# FORESTS, FOREST PRODUCTS AND ENERGY

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## INTRODUCTION

When the Council of the Institute most kindly invited me to give the key-note address on the occasion of this, the 50th jubilee of the Institute, it was suggested that an appropriate theme would be a review of the past, present and future, with particular emphasis on plantation forestry. Well, many people recently have written and talked about the past 50 to 80 years of afforestation in New Zealand. As far as looking into the future is concerned, I believe that this is a job for someone much better informed than I about recent trends and developments, much more flexible in their thinking, and much more imaginative; in a word, much younger. I propose therefore to go off on a different tack, although it is one which inevitably will involve some gazing into crystal balls. My theme is the relationship, or rather the various relationships between forests and energy. These include the questions of energy use in the forest products industry, the possibility of energy farming, and the energetic aspects of forestry as a form of land use.

Probably most of you here are well aware of the seriousness to New Zealand and to the world of what has become known as the energy crisis. You will be aware of the current debates about energy supply, energy demand, energy pricing policies and energy conservation. And you will have your own views on the likelihood and desirability of New Zealand having to go nuclear. You may well have thought out the implications of the pending energy shortages, in New Zealand and elsewhere in the world, on you as foresters; but since some I have talked to are not yet fully aware of their implications, I propose to give a summary of the facts and considerations as I see them.

Immediately one is faced with difficulties. A first one is to decide which of the multiplicity of energy terms to use. For electricity we think in terms of watts for generating capacity and watt-hours for electricity usage. Energy in the form of heat is measured variously in calories, therms or Btu's. The coal industry uses kilograms of C.E.'s (coal equivalents), as

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does a recent textbook on forest energy (Earl, 1975). The oil industry converts all other forms of energy into tonnes of oil equivalent, or alternatively into mbdoe, or million barrels of oil per day. However, the standard international metric unit of energy is the joule. It is such a small unit that people now tend to measure in and to convert other energy units into terajoules, or joules to the power of 12. For what it is worth, one terajoule equals about 280 000 kilowatt-hours, or approximately 25 tonnes of oil, or 40 tonnes of Waikato coal.

A more major difficulty is that any discussions on future energy demands must make many assumptions, some of which can be in the form of reasonably well informed estimates, but some of which come into the category of being mere guesswork. Thus we do not know, globally or for New Zealand, what future populations will be; we do not know how various conservation practices, more efficient energy use and differing pricing policies will effect energy demand; we do not know to what extent people will be prepared to amend their life styles if energy conservation is practised on a significant scale; and we do not how what will be the future rates of growth in gross national product. Thus we do not know with any degree of precision what will be either future *per capita* energy needs or total energy requirements. Finally, we do not know whether nuclear power technology will switch from present types of reactors to fast breeder reactors, or will ever be able to develop safe and economic fusion as distinct from fission power. And because of this major gap in knowledge we have little conception as to the extent to which the world will have to rely on other sources of energy supply.

What is known (approximately) is first the extent of fossil fuels remaining, in New Zealand and the world over, and, secondly, the possibilities and limitations of energy production from renewable resources. With a minor exception these resources rely entirely on the one continuing energy input into this planet, which is solar energy.

In these circumstances all we can do is to make various assumptions as to the minimum, average and maximum values of those alternatives which can be quantified, to set up models incorporating differing combinations of these assumptions and, in the modern jargon, to "act them out" in the form of "scenarios".

## THE FUTURE AVAILABILITY OF ENERGY

From what I have read about these various matters it seems to me that amongst the most pertinent facts and considerations affecting New Zealand's energy future are these:

(1) By the year 2000 the world's reserves of oil will be so depleted that production will have peaked and be on the decline. At some stage in the first few decades of the 21st century they will be almost entirely exhausted. This is not a wild guess but is the considered opinion of experts in the oil industry; it is based on the knowledge of presently proven resources and on quite sophisticated estimates of the diminishing rate at which new fields will be discovered. For this generalisation to be proved wrong — *i.e.*, for oil production to continue in the sort of quantities it has in recent years — it would be necessary for a new North Sea or a new Alaska oil field to be discovered every one or two years (J. C. Fair, pers. comm.).

(2) Oil prices will continue to rise at a dramatic rate, not just to keep pace with inflation in the consuming countries, but also because it will become a scarce commodity. Many people believe that before too long the world will not be able to afford to use oil as its main source of liquid fuel, nor will it be available for either electricity generation or the provision of primary energy in the form of heat. Rather it will be preserved for specialised uses such as feedstock for petrochemical and like industries.

(3) New Zealand has no oil fields of consequence and opinion is divided about the chances of any major ones being discovered. Our only known significant resource is the condensate associated with Maui and Kapuni gas. Nearly 60% of our energy use is in the form of oil, most of which is imported.

(4) New Zealand's gas reserves in the Kapuni and Maui fields amount to about 600 000 terajoules, which is less than twice our current annual energy usage. This gas will be used for primary heating, for electricity generation, and possibly for a petrochemical industry and for some years at least it will lessen our very heavy dependence on imported oil. However, on present planning the Kapuni and Maui fields will be exhausted in thirty years. While geological evidence suggests that the probability of new off-shore fields being discovered is quite high, several fields of the size of Maui, if discovered and proven, would ameliorate only and not avoid future energy crises in New Zealand.

(5) On the other hand, New Zealand does have considerable coal resources, although the estimates vary. The most reliable ones, from the Coal Research Association and confirmed by the Geological Survey of DSIR are 600 000 000 tonnes of measured plus indicated reserves, and 1 200 000 000 tonnes of inferred reserves (15 000 000 TJ and 30 000 000 TJ, respectively).

Current usage is $2\frac{1}{2}$ million tonnes per annum and at this rate the measured and indicated resources would last 240 years. Coal production obviously could expand greatly, and to a large extent could replace oil. There would be economic, environmental and social constraints on the rate of expansion. However, even if these were overcome and if it were possible to recover all the proven and indicated resources, and if it were practical (which it is not) to convert overnight to coal, the measured and indicated resources used to replace fuel oil in electricity generation and in industrial use would last for barely one generation. The Coal Research Association goes further and says that in theory (and with some assumptions) if coal were used to meet all additional electricity generation from now on the proven reserves would be used up in under 20 years (P. A. Toynbee, pers. comm.). Obviously we cannot and will not use our major fossil fuel reserves at this rate: there is another important reason, to which I will return, to suggest that we should not.

(6) New Zealand's coal reserves are still minute by world standards. There are quite enormous reserves of coal in many countries, particularly in U.S.A. and U.S.S.R but also in Australia, enough indeed to look after the world's total energy requirements, even assuming high growth rates in both population and energy use, for several centuries. As world oil surpluses dwindle, without doubt coal will be used increasingly for both electricity generation and conversion into liquid fuels. Furthermore, coal or products derived from it will once again become a major feature of international trade. It is of interest here to note that only 1.8 million tonnes of coal, doubtless available from Australia, would be the equivalent of the two 600 megawatt nuclear reactors which the 1976 Report of the Planning Committee on Electric Power Development envisages as being necessary in the early 1990s.

