the crops, transporting them to processing plants, burning extra energy during processing, and transporting the fuel produced to where it's needed.

Thus it becomes obvious that, even if we did decide to use our existing crops for energy rather than food, most of the fuel needed to keep our transport system running would still have to come from other sources.

Although very rough, these figures of Dr Gifford's give some idea of the size of the renewable energy resource that may be available from our cultivated land using our present farming methods.

Where the soil can take it, intensive farming may, of course, greatly increase plant production. But doing this would mean using much more fertilizer than we do at present, and in most areas irrigating also. Both these measures add to the amount of energy expended on the crop to make it yield more — which may make the exercise somewhat self-defeating. In addition, supplies of phosphorus for use as superphosphate, although plentiful, are not unlimited. For a country like Australia, which already has ample supplies of energy, to use such a valuable unrenewable resource for producing more energy rather than food and fibre does seem questionable.

Fast growers needed

Putting such considerations aside, what sort of energy yields may we achieve if we decide to grow plants for this purpose?

To operate efficiently, a processing works for producing ethanol from plants would require a reasonably constant supply of raw plant material throughout the year. The plant material would have to be harvested and transported mechanically. So the factory would need to be at the

Percentage of energy contributed by different fuels in Australia

	1960–61	1970–71	1973–74	1975–76
black coal	42·1	30·5	28·8	30·7
brown coal	11·6	10·6	10·3	10·6
wood and bagasse	6·7	3·7	3·2	2·7
oil	38·3	49·7	49·1	46·1
natural gas	—	3·5	6·7	7·8
hydroelectric	1·3	2·0	1·9	2·1

Until recently, oil has been providing a steadily increasing proportion of our energy.

centre of a compact region where yields of the plants to be harvested are as high as possible.

In southern Australia, with its extreme seasons, only trees can provide a constant supply, since they store energy — trapped during many seasons — within themselves as wood. Annual plants lose much of this energy through decay during storage.

In the tropics, where rainfall or irrigation permits, plants can grow all the year round. So cultivated plants such as sugar cane, cassava, kenaf, and elephant grass — all of which are said to trap more energy than trees — could supply material for processing at any time.

At present sugar cane is grown on about 300 000 hectares of some of the most productive land in Australia. About 60 000 hectares of this is irrigated. Dr Gifford has calculated that the 2·8 million tonnes of sucrose produced each year, if it were all converted to ethanol, would yield the equivalent of 3% of the current Australian demand for petrol.

The sucrose in the sugar cane makes up only about one-third of the dry matter content of the plant — the remaining two-thirds being cellulose and lignin in the stems and leaves. These contain about 60% of the energy in the unharvested plant, and indeed burning the fibrous bagasse waste produced during sugar processing keeps the mills self-sufficient for fuel.

However, if it's alcohol that's needed, it hardly seems worth using the cellulose parts of the plant. Unfortunately, these also contain lignin, which is a very stable compound that gives strength to plant stems. At present the most effective way of breaking down the lignin and cellulose is to heat the plant material in concentrated hydrochloric acid — a process requiring a lot of heat. Dr Dick McCann and Dr Hugh Saddler, of the Energy Research Centre at the University of Sydney, have shown that converting the cellulose to alcohol requires three times more external energy to be put in as heat than can be extracted from the raw plant material as alcohol.

If this heat isn't to come from fossil fuel, it may be produced by burning some of the cellulose feed, in which case something like two-thirds of the raw plant material will have to be burnt as fuel. Getting the external heat direct from the sun using flat-plate solar collectors would save making such inroads into the raw material.

