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BACKGROUND INFORMATION FOR THE FIRST STEPS TOWARDS IMPROVING THE PULPING OF NEW ZEALAND GROWN EUCALYPTUS SPECIES.

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by Phil Cannon

ABSTRACT

The New Zealand Eucalypt Breeding Cooperative is already breeding three species of eucalypts, namely *Eucalyptus regnans, E.nitens* and *E.fastigata*. The focus of selection to date has been on volume, and, to a lessor degree on form.

However, in view of the fact that the main anticipated use of all three of these species is for pulpwood, the question must be asked, "are there any wood characteristics which might be advantageously selected for as well?"

This paper attempts to answer this question, beginning with a review of pertinent literature from New Zealand, Australia and the world as well as with conversations with some of Australasia's eucalyptus pulp and paper researchers.

The final answer as to what should be bred for is not yet obtainable, however, the consulted sources of information do shed some light.

Where the kraft pulping process is to be used, benefit would be derived for breeding all three eucalypt species for high density although there is some question as to the quality of fibres to be obtained from denser eucalypt wood. Benefits for breeding for other properties (pulp yield, extractive content, fibre characteristics) were far less apparent and may not be appropriate for New Zealand. For mechanical pulping the optimal wood characteristics are far less well defined since it is not even known which pulping process will be best; there are, however, some indications that low density wood is preferable for at least some processes.

One concept that is important for pulping foresters and pulping people used to working with *Pinus radiata* to recognise is that the wood of the eucalypt species is very different from that of the pine. Following on from this fact is the situation where the fibre characteristics sought following pulping of a eucalypt are very different from those of a pine because the pulp will be employed for producing different types of paper. Because of these circumstances, different pulping procedures are appropriate for the eucalyp's wood, especially where mechanical pulp is being made.

BACKGROUND

There are two broad aspects of eucalypt pulping which will be dealt with here:

(1) The first is, why bother to be concerned about eucalypt pulping in the first place
and, assuming the first aspect can be satisfactorily resolved,

(2) which eucalypt pulping experiments are appropriate for the N.Z. Eucalypt Breeding Cooperative to support at this time.

Towards addressing the first topic, it is assumed that if a breeding programme is in place for a species (which is already the case for *E.nitens, E.regnans* and *E.fastigata*) the objective will be to increase the value of such a species through breeding efforts which will enhance the value of that species as efficiently as possible. If breeding for a wood characteristic falls within the bounds of this criteria, then that characteristic should be bred for. Since pulpwood is by far the largest anticipated use of the eucalypts being grown in New Zealand, breeding to increase the amount and quality of that pulpwood or at reducing the cost of processing a unit of that pulpwood makes sense, if it can be done and done efficiently.

Another aspect of this first question is why do the research in New Zealand. As will be seen ahead a tremendous amount of research of this very nature is going on in Australia. Why not just borrow the results of these efforts.

To a large degree, borrowing will take place, but this will not be enough. For one thing different genotypes are being grown in the two countries, under very different environments (the soils in New Zealand's main eucalypt growing areas are derived from volcanic pumice whereas the soils in Australia are commonly derived from sedimentary rocks or slowly-cooled volcanic materials; the climates of the areas where eucalypts grow in these two countries are also significantly different and so too are the biota that is currently present that can feed on the eucalypts). Also, the process for making pulp in different plants in the two countries varies considerably, particularly where mechanical pulps are concerned.

Furthermore it is not kosher to just borrow information and such a practice is not sustainable over the long run. Australians would eventually realise that the transfer of information was unfavourable to them and the sources would clam up. It will be important to be able to trade research information on a tit for tat basis, hopefully with each country contributing research from areas in which it is best equipped and qualified. There will be many formal and informal opportunities for doing this. The formal events in which it will be possible to exchange such information are the annually-held Appita Conference, and the conference titled "Improvement of eucalypts for intensive wood and fibre production" (IUFRO working parties S2.02-09 and P2,02-01) to be held in Hobart in February 1995.

Finally, it is likely that the only way pulping expertise is to be gained efficiently here in New Zealand is through experience, and appropriate experimentation will give useful experience.

If it is then accepted that experiments should be conducted, the next question is, which ones. Towards addressing this question, some brief considerations need to be taken regarding *E.nitens, E.regnans* and *E.fastigata,* the three main species that are to be pulped.

E.nitens is worthy of special comment because it can grow over a wide range of climates in New Zealand. Its ability to withstand winter frosts down to -14°C and summer frosts down to -3°C enable it to tolerate conditions found in approximately 70% of New Zealand. Recognition of variation in the two major good provenances of *E.nitens* is also important. The provenance called "central Victoria" is recognized for having slightly superior growth rates in cooler parts of New Zealand and of having slightly greater frost tolerance than the provenance called "southern New South Wales". However, the southern New South Wales provenance is also capable of very fast growth and is less susceptible to leaf-spotting fungi, a feature which may make it much better suited to the warmer and wetter parts of New Zealand. In fact, both of these provenances have their own breeding programme.

Eucalyptus regnans is an enticing but tricky species to deal with. It is capable of extremely fast growth and excellent form in plantation situations, but this is with the proviso that site and silviculture are adequate; there are a lot of conditions which are adverse to optimal development of this species. When there is too much soil moisture, the species develops *Phytophthora* root rot, when soils are shallow, or otherwise infertile, growth is slow and the trees develop a thin chlorotic crown, when there is too much competition either from weedy species (especially grasses) or neighbouring trees, they fail to put on good diameter growth, where there is ample air humidity during the spring and summer, the leaves can become severely infected by *Mycosphaerella sp. Aulographina sp.* and other leaf spotting fungi. And, when temperatures dip below freezing (-1°C in summer, -7°C in winter) *E.regnans* leaves get scalded. In brief, therefore, *E.regnans* has a tremendous potential on some well drained, well aerated sites below 450 masl on the North Island. It probably should only be grown by foresters who can afford to be very careful.