(7) New Zealand's major exploited renewable resource is hydro-electricity. Some 53 000 terajoules were generated in 1976-7 and the above report envisages 90 000 TJ by the year 1990-1. By this time all the major developments planned will have been completed. There will be scope for further schemes on such rivers as the lower Waitaki, Clutha, Buller, Karamea, Motu, Mohaka, Rangitikei, Wanganui and on a large number of much smaller rivers, and these could bring the total up to about 170 000 terajoules. The potential in the South Island is larger still but could not be realised without detriment to environmental values and without a complete denial of National Park principles; for this reason one would hope and expect that this potential will never be realised.

(8) The second renewable resource being used in quantity is geothermal steam. Currently only one field other than Wairakei has been proven and only one further power station is planned, the generating capacity of both being 310 megawatts. But DSIR scientists are confident that further exploration will disclose the possibility of 2000 megawatts or more. With the high load factor associated with geothermal power generation, this represents an energy potential of over 50 000 TJ.

(9) Other renewable resources have not yet been tapped. Tidal power probably has no place in New Zealand, and the technology of harnessing wave energy has nowhere been developed, much less economically proven. As an energy source it is several decades away, although its ultimate potential could be large. Wind and solar heating must have a place in the New Zealand energy scene; the fact that they will always be relatively minor in no way lessens their importance, or the need to develop them. The Ministry of Energy Resources considers that wind could possibly generate 8% of New Zealand's electricity by the year 2000 and the N.Z. Energy Research and Development Committee (NZERDC) came up with a very similar figure, 9%. Solar energy in the form of solar heating or by other means is considered to have a similar sort of potential. Thus these non-conventional, and as yet economically unproved, sources of incremental energy could between them supply perhaps 20 to 25% of New Zealand's energy requirements.

(10) As far as is known, New Zealand does not have nor is likely to discover any significant reserves of low-grade fossil fuels such as tar sands or oil shales which, like coal, are in abundant supply in other countries. Nor do we have any meaningful deposits of that other non-renewable resource, uranium. If New Zealand does opt for nuclear power (and I for one hope that it does not have to), and if most of the nuclear power industry continues to use thermal reactors burning uranium, then we will have to import our nuclear fuel requirements in some form of raw or processed uranium. Uranium itself is a commodity in short and limited supply; the world's proven resources of cheap uranium ore (*i.e.*, $15 per pound uranium oxide) have a life of under 20 years. We would certainly have to pay dearly for much more costly uranium. On the other hand, if nuclear technology advances to the point where fast breeder reactors replace thermal ones, then the nuclear power industry will have a very much longer life — long enough perhaps to take it out of the fission into the fusion era. Should this happen it will increase enormously the world's future energy supply. This is not the time or place

to debate whether it is desirable for the world to use uranium to make plutonium to breed more plutonium. The only point to be made is that New Zealand's need to become self-sufficient in energy, particularly in the form of liquid fuels, may be lessened if the development of fast breeders makes it less necessary for the world to squander its remaining fossil fuel resources on, in part, electricity generation.

(11) Finally, New Zealand uses about 360 000 terajoules of energy per year. A Ministry of Energy Resources estimate (Ellis, 1975) is that this figure could rise to 605 000 TJ by 1985-6, to 1 100 000 TJ by the year 2000, and to as much as 1 800 000 TJ in 2025. I believe these figures are over-estimates and do not allow sufficiently for energy conservation, more efficient energy use, and declining growth rates in population and GNP. The Power Planning Report envisages electricity demand and hence electricity generation (they should not desirably be equated but traditionally they have been) as more than doubling in the next 15 years. The NZERDC scenarios (Harris *et al.*, 1977) gave a wide range of estimates depending on various sets of assumptions. These estimates ranged from the very low and probably unrealistic figure of 550 000 TJ in 2025 (low New Zealand pollution scenario) through 900 000 TJ (limited growth), to about 2 500 000 TJ in 2025. You can take your pick, but in my view it is unlikely that New Zealand's energy requirements in 2000 A.D. will be less than double what they are today—*i.e.*, 700 000+ TJ—or that by 2025 they will be less than treble — *i.e.*, about 1 100 000 TJ. When considering New Zealand's future energy requirements, I believe we must think in terms of minimum figures of this order of magnitude.

What conclusions can we draw from all this? I suggest the following:

(a) Even if we reduce demand and conserve energy we do not have nearly enough conventional renewable resources to meet energy requirements in the year 2000, much less in 2025. Of the minimum figure given of 700 000 terajoules, hydro-electricity could supply perhaps 175 000 terajoules, and geothermal steam 60 000.

(b) Except for coal, we do not have nearly enough indigenous fossil fuels to make up the difference for any significant length of time, despite the possibilities of more natural gas recoveries. We could mine coal at a much faster rate, but at some cost to our environment, our economy and our conscience.

(c) We will thus continue to be a major importer of energy, particularly in the form of fossil fuels, at a time when these are going to be in short supply throughout the world and very much more expensive than they are today, possibly more expensive than the fragile agricultural-based New Zealand economy will be able to afford.

(d) Wind, solar heating, and other forms of solar energy will all help to meet the shortfall but they will not be able to prevent it.

(e) We thus have a tremendous incentive to develop as rapidly as possible all other sources of renewable energy. An obvious one with possibly the best large-scale potential in the foreseeable future is biomass-conversion, and in the New Zealand context this will almost inevitably involve the use of wood as a source of raw material.

There are further cogent reasons why we should concentrate on renewable rather than non-renewable resources. My generation and that of my parents has been incredibly selfish. In the space of a few short decades we have used up a large part of the best, cheapest and the most convenient energy resource which the world has ever known, a resource, moreover, which took millions of years to create. My children and my children's children are not going to thank us if, in the next few decades, we use up all that is left, and particularly if we squander it in the form of a crude fuel. I suggest that the revolt of youth in the 1960s will be mild in comparison with what will happen in the 1990s, when young people will fully appreciate how massively they have been deprived by their elders, and when their anger and resentment at this will become manifest.

There is a similar and equally important consideration in respect of the developing countries. I quote (Hill, 1976): "The wealthy countries of the western world have developed their economies on cheap energy. There is no way the less developed countries can follow us because there will be no cheap energy available. For the wealthy countries of the world to burn all the available oil and gas in the next 20 years, when they have quite credible alternatives, will be seen by later generations to have been an act of great selfishness." Therefore, quite apart from moral and ethical reasons, it is very much in our own self-interest to ration the remaining fossil fuels in order to minimise the social and political upheavals that must inevitably occur when it becomes apparent that they are nearly exhausted. Whichever way one looks at it, the arguments in favour of using renewable resources, and in particular of mounting the research and developmental effort necessary to demonstrate how they can be used, are overwhelming.

