Wood Protection

Scion Wood Processing Newsletter Issue No. 42 December 2008

# CYPRESS SPECIES, NATURALLY DURABLE ALTERNATIVES TO PRESERVATIVE TREATED RADIATA PINE TIMBER IN BUILDINGS

*Dave Page*

Building standards and associated regulations were changed in 2003/4. This resulted in the exclusion of many indigenous, exotic and imported timber species traditionally used in buildings. While the new standards did not automatically preclude the use of these species, building designs which include alternatives to preservative treated pine often face closer scrutiny as "Alternative Solutions" within the NZ Building Code.

Timber durability is normally determined by placing standard sized stakes in the ground and measuring how long they take to decay. In Australasia, a four step natural durability classification system is used, based on the average life of 50 x 50 mm stakes as follows:

Class 1: (very durable) greater than 25 years;

Class 2: (durable) i.e. 15-25 years;

Class 3: (moderately durable) i.e. 5-15 years;

Class 4: (non-durable) less than 5 years.

There are several features of natural durability that apply to all species

- Natural durability classifications apply only to heartwood. The sapwood of all species is non-durable;
- Natural durability is very variable within species and even within trees. Hence there will always be specific examples of timber from a species that fall outside the durability range given for that species;
- The durability classification of a species where it is used away from ground contact will vary according to exposure conditions. As a general rule of thumb it will be about one class better than when it is used in ground contact; and
- The service life of large dimension components will be proportionally longer than that of smaller components.

### *Natural durability*

We have undertaken in-ground durability tests of four cypress species: macrocarpa (*Cupressus macrocarpa*), Lawson cypress (*Chamaecyparis lawsoniana*), Mexican cypress (*Cupressus lusitanica*) and leyland cypress, (*Chamaecyparis x leylandii*). The results show that the natural durability of heartwood from mature trees is generally towards the upper end of the range in durability Class 3, but with a few early individual failures. Heartwood from two native species, Rimu (*Dacrydium cupressinum*) and New Zealand kauri (*Agathis australis*), has a similar durability classification.

Post tests set up in the early 1960s, showed that macrocarpa was not as good as traditional species used for fence posts, such as red beech, and much less reliable than H4 copper-chrome-arsenate (CCA) treated pine (Figure 1). The first macrocarpa failure occurred after five years and after 26 years, only 16% of the macrocarpa posts remained compared to 88% of the red beech and 100% of the CCA treated pine. Clearly, cypress heartwood could be regarded as "unreliable" in most ground contact situations where a life of 15 years or more is required.

Tests of cypress heartwood in above-ground situations have included fence battens, decking, joinery, weatherboards and roof shingles. Our standard decking tests expose the timber to a quite severe H3 decay hazard. The test used 19 mm thick red beech, and 45 mm thick macrocarpa and H3.1 pine treated using light organic solvent preservative (LOSP). In tests set up in the late 1980s, the first macrocarpa failure occurred after four years. However, after 20 years the condition of macrocarpa was similar to red beech and H3.1 treated pine, with several failures and significant decay in all groups (Figure 2). Decay percentages for the red beech were correspondingly higher than for the 50 mm thick macrocarpa and treated pine because of the decay rating system used and the red beech decking being thinner.

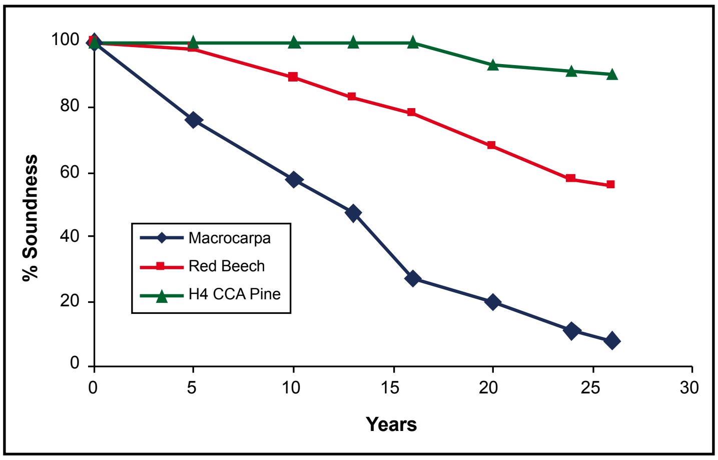


**Figure 1:** Fence Post Durability

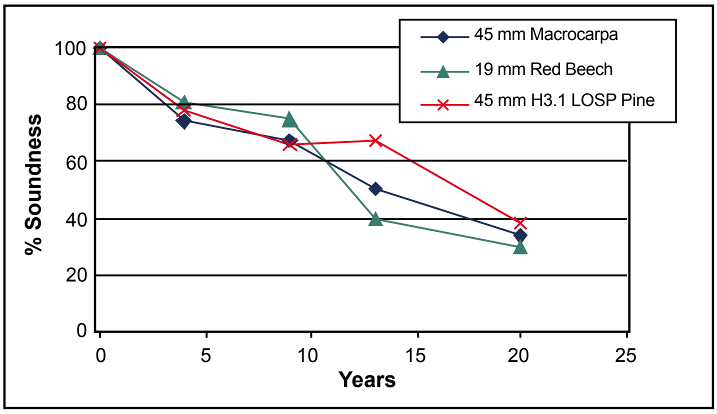


**Figure 2:** Decking Durability

In buildings where we have monitored the durability of the cypresses, decking and other horizontal, fully-exposed components such as balustrade rails, have deteriorated in a similar manner to our decking tests. Most components remained in good condition over 10-20 years but a few failed within ten years. With weatherboards and other cladding components, where the exposed surfaces were close to vertical, there was very little decay and no failures over a 20-year test period.

Most of the cypress timber used in our tests to date has come from mature shelterbelt and woodlot trees. Part of the durability variation that we have seen may be associated with timber taken from younger "top" logs rather than butt logs. We have recently established new tests using stakes cut from younger, plantation grown trees to determine whether age will have a significant effect on the durability classification for these species.

Sapwood makes up only a small proportion of macrocarpa and lusitanica logs from older trees and there is usually sufficient colour difference with heartwood to allow segregation of boards containing sapwood at any stage during manufacture and installation. Lawson cypress logs, however, are often smaller and may contain a higher proportion of sapwood than macrocarpa or lusitanica. There is also very little colour difference between the heartwood and sapwood of Lawson cypress. If Lawson cypress is being used in exposed situations, particularly if the components are structural or of large dimensions, boards containing sapwood should be excluded as the log is sawn.

Decking in the test area at Scion. This is a moderate-high decay hazard test where the decking is only 100 mm above the ground, vegetation is allowed to grow up through gaps between samples and the underside of samples remains relatively damp. The samples sit on a treated bearer at one end and an untreated bearer at the other.

### *Improving Natural Durability*

#### *Preservation*

Cypress sapwood is non durable but is it possible to improve durability using preservatives? Unfortunately, pressure treatment with either light organic solvent-type or most waterborne-type preservatives usually results in limited, patchy penetration. However, sapwood can be treated to comply with the H1.2 specification, using a combination of boron-type waterborne preservatives and diffusion-type processes - as long as this is done when the wood is freshly sawn. Cypress heartwood is very resistant to any preservative treatment.

#### *Protection Coating*

Macrocarpa, lusitanica and Lawson cypress are among the species listed as suitable for use as weatherboards, external finishing timbers, joinery and stairs without preservative treatment in NZS 3602:2003, "Timber and wood-based products for use in building". Dressing grade heartwood is required and it may be used without any surface coating or with a "stain finish".

In situations away from ground contact where there is a low-moderate decay hazard, the application of protective coatings will generally extend the life of naturally durable timbers. Coatings, including penetrating oil stains, do not penetrate far into cypress timber and should be regarded as providing relatively short term, surface only protection. They should be re-applied on a regular basis, i.e. every 3-5 years. Our testing indicates that the service life of sapwood or some less durable heartwood can be extended significantly by regular coating. The effect of coatings on cypress heartwoods is less clear and regular use may do little more than enhance or maintain appearance.

## SUMMARY

- Cypress heartwood is an acceptable alternative to preservative treated pine (at H1.1, H1.2 or H 3.1 treatment specification level). However, a few pieces of lower durability are always possible.
- Cypress heartwoods are moderately durable with the following limitations:
  - in ground contact situations only where an average life of 10-15 years is acceptable and early individual failures can be tolerated;
  - in above ground, horizontal or jointed components, fully exposed to the weather, an average life exceeding 15 years with occasional earlier failures is likely; and
  - in sheathing, where only vertical surfaces are exposed or in structural components where the timber is partly protected and is only wet during extreme weather events, a minimum service life exceeding 20 years is likely.

Wood Protection

Scion Wood Processing Newsletter
Issue No. 42 December 2008

# CHITOSAN AS A POTENTIAL WOOD PRESERVATIVE

*Tripti Singh, Colleen Chittenden, Adya Singh and Robert Franich*

This article discusses preliminary experiments regarding how wood can be treated with a natural fungicide (chitosan), how the chitosan is distributed in the wood cells after treatment and the effect of post-treatment drying temperatures on the impregnation of chitosan into wood.

The fungistatic/fungicidal activity of chitosan against wood decay fungi has been well documented and has been discussed in previous Wood Processing Newsletter articles (No. 38 & 39). Chitosan has also recently been explored as a potential wood preservative, particularly for New Zealand preservative treatment hazard class H3.1. The Bioactives Research Group of Scion has been working for some time to explore the potential of chitosan as a wood preservative.

Chitosan is a polymer of the sugar D-glucosamine and is chemically very similar to cellulose, the main component of wood. Chitosan molecules have an overall positive charge which confers many unique structural and biological properties to this polymer and offers great potential for a range of applications, including wood preservation.

The level of activity of chitosan is highly correlated with its concentration, formulation, and loading in wood. These factors indicate that chitosan performance is related to the application of an appropriate dose.

This study involved vacuum-pressure treatment of air dry radiata pine wood samples with a solution of chitosan. Two drying treatments were used:

(1) Room temperature 20 °C for 48 hours or

(2) Oven dried at 50 °C.

After drying, each set of wood samples was analysed for (a) chitosan content and (b) chitosan distribution in wood cells. Air dried untreated radiata pine was used as a control.

(a) The amount of chitosan incorporated into the wood samples was estimated by determining the glucosamine content of replicate samples using high performance liquid chromatography analysis. Resultsshowed that the samples which were dried at room temperature had the best uptake of chitosan (Table 1).

**Table 1:** Chitosan content in different wood samples

| Sample | Glucosamine (μmol/g) |
|---|---|
| 1 | 166 |
| 2 | 158 |
| Control | 1 |

(b) The distribution of chitosan in wood cells was investigated in cross-sections of the chitosan-treated and untreated-control samples using a light microscope. Sections were not stained with a dye prior to examination, making it possible to capture the natural colour of wood cell walls and the impregnated chitosan material.

Representative images from the light microscopic work are illustrated in Figure 1. The cell lumens are empty in the untreated control (Figure 1a). An orange coloured material (corresponding to chitosan) is present in the lumens of some cells of treated wood dried at room temperature (Figure 1b). Chitosan is also present in the cell lumens of treated wood that was oven dried. However, the colour of impregnated chitosan is dark brown in this case (Figure 1c).

The colour of the chitosan present in the cell lumens of treated wood that was oven dried was darker than that of the chitosan in the cells of treated wood dried at room temperature. This suggested that heating affects the structure/composition of chitosan. To test this theory, some of the chitosan solution was heated at 100 °C then cooled and dried. This heat-treated sample was compared with a control sample that had not been heated. Both samples were analysed using solid carbon NMR spectroscopy and spectra of the two samples are shown in Figure 2.