E.fastigata is a much more forgiving species than *E.regnans,* this is partially because its foliage is much less affected by leaf-spotting fungi. For this reason it can be planted over a wider range of sites than *E.regnans.* Unfortunately it has much slower initial growth than either *E.regnans* or *E.nitens* and is prone to having poor form. It is also vulnerable to *Phytophthora* and frost to about the same degree as *E.regnans.*

In addition to these types of siting observations, silvicultural research is helping find progressively better ways of growing all of these eucalypts. Intensive and vigilant plantation practices are generally required if the genetic potential for growth of these eucalypts is to be realised.

LITERATURE REVIEW

In terms of the best pulping options to explore for the three mentioned eucalypt species and in terms of information concerning which wood properties to breed for, there are three handy sources of information which might be consulted to provide insight.

(1) New Zealand pulp and paper research information;
(2) Australian pulp and paper research information;
(3) The worldwide "literature" on the breeding of eucalypts with specific regard to improving their properties for pulping and paper making.

Each of these will be explored briefly, in turn.

NEW ZEALAND:

In New Zealand, very limited amounts of information on the pulping properties of eucalypts are available to the public. From the industries, NZFP became the only pulp company to have published on the results of some eucalypt research when they published the following:

> Crane, J.A.; Lim, H.H.K.; Iremonger, S.M.; and Blows, W.J. 1987
> Pulping and bleaching of plantation grown *Eucalyptus regnans* and *Eucalyptus fastigata*. Appita 40(5) pp 367-371.

These researches looked at results of kraft pulping and chlorine dioxide bleaching of 3 ages of *Eucalyptus regnans* wood (8, 12 and 20 years) and 3 ages of *E.fastigata* wood (7,12 and 20 years). They found that *E.regnans* gave slightly higher yields of pulp than same-aged wood of *E.fastigata* and that the older *E.regnans* (12 and 20 years old) gave higher yields (54%) than younger *E.regnans* (8 yrs old)(52%) when pulped to the same Kappa number (15). All pulps could be bleached to an ISO brightness of 87+%. The *E.regnans* was determined to have a greater collapsibility than several other hardwood species, a feature which gives handsheets made from its fibre a high tensile index/scattering coefficient relationship and low bulk.

Results of several other studies done by NZFP or by FRI for NZFP remain confidential.

Caxton's has also done a very limited amount of work involving the use of eucalypts as a part of the stock (50% with *P.radiata* wood composing the other 50%). To date this has mainly been kept in house, however it is known that Caxton uses a variation of the Slave Lake process that has been so successrul for pulping aspen in Canada and, recently, Caxton has agreed to provide a large in kind study on the mechanical pulping of *Eucalyptus nitens* and *E.regnans* for the benefit of the Eucalypt Breeding Cooperative (more on this later).

At NZ FRI, the sole publication to emerge on eucalypt pulp has been

> Kibblewhite, R.P.; Bawden, A.D.; and Hughes, M.C. 1991. Hardwood market kraft fibre and pulp qualities. Appita 44(5) pp 325-332.

In this paper, market kraft pulp of 10 different hardwood species/sources (all grown outside of New Zealand) was subjected to various measurements. The significant finding of this effort (see Table 1) was that fibres for most of these species are generally of fairly constant short length (0.75-0.97mm), that *E.regnans* has fibre walls which are thinner than any other hardwood species examined (i.e. it has the lowest coarseness) and that the number of fibres per unit mass of *E.regnans* wood ranks among the highest of all of the hardwoods.

In talking about the implications of this paper, Dr Kibblewhite indicates that the extremely low coarseness of the *E.regnans* fibres may be a bit of a problem when it comes to kraft pulping because the fibres will be too comformable and will not give the bulk and the better light scattering properties that a stiffer fibre might give. (Note stiffness or non-conformability is a virtue in hardwood fibres because it is bulk and light scattering properties that are particularly important for these rather than strength properties (brought on as a result of longer fibres and greater conformability) which are often of considerable importance in softwood fibres). For this reason, it is likely that breeding for greater fibre coarseness may be the logical component of a *E.regnans* breeding programme where that wood would be destined for kraft pulp. If the size and distribution of vessels and the percentage of extractives was the same for all regnans wood, this would mainly entail breeding for greater bulk density.

However, whereas the coarseness of a *E.regnans* fibre may be objectionably low for kraft pulp, low coarseness may be no problem at all in mechanical pulping because in this later process lignin is not removed from the fibres as they are separated from each other. For mechanical pulp, the retained lignin may well endow these fibres with sufficient additional stiffness to allow them to give good bulk. Other properties (such as electrical energy requirements) are more important for mechanical pulping, however so far there are no well defined measurements that can be made on a piece of wood with the hopes of predicting how it will behave during mechanical pulping.

One item, however, which would be important for both kraft and mechanical pulping is to lower the amount of extractives. In kraft pulping extractives are a significant cause of increased chemical consumption and lower pulp yields; in mechanical pulping they interfere significantly with the bleaching process.

Dr Kibblewhite does not have much information in his database on *E.nitens* or *E.fastigata* and indeed has only had the opportunity of looking at some pulp from some five-year-old *E.nitens* from APPM. His initial impression was that it is very similar to the fibre of *E.regnans* (i.e. it has low coarseness) but he would very much like to broaden his database.

Dr Kibblewhite has also contributed two other papers on eucalyptus pulp in the 47th Appita Annual General Conference. They are titled:

(1) Refining energy demand, freeness and strength of separate and co-refined softwood and eucalypt market kraft pulps; and

(2) Reinforcement and optical properties of separate and co-refined softwood and eucalypt market kraft pulps.

Undoubtedly the development of these papers provided some of the insight for his comments cited in the foregoing paragraphs.

This brings us to the most encouraging aspect of eucalypt pulping research in New Zealand; although little has been done on this particular topic to date, the country can count on some outstanding pulp and paper scientists namely:

Stuart Corson John Richardson Karl Murton	Mechanical Pulping
Paul Kibblewhite Bob Allison Merv Uprichard	Kraft Pulping

and these scientists have all expressed an eagerness to look into the potential of eucalypts for pulp. Furthermore, they are backed by excellent laboratories (PAPRO has the best laboratory for studying mechanical pulping processes in the Southern Hemisphere) and by a very experienced laboratory staff.