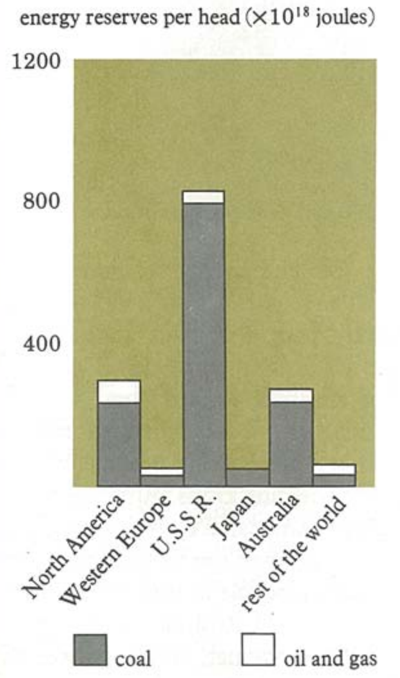
Cassava, perhaps

After considering sugar cane, elephant grass, and kenaf, the two Sydney researchers favour cassava as the most promising crop for producing energy. Sugar has the disadvantage that currently grown crops are unlikely to be turned over for fuel production, and much of the land suitable for cane-growing is already in use. This is because sugar cane requires particularly fertile soils.

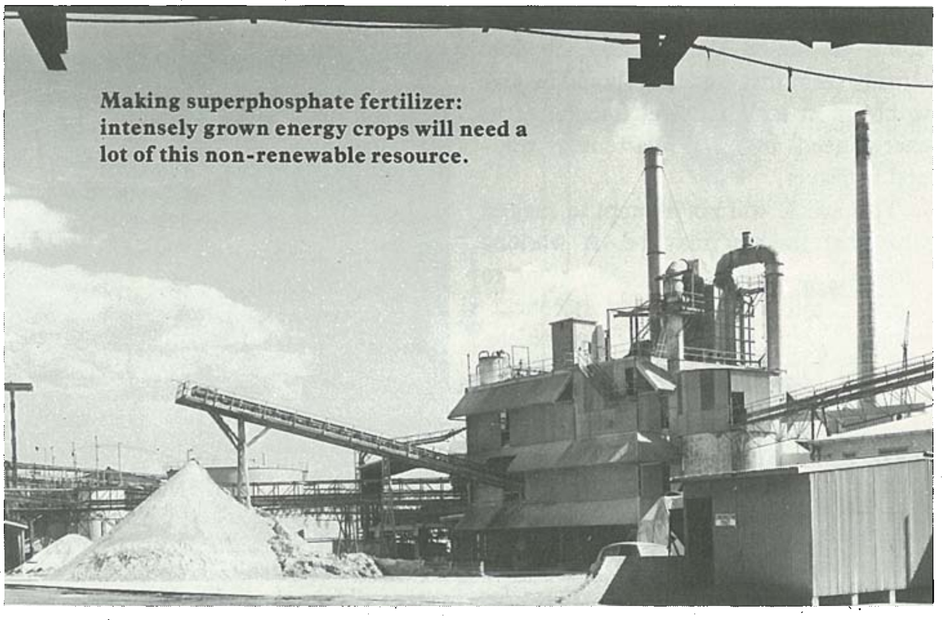
Growing cassava is new to Australia. The first commercial crop was only planted this year. But, as Dr McCann and Dr Saddler point out, the plant appears to be less fussy about the soil than sugar cane. It stores most of the energy trapped during photosynthesis as starch in tubers below ground.

The researchers have calculated that alcohol coming from cassava starch will have much the same price as alcohol currently produced as an industrial solvent. That means that it would cost about twice as much per joule of energy as taxed

How fossil fuel reserves per head compare in different countries



Australians are extremely well endowed with coal.



Making superphosphate fertilizer: intensely grown energy crops will need a lot of this non-renewable resource.

petrol at the pump. However, Dr McCann claims that new technology may reduce the cost of alcohol considerably.

The two scientists assumed, for this calculation, that the cassava came from irrigated areas of about 35 000 ha each, and that the crop yielded 17·5 tonnes of tubers (dry weight) per hectare.

With such yields, they calculate, substituting alcohol for Australia's current demand for motor spirit would require about 1·5 million hectares of cassava. That's about the total area presently under irrigation in Australia, five times the area currently under sugar, and about 20 times the area of the Ord River scheme.