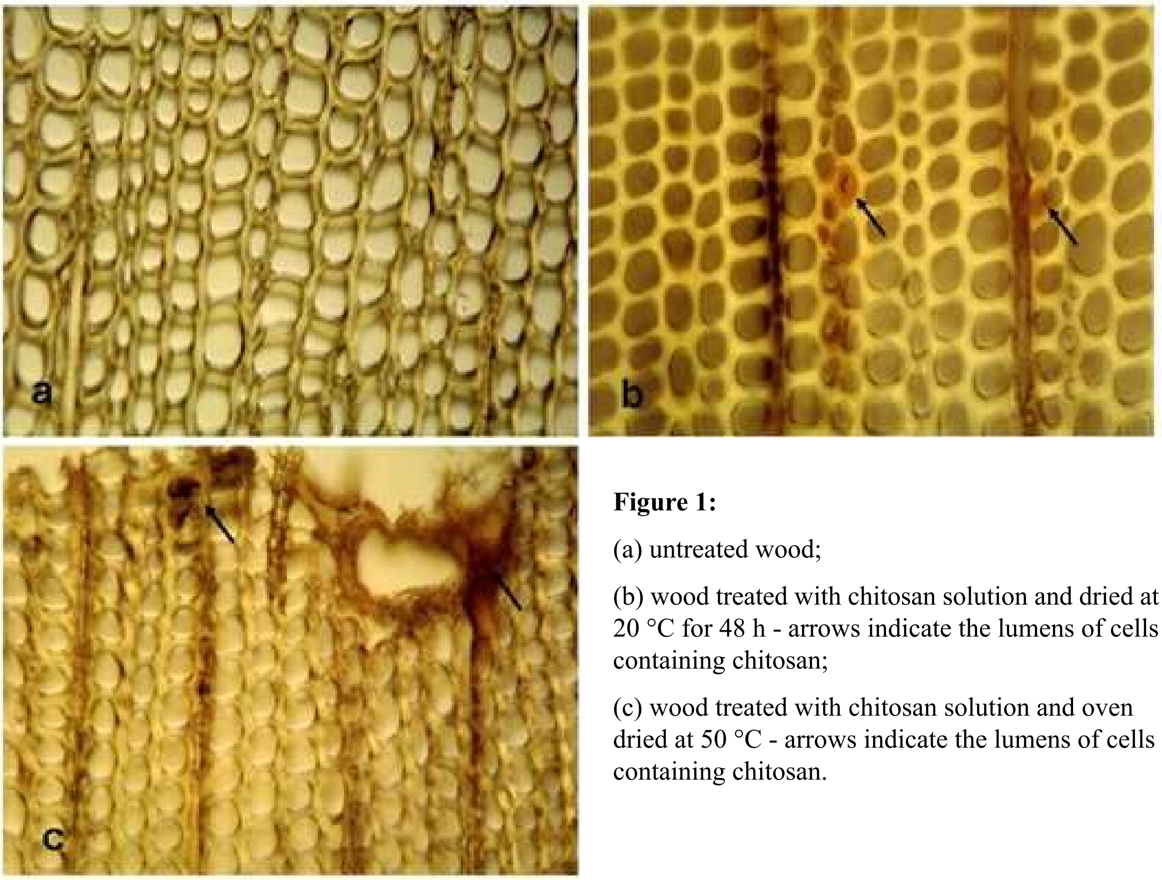


**Figure 1:**

(a) untreated wood;

(b) wood treated with chitosan solution and dried at 20 °C for 48 h - arrows indicate the lumens of cells containing chitosan;

(c) wood treated with chitosan solution and oven dried at 50 °C - arrows indicate the lumens of cells containing chitosan.

Comparison of the two spectra revealed a number of differences. Firstly, two of the peaks in Figure 2a changed shape and position in Figure 2b (shown by arrows) which indicated polymer chain degradation. Secondly, the spectrum of the treated sample contained extra peaks (marked with asterisks) due to changes in chemical structure caused by the heat treatment.

Taken together, the light microscopy and chemical analyses suggest that both the room temperature and oven dried treatments were successful in getting chitosan into wood. However, both the darker colour of the chitosan present in the cells in the oven dried samples and the NMR data point to a change in the structure/composition of chitosan solution during heating. It is not known whether such changes would be detrimental.

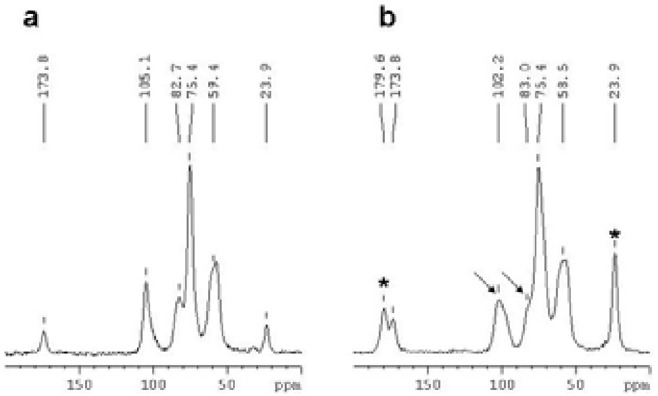


**Figure 2:** Solid-state carbon NMR spectra for (a) control chitosan sample; (b) chitosan sample after heating

Wood Protection

Scion Wood Processing Newsletter
Issue No. 42 December 2008

# DO LOW PRESERVATIVE UPTAKE AND SHALLOW PRESERVATIVE PENETRATION LEAD TO UNACCEPTABLE PREMATURE DECAY IN GLUE LAMINATED RADIATA PINE?

*Dave Page, Mick Hedley and Jackie van der Waals*

## *Background*

In 2006, AS/NZS 1604.5 "Specification for preservative treatment - glued laminated timber products" was amended to require 80% of the cross-section to be penetrated with preservative. The previous penetration requirement was for all "exposed" sapwood (i.e sapwood in the outer laminates) to be fully penetrated and sapwood or heartwood in inner laminates to have a minimum of 5 mm penetration (if the smaller cross-section dimension was 35 mm or less), or 8 mm penetration (if the smaller cross-section dimension was greater than 35 mm).

This was similar to the original NZ penetration requirement, which was a minimum of 10 mm sapwood penetration, irrespective of cross-section size. This was based on what could be practically achieved with grain orientation (which affects permeability) common in glue laminated radiata pine, without resorting to high pressure, high solution uptake processes (70-90 L/m³). With the latter, times required for solvent flash-off can be interminable, particularly if priming is required prior to dispatch from the treatment plant.

When the new penetration requirement was being debated, it was argued by opponents to it that there was no hard evidence to show that greater penetration would result in greater decay resistance. Similarly, apart from some anecdotal instances, there was no proof that previous penetration requirements resulted in extensive premature decay and ultimate failure.

Scion has established a trial using glue laminated radiata pine beams to determine whether or not preservative treatment applied using a "traditional" low uptake (40 L/m³) processes resulted in unacceptable risk of premature decay. Two types of Light Organic Solvent Preservative (LOSP) treatment were used:
H3.1 Azoles formulation and H3.1 Tributyltin naphthenate (TBTN) formulation. Treated and untreated (control) sections of beams were exposed to decay fungi.

## *Sample Preparation and Treatment*

Laminated beams (280 x 65 mm) were cut into one-metre lengths, and end-sealed with a PVA coating. Samples for preservation were then treated using a double-vacuum schedule designed to give a 40 L/m³ preservative uptake. This process was undertaken in the experimental LOSP treatment plant on the Scion campus. After preservative treatment, the sections were held in filleted stacks in a well-ventilated area for several weeks to allow the preservative solvent to evaporate.

One-metre long sections were cut into 225mm long pieces to produce 40 samples for each preservative plus 20 untreated controls. Each sample was end-sealed with epoxy paint. All samples were placed under water sprays for seven days to raise the moisture content above 25%. These were then separated into two groups of fifty (twenty of each preservative treatment per group plus ten controls). One group had Pinus radiata ‘feeder’ blocks attached to them while the other group was left without ‘feeder’ blocks. These ‘feeder’ blocks had been pre-inoculated with two types of brown rot fungi (*Antrodia xantha* and *Oligoporus placenta*) that have been common causes of decay of untreated framing in the Auckland area.

## *Exposure in a Controlled Environment*

Twenty five samples with feeder blocks (ten from each preservative treatment and five controls) plus the equivalent number without feeder blocks were randomly arranged, on a wooden rack in a controlled conditioning room with a temperature of 25° C and 95% relative humidity. (Figure 1).

### *Exposure Outside*

The remaining samples were installed in the outdoor durability testing area at Scion in a “ground proximity” test arrangement. Plastic weed-mat was spread over a flat grassed area and two layers of 40 mm thick porous grey concrete blocks were placed on top of the weed-mat. Test samples were stood on end on the concrete blocks, in two randomly arranged rows. A 400 mm high box had been constructed around the concrete base with a central division running lengthwise between the rows of test samples. The box was lined on all surfaces above the concrete base with kiln-dried untreated radiata pine and the top was covered with two layers of black plastic shade-cloth. The upper section of the box lifts off to provide access to the samples. (Figure 2)

Samples will be assessed for decay at regular intervals and when/if this occurs, samples will be sectioned at the decayed area, spot tested and analysed to determine the depth of treatment penetration which has failed to prevent decay.

**Figure 1: –** Sample blocks in a temperature and humidity controlled conditioning room

**Figure 2: –** Sample blocks installed in the outdoor exposure box. The samples rest directly on the concrete base and are about 25 mm apart in the rows. The box is lined with untreated timber and the upper section, upside down on the left, is covered with shade cloth.

**The trial is being funded by the New Zealand Pine Manufacturers' Association with co-funding from the Ministry of Foreign Affairs and Trade Forest Industry Development Agenda Fund and with in-kind support from Taranaki Sawmills (supply of glue-laminated beams), Osmose (supply of tributyltin naphthenate preservative) and Arch Wood Protection (supply of azoles preservative).**

Wood Drying
**Scion Wood Processing Newsletter** Issue No. 42 December 2008

# WOOD, WATER, SHRINKAGE AND SWELLING RE-VISITED

*John Turner*

During the months of March and April 2008, we received a number of enquiries relating to product problems associated with unexpected shrinkage and swelling of wooden components. These included purlin shrinkage, buckled roof capping, swollen wooden doors, and shrinkage of sarking and flooring. All were considered to be associated with timber produced during last year's 'drier than usual' summer (i.e. Christmas 2007). These enquiries have prompted this article, to remind our readers just what timber movement is all about.

In a living tree, the wood (particularly sapwood) is saturated with water. Most of it is contained in the central cavity (lumen) of wood's hollow, straw-like cells (axial tracheids); but some of it is in the walls of the cells themselves (Figure 1). Such wet wood is referred to as 'greenwood' and, when sawn, is called green lumber. To make it more useful as a construction material, the water is removed to prevent mould growth, and to improve stiffness, strength, and dimensional stability.

During drying of green lumber, water evaporates first from the lumen. The water is released through special holes in the cell walls known as 'pits'. After this initial stage of drying the cell walls still remain saturated and the lumber remains in its original dimension, even though all the water in the lumens has gone. This point, at which the cell lumen is empty but the cell walls are full of water, is known as the Fibre Saturation Point (FSP). For almost all kinds of wood, the moisture content at the FSP is about 30% (based on the ratio of the weight of water to the oven-dried weight of wood). Further drying reduces the amount of water in the cell walls and this causes the wood to shrink. As the moisture content (MC) falls below 30%, wood progressively shrinks until there is no water left, (0% MC or oven dry). The converse is also true – when dry wood picks up water it swells. Typically, the in-service moisture content of wood in heated buildings (air dry) can range from about 4% to 16% annually.