In terms of wood properties of eucalypts in New Zealand, very little pertinent research has been done. However, in an examination of disks collected at breast height from twenty, 14-year-old *E.fastigata* in a progeny test, it was found that density varied from 380 to 540 kg/m^3; in this case each tree sampled came from a different provenance or family. In an examination of two cores taken at breast height of each of 131 *E.nitens* trees (all from the same provenance (Nimmitabel)) it was found that densities varied from 380 to 540 kg/m^3. In subsequent disk samples taken at stump height and at three meter intervals in 12 of these same trees, it was found that core samples had underestimated the density of the stump disk by an average of 30 kg/m^3 and that density increased very slightly (by about 10 kg/m^3) with each 3m. increase in height. In all of these examinations, the Eucalypt Breeding Cooperative provided the samples and the Wood Technology Group made the density determinations.

AUSTRALIA:

Several Australian research groups and industries are also actively engaged in eucalyptus pulping research. The recent creation of the Cooperative Research Centre for Hardwood Fibre and Paper Research has provided a particular boon. As in New Zealand, much information is privileged. However, the Australians have tended to publish much much more on the topic of pulping eucalypts. Initially all of this information was on the pulping of mature trees (as in very big trees from virgin or naturally established forests), but progressively there has been more research done on plantation grown eucalypts.

From the 47th Appita Annual General Conference (held in Rotorua, April 1993) the following articles are of interest:

1. D.J. Allan, M. Cukier, K.N. Maddern, K.L. Nguyen. A feasibility study on the recovery of eucalypt cold soda CMP spent liquor

2. R. Evans, G. Downes, D. Menz, S. Stringer. Rapid measurement of variation in tracheid transverse dimensions in a *Pinus radiata* tree.

3. R. Evans, D. Menz, P. Brennan. Estimation of fibre length variation in *Pinus radiata* and *Eucalyptus globulus*.

4. M.R. Vromen, R.W. Crowe. Magnesium oxide - an alkali substitute for sodium hydroxide in the peroxide bleaching of TMP pine, CSSC eucalypt and bisulfite pine.

5. A. Vincent, K.L. Nguyen, J.A. Mathews. Kinetics of oxygen delignification of eucalypt hardwood kraft pulp.

6. P.J. Nelson, W.J. Chin, S.G. Grover. Bleaching of eucalypt kraft pulps from an environmental point of view.

7. K.N. Maddern, M.J. Neilson, A.G. Jamieson. The production of eucalypt kraft market pulp without the use of molecular chlorine.

8. T.J. Smith, R.W. Wearne, A.F.A. Wallis. Effect of wood sample and bleaching sequence on the levels of chlorinated phenols formed during bleaching of oxygen delignified eucalypt kraft pulps.

9. T.J. Smith, R.H. Wearne, A.F.A. Wallis. Analysis of chlorinated organic compounds formed during bleaching of oxygen-delignified eucalypt kraft pulps.

10. M.D. Williams. Chemimechanical pulps from plantation eucalypts.

11. G. Downes, J.V. Ward. Lignin distribution in differentiating and mature fibres from *Eucalyptus globulus*: a preliminary study.

12. A.F.A. Wallis, F. Chan, K.L. Nguyen, P.F. Nelson. Chemical transformations of eucalypt wood components during kraft delignification.

13. A.J. Michell. Vibrational spectroscopy - a rapid means of estimating pulpwood quality?

Of these articles, 1, 2, 10, 12 and 13 are sufficiently germane to our purpose of determining which wood properties to breed for to deserve brief mention here.

(1) In this article by Evans *et. al.*, a technique is described for rapid measurement of all of the fibre dimensions of a pith to bark core sample of pine (a similar technique is being developed by Evans and Co. for use on core samples of eucalypts)

(2) In this article (Evans *et. al.*) it was found that the proportion of the wood occupied by vessels remained nearly constant from pith to bark in an eight-year-old *E.globulus*. They also found that fibre length increased from an average of 0.6mm near the pith to an average of 1.1 mm near the bark. The density increased from an average of 580 kg/m^3 near the pith to 800 kg/m^3 near the bark but fibre diameter remained nearly constant over this distance. This suggests that cell walls of the fibres are getting progressively thicker from pith to bark.

(10) Chemimechanical pulps were made from *E.regnans, E.globulus, E.nitens* and *E.grandis* and *E.denticulata*(!?) using the cold soda pulping process. The wood samples came from two sites, one considerably higher in elevation than the other.

E.nitens and *E.globulus* were found to give a lower percentage of fines than the other species and to give handsheets with greater tensile strength; this last feature was attributed to a greater conformability of their fibres and greater fibre length.

E.nitens was found to have a lower energy requirement than *E.grandis, E.regnans* and *E.denticulata*(!?).

It was also found that *E.regnans, E.globulus* and *E.grandis* produced lower strength pulps (and required more energy) where they had been planted at the higher elevation site. This was attributed to the effects of frost. *E.nitens* was not affected in this way by the increase in altitude. However, all species, including the *E.nitens* (but to a lesser extent) gave pulps of a lower brightness and required more bleaching when they came from the higher altitude; the reason implicated was that the wood coming from the higher site had more extractives and denser fibre walls.

[Note, one comment to be made here is that Max Williams is assuming that fibres with high conformability are desirable because such fibres tend to give paper strength. Paul Kibblewhite, however, suggests that stiffness would be more of an asset than conformability because stiff fibres give better bulk and light scattering properties which are more important in the fine paper types where hardwood pulp is likely to be used. Any strength that was needed in fine papers could be easily attained by blending in some longer, conformable, softwood fibres with the hardwood pulp before making paper.

(12) This article, by Chan *et al* describes the methods and results of studies to see what happens to the lignin in woodchips as the kraft pulping procedure progresses. At the beginning of a cook, lignin is removed rapidly but then the rate slows quickly. At the end of the cook, the lignins which are being removed have a lower molar mass.

(13) In this article, Dr Michell, explores the use of vibrational spectroscopy to estimate pulpwood quality of old growth eucalypts.