Existing areas of different Australian forest types

	millions of hectares
eucalypt class I	2·7
eucalypt class II	14·2
eucalypt class III	12·3
tropical eucalypt	6·5
rainforest	1·8
cypress pine	4·4
plantation	0·5
total	42·4

If land for growing fuel crops of eucalypts is to come from existing forests, it will have to come from what the Forwood Conference classed as one and two. These classes total 16·9 million hectares. More than half of this area is already reserved for wood production, and a small proportion is in national parks.

If the Department of Minerals and Energy estimates prove correct — that by the year 2000 our demand for motor spirit will have at least doubled — then more than 3 million hectares of cassava will be needed.

Although such areas of land aren't likely to be available (see *Ecos* 12), Dr McCann thinks that it should be possible to obtain, at least, a useful amount of liquid fuel from existing farmland.

Much of the additional land in the north that may be suitable for growing cassava has a 7-month dry season. So it will not be possible to obtain continuous high yields without irrigation, and the experience of the Ord River scheme may make us look twice at putting in new ones.

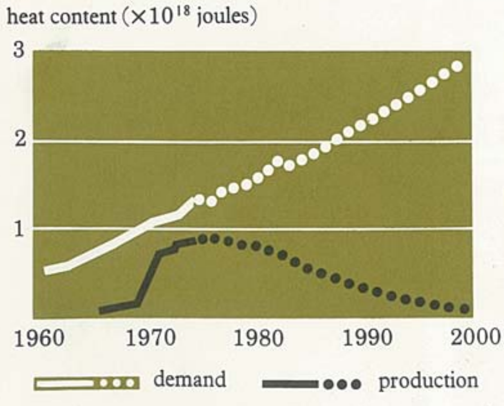
. . . or wood?

What about the southern forests? Can they provide large quantities of fuel? After all, 100 years ago American forests were still supplying more than half of the fuel consumed in the United States. Today, Australian forests contribute less than 1·5% of our energy.

Ecos 9 reported a study by Mr Jim Siemon for the CSIRO Solar Energy Studies Unit, which concluded that we could possibly obtain half our liquid fuel requirements in the year 2000 as ethanol from plantations of fast-growing eucalypts.

To achieve this, we'd have to plant 13 million hectares of plantations, which would have to yield 12·5 tonnes of stem wood per hectare each year.

Australia's demand for crude oil compared with local production



Barring the discovery of a massive new oil-field, Australia will soon have to vastly increase its crude oil imports. Projections of demand came from the former Department of Minerals and Energy, and those for production from the Institution of Engineers.

As mentioned earlier with the example of converting other cellulose wastes to alcohol, only about one-third of the harvested wood would actually be converted to ethanol. We'd have to use the other two-thirds for providing heat to power the conversion process. If we could obtain much of that heat directly from the sun using flat-plate collectors, then perhaps only 7·5 million hectares of plantations would suffice.

Other studies have come up with different figures, most of them higher. One by Dr Geoff Gartside of the CSIRO Division of Chemical Technology suggested that 23 million hectares rather than 13 million hectares may be required to produce half our liquid fuel needs in the year 2000. Dr Gartside assumed that the plantations yielded only 10 tonnes per hectare each year.

These differences aren't important, they simply reflect differences in the assumptions used in calculating the figures. What all the studies show is that, if we are going to obtain a substantial proportion of our liquid fuel from wood, we'll need colossal areas of plantations. By comparison, the present pine-planting program is puny. This aims at establishing just over one million hectares of plantations by the year 2010, yet even this modest (by comparison) program has produced a good deal of dissension in the community.

When considered as a problem of land use, the prospect of planting millions of hectares of plantations, be they eucalypt or pine, seems daunting indeed.

Take the figure of 13 million hectares, for example; where do we find this much land without greatly biting into farmland already used for growing food? (Presumably growing food will take precedence.) Another problem is where do we find this much in areas where the rainfall and soils will permit plantations to

Some wheat-farmers may be able to make their farming operations almost completely independent of fuel brought in from outside.

produce even 10 tonnes of wood per hectare, regardless of the consideration of avoiding using land currently used for growing food?

Obviously, the first place to look is in our native forests. In their present form, these cannot provide anywhere near enough wood.