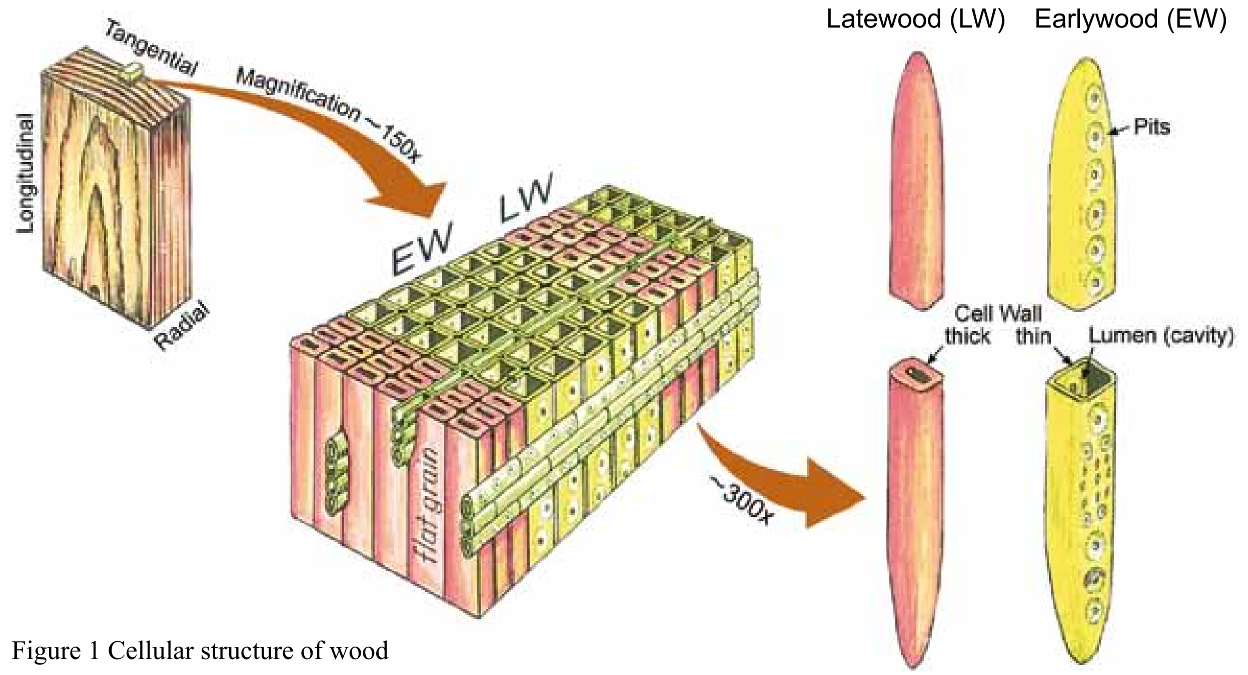


Figure 1 Cellular structure of wood

Wood cells are laid down in concentric circles. Light coloured, thin walled earlywood is laid down in spring and darker, thick walled latewood develops during late summer and autumn (Figure 1). This wood constitutes the annual growth rings, with their length parallel to the trunk of the tree. Timber does not shrink or swell equally in its main axial directions (length, width, and thickness) during drying. Shortening along the grain, i.e. longitudinal shrinkage, is very small (about 0.1% from green to bone dry, expressed as a percentage of the green dimension) and is usually ignored. There are exceptions of course (see Box 1). In contrast, shrinkage across the grain, whether around the growth rings (tangential shrinkage) or across them (radial shrinkage), is substantial, and should be accounted for in the design of just about anything made from wood. Though shrinkage values vary considerably among woods, shrinkage, from green to air dry, averages about 4% tangentially and about 2% radially.

## Box 1: Abnormal Longitudinal Shrinkage

Some of the very large shrinkages experienced are related to the presence of compression wood. This is a form of wood that develops on the underside of the stem, in response to displacement from vertical. The purpose of compression wood is to provide a growth correction function to restore the stem to the vertical. It has the ability to expand along the grain while being formed, thus slowly bending the stem back to its vertical position. Such wood has comparatively large longitudinal shrinkage of 0.5 to 1%, which, in association with a 4 or 5 m length, has the potential to shrink by 25 –50 mm!

Another issue is 'twist' – which can happen if there is spiral grain in the timber (see the article in this issue entitled: "Spiral Grain in Radiata").

The amount of moisture in wood is related to the temperature and moisture content of the surrounding air. All timber will absorb or lose moisture if the surrounding atmosphere changes in humidity. For example, wood will lose moisture if the air around it dries, causing the humidity to decrease. Any such loss of moisture from the wood will tend to cause shrinkage to occur. The rapidity of such a loss will depend on how dry and hot the air is, how thick and permeable any surface coating on the wood is, how 'wet' the wood is, and how long the period of lower humidity continues. Conversely, wood will absorb moisture and swell if the air around it gets wetter, causing the humidity to increase.

Over a hot dry period, with associated low humidity, wood will tend to dry to lower levels than normal. In some cases those supplying products had used wood dried to recommended average exterior conditions (12-16% MC) when, in fact, the actual EMC (see Box 2 for explanation) had dropped below these levels. This resulted in further shrinkage of their products when exposed to exterior conditions. Others used wood that had been dried and stored before machining, thus when machined it was drier than expected and on exposure to autumn exterior conditions swelled more than anticipated.

Knowing just what the moisture content of your stock is, its variation, and whether it contains compression wood, is vital to avoid these un-expected shrinkage/swelling problems. Some guidance of what levels of shrinkage/swelling can occur is provided in Box 3.

## Box 2: Equilibrium Moisture Content

The Equilibrium Moisture Content (EMC) is the moisture content that wood will attain if held long enough at constant atmospheric conditions of temperature and humidity. In practice, the air conditions that determine EMC are always changing (e.g. day or night, summer or winter). Therefore, average EMC conditions are quoted for internal and external conditions. For example, heated buildings are considered to have an average EMC of 6% - 10% MC year round while unheated buildings have a wider range of EMC (12% - 18% MC). Outside, the average EMC is 14% MC in summer and 18% MC in winter.

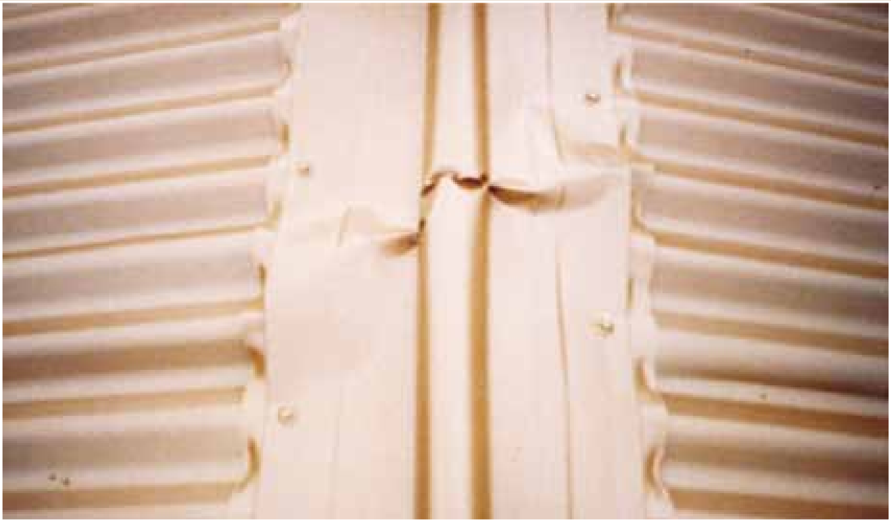
## Box 3: Guidance on What Levels of Shrinkage/Swelling Can Occur

The FSP of radiata is accepted as 27% MC, i.e. the wood will start to shrink below this MC. Drying the wood to an MC of 12% will result in 4% tangential shrinkage and 2% radial shrinkage.

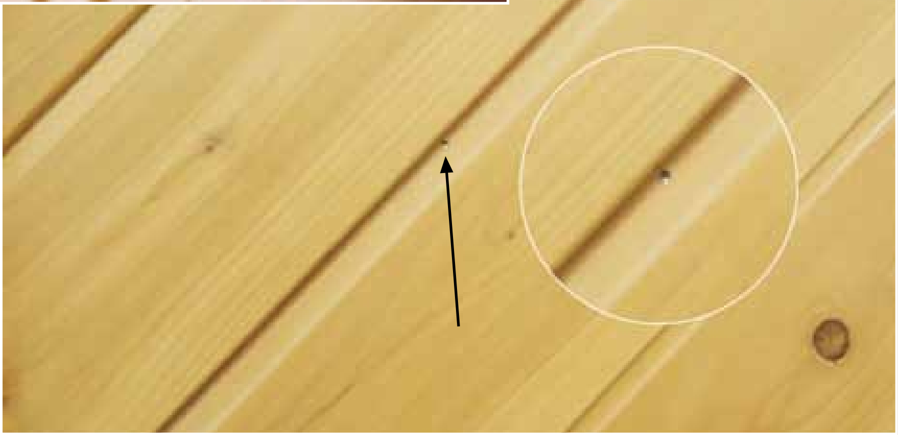
Consider a piece of flatsawn radiata 200 mm wide (*i.e. the growth rings are parallel with the wide face of the board*). Reducing the moisture content from 27% to 12% MC will cause the flatsawn face to shrink by 8 mm (i.e. 4% of 200 mm).

Another way of looking at it is to calculate how much the wood will shrink for every 1% loss in moisture content. To dry to 12% MC, the wood will lose 15% MC (i.e. 27%-12%). Since it shrinks 8 mm for 15% MC loss, it will shrink by 0.53 mm (i.e.8/15 mm) for each 1% loss in MC.

Suppose our piece of 200 mm wide wood was put outside when the MC was 14% but during a long dry period it subsequently dried down to 10%. This 4% decrease in MC would shrink in width by 2 mm. Equally, if our piece of 200 mm wide wood had been stored (rough sawn) under dry conditions, during such a dry period (10% MC) and then machined to 190 mm and put outside once the dry period was over (say in 16% MC) then it could be expected to swell in width by 3 mm.



Buckled roof capping



Shrinkage of diagonal wall sarking leading to exposure of ‘hidden’ nail

Wood Drying

**Scion Wood Processing Newsletter** Issue No. 42 December 2008

Steve's FAQ Corner

# WHY DOES MY KILN HAVE IMPLOSION VENTS FITTED?

*Steve Riley*

Implosion vents are a safety device fitted to modern softwood kilns that are designed to reduce pressure build ups. A large pressure difference between the inside and outside of the chamber can arise during drying due to condensation. If this pressure difference is not quickly alleviated, the panels or doors (or both) can be sucked inwards and destroy the chamber's integrity.

A kiln implosion can occur when the humidity inside the kiln is high and then a large amount of condensation occurs very quickly. Rapid condensation will occur if a large amount of highly humid gas is suddenly brought into contact with a large surface that is at a temperature well below the dew point of the gas. This means the gas (steam) is rapidly turned into liquid water. The density of steam (0.6 kg/m$^3$) is at least a thousand times lower than that of liquid water (1000 kg/m$^3$). This means that water occupies a thousand times less space than it did as steam. As a result, a void is created with a very much lower pressure than the atmosphere. If the chamber is well sealed and this void cannot be filled immediately with air from outside, the difference between atmospheric pressure exerted on the outside walls and that inside the chamber can be very high. If this pressure difference is high enough, an implosion will occur that can seriously damage the panels and doors of the kiln. To avoid such a catastrophe, kiln manufacturers usually install special implosion vents, which can immediately react to equalise a negative pressure difference.

The risk of implosion is greatest after pre-steaming cold wet timber with the fans off. During the pre-steam, the water-bath fills the chamber with steam at atmospheric pressure. Since the fans are off, most of the steam sits in the chamber and the steam temperature will be high (up to 100 ºC). If the fans are now turned on, the steam in the chamber will be forced onto the cooler timber stack and chamber walls, and there will be an immediate rise in condensation rate.

The risk of implosion is lower when fans are used during the pre-steam. This is because the wood has more of chance to preheat and a sudden change in condensation rate usually does not occur.

When wood is post-steamed (i.e. after drying), the temperature difference between the wood and steam is not so great and, thus, the rate of change in condensation rate is also minimised. However, implosions can occur if a very cold stack is put into a pre-warmed kiln or even during circulation reversals when warm humid air built up during a long reversal delay is forced onto the cold side of a stack. Thus, the important things to note are:

(1) if implosion vents are fitted make sure they are working;

(2) if you pre-steam without fans and your kiln has no implosion vents, be aware of the options:

  (a) fit implosion vents;

  (b) ensure vents are open before fans are turned on; or

  (c) at the very least change to steaming with fans on (at low speed).

(3) if you have no implosion vents and your procedures comply with the following, you may be OK if:

  (a) you never heat up cold (i.e. near to 0 ºC) timber, and

  (b) you never have fan reversals when the timber is cold.

*Each issue we will delve into our files and give answers to frequently asked drying questions, trying to add to our general understanding of the technical issues behind the art of Wood Drying*

Wood Drying
Scion Wood Processing Newsletter
Issue No. 42 December 2008

# IF I SLIGHTLY CHANGE MY RADIATA PINE DRYING SCHEDULE, HOW MUCH DOES MY DRYING TIME ALTER?

*Steve Riley*

Kiln operators often have to alter schedule details for a range of reasons such as speeding up or slowing down a charge to meet a shipping date, or simply slowing down the fans so as not to annoy neighbours with fan noise. Since radiata pine is so permeable, it is easy to dry and can withstand quite wide variations in dry bulb (DB), wet bulb (WB) and air flow. Drying times are very much dependant on various factors (e.g. wood size, stack width, heat up rates, fan reversals) that are not considered part of the schedule. The following article provides guidelines for adjusting expected drying times and the reasoning behind them for a given kiln, stack size and wood dimension and initial moisture content.