I suggest that there is another conclusion which could be drawn. We may be behaving like the Gadarene swine. We are in danger of running ourselves into so severe an energy crisis in the next 20 or 30 years that we may be forced to take the decision to generate what inevitably will be increasingly costly nuclear power, not because it is necessarily the right or the best decision, but solely because we have failed to explore all other alternative possibilities. In particular, we have planned for no more than a few years ahead; our planning has been for 10 to 15 years at the most. And we have failed badly to devote anything remotely approaching adequate resources to the many necessary aspects of energy research and development. Some people will consider it a tragedy if we do go nuclear. If nuclear power does prove to have unacceptable risks or is otherwise disastrous, then it will be doubly tragic if we have gone nuclear for the wrong reasons.

The implications of these conclusions have been obvious to many people for a number of years but particularly since the 1973 oil crisis which brought them sharply into focus. I think that as foresters we in New Zealand were slow at first to appreciate their significance. Thus the Forestry Development Plan of the Otago Planning District put out by the Forest Service in 1974 envisaged the possibility of making 1000 tonnes of RGP in A.D. 2001 to 2005; but there was no mention in the whole document of energy requirements, much less of energy costs or energy availability. There is no indication that the Council of this Institute has given the matter any thought. Annual reports of the New Zealand Forest Service have had little to say. The forest industries have been preoccupied with energy costs and costs alone. And recently a joint Lands Department-Forest Service Land Use Study of South Westland, an area with surely a higher than average potential for small hydro schemes, omitted energy production as one of the several alternative forms of land use they were attempting to evaluate.

Others were quicker off the mark than foresters. A symposium was organised by the Physics and Engineering Laboratory (PEL) of DSIR in 1975. Its proceedings, entitled "The Potential for Energy Farming in New Zealand", cover the ground most thoroughly. Earlier, in 1974, the New Zealand Energy Research and Development Committee had granted a series of three contracts on "Automotive Fuels from Cellulose Materials". One, to Lincoln College, was concerned with sugar beet but the other two involved wood cellulose. Cawthron Institute is investigating a coupled continuous fermentation system to produce alcohol and methane from wood sugars; and Auckland University, as is the Forest Research Institute, is working on an acid hydrolysis system, also using wood sugars as raw material. The PEL symposium dealt not only with the work on pyrolysis and gasification of wood being done at PEL itself (Cousins, 1975), but also had contributions from the Maiden Committee contractors (Mulcock, 1975a, b; Thornton *et al.*, 1975; Titchener, 1975) and from the Ministry of Energy Resources (Ellis, 1975), as well as from Uprichard (1975) and Williams (1975) of the Forest Service.

Most importantly of all, it was a team of engineers and economists working for NZERDC on a series of so-called scenarios (Harris *et al.*, 1977) which dramatically highlighted the role which forestry may be asked to play in future energy policies. Their "limited growth" scenario assumed, *inter alia*, a low and peaking growth in population, little or no growth in productivity, less emphasis on economic growth (though still with a high standard of living), more emphasis on non-renewable resource conservation, and, of most importance, the greatest possible use of renewable resources. It came up with the startling conclusion that under these assumptions not only could New Zealand avoid the nuclear option but by the year 2025 wood alone could supply all of New Zealand's liquid, gaseous and solid fuels, amounting to about 60% of our total energy requirements. There was no forester on the group which made this study.

A praiseworthy exception to our professional dilatoriness has been a small group in the Forest Research Institute, led by Uprichard, studying the technology and economics of making ethanol from wood by the dilute acid hydrolysis-fermentation route. Already Whitworth has published several valuable papers on the production of liquid transport fuels from cellulose material (Whitworth, 1976, 1977 and in press) and Uprichard gave a comprehensive paper entitled "The Potential of Full Tree Utilisation" to the 1975 symposium. Uprichard and Corson (1976) have published an informative article on energy use in chemical and mechanical pulping. Others have been active in the background research.

During the last 18 months, as the importance of the subject became more obvious, there has been a spate of activity inside and outside New Zealand. In New Zealand, industry is taking a much greater interest in energy, stimulated partly (but far from wholly) by the published results of another NZERDC contract "Forest Industry Energy Research"; the Forest Research Institute has commenced a study on the economics of energy farming, and is otherwise stepping up its related research activities; the NZERDC is giving a high priority to biomass-energy research and will soon be organising a team to undertake a systems study of the various paths or routes available; the National Research Advisory Council has accorded energy research, particularly biomass-energy, a top priority and is doing everything it can to get more money channelled into these activities; and finally many foresters, inside and outside the Forest Service, are realising that soon they may have to think of forest yields in terajoules as well as in cubic metres or tonnes.

## ENERGY USE IN FOREST INDUSTRIES

Turning now to the subject of energy use in forest products processing: the first preoccupation which the industries showed with energy was its cost rather than its availability, and today this is still so. This preoccupation is a comparatively recent phenomenon. In the early days when sawmilling was virtually the only technique of wood conversion, energy cost nothing. The bush sawmill was powered by a boiler fired with slabs; the bush locomotive, likewise, was driven by energy derived from either mill slabs or some other form of firewood, as was the hauler which brought the logs in to the landing. It was indeed that rare and enviable thing (except for the minor energy content in the manufacture of its boilers, saws, tram rails and other bits of hardware), a completely closed energy system.

When the industry moved into the next stage of sophistication, the breaking down and reconstituting of cellulose fibres into different types of panel board, it used fossil fuel energy in the form of either coal or oil, but both at cheap prices. Energy cost was not a major factor in the price of the final product, or in the profitability of its manufacture.

It was not until the advent of pulp manufacture by mechanical groundwood techniques that the industry first became really concerned about energy costs. Mechanical groundwood, whether stone or refiner, is electrical-power intensive; though contrary to popular belief not nearly as energy intensive as chemical pulp, particularly if bleached pulp is the end-product. I well remember the dismay at the power costs involved in producing the first tonnes of stoneground woodpulp made in New Zealand; these costs were small by today's standards; although, as an aside, they were still several times the cost of the stumpage paid at that time for the raw material.

It is perhaps worth commenting here on the attack which some people have made on the so-described greedy power requirements of the forest products industries. Their favourite target is mechanical pulping.

The critics have gone into print on this. Thus, Salmon (1975) has stated that, in the year 2005, processing the 35 million cubic metres which the 1975 Forestry Development

Conference gave as a target would take over 19 000 gigawatt-hours or more than the total annual consumption of electricity in New Zealand for all purposes today. Salmon assumed a product mix of 50% sawn timber, 25% kraft and 25% RGP; he had no basis for his assumptions nor did he explain the conversion factors used. Melhuish (1975) in another context made the even less justifiable assumption that the product mix would be 50% RGP and 50% other types of forest products. But she did quote authoritative conversion factors; she came up with a figure of 13 300 gigawatt-hours for RGP alone, a third less, but still a matter of concern if her assumptions were anything like correct.