Samples of chips from 30 trees were pulped to a Kappa number of 15 and representative subsamples of these were milled, compacted into small discs and then subjected to 34 wavelengths of light in the mid-infrared spectrum. Good correlations were found between the frequencies of light most commonly absorbed and soda charge, lignin content, hot water and alkali solubles. Pulp yield could also be well predicted (the correlation was 0.944) when a multivariate model was used.

[Unfortunately, for our purposes, the wood subtrates being looked at were from different aged but mature eucalypts and of a mixture of species grown on different sites. Because these woods are much more hetero-geneous by nature, and generally have far more extractives and a much broader range of pulp yields, it is reasonable to expect that it might be fairly easy to pick up significant correlations between absorbed light and the magnitude of a given property. On the other hand, when screening a population of trees all of the species and same age, and growing on the same site, there will be much less variation in each of these properties, so a very precise technique would be necessary to detect significant differences. It is not known yet whether these spectroscopy techniques will be sufficiently precise to be used on plantation-grown eucalypts of the same age and species. It would be handy if they were]

The 46th Appita Annual General Conference (held in Hobart, Tasmania) also contained several papers germane to eucalypt pulping. Some of these have been superseded by the 47th Conference, and some appear in APPITA (see ahead) but two of these papers, which occur in neither of these references, will be dealt with here.

1. Orme, R.K. Genetic improvement of *Eucalyptus globulus* and *Eucalyptus nitens*.

2. Raymond, C.; Balodis, V. and Deane G.H. Pulp yield and hot water extract of *Eucalyptus regnans* provenances.

(1) In this article, Keith Orme states that by measuring basic density, the amount of extractives which can be removed using NaOH and the amount NaOH consumed, that individual trees can be ranked in a pulp index which is suitable for use in a tree improvement programme.

The formula is:

Selection index = 2 x (B.D. + NaOH extractives + NaOH Usage) + (Diameter + Bark Diameter)

Trees (about 60 in total) with point scores in the top 10 to 15% of all trees sampled are to be returned for the next breeding generation.

(2) In (2), the authors also looked at the possibility of using extractive content as a basis for discriminating between individuals. However, as compared with the previous paper, these authors used hot water extractives and were concerned with kraft pulp yields. Their conclusion was that the hot water extractives content was a poor predictor of kraft pulp yields when comparing trees of the same species and age and growing on the same site.

In summary, therefore, the idea of using extractives as a predictor of wood quality for pulping worked for one kind of mechanical pulp, but did not work for a kraft pulp.

There is one other article from an Appita General Conference proceedings which cannot be overlooked, this one comes from the 1990 Conference.

Dean, G.H.; French, J. and W.N. Tibbits. 1990. Variation in pulp and papermaking characteristics in a field trial of *Eucalyptus globulus*.

These authors did an exhaustive study of the literature and of the wood of 18 seedlots in an eight-year-old progeny trial of *E.globulus*. Pulp yield, basic density, moisture content percent and bark content percent were all found to be highly heritable and it was concluded that by using modern selection techniques, it would be possible to make substantial savings in growing, transport and processing costs in plantations grown from select material.

They also found that the Pilodyn technique was adequate for estimating specific gravity when samples were made at four locations about the stem.

Many other articles on the pulping of eucalypts in Australia are also to be found in the journal Appita. The following references (beginning with the most recent) are of particular interest to our current task.

> Irvine, G.M.; Wallis, F.A. and Wearne, R.H. 1993. The effect of process variables on the oxygen delignification of kraft pulps obtained from a mature eucalypt wood. Appita 46(1) 44-48.

These authors found that the initial Kappa number (an indication of the amount of lignin after the kraft pulping stage), the alkali level and the reaction temperature were more important in determining the final Kappa number (the amount of lignin after oxygen delignification) than were oxygen pressure and reaction time. They also concluded that if there were to be some improvements in the kraft pulping process, they would have to be before the kraft process began (rather than during the process) as, for instance with the soaking of the chips.

> Farrington, A.; and Malcolm, J.P. 1992. Peroxide steep bleaching of eucalypt magnefite pulp to high brightness. Appita 45(4) 389-392.

Metal ions (Fe and Al) from the wood commonly remain in the wood following pulping of plantation-grown *Eucalyptus regnans*, and this interferes with the bleaching process. When chelants are added (i.e. EDTA, or DTPA) and the pH is adjusted to 2.5 a large proportion of the metals were removable. Adding more chelant (up to 0.4% of the oven dry pulp weight) and increasing the acidity (to pH 1.5) can remove even more metals but may be antieconomical.

> Abbot, J.; and Wright, P.J. 1992. Kenetic phenomena during alkaline peroxide bleaching. Appita 45(5) 332-335.

[Alkaline Peroxide Mechanical Pulp (APMP) has been hailed by some as an exceptionally promising process for mechanically pulping eucalypts, however, to date most work on this process has been done with aspen]. In this article, the authors tried, with limited success to develop kenetic models to explain how and how fast the alkaline peroxide reacts with three known chromophores in mechanical pulp of mature *E.regnans*. [This is important because when chromophores form, the pulp gets darker; when they are removed, the pulp gets brighter]. More work needs to be done.

Williams, M.D.; Chin, C.W.J. and Nelson, P.J. 1992. A pilot plant study of alkaline peroxide bleaching of chemimechanical pulps from *E.regnans.* Appita 45(1) 14-18.

The authors give an excellent introduction as to why mechanical pulping of eucalypts is important for Australia's future, and describe several of the advances made recently which make chemimechanical pulping of eucalypts a better prospect for use in tissue and printing papers (the use of DTPA prior to bleaching and other means of increasing pulp brightness). In the experiments reported here, they found that by bleaching the chips in NaOH during the PREX stage (the pressure screw before the refiner) or in refiner rather than bleaching after the refiner stage that considerable amounts of energy could be saved and that there was no appreciable reduction in either pulp brightness or strength properties. The lower energy requirement was attributed to the softening and swelling of the fibres and good impregnation during their period of soaking in the NaOH solution. [Note, the system with NaOH bleaching in the PREX screw corresponds with the APMP (Alkaline Peroxide Mechanical Pulp) process].