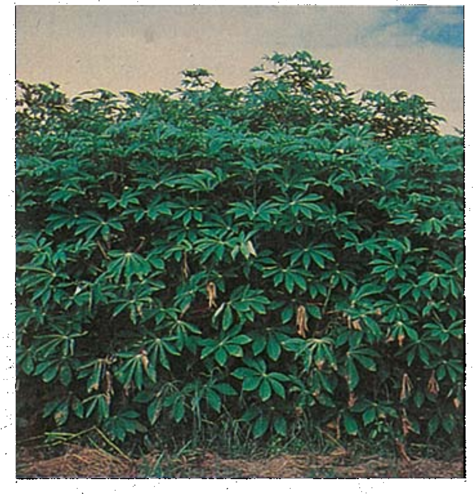
Not enough forest

As an exercise before the Forwood conference in 1974, the Panel on Forest Resources divided our native eucalypt forests into three classes, representing different levels of productivity if harvested. No figures were put on these levels. However, according to Dr Ross Florence and Dr Ken Shepherd, of the Forestry Department at the Australian National University in Canberra, class one (which represents mainly wet sclerophyll forests) yields about three-quarters of a tonne of sawlogs per hectare each year. Class two, which consists of less-productive wet sclerophyll forest and some dry sclerophyll forest, yields about one-quarter of a tonne per hectare, and the dry sclerophyll woodlands of class three yield even less.

Intensively using these forests (by clear-felling and using whole trees) may increase the yield two or three times. Yet, the scientists think, it would be almost impossible to manage these native forests in such a way that their yield doubled.

Native forests cannot produce enough to make harvesting them for fuel viable. Even so, the classes probably can be used as a guide to the potential maximum productivity of plantations grown on the same land.

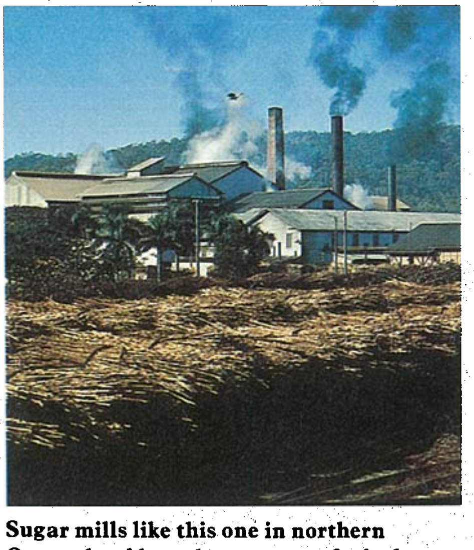
In general, the Canberra scientists think, land supporting class-one forest can be expected to support the most productive plantations, since this forest grows where the soils and rainfall are best. However, trees on some class-two land will probably respond more to fertilizer; so, with management, greater improvements in productivity can be expected on



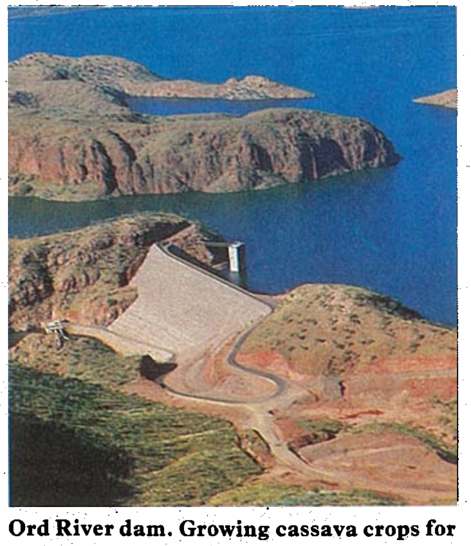
Cassava growing near Innisfail, Qld. Could starch from this plant be converted to ethanol to provide a substantial fraction of our liquid fuel needs?

It's theoretically possible to use wheat straw as an energy source — but is it feasible?

Oil being unloaded at Westernport. By 1985, two-thirds of our oil will have to be imported.



Sugar mills like this one in northern Queensland burn bagasse as a fuel, thus making themselves self-sufficient.