### *Varying Air Flow*

If all other factors are kept equal, increasing air velocity will decrease drying time. However, the decrease is not linear. The conditions within a drying stack when the velocity changes are quite complex because the heat transfer and mass transfer rates change differently with velocity. This means that the temperature and humidity profiles across the stack will also vary which, in turn, affects the drying rate. To complicate matters still further, the drying rate tends to be more limited by internal wood moisture movement than the external conditions later in the drying process.

Experimentally it is difficult to find an exact relationship between air velocity and drying time, as it is very hard to have exactly comparable conditions and only vary the air velocity. Figure 1 shows experimental data from four experiments, with each set of points representing sets of charges with similar DB and WB and stack size. Looking at the shape of each curve it is difficult to generalise, as some curve up and others down. This ambiguity in empirical data has led to the conclusion by some that drying time is inversely proportional to velocity, but this would be contrary to other experience.

Model results (Figure 2) show a non-linear result with an increase in air velocity (v) on decreasing the drying time. Another way of looking at the problem is to assume a stack's drying rate in terms of air velocity is determined by overall surface heat transfer. In a classical flat plate heat exchanger with a turbulent fluid (i.e. similar to a timber drying stack), the surface heat transfer value is generally considered to be proportional to $v^{0.8}$. This is likely to represent the early (constant rate) part of the drying schedule. However this relationship changes to $v^{0.5}$ towards the end of the drying process, (Keeye, 1972).

Since drying time is inversely proportional to drying rate it is reasonable to assume drying time is $v^{B}$, where B ranges from -0.5 to -0.8. The graphs in Figure 2 have power curves ($y = Ax^{B}$) fitted and B is, in fact, about -0.6 which agrees with this. Fitting power curves to empirical data (e.g. Figure 1) gives an average exponent (B value) very close to -0.5 (i.e. inverse square root) so we propose this as a **rule of thumb**. This is a graphic example of how careful one must be when interpreting kiln drying data – a careful balance of theory and empirical methods must be kept.

Thus, we propose if only the air velocity is changed:

$$\text{new drying time} = \text{old drying time} \times \sqrt{(\text{old velocity}/\text{new velocity})}$$

It should be noted that there is evidence that drying uniformity is affected by air velocity – increased air flow does reduce final variability slightly. Thus large changes in velocity may need an extra correction and a future article will discuss this. Also, if the velocity change is only in the first part of drying it would be more correct to use B = -0.8, but rules of thumb aren't supposed to be too detailed.

### *Varying Temperature and Humidity*

When wood temperature rises, moisture can flow through the wood more easily. In addition, as dry bulb temperature increases, the moisture carrying capacity of the air increases. It is no surprise, therefore, that drying rate increases as operating temperature increases. As far as developing a rule of thumb for extrapolating drying time when temperature and humidity change, consider that most moisture removed is free water.

This removal can be assumed to occur from a liquid (the free water in the wood) to an air stream (air flowing through the fillet space). The vapour pressure of water (PVs) in the air mixture is less than the vapour pressure (Pvs) of the liquid in the wood. This vapour pressure difference drives most of the drying and strongly determines drying time. Towards the end of drying, the drying rate is determined by the difference between the wood moisture content (MC) and the equilibrium moisture content (EMC) of the air. Vapour pressure differences and EMC values are calculated and presented in Table 1 over a range of DB and WB temperatures that include accelerated conventional temperature (ACT) and high temperature (HT) drying schedules. Different ways of plotting this data have been used to formulate a simple rule of thumb:

- Figure 3 shows that at each DB temperature, vapour pressure difference (i.e. drying rate) is very much dependant on the difference between DB and WB (called ‘WB depression’) rather than the DB temperature. This is indicated by each line being essentially flat;
- Figure 4 shows that over the DB temperature range, average vapour pressure difference (i.e. drying rate) increases pretty much linearly with WB depression. Thus drying rate above fibre saturation is pretty much linearly dependant on WB depression;
- Figure 5 shows that, within a drying class (i.e. ACT or HT), the final EMC of the air drops roughly linearly with WB depression. This shows that within drying classes in the later stages of drying, drying rate is still pretty much linearly dependant on WB depression.

Thus, as a rule of thumb: if other factors are kept similar, drying time is inversely proportional to the difference between DB and WB. Expressed as a formula, we have:

new drying time = old drying time
x (old WB depression/new WB depression)

Note that the slopes of the lines in Figure 3 increase slightly at higher depressions, showing temperature is having an increasing effect. We also know that diffusion inside the wood is increased at higher temperatures. Thus, this rule of thumb is best when used within drying classes (as they should be when comparing kiln loads in similar kilns).

*Keeye*, R. B. (1972). *Drying Principles and Practice.* New York: Pergamon Press pp 150, 197-198

Table 1: Data used in Figures 3-5

| DB (°C) | WB (°C) | DB-WB | PVs (Pa) | Pvs @WB (Pa) | Vap Diff (Pa) | **EMC (%)** |
|---|---|---|---|---|---|---|
| 40 | 30 | 10 | 3618 | 4246 | 627 | 8.2 |
| 50 | 40 | 10 | 6749 | 7382 | 633 | 8.6 |
| 60 | 50 | 10 | 11709 | 12348 | 640 | 8.6 |
| 70 | 60 | 10 | 19297 | 19943 | 646 | 8.5 |
| 80 | 70 | 10 | 30549 | 31202 | 653 | 8.2 |
| 90 | 80 | 10 | 46768 | 47428 | 660 | 7.9 |
| 100 | 90 | 10 | 69554 | 70221 | 668 | 7.5 |
| 109 | 99 | 10 | 97257 | 97932 | 675 | 7.2 |
| 40 | 20 | 20 | 1096 | 2339 | 1244 | 3.4 |
| 50 | 30 | 20 | 2991 | 4246 | 1255 | 4.5 |
| 70 | 50 | 20 | 11069 | 12348 | 1279 | 5.0 |
| 90 | 70 | 20 | 29896 | 31202 | 1306 | 4.8 |
| 110 | 90 | 20 | 68886 | 70221 | 1336 | 4.3 |
| 50 | 20 | 30 | 474 | 2339 | 1865 | 1.1 |
| 70 | 40 | 30 | 5482 | 7382 | 1900 | 3.0 |
| 90 | 60 | 30 | 18005 | 19943 | 1939 | 3.2 |
| 110 | 80 | 30 | 45447 | 47428 | 1981 | 3.0 |
| 130 | 100 | 30 | 99477 | 101504 | 2027 | 2.5 |
| 70 | 30 | 40 | 1736 | 4246 | 2510 | 1.2 |
| 80 | 40 | 40 | 4849 | 7382 | 2534 | 1.8 |
| 100 | 60 | 40 | 17358 | 19943 | 2585 | 2.1 |
| 120 | 80 | 40 | 44787 | 47428 | 2641 | 1.9 |
| 140 | 100 | 40 | 98801 | 101504 | 2703 | 1.5 |
| 90 | 40 | 50 | 4215 | 7382 | 3167 | 1.0 |
| 110 | 60 | 50 | 16712 | 19943 | 3231 | 1.3 |
| 130 | 80 | 50 | 44127 | 47428 | 3301 | 1.2 |
| 150 | 100 | 50 | 98125 | 101504 | 3379 | 0.7 |
| 100 | 40 | 60 | 3582 | 7382 | 3800 | 0.5 |
| 120 | 60 | 60 | 16066 | 19943 | 3877 | 0.8 |
| 140 | 80 | 60 | 43467 | 47428 | 3962 | 0.7 |
| 160 | 100 | 60 | 97449 | 101504 | 4055 | 0.2 |

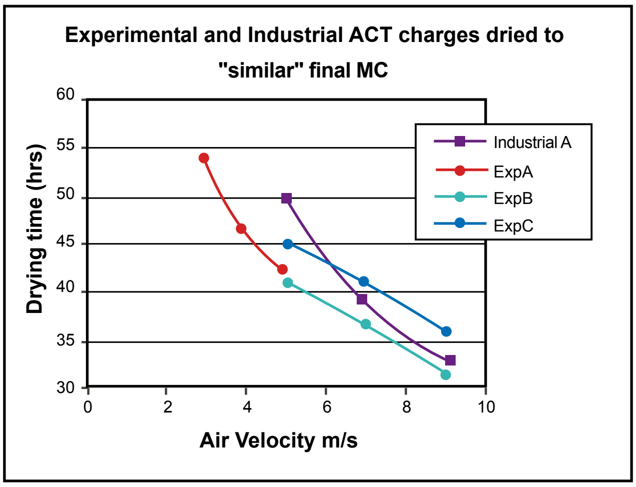


Figure 1: Experimental data showing ambiguous (curve up or curve down?) relationships between drying time and velocity.

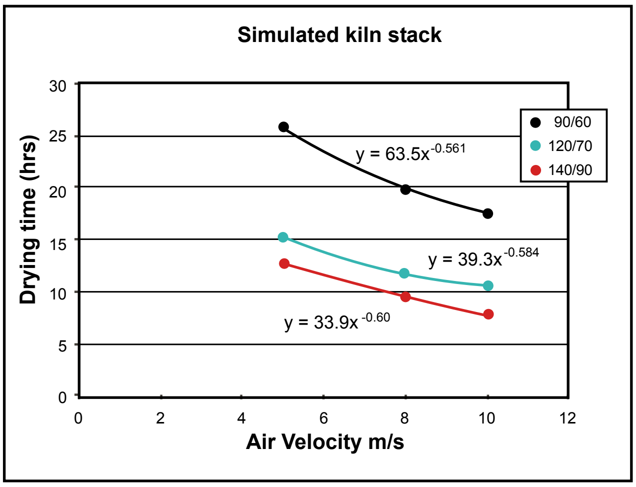


Figure 2: Simulated kiln runs show a definite power relationship, with a decreasing effect of velocity on drying time

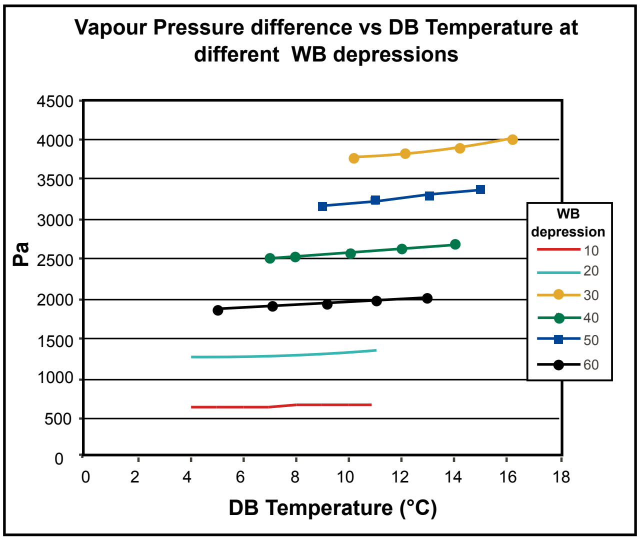


Figure 3: Vapour pressure difference (i.e. drying rate) is pretty much dependant on WB depression

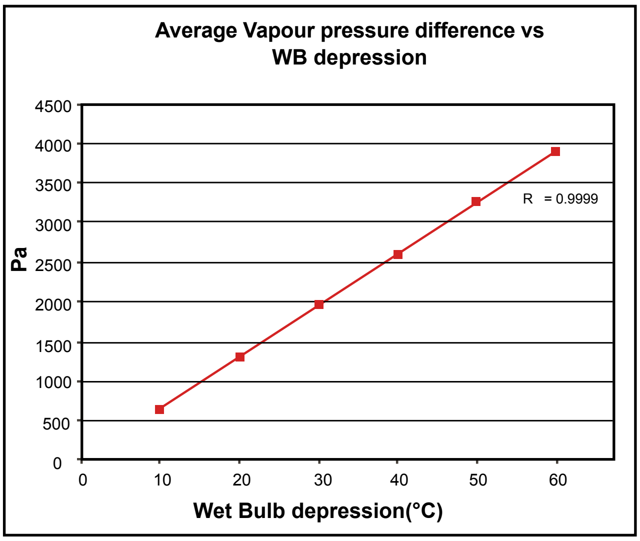


Figure 4: Vapour pressure difference increases linearly with WB depression

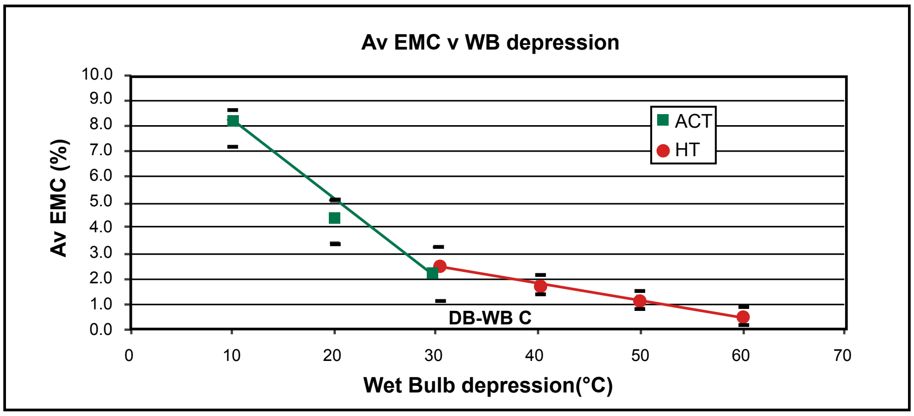


Figure 5: EMC pretty much decreases linearly with WB depression within drying classes (ACT/HT), indicating that drying time decreases roughly proportionally with WB depression at the end of drying as well.