Now, nobody knows what the product mixes in the future are going to be. But those of us who had a part in planning a planting programme so large that the resource created would in theory enable a new 600 tonne per day pulp and paper mill to be built every two to three years after the year 2000, were under no illusions about the likelihood of this ever happening. We realised that there would be many constraints, water, capital, skilled labour, engineering infrastructure and, not the least, energy; and we assumed that much of our exportable surpluses would continue to be sold in the form of logs or sawn timber. We probably gave insufficient thought to the energy requirements of logging and of log and timber transport to export ports, but at least we knew that they would not make the same demands as would pulp and paper.

Whatever the products mix may be, the fact is that the energy requirements for one tonne of refiner groundwood pulp, admittedly all in the form of electricity, are about one two-hundredths of a terajoule, whereas for bleached kraft they are nearly three times this quantity. The explanation, ignored by many people, is that there is a very large heat energy requirement in kraft pulping and that this comes largely from burning the black liquors. Just as 100 years ago the sawmilling industry powered itself wholly on its industrial wastes, so today does the kraft pulping industry, to a lesser extent but still to a very considerable degree.

Nevertheless, it is true that mechanical pulping is extremely electrical-power intensive, about twice as much so as chemical pulping. Further, mechanical pulp, because of its higher yield, uses more energy *per cubic metre* of wood than does chemical pulp. On this criterion, the factor becomes four instead of two. And if the comparison is made on the basis of added value per unit of electricity consumed, mechanical pulp comes out even worse still. A famous international wood industries expert once taught me a lesson by saying: "The most efficient ways in which a country can export its cheap hydro-electric power are in the forms of aluminium and groundwood pulp."

It is a fact also that the forest products industry, by comparison with other sectors, is a high energy user. Contributing only 10% of New Zealand's total factory production, the forest product industries consume 25% of all industrial energy, including self-generated sources such as black liquors and wood wastes. Excluding these, they consumed in 1974 6% of all energy used in New Zealand, and 17% of all energy used in industry. For electricity the usage was 9% of all consumers and 24% of all industry. Obviously as forestry grows in importance as a more major feature of the New Zealand economy, and as its level of processing increases, the energy requirements of the industry are going to increase both absolutely and relatively. I have argued that energy will get scarcer as well as dearer. Thus future forest products industries could be faced with problems of availability as well as cost; the country just may not be prepared to allocate to it all the energy it requires.

It was doubtless this consideration which led the NZERDC to let the major contract referred to above, "Forest Industries Energy Research". I do not propose to discuss the published report (Beca *et al.*, 1976) at length, partly because of its highly technical nature, but more so because its discussions of energy problems and of energy flow patterns and balances, highly relevant though they are to different types of processes and to given forest industry units, are not wholly relevant to the theme of this paper. Nevertheless, some very pertinent conclusions emerge, particularly in respect of energy conservation. My interpretation of these and of some other trends (and here I must acknowledge the assistance given to me by one of the main authors of the report, V. Jowsey), is as follows:

(1) About one-third of the energy requirements of the industry is supplied by its own internal products — *i.e.*, wastewood, black liquor, etc.

(2) In recent years the industry has increased its usage of these products, particularly wood waste which now supplies perhaps 10% of all the energy needed. There is room for some further increases but not much; probably 80% of all mill residues are now being used and the remaining 20% are scattered around the country in small indigenous and exotic sawmills.

(3) The trade in wood waste which has developed recently, and which has contributed to this growing usage, is an indication of several trends: higher oil prices, a realisation that *any* wood is a fuel of value, and a growing need

to comply with more stringent clean air requirements.

As an aside here it could well be that future generations may consider it a stupidity that currently one department of state, for what could be a temporary military reason, is crushing and burning thousands of acres of a good adventitious and hence free energy forest. Over 30 years ago I went into print and said that one day there would be a pulp industry at Waiouru based on the large *Pinus contorta* forest then developing to the east of the Desert Road. Well, I did not think out the obvious, which is that this resource should be matched with that of Karioi Forest. Now we have the prospect of a Karioi-based thermomechanical pulp industry with a high energy demand, and apparently no thought having been given to satisfying this demand from the free energy forest next door.

(4) The industry is not particularly efficient in its burning of wood wastes. New systems of high temperature incineration using Vortex and fluidised bed boilers should be developed faster than they are, and adapted to New Zealand conditions. Better housekeeping as well as better equipment could increase efficiency significantly and hence reduce the volume of wood waste required per unit of process heat.

(5) One type of under-utilisation results from the inability of some companies to burn boron-treated residues. For this and other reasons there is an argument in favour of industries being so organised that timber treatment is always the last stage of processing. I am not aware that this principle has previously been stated.

(6) The estimated savings which the industry could make in the short, medium and long term from process savings substitutions, and the wider use of wood wastes, indicate a possible reduction in total energy from 3% to 5%, but of more importance a reduction in external fuel imports from 45% of the total down to 27%.

(7) Despite the opportunities for in-house improvements in the efficiency of providing energy from wood residues, and the possibility of using some if not all of the 20% currently being dumped or burnt without use, by far the greatest potential for fuel substitution (and hence outside energy conservation) is in the use of forest rather than mill residues. Although one company at least, Tasman, is burning in its boilers instead of *in situ* the woody content made available from pre-planting land clearing operations, no one as far as I know is harvesting and using as energy the very large volumes of logging wastes

left on the forest floor. Once this source has been tapped to the extent that is economically and biologically desirable, the only further opportunities for self-sufficiency in energy in the forest processing industries would be at the expense of forest yield, a point made very vividly in the report under discussion.

## FOREST ENERGY FARMING

Now, this brings me directly into the next subject. There is now a wealth of literature on forest energy farming, from U.S.A., England, Australia and in New Zealand from the authors already cited. An important contribution to our knowledge is in the Stanford University publication *Biomass Energy Chains,* reporting the findings of a major interdisciplinary systems study carried out at the university in 1975. It was attended by a New Zealander, Troughton of DSIR, who brought the stimulus back to the Physic and Engineering Laboratory.

The Stanford study looked both at alternative biomass resources, and at the varying routes or paths by which they could be converted into different forms of energy. This, of course, is exactly what we must do in New Zealand and have made a start in doing. We must look at alternative crops and, at the laboratory pilot plant and pre-commercial scale, at alternative processes. We must then select those that seem to be the most promising for the types of energy which we will most need. I do not believe that we should pin our faith on any one crop or any particular route or process but that we should try many. And as far as energy types are concerned, although direct heat and electricity generation are both possibilities, and the former will be of particular importance locally, I have argued that liquid fuels will probably be our highest priority.