Ord River dam. Growing cassava crops for energy on a year-round basis will require irrigation.

this land. Nevertheless, much of the time, yields will still be highest on class-one land. Areas supporting class-three native forest cannot be considered for highly productive plantations, since the rainfall is too low to permit adequate growth.

Experiments by Mr Robin Cromer of the CSIRO Division of Forest Research have shown that selected sites with high rainfall on class-two land, given large applications of fertilizer and careful weed control, supported plantations of southern blue gum (*Eucalyptus globulus*) that yielded 4 tonnes of dry stem-wood per hectare each year during the first 4 years after planting. Yields from these plantations were increased to 5½ tonnes per hectare per annum by including branches.

Forecasts dodgy

Mr Cromer thinks that selectively bred lines of the most-productive eucalypts should be able to give higher yields than this. Certainly they can overseas, but in Australia the planted eucalypts have to withstand attacks of insects that have evolved with them, while the overseas plantations grow with much less attack.

Mr Kurt Cremer of the same Division thinks that it would be difficult to average more than 10 tonnes of wood each year per hectare of land in classes one and two. And achieving even this would require use of whole trees, which could have undesirable effects on the environment.

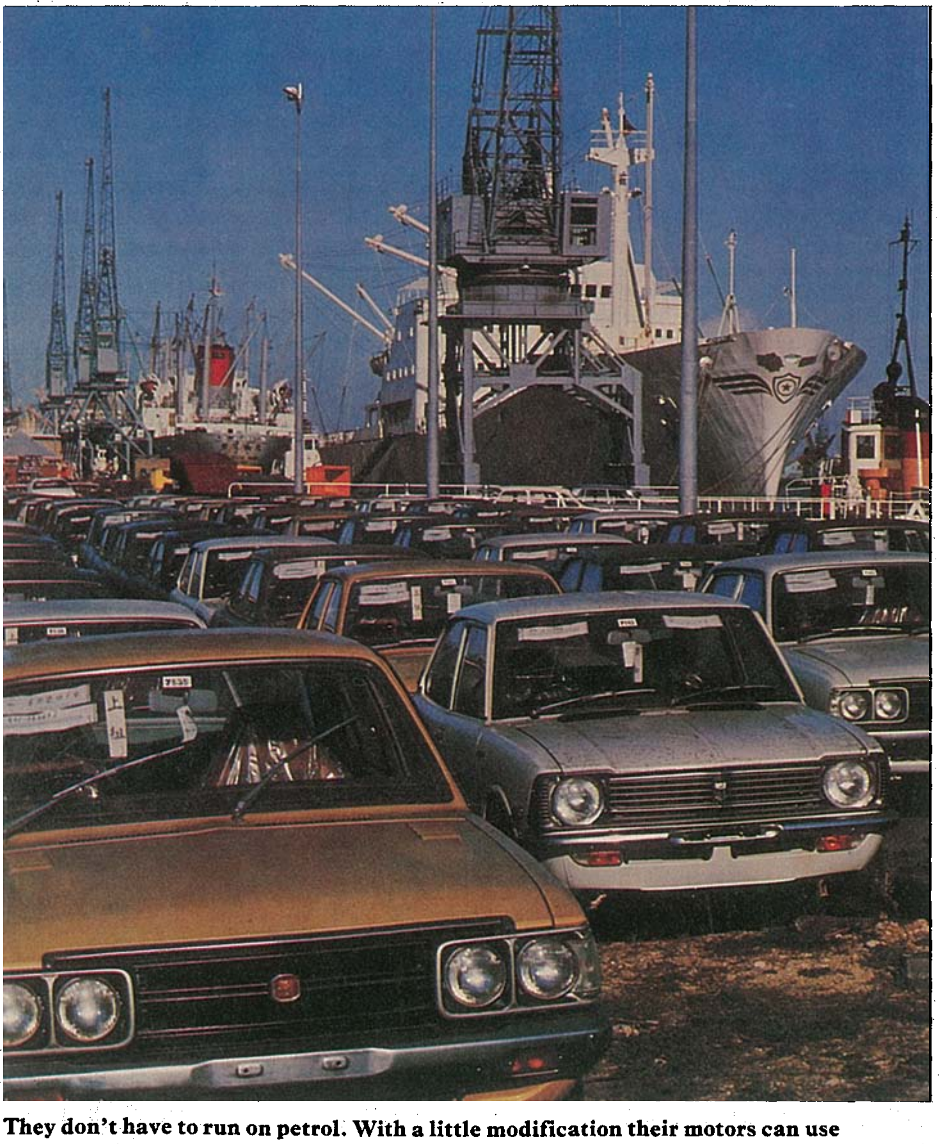
One of the difficulties about predicting what sort of yields may be obtained from plantations of eucalypts in the long term is that nobody has yet grown more than a single generation. We are a little better informed with pines, some plantations of which are well into the second generation.