Michell, A.J.; Chin, C.W.J.; and Nelson, P.J. 1991. Bleaching and yellowing of eucalypt chemimechanical pulps. Diffuse reflectance spectra of oxygen bleached pulps. Appita 44(5) 333-336.

The authors explain that although production of mechanical pulps is increasing rapidly (because of the favourable properties and economics of such pulps) it is difficult to bleach these pulps to a high brightness and have this level of brightness be maintained for the life of the product. This paper describes an experiment in which bleaching is done with oxygen, sodium borohydride and hydrogen peroxide. The result was that lower but slightly more stable brightness levels were achieved. [Still, the final level of brightness after 4 hours of exposure to UV light was only a brightness of 53, far below the level (80) achieved right after bleaching; some other treatment is required to prevent the lignin-bourne chromophores from switching back to the dark state].

Hillis, W.E. 1991. Eucalypts: Chemistry, uses. Appita 44. 239-244

The author states that the most unusual chemical feature of eucalypt pulpwood as compared with other hardwood pulp, is the high amount of polyphenolic extractives and kino. The most satisfactory pre-extraction is with sodium hydroxide for 80 min at 98-100°C.

Commonly there are large variations in the cell wall chemistry. For example, in samples from 10-year-old *E.globulus* trees from Portugal, the cellulose content varied from 49-58% (mean 53%) and lignin varied from 17.4 to 20.9% (mean 19.5%). Through genotypic selection the authors report a 3% increase in cellulose content.

The success of the cold soda process for pulping *E.regnans* is probably due to the high level (86% of all hemicellulose) of a certain type of hemicellulose (0-acetyl-4-0-methyl glucuronoxylan); In mature eucalypts, where acid conditions have prevailed in the heartwood for some years, much of the wood will have been hydrolysed. This is not the case with young [as in plantation-grown] eucalypts, so the cold soda process might not be as good for these woods.

The amount of extractives in mature heartwood of mature eucalypts can be considerable and varies from 17 to 43% of wood weight. Pulp yields and pulp chemical consumption also vary widely (i.e. 40 to 56% for *E.globulus*) and are closely related to extractive content. There are many different types of extractives, they interfere with pulping and coping with them is a major challenge in pulping eucalypts. Young, plantation-grown eucalypts have far lower levels of extractives.

The first cold soda eucalypt pulps were made in Australia in 1917, Newsprint (1921), hardboard (1938), kraft (1939), bleached soda (1939), NSSC (1962), oxidative recovery of soda black liquor (1947), CTMP (1974) and anthraquinone-alkali (1977) are other pulping processes or break throughs on pulping processes which have been pioneered on eucalypts in Australia.

> Page, R.E.; and Schmitt, A.J. 1990. Overview: technological advancements of the paper/printing industry by the year 2000. Appita 43(3) 222-228.

These authors make several observations which will have an effect on the use of hardwood fibres. At present offset printing accounts for 45% of all printing processes. Colour advertising is the big consumer of printing papers and this use really puts the paper to the test because it has to handle several different colours and different press units,

- De-inked pulp, especially when it is fractionated, can be used to provide a very cheap source of paper furnish [Note : here it would be competing with hardwood fibres]

- Sheets will be stratified meaning that high quality fibres will be layered on the outside of a paper to give it good brightness and smoothness while the cheaper, less presentable fibres will go in the inside to give good bulk and good bonding. This technology is already happening for tissue and towel grades.

- Big advances are expected in the technology for improving sheet quality with changes occurring especially at the wet end and the dry end of the paper machines.

- The surface of a piece of paper will receive a tremendous amount of attention, especially in terms of the sizings which are applied.

Clark, N.B. 1990. The effect of age on pulpwood quality. Part 2. The kraft pulp properties of Victorian *Eucalyptus regnans, Eucalyptus delegatensis* and *Eucalyptus sieberi.* Appita 43 208-212

Average basic density of *E.regnans* and *E.delegatensis* was found to increase from 440 to 520 between 15 and 40 years of age and then to level off. *E.regnans* kraft pulp quality tended to improve up to about 40 years of age. *E.,regnans* pulps had a higher freeness and opacity than the pulp of the other two species.

Clark, N.B.; Logan, A.F.; Philips, F.H. and Hands, K.O. 1989. The effect of age on pulpwood quality. Part 1. The kraft pulp properties of southern Tasmanian *Eucalyptus regnans* and *Eucalyptus obliqua.* Appita 42(1) pp 25-32.

Samples of wood from natural regrowth *E.regnans* stands less than 10 to more than 110 years of age were collected at 10 year intervals. These were then chipped, pulped (to a Kappa number of 20) and bleached. Tree density increased almost linearly up to 75 years of age. Fibre length was shortest in the lowest age class. *E.regnans* had less extractives and lignin than *E.obliqua.* There were only small increases in extractive content with increases in age. The amount of alkali required to pulp *E.regnans* to Kappa 20, decreased with the age of the material up to age 60 and thereafter increased. Most of the pulps bleached well and similarly although those from the oldest wood samples were somewhat darker.

Pulps from trees over 20 years of age had more strength. Bleached pulps were slightly weaker than unbleached pulps of the same age.

Bland, D.E. 1985. Eucalypt lignin. Appita 38(1) 53-56.

Lignin is formed in *E.nitens* through the shikimic acid, phenylalanine, cinnamic acid pathway. It can be extracted from *E.regnans* wood using methanol at 150°C and then can be further separated using paper chromatography. It can also be extracted using sodium hydroxide indicating that there are alkali sensitive bonds between the lignin and the carbohydrate [cellulose]. Three types of lignin have been recognized and they have molecular masses of 35,000; 52,000 and 90,000 respectively. Lignins are soluble in acetone, alcohol and to a degree in aqueous alkali (depending on the amount of alkali in solution) but not in water. The glass transition point occurs gradually between 45 to 58°C. The amount and type of lignin varies in different parts of a tree; gualacyl-syringyl type lignin is the most common type in the heartwood and sapwood of the tree. When subjected to strain, Eucalyptus spp. form a reaction wood on the tension side. The percentage of lignin is low in tension wood but appears to be bonded to the polysaccharides more tightly.