Alternatives considered so far are sugar beet, other crops such as artichokes, grains and trees. Sugar beet has the enormous advantage over wood that nature has already accomplished for us the first step — the manufacture of sugars. Since the hydrolysis of cellulose to wood sugars has a far greater energy input than the subsequent fermentation stage, which is common to both, it is probable that the energy balance will be much more favourable. But sugar beet is a seasonal crop, harvestable for only a few months of the year and not easy to store; it will be difficult for a large sophisticated liquid fuel industry to overcome the economic and sociological problems associated with seasonality. Sugar beet has another major disadvantage (which it may share with some tree species) that its culture generally requires reasonably flat and fertile land; growing sugar beet for energy must necessarily compete for land with the most intensive forms of cropping in New Zealand. A further disadvantage could be its fertiliser requirement, involving a high energy input into its growth.

Wood has these advantages: It can be harvested the year round and can be stored easily, either on stump or after harvesting; forests can be grown on a much wider topographical and edaphic range of sites than agricultural crops; the fertiliser requirements of energy forests are probably not as high; and it is a versatile material which can be put to many other uses if it is not needed for energy. It is versatile both in an unprocessed or a mechanically processed form, and also at various stages of biological and chemical processing; thus, if need be, wood sugars could be diverted from energy usage to food manufacture or used as a feedstock for chemical industries. Amongst wood's disadvantages are its bulk, and hence its high cost of transport; the difficulty (except in the pyrolysis path) of using one of its main constituents, lignin; the vulnerability of forests, particularly monocultures, to insect and fungal damage, to fires and to climatic hazards; and possibly the relatively unfavourable energetics compared with crops such as sugar beet of conversion to liquid fuels. I think it could be concluded that on balance wood has so many advantages that forests must be a major (if not the only) source of biomass energy in New Zealand.

Foresters must now think hard about how this will best be achieved. We must think, first as to whether we will try to grow pure energy crop plantations, and if we do whether this will involve full tree utilisation with its attendant implications on nutrient recycling; or whether we should attempt to combine conventional sawlog or pulpwood forestry with energy production; or whether again, as is most probable, we should do both. If we opt for growing forests jointly for conventional products and for energy, then in New Zealand we are almost inevitably locked into *Pinus radiata*. If we are growing forests for energy alone then we could have a choice of other species and other genera. Many people have opted for *Eucalyptus*. The reasons presumably are that some eucalypts on some sites have phenomenally fast growth rates, some have the additional ability to coppice and are thus suitable for mechanical harvesting, and some also produce wood with a high calorific value. But it is dangerous to generalise about them. The Stanford study was over-obsessed with eucalypts; the study team did not include a forester, a fact which is obvious when one reads the report and sees the generalisations that are made about this genus. There is a danger that just as the thinking of the Stanford study has been transferred to PEL, so could be this rather uncritical preoccupation with *Eucalyptus* as the best energy genus.

Nevertheless, eucalypts have such a claim as the best of all tree genera for energy production that it is worth considering their place in New Zealand in more detail. Many sites in New Zealand are suitable and many species can be grown successfully here. Yet large scale *Eucalyptus* culture has generally been a failure, and the successive waves of enthusiasm for its practice have been relatively short-lived. There are many reasons for this, but the main one I think is that none of the faster growing eucalypts which have shown such promise locally have, until recently, proved capable of forming well-stocked uniform forests over large areas. In other words either foresters in New Zealand knew insufficient about *Eucalyptus* silviculture, or else the species were far more sensitive to minor site differences than *Pinus radiata* and several other softwoods. A second major reason is that the eucalypts which have been most successful in New Zealand from the view-points of vigour, of frost tolerance, and of ability to tolerate a relatively wide range of site differences, belong almost entirely to the non-coppicing ash group. Thirdly, those eucalypts which did show vigour over a range of sites and did have the coppicing habit, unfortunately proved susceptible to *Paropsis* attack. More recently, and very close to here, there has been a breakthrough in *Eucalyptus* culture, and large areas of *Eucalyptus regnans* are being grown most successfully. Not only is the stocking good and the crop uniform, but the species is outgrowing radiata pine in height, diameter and volume growth. The success is due to improved seed sources, vastly improved nursery techniques, heavy culling in the nursery beds, careful land preparation, conscientious releasing, and the application of the fertiliser urea at the time of planting. However, the sites used are good (the site index being a radiata 100 ft equivalent); and since *E. regnans* is relatively frost tender this success will not be transferable to higher altitude sites where the alternatives will be *E. delegatensis* and *E. fastigata*. Neither of these shows the same vigour as *E. regnans* on good sites although *E. fastigata* has shown exceptional promise on the Kaingaroa plateau. Both have the same disadvantage of *E. regnans* of inability to coppice.

The coppicing species which are so susceptible to *Paropsis* and which therefore have tended to disappear from the forestry scene in New Zealand are *E. globulus*, *E. viminalis* and *E. ovata*. All of these are vigorous, relatively undemanding in site requirements, relatively frost-resistant, and with the potential to produce a good dry weight production per hectare, if only *Paropsis* could be controlled. Because of the enormous advantages of being able to harvest mechanically, particularly on a coppice type of silviculture, it could be argued that, for energy development purposes alone, there is a good case for a more intensive research effort than has previously been mounted into the biological control of *Paropsis*. What is not known, even granted the success of such a campaign and the successful cultivation of these species, is whether, like *E. regnans*, they will need a regular application of nitrogenous fertiliser to create and maintain the necessary vigour. If this is so, then there could be a significant energy input into growing them for liquid fuel production, and the total energy balance may prove to be less favourable.

Although *Eucalyptus* and other coppicing hardwood genera such as *Salix, Alnus, Pseudoplatanus* and *Betula* certainly merit consideration and experimentation, it is probable that radiata pine will prove to be the major energy species, just as it is the major species for other purposes. I do not myself think that this matters at all; *P. radiata* in the future, as it has been in the past, will almost certainly be the highest volume producer over a very wide range of sites. Despite the dangers of monoculture, you do not lightly ignore a species which will outgrow nearly all others from the North Cape to the Bluff, from sea level to 1000 metres and in rainfalls from 400 mm to 4000 mm per annum. And despite some of the claims made for the growth and dry matter production of plantation-grown eucalypts in tropical countries, and of other tropical plantation species, *P. radiata* in New Zealand still rates highly by world standards as an efficient dendrological converter of solar energy into cellulose. The invalidity of the comparison between the proven performance of radiata pine in New Zealand and the implied ability of some eucalypts to outgrow the dry matter production in tropical countries, an implication made by reason of the much faster height growth, was brought home to me in Brazil. There *Eucalyptus alba,* grown on a five- to six-year coppice rotation for pulpwood, has a quite phenomenal rate of height growth: stands I saw had a mean height of 45 ft at two years ten months and 56 ft at three years nine months; but the mean annual increment was, from memory, only something of the order of 20 to 25 $m^3$ per hectare — *i.e.*, very much the same as a good average New Zealand radiata pine site.