If we want to grow wood for fuel, we will need to grow many generations without a loss in productivity. In addition, we'll have to find some way to recycle phosphorus, potassium, and other minerals: otherwise, growing high-yielding plantations will require large applications of fertilizer each generation — a process that uses considerable energy.

According to the Forwood Panel on Forest Resources, the land in classes one and two amounts to 17 million hectares — about the same as the total area cultivated in any one year in Australia. More than half of this is already reserved for wood production, and a small, but steadily increasing, proportion is being incorporated in national parks.

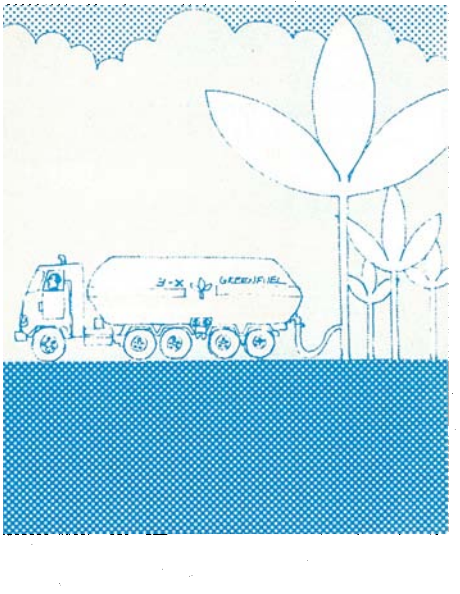
It seems unlikely that the land now used to produce valuable wood will be turned over to plantations for fuel production and, from today's viewpoint, even less likely that a large segment of the community will tolerate land in national

The prospect of planting millions of hectares of plantations, be they eucalypt or pine, seems daunting indeed.



They don't have to run on petrol. With a little modification their motors can use ethanol, which can be made from plants. According to one estimate, ethanol made from the cassava plant would cost about twice as much as taxed petrol at the pump.

Coal-mining at Goonyella, Qld. Coal is usually mentioned as the most likely raw material for making liquid fuel.



We already consume twice as much energy in the form of oil as is stored in our agricultural crops.

parks (and quite probably large areas outside also) being used for this purpose. So, at most, only a few million hectares seems likely to come from existing native forests.

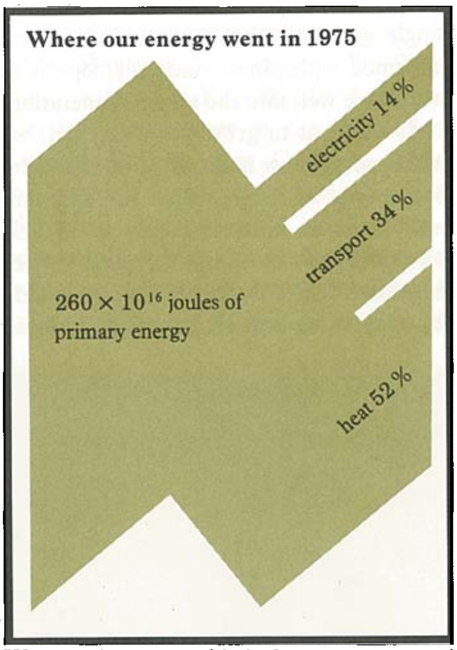
Where can the land come from then? Mr Henry Nix of the CSIRO Division of Land Use Research has calculated that some 25 million hectares of land in Australia could still be used for agriculture. But nearly all of this is country away from the coast in northern New South Wales and southern Queensland. It has a relatively low and erratic rainfall, and wouldn't be suitable for growing productive plantations.