A study of eucalypts native to different latitudes showed that they had different lignin values. Eucalypts from the more northerly latitudes had up to 30% lignin, whereas those from the southerly distribution of the genus had only 20% lignin. Also the percentage of this lignin which was 'Klasen' lignin was 10% for the tropical species and 50% for the temperate species. There is very little known about tree to tree variation in lignin composition.

Bamber, R.K. 1985. The wood anatomy of eucalypts and papermaking. Appita 38(3) pp 210-216.

Eucalypt fibres are spindle-shaped with sharp pointed ends and have small pits which are semi-bordered. Within the genus, there is a large variation in vessel size (from 54mm to 189mm) and density. The relationship of fibre wall thickness to the lumen or whole cell diameter largely determines the wood density. Starch is stored in the sapwood in amounts that vary roughly inversely with tree growth rate. Following injury, tylosis can form through the half-bordered pits connecting the ray cells and the vessels. In eucalypts the transition from sapwood to heartwood is characterised by the blocking of the vessels with tylosis, the resorption of starch and nutrients, the deposition of materials, mainly polyphenols, and the loss of protoplasm. The heartwood colour is caused by the buildup of polyphenols, these also cause the heartwood to be more acid (pH4) than the sapwood (pH5) and to have a higher density. Within a species the width of the sapwood is relatively constant throughout the age of the tree although there are marked differences between species.

Some eucalypt species, including *E.regnans* and *E.delegatensis* are semi-ring porous which means that they lay down more and larger vessels and longer but relatively thinner-walled fibres during the spring than during the winter. This probably affects their pulping and papermaking properties adversely.

There are also large within-tree variations (fibre diameter, wall thickness, fibre length, vessel diameter and frequency) which correspond to wood forming at different periods in a trees life. For example, the basic density of twenty-year-old *E.grandis* is about 0.58, whereas the basic density of five-year-old *E.grandis* is about 0.40.

Growth stresses and tension wood can also form in eucalypts; the latter can effect a tree's suitability for pulp to some degree by producing wood with less lignin but shorter fibres. Also, because of extreme tension, the corewood can collapse ("brittle heart") which causes a lot of fibre breakage. This is rarely a problem in young eucalypts.

In eucalypts, liquids can move relatively easily in a longitudinal direction through the vessels because these loose their ends during development and collectively form long tubes. Flow between other cells in radial or tangential directions, however, must take place through pits and thus is restricted by both the small size of the pit aperture and the pit membranes. These pit apertures can be occluded by outgrowths of the cell wall, and movement of liquid can also be restricted by the formation of tylosis and large amounts of deposits.

There are several aspects of eucalypts wood anatomy which affect its processing and utility. Straight out mechanical pulping is not advisable because the short fibres would be made even shorter due to mechanical damage. One way to get around this is to soften the lignin bonds with heat. When chips are subjected to

120°C of heat for a while, fibres tend to separate between the S_1 and S_2 layers when mechanically pulped which gives fibres with a cellulose-rich surface which is good for bonding. However, when more heat is applied (temperatures up to 150°C) the separation takes place in lignin-rich sections of the wall and does not leave fibres with good bonding properties. Another way to promote fibre separation is to treat chips with sodium hydroxide before mechanically pulping them; this softens the lignin, causes the wood to expand and minimises damage to the fibres.

Yet another way of pulping eucalypts is to apply a chemical to the chips which will selectively degrade the lignin without destroying either the cellulose or the form of the fibre. [This is the idea behind kraft pulping].

Once the fibres are separated from each other, they can be further prepared by beating. Basically this causes the cell wall components to become more splayed out so that they will be able to form more and stronger contact with other fibres that have been similarly prepared. This (beating) can increase the bursting strength of a piece of paper four-fold.

The suitability of eucalypts for papermaking is also influenced by whether the wood is sapwood or heartwood, juvenility, the presence of kino veins, proportion of non-fibrous tissue, vessels and type and abundance of extractives.

Obviously the Australians have already published a lot, but this author has the distinct impression that what is published only represents the tip of the ice-berg compared to the knowledge that is currently being obtained. For example, according to Geoff Dean[1] (personal communication) APPM is running 1500 experimental kraft pulp bombs per year to determine the pulping characteristics of their eucalyptus breeding populations [For *E.nitens* each of five trees from each family were sub-sampled, chipped and chips mixed to form a family composite for that trial; they have done 800 family composite samples to date], they also measure basic density, pulp yield (to a kappa no. 18) soda requirement, kappa number, shives, fibre length and coarseness.

Similarly at places like the CRC in Clayton and ANM in Hobart, there is a lot of research going on on eucalypt pulping but it may take many more years before it

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1 Geoff Dean, pulp researcher for APPM, Burnie, Tasmania.

Besides research information from Australia, there is also information on eucalypt pulp and papermaking properties from around the world. In this present review only a very few of these references will be examined due to time constraints at the time this report is being written.

Zobel, B.; Campinhos Jr. E.; and Ikemori, Y. 1983. Selecting and breeding for desirable wood. Tappi J. 66(1) pp 70-74.

The authors begin with the concept that uniformity and wood specific gravity are important for pulping. There are many causes of non-uniformity. In *Pinus taeda* about 70% of the total variability in wood is due to tree to tree differences. Tree straightness and form also have an effect, the quickest and often easiest way to develop better wood (for *Pinus taeda*) is to manage the forests and genetically develop trees that are straight and have small horizontal limbs.

Wood variability can also be reduced by controlling the environment within a stand through silvicultural manipulation and a constant rotation age.

The best way to make wood better and more uniform is through breeding. At Aracruz it was found that there was huge variation in *E.grandis* trees for specific gravity (0.35 to 0.85) and for pulp yield (41% to 55%) with most in the range of 48% to 52%. The company breeds for high cellulose yields which also have high-specific-gravity.

These authors state that improving cellulose yield can only be done using vegetative propagation, control-pollination, or two-clone orchards since genetic gains in cellulose are very small when using the standard seed orchard approach.