Some recent papers have made far more extravagant claims for eucalypts, both temperate and tropical, but without specifying species or sites. Similar claims have been made for tropical hardwoods, without in this case even specifying families or genera, much less species. We need to know a lot more about these claims before we accept or reject them, for this reason. Should it be possible to grow eucalypts or other tropical hardwoods in South East Asia deliberately as energy forests, to achieve the dry weight production which is claimed for them, to convert this production into liquid fuels, and to market the end products at competitive prices, then New Zealand may be better off to use its land to grow food and fibre for export and to continue to import its liquid fuels with the earnings so generated. By the same token, if the world's massive resources of coal are converted into liquid fuels at economically competitive prices, then once again we may be better advised to import our petrol and oil and to use our land for other purposes. Nevertheless, I believe that for many reasons, economic, political, conservation of overseas funds, and above all assured security of supply, we will not rely on liquid fuels from overseas coal, or from tropical forests, but we will instead get all (or nearly all) our energy from local renewable resources, rather than from imported overseas ones.

If this conclusion is correct, and New Zealand is to grow pure energy forests (whether of *Pinus*, *Eucalyptus*, or some other genus), we must now do a lot of thinking about and a lot of research into such matters as stocking, rotation, minimum site requirements (*i.e.*, the lower threshold of productivity which would be acceptable), maximum slope limitations (*i.e.*, the extent to which we would have to use land which by reason of its topography could be in high demand for other types of cropping), and size and location of energy forests. At least three of these considerations, rotation, size and location of forests, will be influenced by the type of energy we wish to produce — primary heat, electricity, gas, or liquid fuels. This in turn will dictate the nature of the processing technology, and the process used will itself have direct effects on forest management considerations. It is thus appropriate here to consider briefly the different routes by which wood could be converted into energy.

## CELLULOSE CONVERSION ROUTES

First, of course, wood can be burnt in the open, or in stoves, for domestic heating and cooking. As an aside, of the countless millions of tonnes of wood which the world's forests have grown over the past half a million or so years during which man has purposefully been felling and using forests, almost all of it has been used as a source of primary energy — *i.e.*, for cooking and heating. Even today nearly half of all the forests felled in the world are still used as domestic fuel; and in underdeveloped countries this figure is as high as 80 or 90%. It has generally been thought that these percentages would drop and that the trend inevitably would be for wood to be converted into sawn timber and other products for shelter, furniture and other artifacts, or converted into pulp and paper products. It would now seem that the trend could perhaps be reversed and that world forests may well have to revert back more to their original role.

Secondly, wood can be burnt in furnaces to produce steam for process heat, and this is its main energy use in New Zealand today, largely, as already indicated, in the forest products industries. The steam so produced could alternatively be used for electricity generation, although the efficiency of energy conversion would not be high. By heating wood in an oxygen-free atmosphere at temperatures high enough to cause decomposition, wood can be subjected to destructive distillation or pyrolysis. The products are charcoal and a fuel gas containing carbon monoxide, hydrogen, carbon dioxide and methane, plus smaller quantities of methanol, turpentine and tars. With higher temperatures, specially designed burners and a controlled amount of oxygen, the charcoal itself can be consumed and, apart from some ash, fuel gas alone produced; this process is known as gasification. Fuel gas whether from pyrolysis or gasification could be burnt on site (or piped) for direct heating, it could be used for electricity generation, or it could be converted into synthesis gas by the removal of methane and carbon dioxide. From synthesis gas it is possible to manufacture liquid fuels such as methanol, synthetic petrol or diesel oil. Wood-derived fuel gas as a means of providing process heat in the forest products industry may or may not have immediate advantages over hog fuel for firing boilers, but it will be seen that in other contexts gasification has a wide range of possibilities, not the least of which is that it gives one route from wood to liquid fuels.

The other routes are chemical and biological rather than physical. Cellulose can be converted to wood sugars by various chemical processes (of which on current thinking the most appropriate appears to be the so-called Madison process involving hydrolysis with dilute sulphuric acid at high temperatures and pressures). The wood sugars can then be fermented using yeasts to ethanol. Alternatively, it may be possible to hydrolyse wood biologically, by the use of enzymes, but a great deal of research is still needed into this process; once again the end product of enzyme hydrolysis could be fermented to ethanol. Another possibility is the anaerobic digestion route whereby bacteria convert cellulose to organic acids, and further bacteria convert these acids to methane.

Research into these processes is being done at Auckland University (a concentrated sulphuric or hydrochloric acid hydrolysis), at the Forest Research Institute (a weak sulphuric hydrolysis), at Physics and Engineering Laboratory, DSIR (gasification), and the coupled continuous fermentation system at Cawthron. Research on alcohol from sugar beet is being undertaken at Lincoln College, and on the production of methane from agricultural crops by the Ministry of Agriculture and Fisheries at Invermay.

The research effort is meagre when one considers the magnitude of the problem and the great potential for worthwhile returns of national importance. Research is hampered by a paucity of skilled workers, but more so by the lack of adequate laboratory equipment. Currently workers in this field cannot make enough wood sugars to do the necessary experimentation with different fermentation processes; the money involved is not great and it is hoped that the Government will recognise this as being of a high priority and will make the necessary financial provision.*

However, a much larger problem is looming; very soon (if not immediately) it will be desirable, indeed essential, to move from the laboratory bench to pilot-scale plants. In the case of gasification the money involved need not be large — PEL estimates that the cost of a 20 tonne per day gasification plant would be between $60 000 and $100 000. On the other hand, preliminary estimates for a 20 tonne per day hydrolysis fermentation plant amount to over $1 000 000. In neither case could it be said that the economics have been proven; indeed it is largely for this reason that pilot scale or pre-commercial plants are necessary. Industry cannot be expected to install them without considerable financial incentives.

The question, and it is currently one of the most important in the whole field of forestry energy farming, is how can the necessary finance be arranged. If petrol tax moneys cannot be allocated, I have three suggestions. The first, already being canvassed by other people, is that pilot-scale wood-based liquid fuel or fuel gas plants would be desirable ventures for the Development Finance Corporation to finance. The second is that the New Zealand Forest Service Waipa Sawmill should revert, in part at least, to its original role as a demonstration unit, a role which no government has yet officially changed. Just as Waipa led New Zealand into sawmilling techniques designed to convert small diameter, knotty, exotic sawlogs, and subsequently (at some loss of profit) pioneered developments in the field of timber preservation, so could it be used

*It is understood that this has now been done.—Ed.

as an instrument of government policy to undertake pilot-scale or pre-commercial trials, in the first instance of gasification, and at a later stage, in conjunction with FRI, in the hydrolysis of wood and subsequent manufacture of alcohol.