### Box 1: Examples using these ‘Rules of Thumb’

1. For 20 hours you must slow the fans of a 90/60 kiln by 15% (from 5 m/sec to 4.25 m/sec) to reduce noise in a residential area. To compensate for the reduction in air flow the drying time will be extended. What will the new drying time be?

   Since air velocity is proportional to fans speed, air velocity through the stack will be 15% less, and

   new time = $2 \times \sqrt{\frac{\text{old velocity}}{\text{new velocity}}}$ $= 20 \times (5/4.25)^{0.5} = 21.7$ hours

   If this step was in the very first part of drying (constant rate period) it would be more correct to use:

   New time = $20 \times (5/4.25)^{0.8} = 22.8$ hours

2. A charge that is normally dried at 120/85 in 18 hours after reaching setting is needed urgently. If you drop the WB to 75 °C, what decrease in process time should you expect.

   New time (after reaching set point) = old drying time x (old DB-old WB)/(new DB-new WB)
   = 18 x (120-85)/(120-75)  = 14 hours, i.e. process time is calculated to reduce by 4 hours.

   Keep in mind, that even though individual results will vary, these ‘rule of thumb’ calculations provide a guide of what will happen, on average, over a number of similar charge setting alterations.

# OPPORTUNITES FOR SAWMILLS TO CUT ENERGY COSTS

*Ian Simpson*

In 2006, Scion undertook a survey of the electrical motors used by the sawmill industry for kiln drying as part of an Industrial Motor Efficiency Project coordinated by the Electricity Commission. This survey indicated that motors used in the timber drying process are typically over 10 years old and are between 4% and 8% less energy efficient than the new motors now available in the marketplace. Research has also indicated that old electric motors are most often repaired and returned to service after failure. This is despite replacement with a new motor being a more cost-effective solution for the owner, in many cases.

With the electric motors used in the timber drying process alone consuming on average 57% of total electricity used by sawmills, replacing these motors with more efficient options during scheduled maintenance or at motor failure represents a significant opportunity for saw mills to reduce electricity costs.

The Electricity Commission is currently rolling out a nationwide programme that includes assisting motor users develop robust motor replacement (*vs* repair) policies and a motor-repairer quality accreditation scheme. The programme also includes a “Motor Bounty” scheme where substantial financial subsidies are paid for failed or operational motors when these are replaced with higher-efficiency options.

Further information on the outcomes of the Industrial Motor Efficiency Project will be covered in more detail in the next issue of the Wood Processing Newsletter (Number 43) 2009.

Full details of the Motor Bounty Scheme can be found at www.motorbounty.co.nz. Information on other aspects of the Electricity Commission’s industrial efficiency programmes is available on http://www.electricitycommission.govt.nz/opdev/elec-efficiency/

Wood Quality

Scion Wood Processing Newsletter Issue No. 42 December 2008

# ENHANCED PENETRABILITY OF RADIATA WOOD BY BIOENGINEERING

*Adya Singh, Uwe Schmitt, Bernard Dawson and Catherine Rickard*

Developing high value products from radiata pine through enhancement of wood properties such as stability, hardness and durability will enable radiata to compete well with premier hardwood species on the world market. Developing bioengineered products will also ensure that the technology applied is environmentally sound. Many previous attempts have been made to enhance the properties of products made from radiata wood. These have employed a range of chemical, physical and mechanical processes with varying success. A major difficulty with chemical-based technologies lies in achieving uniform chemical impregnation of wood cells. This is because kiln drying causes changes to the radiata wood that severely restrict the entry of solutions. More specifically, pits (membrane lined openings) between wood cells close irreversibly (aspirate) during drying. This process is common during the drying of many types of conifer. Scion has adapted a bioengineering process that keeps the pits open during drying so that dried radiata wood is permeable to molecules of all size ranges. This process involves the removal of pit membranes using bacteria. To understand what pits are, their function and why they aspirate during drying, we need to first examine the structure of radiata wood.

## *The Structure of Radiata Wood*

Radiata wood consists of two interconnecting tissue systems, axial (up and down the tree) and radial (across the tree). The axial system is composed largely of one cell type called 'axial tracheids' (the tubes that transport water in trees). The radial system is composed of two different types of cells, ray tracheids and parenchyma (collectively referred to as 'rays'). The walls of all tracheid cells (but not generally parenchyma cells) contain lignin in addition to cellulose and hemicelluloses.

Axial tracheids form the bulk of wood and, therefore, are the main elements in any consideration of wood properties. The axial tracheids produced during spring (early wood) are thin-walled cells of a large diameter. In contrast, axial tracheids produced during summer (late wood) are thick-walled cells with a smaller diameter. All tracheid cells are interconnected with 'bordered' pits, so-called because the cell wall overarches the pit cavity. The structure of bordered pits in radiata as well as other conifers is highly specialised. The pits consist of a membrane with a central, relatively impermeable part (called a 'torus') and a surrounding, highly porous part (called a 'margo') that suspends the torus within the pit cavity (Figure 1).

Liquids and dissolved substances enter kiln-dried wood via both axial and radial systems, and, upon entry, their movement occurs largely via pits. However, kiln drying generally causes pits in the majority of axial tracheids to aspirate, which severely restricts the flow of liquids. Aspiration commonly occurs in early wood. This is because the pits connecting the axial tracheid cells in early wood have a membrane that is sufficiently large and thin enough to deflect under the tension caused by water escaping from the wood during drying. As the pit membrane deflects, the torus acts like a plug which blocks the pit aperture and results in its closure, Figure 2. This blockage by the torus renders the wood impermeable to impregnation solutions. Figures 3 - 5 show micrographs of aspirated bordered pit membranes. In contrast, the pits connecting late wood axial tracheid cells remain unaspirated because the pit membranes in these cells are too short to reach pit borders upon deflection during drying. The situation is similar for ray components. This means that liquid flow can occur through late wood and rays in radiata pine, which explains their higher permeability than early wood.

## *Bioengineering of Radiata Wood*

Early wood in radiata pine constitutes the bulk of wood, so the issue of pit aspiration upon kiln drying is an important issue. Recognising this, we have successfully created a bioengineering process that enhances the penetrability of radiata wood. This process involves the bacterial destruction (removal) of pit membranes.

The bioengineering process we employed is commonly known as 'ponding'. It involves submerging freshly sawn radiata boards in deep troughs for a prolonged time with the aim of exposing the wood to bacteria that are naturally present in stagnant water. The experiments were carried out in a glasshouse to encourage the production of bacteria. The boards were removed from the troughs after periods ranging from two to twelve weeks. They were examined to assess both bacterial colonisation of wood and pit membrane removal. Wet boards were examined using two types of microscope. The boards were then air-dried and examined again, using two different types of microscope. After this assessment, the air-dried boards were coated with varnish then examined again to determine the extent of coating penetration into wood. In all cases, control (unponded) boards were included for comparing pit condition and coating penetration.

Bacterial colonisation of wood cells and pit membranes is illustrated in Figures 6-8. A pit which has lost its membrane due to bacterial attack is shown in Figure 9. Figure 6 shows various bacteria in axial tracheids from wet wood. The greatest bacterial populations are associated with pits. Bacteria were stained with a fluorescent dye so show up as bright specks. The detailed observations of pit regions revealed a range of structural features suggestive of pit membrane breakdown. They also showed clumps of bacteria on pit membranes. The close affinity of bacteria for pit membranes is clearly evident in air-dried wood, where bacteria are abundantly present in the pit region but not on pit borders, Figure 7. When the pit membrane has been removed, bacteria probably move on to other pit membranes which are still intact. The air-dried wood shown in Figure 8 illustrates that bacteria are no longer present within a pit that has lost its membrane.

### *Penetrability Enhancement*

When aspirated, pit membranes form a barrier to impregnation by solutions designed to enhance wood-properties. Therefore, removal of the pit membrane should improve wood impregnation by improving permeability. This hypothesis was supported by a comparison of varnished ponded boards and varnished, but un-ponded, control boards. A distinctly greater penetration of varnish was observed in the ponded wood compared with control wood, Figures 9 and 10 respectively.

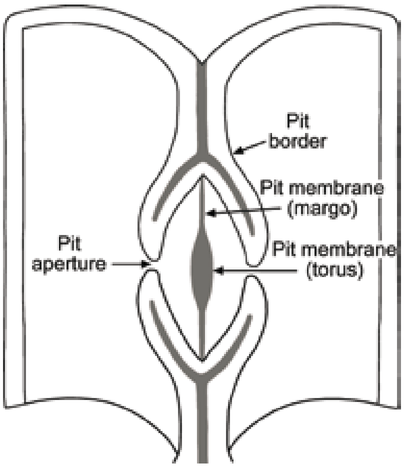


Figure 1. Sectional view of an unaspirated bordered pit between adjoining tracheids

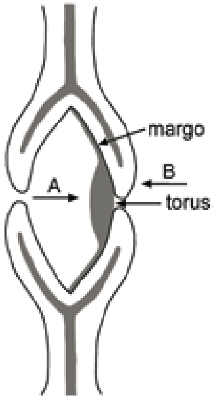


Figure 2. Sectional view of an aspirated bordered pit. Views from directions 'A' and 'B' are shown in Figures 4 and 5 respectively.

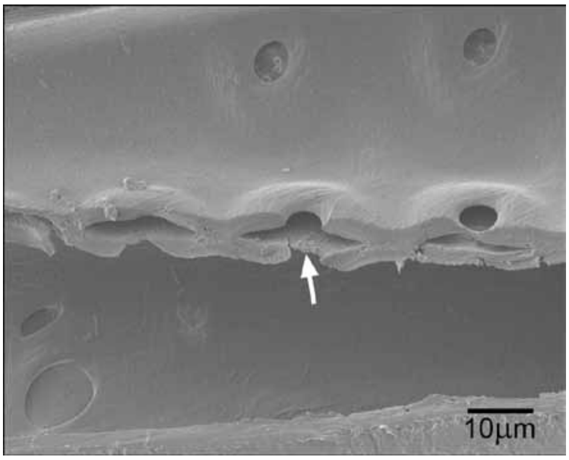


**Figure 3:** Cross-sectional and face views of bordered pits. The arrow points to an aspirated pit membrane. Scale bar = 10 µm.

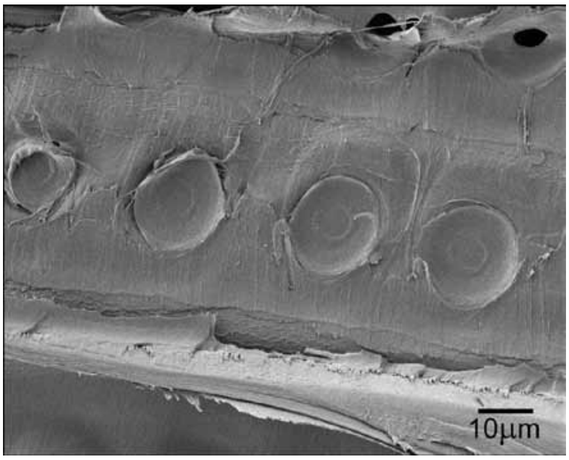


**Figure 4:** Aspirated bordered pits in surface view, as visible from the cell lumen side (view 'A', Figure 2). Scale bar = 10 µm.