A total of 4,500 trees were selected for phenotypic characteristics, 3677 of these were tested for specific gravity and, of these, 1626 for bleached pulp yields. Of these, 614 have been chosen for pulp yields greater than 50%. Other characteristics of these chosen trees were that they had:

(1) specific gravity without bark greater than 530 kg/m^3;
(2) an estimated bleached pulp yield of at least 51.5%.

Based on these and subsequent tests, 25 clones were chosen for testing in a range of environments. There was no relationship between specific gravity and either bleached pulp yield or rooting ability. By planting clones in large (10-20ha) blocks there is a good opportunity for improving wood uniformity. Through this improvement program, productivity has increased from 36 m^3/ha/yr over a 7-year rotation to 70 m^3/ha/yr over a 5.5 year rotation.

> Vasconcellos Dias, R.L. and Claudio-da-Silva, E. Pulp and paper properties as influenced by wood density - Same species and age of Eucalyptus. Proceedings of 1985 TAPPI/CPPA 9th Fundamental Research Symposium, Oxford.

Density of wood is highly variable and heritably and is an important selection parameter for selection of new forest plantations at Aracruz. This paper looks at the correlations between wood density and other wood traits such as lignin content, fibre length, extractives content etc.

Pulping evaluations indicated that pulp yield increased when basic density increased from 418 kg/m^3 to approximately 470 kg/m^3 but decreased from this point up to 666 kg/m^3 accompanied by a steady increase in rejects content. Nevertheless, an estimator for digester yield showed that production capacity can be improved through utilization of even denser woods.

The properties of paper were shown to be strongly correlated with variations in basic density. Sheet consolidation and fibre bonding decreased almost lineally with wood density as a consequence of lower flexibility in denser woods. The porosity of handsheets showed an almost exponential increase with wood density. All apparent variations indicated that selection of *E.grandis* trees with wood densities beyond a certain level may result in an undesirable combination of paper properties, for most end uses.

The choice of the raw material seems to be the most important and economical way to achieve the desired characteristics in a piece of paper.

Pulp yield, brightness and strength decreased significantly with an increase in wood basic density while alkali charge and refining demand increased in the same way.

In the experiment performed by these authors, 25 *E.grandis* tree were chosen which were all of the same age (7 yrs) but had densities which varied from 418 to 666 kg/m^3.

There was no correlation between density and extractive content, but lignin content was positively correlated and pentosan content negatively correlated with this parameter. There were also some anatomical correlations with greater density, namely;

a steady reduction in fibre diameter accompanied by an increase in fibre wall diameter.

However, the vessel dimensions and their proportion stayed constant and there was no correlation between fibre length and basic density.

For the pulping yield study, a second order polynomial (quadratic) equation provided the best fit for the relationship of pulping yield with basic density with a maximum at 470 kg/m^3 (note : this apparently is different than with conifers).

In terms of amount of straight out digester production, this higher yield of a medium density wood is completely overshadowed by the much greater amount of wood (hence fibres) contained in a unit of even higher density wood. However, there are other factors such as chemical consumption during pulping and bleaching and black liquor characteristics which may also have a bearing on pinpointing the optimal density.

On the basis of this investigation, the authors concluded that cooking yield would decrease above 470 kg/m^3, but that digester production would benefit from higher density woods until at some point impregnation and/or overcharges in the recovery system became excessive. These authors speculate that the optimal density, from an economics point of view, might be just below 600 kg/m^3, although they leave in the qualifier that if better pulp quality was desired (more strength, less bulk, less opacity and less porosity) an even lower density (perhaps 500 kg/m^3) would be the optimal.

Valente, C.A.; Mendes de Sousa, A.P.; Furtado, F.P.; and Carvaho, A.P. 1992. Improvement program for *Eucalyptus globulus* at PORTUCEL : Technological component. Appita 45(6) pp 403-407.

PORTUCEL has 65,000 ha of *E.globulus* forest and produces 500,000 tons of kraft pulp per year. The tree improvement program is charged with finding genetic means for improving *E.globulus*' already excellent qualities for use in a wide range of high quality bleached papers. Genetic means for making wood fibre separation and bleaching even cheaper and for lowering refining energy even further are the specific advantages sought.

As with this present exercise, the authors begin with a review of the literature. They found that basic density is unanimously recognized as a heritable trait and as one of the main characteristics of wood. They cite other authors as indicating that it is better to use high density wood (of eucalypts) wherever it is marketed by volume. However, they also recognize that very high density may cause some problems at the handsheet level (the same as cited in the previous paper). On the basis of these considerations, and others, the authors felt that a tree improvement program should aim at selecting trees with densities between the second and third interquartiles. More specifically, this means that from the *E.globulus* resource which varied from 470 to 650 kg/m^3 at age 12, PORTUCEL would be looking for trees with a density of 530 to 580 kg/m^3.

CONCLUSIONS FROM THE LITERATURE REVIEW AND INTERVIEWS:

On the basis of the foregoing exercise, it might be seen that the ideal woods for making kraft or mechanical pulp can be quite different. A breeder of eucalypts for kraft pulp could divide wood characteristics into 3 broad categories based on present knowledge:

(1) those that are obviously worth breeding for

(2) those that could be worth breeding for
   (a) if there was a particular fibre quality that was being sought
   (b) if there was a cheap enough test available for testing a large number of individual trees (i.e. the top performers in a breeding population).

(3) those that are not worth breeding for.

The characteristic that falls cleanly into category (1) is density or the closely correlated variable, coarseness. From the literature available and from the density data that we have for *E.fastigata, E.nitens* and *E.regnans* (they all run from the high 300's to the low 500's over a 15 year rotation) it would appear that if New Zealand is to produce either market kraft eucalypt pulp or chips that can be used for this purpose, then breeding for as high a density as possible without sacrificing other tree growth and form characteristics excessively makes good sense. Roughly this might mean selecting from among those trees that had densities greater than (very) approximately 480 kg at 14-years of age[2] (or 400 at age 6).