Thirdly, this paper has stressed the fact that processing the large volumes of wood which New Zealand is growing will place very heavy demands on New Zealand's energy resources in the future. It has also stressed that the forests themselves can help them meet this energy demand. The forest products industries are going to be hard bit by rising energy costs but of all industries they have the opportunity to reduce these costs by using some of their own resources. They therefore have a great incentive to make this possible. In another field the industry itself pressed for a joint industry-government research effort; this was in logging, and today we have the healthy and growing Logging Industry Research Association. I suggest that it could well be in the best interest of the forest industries and of New Zealand for the formation, perhaps not now but at least in a few years, of a generously funded and endowed Forest Energy Research Association, to which industry itself also contributes. I commend this thought to both the forest industries and the Government.

## IMPLICATIONS FOR FOREST MANAGEMENT

Turning now to the influence of processes on forest energy farming. The size of the energy forests will be affected in two ways — first, through the minimum scale of conversion operation which is considered to be economic, and secondly through the degree of efficiency of energy conversion. No one yet knows what is the minimum economic size for a gasification plant; indeed, there is probably no single answer since the size will itself be dictated by the use to which the fuel gas is put. Technologically it is probable that the plants could be quite small; and if the gas is piped, rather than used *in situ*, then one could envisage a large number of small plants. It would be a great boon to New Zealand forestry if, in the areas where there is no market for pulpwood, fuel wood markets could be created. These would give small forest owners, particularly farm foresters, an outlet for thinnings and logging waste, and likewise give small sawmills and other processing industries an economic answer to their residue disposal problems.

On the other hand, if liquid fuel is to be produced, then almost certainly the scale of operations will have to be larger. Again we do not know what sort of scale would be most economic but Titchener (1975) has suggested that 225 air-dried tonnes per day would be practicable. Assuming a yield of 15 tonnes per hectare year, this would require a forest of only 4300 ha. As a matter of interest, Titchener in the same article estimated that 100 such plants would supply all New Zealand's road fuel requirements.

The efficiency of conversion for different products and by different processes must also obviously affect the areas of forest required for given forms of energy. To illustrate this point, Troughton and Cave (1975) in their calculations of the total forest area required to meet all New Zealand's current energy requirements (360 000 terajoules) quoted 1.5 million hectares for low-grade gas, 2.1 million hectares for methane, and 2.9 million hectares for electricity or transport fuels. Note that the difference in estimates of area requirements is of the order of 100%.

The other important interrelationship between type of process and the forest grown to supply it is in the field of nutrients. In the hydrolysis-fermentation process it is reasonable to suppose that the key elements, potassium, phosphorus, nitrogen, magnesium, etc., would be unaffected and hence (in theory) available for return to the forest; although if the lignin is burnt for process heat the nitrogen would be consumed. One of the areas still in need of research is concerned with the techniques and costs of recovering and re-applying these elements. On the other hand, the gasification route, involving as it does much higher temperatures, may either consume certain elements or render them into an insoluble glassified form, with the result in either case that there is an unavoidable loss. We do not know the constituents of the ash from gasification and once more we must mount the necessary research to find out.

I am led now to one of the major matters for consideration if we are to practise energy forestry. It is the extent to which whole tree logging is an essential facet of the operation, and if so what will be its effects on the nutrient cycle. It has already been pointed out that forest wastes now constitute the only sizeable unused resource; they offer the only major possibility for making liquid fuels from sources other than pure energy forests or, at the expense of pulpwood or sawlog yields, from parts of existing commercial forests. What is of particular importance is that they are available now; there is no need to wait for energy forests to grow. The resource is considerable. C. J. Kerr of Tasman, in conjunction with the Forest Service, has done a preliminary survey of the weight of the chipped material from the crowns of trees which would become available annually if all forests of all tenures on tractor country in the Bay of Plenty were managed on a 20-year rotation. The total comes to no less than 1 600 000 green tonnes annually, say, 700 000 air-dried tonnes, more than enough (again according to Titchener) to enable all petrol used in New Zealand to have a 10% ethanol blend.

This large resource could be further and quite considerably augmented by the use of stumps, a practice that is developing in some other countries. It is not recommended here for a variety of reasons: stump removal would play havoc with soil profiles, and on many soils could create drainage problems; it would further deplete the soil of possibly available nutrients; it would be an energy-intensive operation; the stumps would require cleaning to remove mud and stones whether they were to be used for hydrolysis or for gasification, and this latter process would also be energy-intensive as would chipping material of such an ungainly shape. Let us therefore consider the above-ground biomass only.

The research work at FRI carried out by Will (1964, 1968) and more recently Madgwick (1977) has given us some good information on which to measure the nutrient depletion which could be caused by whole tree logging. Madgwick's work shows that, whereas in a 22-year-old stand stemwood comprises 70% of the above-ground dry matter, it contains only about 20% of the nitrogen and phosphates, 40% of the potassium, and 50% of other elements. By contrast, the needles and branches contain nearly 60% of all nitrogen and phosphorus and over 30% of potassium and magnesium. Further, the amount of nutrients in the crown at the time of felling is only about one-tenth that which would have been returned to the soil by needle fall during the life of the stand. From these figures we can conclude that, on pumice soils anyway, the rate of soil depletion in conventional logging with only the stemwood removed is slow, but that it would be increased to an undesirable extent if whole tree logging were adopted. Further evidence of the nutrient importance of needles and small branches comes from Madgwick's simple but telling statement "thinning to waste at age 8 . . . is equivalent to a very heavy application of fertilizers to the remaining trees".

Since in energy forestry we must aspire to the optimum or near-optimum re-cycling of nutrients, thus avoiding the need to apply energy-intensive fertilisers; and since we are also interested in maximising dry matter production, it would seem that the best solution is to devise a means whereby the leaves and small branches are not removed but that all chippable wood is. This could possibly be done in two ways. One is by the use of flail debarkers, which are currently operating successfully at Kaingaroa Forest. Flail debarkers can be used only in clearfelling, on trees which are reasonably uniform and are not very heavily branched, and on country of easy topography. Their use would have the advantage that the nutrient-bearing needles and branches would be put back on the forest floor *in situ*. There is probably a research need to develop specialised flail debarkers which could operate on the crowns of 20 to 25 year old radiata pine and on country of at least moderate topography. The other possible method would be to separate mechanically from the solid wood chips the macerated needles and pulverised bark which emerge in an air-stream from a whole tree chipper, and to return this material to the forest. A disadvantage would be the cost of spreading it. Again research is necessary to see how practical and economic this approch would be.

The work of Madgwick and Will has a further major implication on energy forest management. Because the proportion of solid wood to needles and branches increases with age, it follows that the proportion of nutrients removed must decrease with age. Thus the shorter the rotation the more rapid the rate of nutrient depletion. This could be a compelling argument against short rotations for energy forestry, whatever the species.