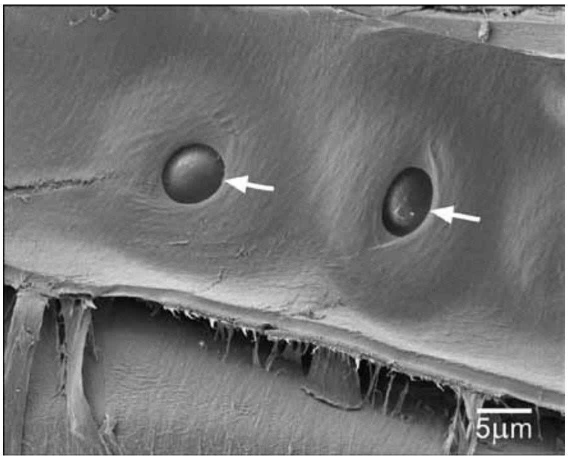


**Figure 5:** Aspirated bordered pits in surface view (view 'B', Figure 2) showing blockage of pit aperture by torus (arrows). Only the torus is visible through the pit aperture. Scale bar = 5 µm.

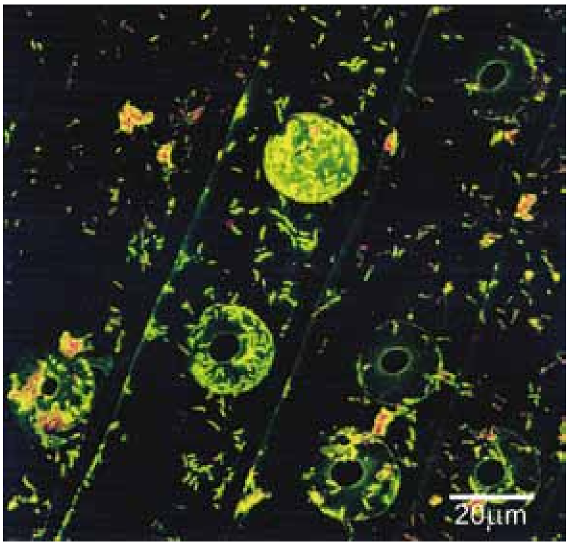


**Figure 6:** Section from wet wood showing bacteria associated with pits (bright specks). Scale bar = 20 µm.

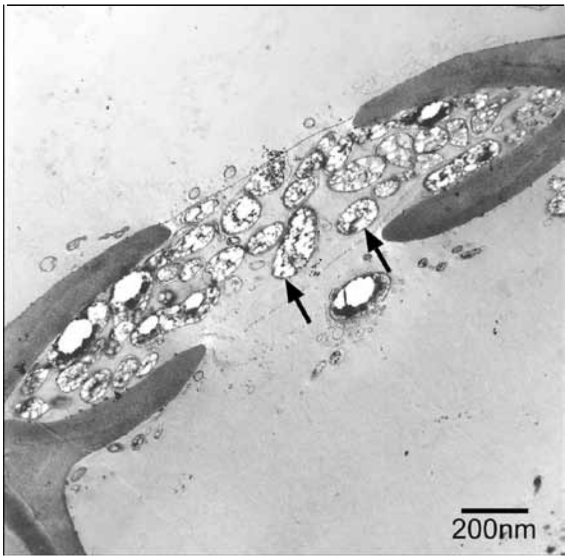


**Figure 7:** Section from ponded wood showing a large population of bacteria (arrows) in the pit membrane region. Scale bar = 200 nm.

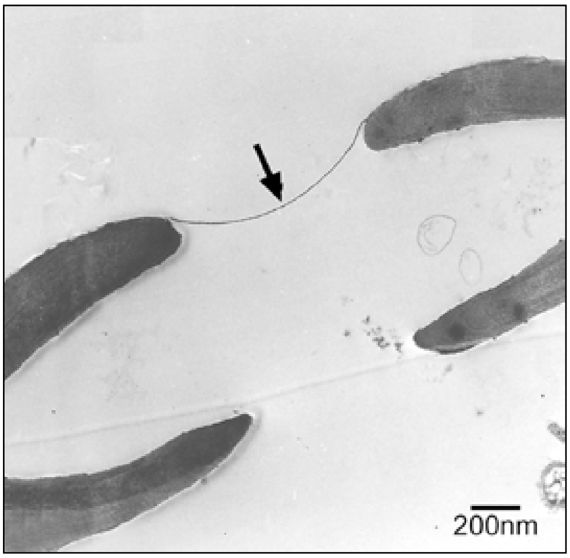


**Figure 8:** Section from ponded wood showing absence of pit membrane and bacteria. The material at the arrow could be extractive residues. Scale bar = 200 nm.

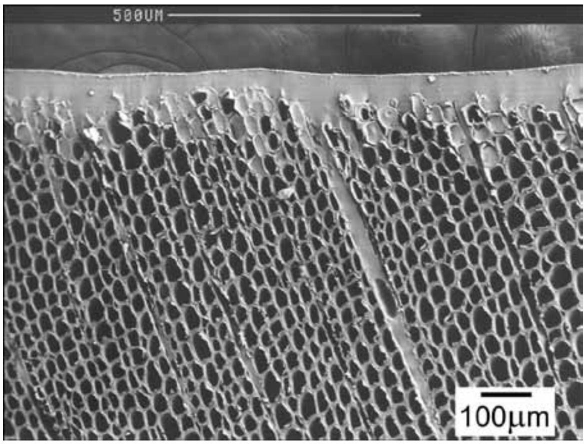


**Figure 9:** Section through varnished control (unponded) wood. Coating penetration extends to only a few tracheids deep from the surface. Scale bar = 100 µm.

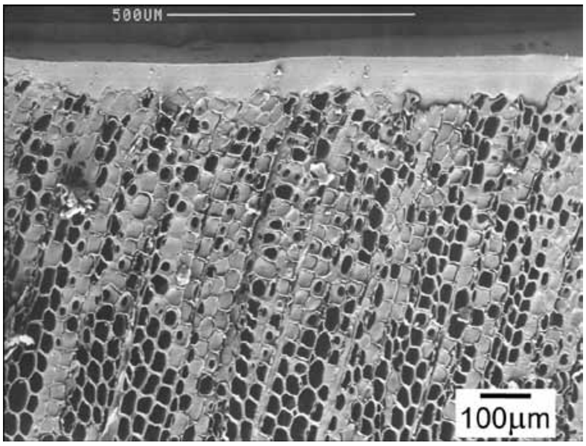


**Figure 10:** Section through varnished ponded wood. Coating penetration is deep. Scale bar = 100 µm.

Wood Quality
Scion Wood Processing Newsletter
Issue No. 42 December 2008

# HEARTWOOD FORMATION AND DEVELOPMENT

*Ping Xu and Dave Cown*

Mature trees contain an outer water-conducting zone (sapwood) and an inner "dead wood" zone (heartwood). Heartwood is a natural feature in the development of tree stems, and has physical and chemical characteristics different from sapwood. These differences include darker colour, higher extractives content, less permeability, slightly higher wood density, better durability, and less shrinkage in heartwood. In some species, heartwood is a desirable stem component for applications requiring stability and durability. However, some high-value, solid wood appearance products specify sapwood. The presence of heartwood adversely affects preservative treatment and potentially lowers the value of clearwood products that require uniform light colour. Also, the presence of heartwood is a disadvantage for paper and wood composites due to the darker colour and higher extractives content.

While the end-product value of forest stands is now acknowledged to be a function of both wood volume and quality, effective management of heartwood formation could add further value. There is international interest in research examining heartwood of both conifers and broadleaves in terms of:

(1) predicting heartwood development in current and future forest stands; and

(2) the key factors influencing heartwood formation.

Plantation grown New Zealand radiata pine has a relatively small proportion of heartwood. Only about 20% of the volume of a 30 year-old radiata pine tree is heartwood.

A few studies have attempted to model the development of heartwood in relation to utilisation needs, but available publications are limited, particularly for radiata pine. Data are available on heartwood diameter for given tree ages and disc heights, which have been collected over the years from sites throughout New Zealand.

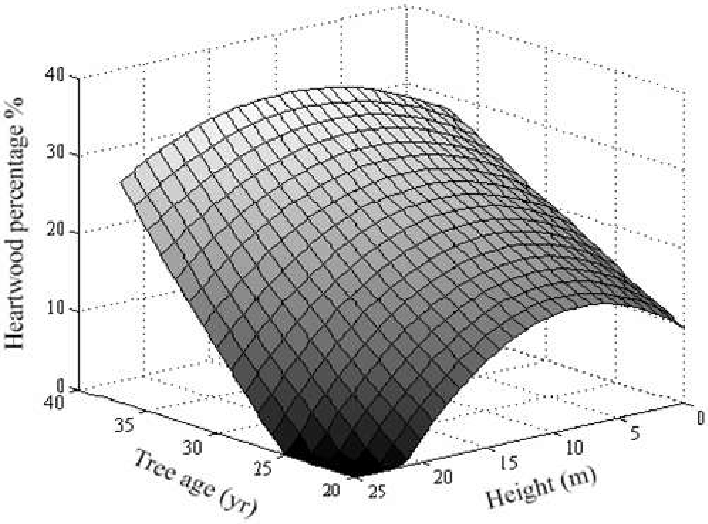


**Figure 1:** Heartwood percentage as a function of tree age and height in the stem

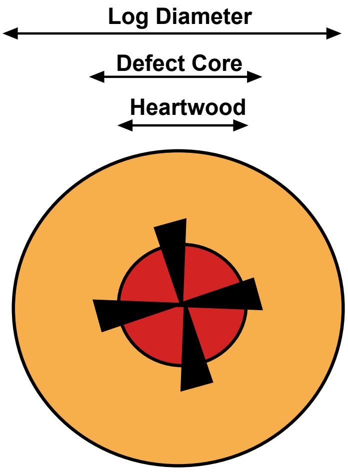
Recent work at Scion has established new models with which to analyse this data. The aims of the models are to:

(1) predict heartwood percentage by tree age and height in stem;

The results of the analysis demonstrated that both tree age and height in the stem are key parameters in predicting heartwood percentage. Tree age is the single most significant factor influencing heartwood development. At a given tree age, the average heartwood percentage varies in a complex (polynomial quadratic) fashion with height in the stem, that is mid logs have the highest percentage heartwood content, Figure 1. The new models were validated statistically (using t-tests at 95% confidence level), and the difference between the predicted and the measured mean value was shown to be insignificant.

(2) predict heartwood rings by crop age at breast height.

Analysis of data collected on the number of heartwood rings showed that the rate of heartwood formation in terms of annual rings is highly predictable so good, regional growth models have been developed. Thus, the extent of heartwood within the stem can be predicted in relation to the size of the defect core, Figure 2. In this way regimes can be manipulated to ensure that high value clearwood can be optimised in pruned radiata pine butt log.



Log diameter and heartwood expand with age. Defect core is fixed after pruning.

**Figure 2:** Defect core and heartwood development within a log

Wood Quality

**Scion Wood Processing Newsletter** Issue No. 42 December 2008

# SPIRAL GRAIN IN RADIATA

*Dave Cown*

**Figure 1:** Radiata log with severe left-hand (S) spiral grain

Radiata pine suffers from a reputation for "instability" – seen in rejection during wood drying or "movement" in use. Spiral grain has been shown to be one of the major factors involved in wood distortion in radiata pine and other species. Spiral grain in radiata pine has been shown to be higher than in other common commercial softwoods such as spruces and southern pines, and has a strong impact on end product value. Studies in New Zealand have suggested that grain angles in excess of 5° can cause twist in lumber.

Despite intensive research worldwide, the fundamental cause has not been identified. Individual studies of the effects of site silviculture and genetics often offer contradictory conclusions.

The highest grain angles normally occur within the juvenile wood, but it has been established that it is highly variable within stems – the more detailed the analyses, the more variation is uncovered at all levels (from within rings both radially and circumferentially, to longitudinally along the stem).

Spiral grain may be of little significance to forest growers, but its impact on product value suggests that it should be catered for in planning models. Therefore, a much better understanding of the causes of spiral grain is required.

Numerous studies have documented the radial and vertical within-tree patterns for softwoods, and confirmed a generic **S** (left-hand) to **Z** (right-hand) development from pith to bark with tree age. It has been confirmed that logs with an external **S** pattern (such as the one shown in Figure 1) are more likely to result in twist.