Another source may be agricultural land in high-rainfall areas that is only marginally economic under its present use. Nobody seems to know how much land would be involved. Some is in fact being bought for forest planting, particularly in Victoria. It isn't likely to total more than a million hectares and, to be usable, large segments will need to be concentrated around population centres to keep harvesting and transport costs down.

'Cocktail' best bet

So in practice, obtaining millions of hectares of land suitable for growing high-yielding plantations will be very difficult. Moreover, any trees grown for this purpose could also be used for paper-making.

This inability to compete with alternatives is, of course, the problem when growing any crop for fuel. Sugar is valuable, and even the starch in cassava may be more valuable for other purposes than for conversion to energy. So what can we conclude?



We use about one-third of our energy as liquid fuel for transport. Can alcohol be used as a substitute?

Without doubt, if we really need to, we can grow a small portion of our fuel needs from energy crops. If we want to obtain a useful proportion of our liquid fuel from renewable plant resources, then the answer doesn't seem to be to try to grow a single type of tree or other crop. Instead we will have to go for a 'cocktail'.

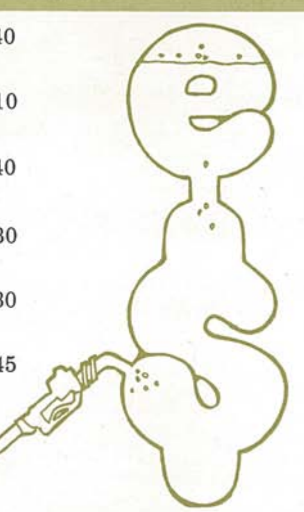
One further source of plant material not so far mentioned is the wastes left behind by existing food- and fibre-growing agriculture. Dr Gifford has calculated that after the wheat harvest has been brought in, the equivalent of some 20×10^{16} joules remains as wheat stubble in the paddocks. In addition, sawmill wastes (resulting from the process of cutting logs into planks) and other slabs and residues remaining in the forests after logging represent another 20×10^{16} joules. On top of this, yet another potential $6{\cdot}4\times10^{16}$ joules finishes up in organic matter in urban garbage and sewage.

Added together, these make up the equivalent of about 15% of Australian energy consumption in 1974. Perhaps these organic wastes can make a small but useful contribution to our energy supply?

Considerable research has already gone into finding uses for sawmill wastes (see *Ecos* 12). The CSIRO Division of Building Research's recently announced development of a sawdust building brick is but one example. And a quite substantial amount of liquid or gaseous fuel could be recovered from the wastes, even

The cost of energy from different liquid fuels

fuel	raw material	manufacturing process	comparative cost ($ per 10⁹ joules)
alcohol	cassava tops and tubers	enzyme hydrolysis and batch fermentation	8·40
alcohol	eucalypts	enzyme hydrolysis and batch fermentation	20·10
alcohol	eucalypts	acid hydrolysis and batch fermentation	13·40
pyrolytic oil	wheat straw	flash pyrolysis	3·30
pyrolytic oil	eucalypts	flash pyrolysis	4·30
petrol at 15·4 cents per litre			4·45



The calculations of Dr McCann and Dr Saddler suggested that in 1976 the energy in alcohol made from cassava would cost about twice as much per joule as that in petrol. Flash pyrolysis is still only at the experimental stage.

though most existing sawmills cannot burn the wastes as fuel.

Of interest here is some more research carried out by the Division of Building Research. Each year, sawmillers in Gippsland and southern New South Wales already supply about 150 000 tonnes of wood chips to the Eden terminal. These come exclusively from slabs and edgings produced during sawmilling, and make up about one-eighth of the woodchip output from Eden. While the millers derive a worth-while profit from selling the chips, scientists at the Division have calculated that the waste may be worth more if used as an energy source. It seems that using the currently chipped sawmill residue as a simple fuel for near-by country industries rather than for the production of pulp may come to offer a better return.