On present knowledge it would appear that it should be practicable to separate needles and branches and leave them on the forest floor; and that if this is done, and in addition if the nutrient-bearing residues from the conversion process can also be returned, then we may be able to practise a compromise type of whole tree energy forestry which is efficient enough in nutrient re-cycling to continue for many rotations before any fertiliser input becomes necessary.

One wonders whether we should not be doing more research to evolve biological means of maintaining soil fertility, particularly in respect of possible nitrogen deficiencies. In the forest-cum-grazing concept it should not be too difficult, through clovers and animals, to maintain a good nitrogen balance. In more conventional forest management systems it may be prudent to look for nitrogen-fixing species either as an admixture, or as an understorey or as a temporary part of the successional stage. Why, for instance, should the benefits which lupins can confer on sand sites not be transferred to other soil types? And why should alders have found a place only in mountain re-vegetation work? Are there other nitrogen-fixing genera whose development would be compatible with acceptable regimes of radiata silviculture? Answers to these questions again are of importance to energy-self sustaining forestry, whether or not the end products are energy itself, the more normal forest products, or are a mixture of both.

Whatever the answers, we could safely make a start by harvesting current logging waste in sufficient quantities to fuel one or two of the types of pilot plant which have been suggested. Logging waste is costly material to collect, and the landed cost per oven-dry tonne would certainly be well above what one could afford to pay to make ethanol as a commercial petrol substitute, or methanol as a source of commercial fuel. But the material is there; it is an energy source currently being wasted; and somebody has got to commence operations on a less than economic basis so that we do know the answers to all the many technological and engineering questions by the time that operations do become economic. And, at the rate at which oil prices are going up, this time might not be so far away. It will be a great pity if nationally we do not start making energy from renewable resources just as soon as it is economic to do so, solely because we have not done the necessary research and development work in time. What a good joint exercise this would be for the Forest Research Institute and Waipa Sawmill, and what a feather in the cap it would be for the Forest Service if within, say, three years (which I believe to be possible) it demonstrated to the rest of the country what could be done by having every Forest Service vehicle in Rotorua Conservancy powered with 20% of ethanol made from logging wastes. A plant with an input of only four tonnes of oven-dry wood per day could supply it. It would cost very much less than the $1 000 000, 50 tonnes pilot plant already mentioned.

## FARMING AND FORESTRY ENERGY USAGE

There is little time to discuss the final subject, the relative energy demands of forestry and farming as forms of land use. It is probably reasonable to assume that New Zealand agriculture cashes in pretty well on renewable energy resources; it uses solar energy to grow pasture for twelve months of the year; it uses clovers to fix atmospheric nitrogen; and it uses animals to distribute and re-cycle nutrients. True, it has an energy input in the form of phosphate fertilisers and the aviation fuel to distribute them, in the other direct uses of liquid fuels, and in the indirect usage of other fossil fuels in the manufacture of the hardware involved in New Zealand's type of agriculture. But it is probably a small energy input compared with intensive cropping systems in other parts of the world. Professor Corbett at the Joint Centre for Environmental Studies at Lincoln College is involved in a NZERDC contract on the energy costs of crop production in New Zealand. His results will give us more information on these things; they may well show that by world standards New Zealand farming does not use, or need to use, large per-hectare units of fossil fuels to be productive. If so, this is extremely fortunate provided that the end products of New Zealand agriculture, particularly animal proteins, are things that the world will continue to want and will be able to afford.

How does forestry compare? We do not know, but the work being done by Fraser and others at the Forest Research Institute is starting to give us the answers. Once again the indications are that by world forestry standards radiata pine silviculture in New Zealand is not an energy-intensive form of forestry. As in many other plantation forestry operations, there is a high initial energy input into land clearing and a high energy usage in logging, but, during the course of the development of the crop, the energy usage is not great. Even the suggested methods of re-distributing the nutrients in needles, bark and small branches following logging could have a positive energy balance in that they could remove the need for windrowing and other land preparation operations requiring the use of heavy machinery.

It is important to make these energy comparisons between farming and forestry, because energy usage must in future be one of the many criteria on which land-use decisions are based; and the scarcer and more expensive energy becomes, then the more important will energy be considered as a criterion.

## CONCLUSION

To summarise, the production of energy from forests could go through four stages. We are already on the first, which is the use of industrial residues, including black liquors, for in-house energy. We are about to enter the second, which will be the use of forest residues for the further energy needs of the forest products industries, and possibly for some outside use also. The third may well come from the diversion of part of a forest crop to energy production, so that a given forestry-cum-forest industries complex becomes a closed energy system. It would not be too difficult to calculate for forests and industries of specified sizes and types just what proportion of the forest would have to be so diverted. In considering this sort of proposition we must be aware that the efficiency of the conversion process will determine the extent to which it is desirable to pursue it. Thus the electricity needs for, say, thermomechanical pulp could well be provided more economically from other sources. This does not mean that the conceptual goal of energy self-sufficiency need be abandoned, as long as the equivalent amount of forest-based energy is substituted and fed into the national energy system. And finally, of course, there is the fourth and ultimately most important stage, the growing of forests for energy and energy alone.

As a final thought, it was suggested earlier that most of the wood used by man to date has been for fuel. Another extremely important way in which, historically, man has deliberately used the solar energy-photosynthesis phenomenon for his own welfare has been in the field of fertilisers. I refer here to the practice known as shifting cultivation. Provided that over-population did not lead to too short a period of bush fallow, with subsequent soil depletion and soil erosion (as unhappily only too often it did), shifting cultivation was not the primitive and destructive type of land use which it has generally been thought to be. Rather it was a very neat self-sustaining closed energy system which successfully supported a classical well balanced ecosystem involving mankind as well as other biota. I believe it has many lessons for us as foresters in the pending era of energy crises. Odum (1970) illustrated the point vividly when he said, "What a sad joke that a man from an industrial-agricultural region goes to an under-developed country to advise on improving agriculture. The only possible advice he is capable of giving from his experience is to *tell the under-developed country to tap* the nearest industrialised culture and set up another zone of fossil-fuel agriculture. As long as that country does not have the industrial fuel input, the advice should come the other way. The citizen in the industrialised country thinks he can look down on the system of man, animals and subsistence agriculture. Yet if fossil and nuclear fuels were cut off, we would have to recruit farmers from under-developed countries to show the now affluent citizens how to survive on the land while the population was being reduced a hundredfold to make it possible." For "agricultural" in this quote read "silvicultural", and for "agriculture" read "forestry".

Foresters have the chance to make enormous contributions to New Zealand's energy requirements. If energy use is kept to reasonable proportions, as it could be if we accept lower growth rates in population and in G.N.P., and if we adopt sensible conservation measures, forests could supply all New Zealand's liquid fuels and more besides. There would be some land-use conflict, but not too serious a one. But if foresters are to make this contribution, and make it a lasting one, they will not be able to do it on the basis of "fossil fuel forestry".

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