A recent study examined a single stem in detail (4 logs, 12 discs; 16 circumferential sectors). Figure 2 illustrates how the angle of the spiral grain can vary within a single log.

### *Variations Within Discs*

The 12 discs were cut into 16 segments as shown in Figure 3. Growth rings were removed progressively from the outside and scribed to indicate grain angles. Results are summarised in Figures 4 and 5 to highlight both radial and circumferential variations.

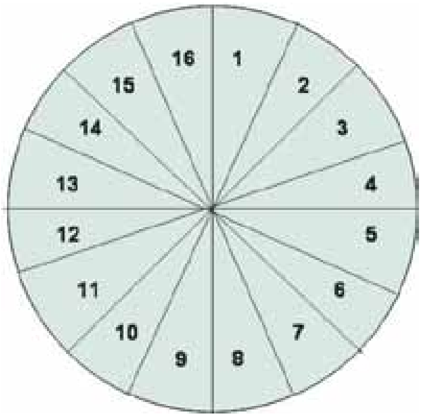
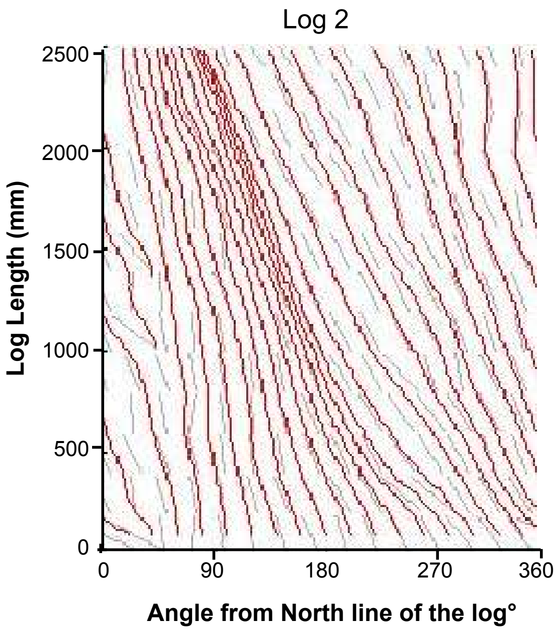


**Figure 3:** Disc sectors



**Min angle = 2.54°**
**Ave. angle = 8.61°**
**Max angle = 12.9°**

**Figure 2:** External Spiral Grain Angle Around Log

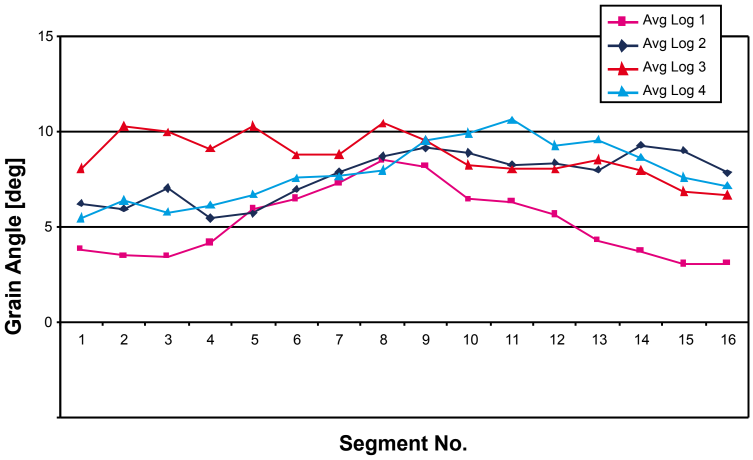


**Figure 4:** Circumferential Trends - Logs 1 - 4

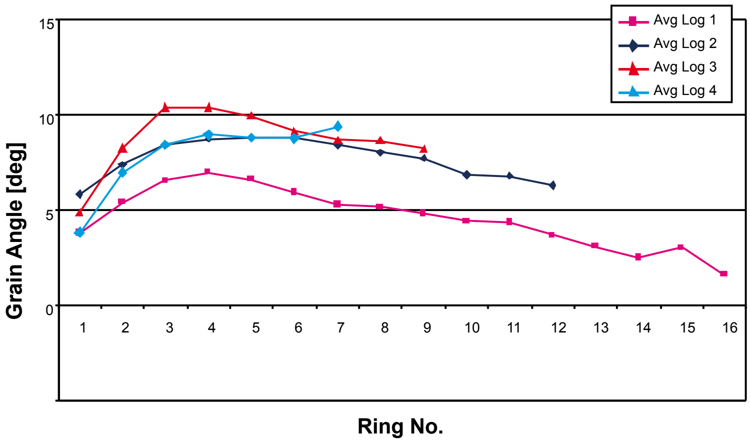


**Figure 5:** Pith-to-bark Trends - Logs 1 - 4

### *Key Points:*

- General patterns within stems are well known, but individuals are more highly variable than has been generally acknowledged in the literature. Not only does spiral grain vary with growth ring number and tree height, but it also varies significantly around the circumference of the stem. Assessment of spiral grain along a radius or diameter is not necessarily representative of the stem as a whole.

  **More data can be collected using modern tools such as Spiralometer and laser technology (see Boxes 1 & 2). However, this additional data simply reveals more variation!**

- Most problems arise from juvenile wood characteristics so cannot be identified on the exterior of stems and logs, except in extreme cases.
- Individual stems show greater variability than any other identified sources. This knowledge should be used in designing sampling procedures for specific needs, as “accurate” descriptions would be exceedingly costly.

### Box 1

**The Spiralometer** is a laser scanning tool developed in NZ in order to permit continuous measurements of spiral grain from pith to bark, using breast height increment core samples. It uses the principle that light is transmitted better along fibres than across them, so that fluctuations in laser light transmittance through a rotating core will indicate grain direction. One advantage of this tool is that data is obtained without destroying the sample. Several improvements have been made to the original tool to make it more suitable for routine laboratory work. Cores can now be scanned relatively quickly to determine the radial variation in grain angles and summarised by either radial sections or growth rings. It is expected to be most useful in genetic studies.

### Box 2

**The T1** laser tool was developed in Sweden and involves scanning of the surface of logs or boards. A circular laser dot is “attenuated” by the surface fibres along their length, thus identifying the grain direction. This information is picked up by a camera and computer to map the surface.

**T2** is a laser-based technology that measures the intensity distribution of the reflected pattern of a laser dot beamed on to the radial surface of wood. This indicates the fibre ‘dive’ (the angle at which the fibre slopes into the wood) and the surface grain angle. When applied to wood samples, fibre surface and dive angles are measured simultaneously.

Wood Quality
Scion Wood Processing Newsletter
Issue No. 42 December 2008

# ARE WE READY FOR REDWOOD?

*Dave Cown and Russell McKinley*

A lot of interest has been shown recently in growing redwoods in New Zealand. There are a few spectacular examples of what might be achieved, such as the Redwood Grove in Rotorua, but there are also many less noteworthy plantations around the country.

The main uses foreseen for the timber are those for which North American redwood has a good reputation – exterior and interior joinery, and weatherboards. However, local processing has only been on a small scale so, at this point, the potential quality of New Zealand plantation-grown redwood is largely unknown. The few studies completed on the wood properties and performance of New Zealand grown redwood indicate a large variation in wood density and also possibly in durability.

What has emerged from the research work to date is that lumber grade recoveries and basic wood properties are highly variable according to planting stock, siting, silviculture and rotation age. It is clear that, given the right site, excellent volume growth is possible. If the lumber can be proven to be equally impressive, the future of redwood is assured. What we need then is a study into redwood wood quality and sawing.

The good news is that the Redwood Group, under the Future Forests Research consortium, has just such a study underway. Its objectives are:

(1) improving the plantation management of redwood for high quality uses;

(2) documenting lumber grade recovery; and

(3) in the longer term, improving the durability of the lumber.

The study's sample stand in the Mangatu Forest (East Coast) was assessed during June and July 2008 and 13 stems selected (DBH 390 to 842 mm; height 29 to 41 m) for a wood properties and sawing study at the Waiariki Timber Technology Centre, Rotorua. From each stem, breast height (BH) increment core samples (at least 50 mm of sound wood) were collected for analysis of the outerwood density distribution. At the time of felling, logs were assessed for acoustic stiffness with a Hitman HM200 and discs (50 mm thick) taken from the butt end and the top of each 5 m log recovered. In the laboratory, the discs were assessed for wood density and shrinkage (tangential, radial and longitudinal) in 5-growth ring blocks.

**Figure 1:** Logs on the log deck at the Waiariki sawmill

The volume of the sample trees ranged from 0.84 to 4.01 $m^3$. Outerwood density values in the sample stems ranged from 274 to 420 $kg/m^3$, and whole log density values from 263 to 400 $kg/m^3$. These values from the Mangatu site covered most of the range observed in other studies of New Zealand redwood and confirm that tree-to-tree differences are probably the major source of variation in existing stands. With the exception of the butt disc, there was little variation in average density values from pith to bark. This confirms the low density and low within-tree uniformity encountered in redwood stems. The correlation between the outerwood and the whole log density values was excellent at 80%.

The heartwood content of stems varied from 44 to 66% and shrinkage values remained fairly uniform throughout. Longitudinal shrinkage values in this study were similar to radiata, i.e. an average value of 0.3% for the inner rings at the extreme base of the stem. Elsewhere longitudinal shrinkage was inconsequential. For radial and tangential shrinkage, there were small increases from pith to bark and with height in the stem but insignificant differences between heartwood and sapwood.

**Figure 2:** Sawn redwood timber

The acoustic stiffness values measured at time of felling showed no correlation with tree density or heartwood content. However, there were relatively useful correlations between stiffness and all three shrinkage parameters measured, explaining between 33 and 46% of the observed variation in stiffness.

The mean wood property values for New Zealand redwood found in this study conform to the average from other, similar studies on redwoods. This reaffirms the uniform nature of redwood regionally. However, the high tree-to-tree variation suggests improvement in redwood quality is most likely to come from the selection of clones with average or above wood density, and with improved durability.

Environment

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# BIOENERGY OPTIONS FOR NEW ZEALAND - SITUATION ANALYSIS

*Peter Hall*

"Bioenergy Options for New Zealand" is a FRST funded project lasting 22 months that has published two reports so far with two more planned. The first of these four reports is the Situation Analysis. This covers an assessment of New Zealand's biomass resources (residual and potential) and biomass to user energy conversion technologies (mature and developing).

The Situation Analysis study shows that New Zealand has the potential to fuel itself from renewable resources. This ability is due to a low population density and large areas of land suitable for agriculture and forestry. It is theoretically possible for New Zealand to be self-sufficient in terms of liquid fuels by using sustainably managed forests, while having low impact on domestic and export food production. Along with the energy from these forests will come ancillary benefits including flood mitigation, improved water quality, erosion control and carbon sequestration. However, before forests are purpose-grown for bioenergy on a large-scale, there is the opportunity to utilise a large range of existing residual biomass resources as energy resources. The wood processing industry is a good example as it is already a major producer and user of bioenergy generated from residual biomass.

**Table 1:** - Assessment of potential energy from residual biomass resources, assuming 80% is available to use (PJ/year)

| Type / source | 2005 | 2030 | 2050 |
|---|---|---|---|
| Forest Residues | 14.6 | 34.4 | 29.5 |
| Wood Process Residues | 7.0 | 9.1 | 18.4 |
| Municipal wood waste | 3.5 | 2.2 | 2.9 |
| Horticultural wood residues | 0.3 | 0.3 | 0.3 |
| Straw | 7.3 | 7.3 | 7.3 |
| Stover | 3.0 | 3.0 | 3.1 |
| Fruit and Vegetable Culls | 1.2 | 1.2 | 1.2 |
| Municipal Biosolids | 0.6 | 0.7 | 0.7 |
| Municipal solid waste , landfill gas | 1.9 | 2.0 | 2.0 |
| Farm Dairy | 1.2 | 1.2 | 1.3 |
| Farm Piggery | 0.1 | 0.1 | 0.1 |
| Farm Poultry | 0.0 | 0.0 | 0.0 |
| Dairy Industry | 0.4 | 0.4 | 0.5 |
| Meat Industry (effluent only) | 0.5 | 0.5 | 0.6 |
| Waste oil | 0.2 | 0.2 | 0.2 |
| Tallow | 3.6 | 3.6 | 3.6 |
| **Total** | **45.9** | **66.5** | **72.0** |
| Available Biomass as % of Consumer Energy | 8.5 | 9.2 | 8.1 |
| Available Biomass as % of Primary Energy | 6.6 | 7.5 | 6.6 |

From Table 1 we can see that:

- all available biomass residues combined would meet only approximately 10% of New Zealand's current energy demand; and
- woody biomass makes up the bulk of the residual biomass (55%). Of this, around one-third is from wood processing residues that are currently not utilised for energy.