Another interesting line of research being followed in the Division suggests that powdered charcoal mixed into fuel oil may extend how far the oil goes.

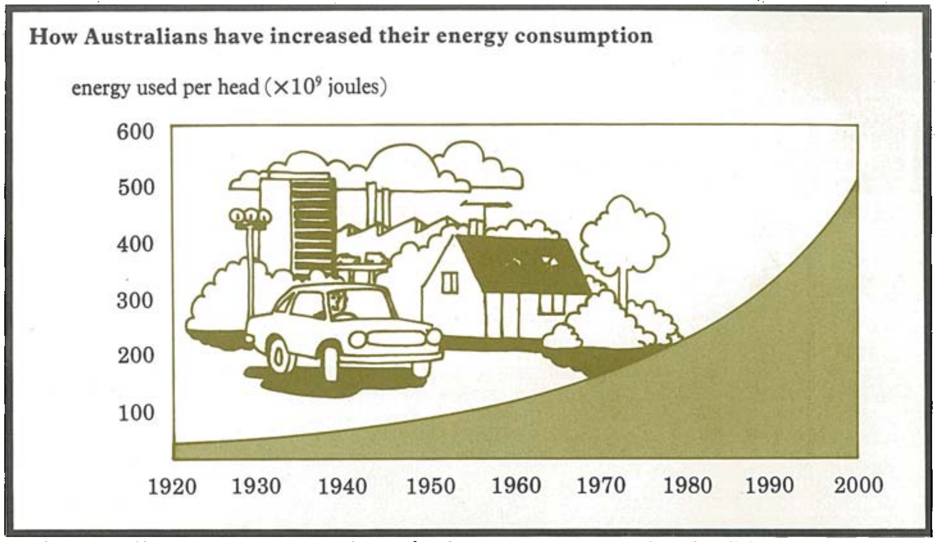
Using wheat straw

Dr McCann and Dr Saddler have investigated using the residue of wheat straw remaining in the paddocks after harvesting. The problem here is to collect and process the residue without using more energy than is harvested.

Their studies suggested that, from the national viewpoint, collecting the straw residue would not make much of a contribution. However, at the farm level the residues could make a very great impact.

Another article in this issue looks into using wastes such as straw by digesting them in methane digesters on the farm. By this means, some wheat-farmers may be able to make their farming operations almost completely independent of fuel brought in from outside. But successful on-farm digesters have not been perfected yet, and even when they have, not all wheat farms by any means will be able to take advantage of them. In fact, according to Dr McCann and Dr Saddler, using stubble is only a possibility for farmers growing wheat on some heavy soils. For example, on light sandy soils common in the mallee and other parts of the wheat belts, much of the stubble must remain behind to conserve the soil.

Perhaps it's in country areas that fuels made from plants will have the most impact. Agricultural residues will play their part and, although growing crops specifically for producing energy doesn't look too promising, it may well be possible, as Dr Gartside has suggested, to grow multi-purpose plants that can contribute food, fibre, and energy.



Each Australian now consumes about six times more energy than he did in 1920.

Compared with our cities, the country areas where all our food is grown do not use a great deal of fuel. For example, only about 5% of our liquid fuel is used directly on the farm. Already the cost of bringing petrol into many remote areas is high. Figures showing the real cost of petrol at country centres are hard to come by, since government subsidies and the internal pricing policies of the oil companies mask the true position. However, in some regions it may well be that producing alcohol for local consumption would cost no more. The CSIRO working party mentioned earlier in this article is looking into this at present.

From the national point of view, keeping our agriculture relatively independent of fossil fuels could have immense economic importance.

Organic wastes produced in Australia each year

	energy content ($\times 10^{16}$ joules)
cereal straw	20
bagasse from sugar cane	4
urban solid wastes	7
sawmill wastes	4
wood left in forests	20
sewage	0·4

More about the topic

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