The only exception to this might be if there was some characteristic about the fibres from a lower density wood which was prized sufficiently to economically compensate for a lower yield of pulp fibres. For instance, it might be important to breed for a thinner wall to lumen ratio in order to get better conformability and consequently higher strength papers. However, it is apparent that adequate strength can be had by mixing in 10 to 15% softwood (long) fibres with a hardwood pulp for most fine papers, so breeding of eucalypts for this thin wall feature makes little sense at present.

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2 Note: the importance of having higher density wood may also be a reason for having somewhat longer rotations (say 15 years) rather than shorter rotations (say 8 years).

How to measure density of a large number of samples and in a non-destructive way could present a problem, however Dean *et al* (*op cit*) did a careful study of several options and found that by taking several samples per tree using the Pilodyn technique an adequate result was obtained. It is also well worth following the progress of Evans and colleagues at the CRC for Hardwood fibre and Paper Science (in Clayton) since it appears that they will soon have a good means for measuring fibre coarseness (which could replace density as the main wood characteristic to be measured).

Breeding to increase pulp yield could make sense in the case where a sufficiently large area of land is to be planted with the species being bred. However, testing a large number of samples (even if the micropulping technique employed by APPM were adopted) is extremely expensive and probably is not worth the investment unless something like 2000 ha per year are being planted with a given species in a given area. A further caution against breeding for pulp yield might be taken from Zobel *et al* (1983) who claim that breeding for pulp yield only makes sense where the species can be cloned. At present cloning is not really very successful with the temperate eucalypts although there have been some important advances recently.

If it is ever decided to breed for pulp yield, it would also be worth measuring samples for soda requirement, shives, fibre length and coarseness since these characteristics would require little additional effort to obtain under such circumstances.

Another feature which might be bred for is low extractive contents, particularly in *E.nitens* which has such a large variability for this characteristic. However, at present (and until more can be learned about the heritability of this characteristic) perhaps only the very worst trees for extractives (the worst 20%) should be excluded from future breeding activities. The extractives situation may also be managed by keeping rotation ages shorter (say 10 years) rather than longer (say 20 years) since extractive content in *E.nitens* tends to almost double in *E.nitens* during the teen years according to Patrick Milne (FRI, Rangiora). This assumes that density cores are to be taken and that sufficiently accurate estimates of a trees extractives contents can also be obtained from these samples.

Aside from those wood characteristics mentioned above, all other characteristics would fall into category (3), i.e. those not worth breeding for for kraft pulp.

When considering the production of mechanical pulp from eucalypts, the exact criteria for determining which kind of wood is best are not yet clear but appear to be very different from criteria which make good kraft pulp. For mechanical pulp the first requirement a breeding program should probably be oriented towards lowering the energy requirement required to separate fibres mechanically after first having softened the chips (probably with cold soda or some equivalent) and without causing undue damage to the fibres. Another very important characteristic in mechanical pulping is the bleachability of the fibres.

Currently not much is known about how wood characteristics affect the level of energy required for refining in eucalypts, but a lot is being learned in Australia. Also, PAPRO has recently been learning a lot about the influence of wood structure on the energy requirements for mechanically-pulped *Pinus radiata;* some short cuts may therefore be possible when learning about the eucalypts.

One observation that has been made both for pine and in one plant (ANM, Tasmania) where *Eucalyptus regnans* has been pulped is that lower density woods generally have lower energy requirements than do high density woods. This statement needs to be addended to point out that it is known that the correlation between density and energy requirement is not a good fit. Other characteristics which have been implicated for having a bearing on this problem are the amount of lignin (the lignin content varies from about 17 to 21% in some eucalyptus and is directly proportional to energy consumption) the location of the lignin in the cell wall - middle lamellae complex and the amount of extractives.

In mechanical pulping extractives interfere both with the action of the sodium hydroxide for softening the lignin in the cell wall and with bleaching. Both of these problems can be overcome but at greater chemical consumption and higher cost, therefore there is a general desire to lower extractive content .

From the foregoing synopsis, it can be seen that the objectives of breeding for pulpwood for kraft and mechanical pulp are (with the exception of extractives which are to bred against in both cases if they are to be bred for at all) different when it comes to wood properties. For kraft as high a basic density or as possible as high a chemical pulp yield, combining these two, or as high a digester productivity as possible are the main trait(s) to chase.

With mechanical pulp a low energy requirement for refining (while still giving good and easily-bleachable pulp) is the main trait being sought. However, it is not quite just that straight forward. We also need to learn if the fibre quality produces through kraft pulping is any different when it is produced from high medium or low density wood of *E.nitens, E.regnans* and *E.fastigata,* and in particular if there might be any significant advantage in using any but the highest density trees from these three species for commercial seed production.

With mechanical pulping a low energy requirement for refining and minimal bleaching requirements are the main traits desired, but a lot of pieces to the puzzle are still missing. Whereas with kraft pulping there is only one basic procedure with a few minor variations, with mechanical pulping there are several possible options and the best is not yet defined. Before getting too carried away with deciding which characteristics might be most desirable in eucalypt wood that is to be mechanically pulped, therefore, perhaps it would first be wise to conduct a study to find out which is the most appropriate for a minimal number of substrates that are likely to be mechanically pulped (i.e. wood of approximately fourteen-year-old *E.nitens, E.fastigata* and *E.regnans*) and then, pending the definition of the best process, proceed with the next step of determining the optimal properties that that subtrate might attain through breeding.

In conclusion, therefore, there has been a groundswell of experimentation and experience with the pulping of eucalypts which has become increasingly evident in the literature. The main eucalyptus species being grown in plantations in New Zealand (*E.nitens, E..egnans* and *E.fastigata*) can all be pulped using both kraft and mechanical pulping procedures with apparently some degree of success. However, there are still some important questions to be resolved. For kraft pulp, one of the most important is whether high density wood (e.g. 530 kg/m^3) of a given eucalypt species can be pulped as well as a low density wood (e.g. 400 kg/m^3) of the same species.

With mechanical pulping there are a lot more questions which need to be resolved. Two of the most basic ones are which process is the best to use and how do the different species or provenances of eucalypts being grown compare as substrates for mechanical pulp.