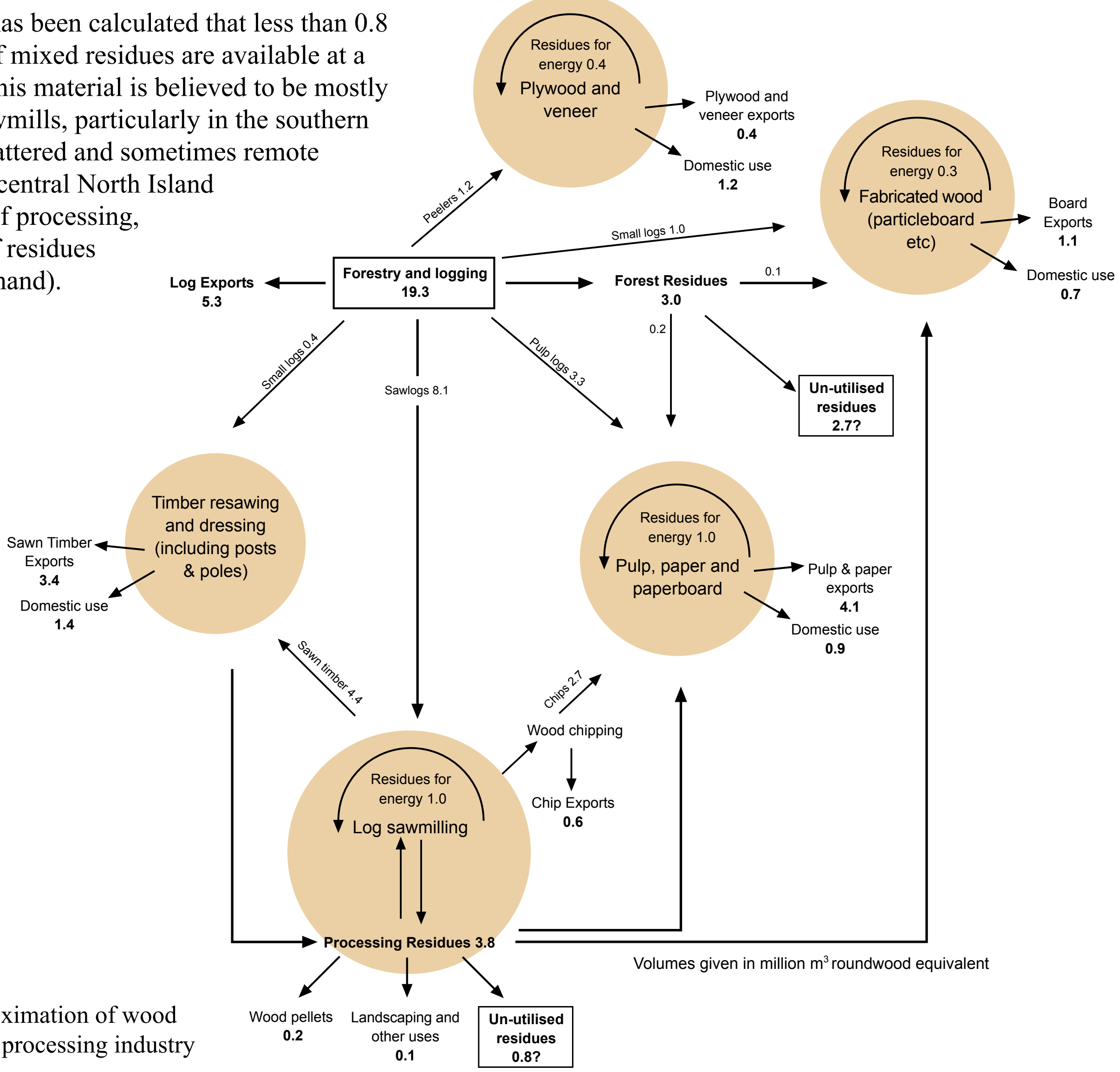
### *The Resource*

New Zealand has a range of bioenergy options available that could provide a meaningful contribution to the nation's energy future. Current energy production from biomass is in the order of 45 PJ per annum. Biomass residues could contribute another 60 PJ per annum. This contribution could theoretically rise to 90 PJ in 2050, based on increasing residues from increasing volumes of forest harvesting and wood processing. Residual biomass resources, in descending volume order, include wood residues, agricultural residues, municipal wastes and industrial wastes from various sources (Table 1).

The wood processing industry is the largest user of bioenergy in New Zealand, consuming around 2.7 million tonnes of wood residues, equivalent to 22 PJ, per annum. Wood residues from wood processing are also used as domestic firewood and increasingly for making wood pellets for domestic and commercial use.

New Zealand sawmills generate 3.5 million tonnes of wood residue produced from debarking and other primary breakdown operations. An additional 0.6 million tonnes comes from other wood processing sectors. Of this 4.1 million tonnes, over 3 million tonnes is used in other wood processing operations or for bioenergy. This leaves approximately 1 million tonnes of residues available for expanding current uses or developing new opportunities.

Of this 1 million tonnes, it is estimated that the wood pellet market uses 0.2 million tonnes and landscaping and other users use 0.1 million tonnes. Based on these assumptions, it has been calculated that less than 0.8 million tonnes of mixed residues are available at a national level. This material is believed to be mostly from smaller sawmills, particularly in the southern North Island (scattered and sometimes remote processing) and central North Island (large volumes of processing, where supply of residues is exceeding demand).



Volumes given in million m³ roundwood equivalent

**Figure 1:** – Approximation of wood flows in the wood processing industry

It is often difficult to get exact measures of material flows within the industry, as much of this information is:

- commercially sensitive;
- changing with price and other industry circumstances (mill closures, shifts worked);
- inaccurately measured or estimated; and/or
- not centrally recorded or reported.

Interactions between industry sectors are also complex, Figure 1. Until more accurate wood flow and residue flow statistics are derived from the wood processing sector, the amount of wood processing residues available for energy use by other industries will remain uncertain.

### *Future Availability Trends*

There is on-going development of wood residue use within the wood processing industry, with recent conversions of lumber drying kilns from gas to wood processing residues. Lumber drying has been increasing in the last 10 years and demand for residues suitable for making wood fuel pellets is also expected to increase. There is also predicted to be an expansion in wood supply, and if this leads to an associated increase in processing, then the supply of residues will also increase. However, as the processing volume increases so does the energy demand of the industry.

In the short term it is likely that the use of residues will continue at around the same proportion as it is currently. If fossil fuel (gas and coal) prices rise in the medium term, the proportion of residues that are used within the wood processing industry is likely to increase in response. The dynamics of the wood processing industry will have a pivotal role in influencing future availability of residues for bioenergy production, especially for sectors outside the wood processing sector.

There are barriers to the uptake of bioenergy that are not limited simply to the cost of the fuel. In some sectors there are issues around the consistency of the quality of the fuel, and further, there are concerns over guarantee of supply. This has a major impact on users outside the wood processing sector. If an investor is looking to move to a bioenergy plant, they need to be sure that the fuel supply is reliable. This is often difficult to obtain in the case of wood processing residues. Thus, the use of wood processing residues for industrial heat is likely to be limited in the short to medium term to within the wood processing industry.

### *The Goals*

The Labour Government set targets for increased use of renewable energy which would see New Zealand being carbon neutral in:

- electricity by 2025;
- industrial energy by 2030; and
- transport fuels by 2040.

It is too early to say what targets the incoming National Government will set.

In order for New Zealand to be sustainable it must not only be carbon neutral, it must also be economically competitive and have economic growth. Such growth has to occur in an increasingly resource constrained world, therefore it is necessary to:

- meet energy demand from renewables;
- manage land sustainably; and
- maintain a robust export sector whose sustainability can be verified and defended.

### *The Solution*

New Zealand can reduce emissions from industrial heat and transport through efficiency gains and by substituting bioenergy for fossil energy. The use of residual biomass is a logical starting point, and a step in the direction of renewables. However, the total amount of energy available from residual biomass is relatively small (around 10%) in comparison to total energy demand. If we focus on the use of residual biomass for heating then we have the potential to create 25 to 30% of the national heat demand. The use of residual biomass has environmental benefits as well as energy value, and the technologies to extract energy from wastes are maturing. For example, using anaerobic digestion on meatworks and municipal effluents to produce methane for a gas motor genset is now close to economical viability.

The use of wastes for energy will have large impacts on greenhouse gas emissions because biomass resources tend to produce methane when dumped as landfill. If fossil energy is displaced by the use of energy from residual biomass, there will be a double gain in reduced emissions, along with other environmental benefits. This is particularly relevant to materials such as municipal effluents, biosolids and solid waste.

There is frequent media comment about the use of biomass residuals to create energy (e.g. waste vegetable oil to biodiesel). The key thing to remember is the relative scale of the opportunity provided by the resource and the demand which it is being used to meet. New Zealand's total energy demand is around 740 PJ per annum, with around 210 to 220 PJ being in liquid fuels. However, the waste vegetable oil resource is only 0.2 PJ. Whilst it is always a good thing to utilise wastes and residuals where possible, a sense of perspective on their ability to meet a large scale energy demand must be kept.

The next logical step is to grow biomass for energy. In this scenario the limiting resource becomes land. If New Zealand is to achieve bioenergy goals without competing for land with food crops, it is necessary to consider growing medium- to long-rotation forests on marginal lands. These forests would have to be significantly greater in area than the existing planted estate (1.7 million ha). To meet the country's total heat demand, a dedicated bioenergy forest estate of 700,000 ha would be required. To meet the liquid fuels demand a further 2.5 to 2.8 million ha would be needed. A finding of the EnergyScape study (NIWA 2008) was that New Zealand has significant resources which can provide renewable electricity (hydro, geothermal, wind, marine) and fossil resources (coal) to provide heat, the future problem supply area will be liquid fuels.

Use of biomass from forests (including purpose-grown forests) to produce liquid biofuels has fewer environmental concerns than intensive cropping of arable land because forests:

- do not require intensive fertilisation;
- do not require irrigation;
- do not cause nutrient rich run-off; and
- do not compete for high value land used for production of food crops such as corn, wheat and vegetables.

Forests also provide an energy store that can be used when required or processed into other valuable products.

New Zealand has at least 830,000 ha that could be cost effectively used for forestry. Some estimates indicate that there could be as much as 3.0 million ha.
A combined energy forest estate of approximately 3.2 million ha could provide most of New Zealand's heat and liquid fuel demand.

### *Converting Biomass into Energy*

Biomass can be used to produce heat, power and liquid fuels, along with other products. Energy products from biomass can be produced in a range of forms (solid, gas, liquid) that can be handled by existing infrastructure in many cases. Biomass has advantages over fossil fuels because it:

- is renewable;
- produces less greenhouse gas;
- is widely distributed; and
- utilises and/or mitigates wastes.

The logical route for biomass resources is largely for heat and liquid fuels, with some ancillary electricity via cogeneration.

Energy outputs can be derived from biomass using a range of existing or developing technologies. Conversion technologies commonly used in New Zealand to produce heat, biogas and biodiesel include combustion, anaerobic digestion and chemical/mechanical methods. Emerging technologies for the production of liquid biofuels include: enzymes to ethanol, gasification (using the Fischer-Tropsch process), and pyrolysis.

The use of biomass resources, which are diverse and widely distributed, is technically feasible, but costs are highly variable. Significant barriers to the use of biomass for bioenergy are:

- guaranteeing quantity and quality of biomass feedstock supply to conversion plant; and
- operating processes on a scale large enough to be economic.

The next report in the series is a Pathways analysis where a range of routes from biomass resource to user energy (such as waste wood to ethanol or straw to heat) are subject to life cycle assessment. The yet to be published reports are a Research and Development Strategy and an Assessment of the land use, environment and economic impacts of large scale bioenergy from forestry.

The full reports from the Bioenergy Options for New Zealand project can be found on the Scion website at:
http://www.scionresearch.com/bioenergy+report.aspx