1.0 Introduction
Technologies for the modification of wood have been known for decades. Commercial implementation of these technologies has been restricted in the past due to economic considerations that meant the resulting product would need to command too high a price in the market place to justify the return to an investor of any capital outlay. Technological advances, regulatory changes, green building practices, environmental concerns and in some cases, new science, have meant that market price points for a number of modified wood products, while still commanding a premium over some of the more traditional hardwood products they compete against, are today at a level where investors are prepared to back some of these technologies.

This paper reviews several such technologies that are being commercially exploited today. Branded wood products are being sold, principally in the construction and furniture industries, to compete against hardwoods that are perceived to be less “green” as a result of publicity around illegal logging and the destruction of the rainforests. The commercialisation of three of these technologies has evolved out of Europe. The fourth technology has a New Zealand base and is founded on the Indurite™ technology developed originally by the NZ Forest Research Institute (now known as “Scion”).
2.0 Background – a little bit of Science!
Arguably, a number of manufacturing processes could be deemed to “modify” wood. Converting wood chips into pulp; adding chemical preservatives to enhance durability; and gluing “back together” wood components to produce engineered wood products like LVL, plywood or fibreboards all modify the properties of the underlying wood feedstock to produce a better, fit-for-purpose material.

The term wood modification is used more specifically to indicate that there has been a permanent chemical change in the cell wall structure at the molecular level. Additionally, it is now accepted that wood modification results in a wood product that does not exhibit toxicity in service, does not release toxic materials at the end of its service life e.g. when incinerated, and the mode of action for any biological resistance is non-toxic i.e. no biocide added.

In general, the three most common ways to modify wood under this definition and bring about permanent change in the cell wall structure are:

1. Chemical modification
   o Direct chemical reaction by introducing chemical compounds
2. Thermal modification
   o Thermal treatment at elevated temperatures > 180°C, in the absence of air.
3. Biological modification
   o Indirect chemical reaction by introducing biological organisms e.g. enzymes.

From a commercial perspective, only (1) and (2) are at the point where technologies have been commercialised and modified wood products are being produced, re-manufactured as necessary and sold to the consumer.

Interestingly, most of these commercialised wood modification technologies result in a reduction of the chemical OH groups in the cell wall of wood. These OH groups attract water molecules through a process known as ‘hydrogen bonding’ causing wood to swell. Lower numbers of available OH group sites in the cell wall means that modified wood is more hydrophobic and shrinks and expands to a lesser degree during any seasonal humidity cycling. Modified wood is therefore more stable than its unmodified wood precursor and this is frequently reported in the technical literature associated with commercially-available modified wood products.
3.0 Commercial technologies: chemical modification of wood

There are essentially three types of chemical systems being used today to produce chemically-modified wood products. They are:

1. Acetylation
2. Furfurylation
3. Wood hardening i.e. Indurite™ and its derivatives

3.1 Acetylation
The acetylation of wood is a well-known technology – reportedly being studied as far back as the early 1900s. The process is essentially as follows:

- Impregnation of wood with acetic anhydride
- Heating to around 70°C to create the exothermic reaction
- Acetic anhydride reacts with the OH groups of the cell wall converting them to acetyl groups.
- Acetic acid is created as a byproduct and it is removed along with any unreacted acetic anhydride.

The durability and stability of the wood are significantly enhanced through the creation of acetyl groups within the wood. The main drawbacks of the process have been that some of the acetic acid byproduct is retained in the wood, giving a vinegary smell and ongoing deterioration in wood quality, as well as the economics associated with re-converting the recovered acetic acid back to acetic anhydride so it can be re-used.

Figure 1. Schematic of the acetylation reaction with wood.

The commercialisation of acetylated wood is being driven today by the efforts of Titan Wood Ltd. See www.titanwood.com. The diagram in Figure 1 was taken from published Titan Wood literature.
Titan Wood Ltd.

- Titan Wood Ltd produces an acetylated wood product that is branded as Accoya® wood. It is clear i.e. retains the natural wood features and its primary markets are exterior - cladding, decking and structural as well as window joinery.
- The primary goal of Titan Wood Ltd is to maximize returns through licensing its production technology to produce Accoya® wood.
- Titan Wood Ltd is a subsidiary company of Accys Technologies PLC (“Accys”).
- Accys listed on the London Stock Exchange’s AIM market for smaller, growing companies on 26 October, 2005. They placed 27,000,000 new Ordinary shares at €1.00 each raising €25,850,000 after expenses.
- These funds have been used principally to fund the construction of a 30,000m³ production unit in Holland.
- In May 2007, Accys entered into arrangements with Celanese Corporation (a NYSE-listed chemical company with specialist knowledge on acetyl) whereby Celanese had exclusive rights to supply acetyl to any Titan Wood licensee in return for an investment of €22,100,000 through placement of 8,115,883 new Ordinary shares at €2.72 per share.
- On 18th September 2007, the company was admitted to trading on Euronext Amsterdam by issuing 5,000,000 new Ordinary shares at €4.10 per share raising €18,500,000 net.
- Two licensees, one in China and one in the Middle East, have signed for annual capacity of 500,000m³ and 150,000m³ respectively at published pricing of €200 per m³ of capacity plus 22 per m³ annual capacity royalties.
- This allowed the company to report revenues of €27.3 million and an audited net profit of €4.1 million in their latest Annual Report for the financial year ending 31 March 2008.
- This Annual Report also shows Accys has no debt and a cash position of €46 million. They made their first dividend payment to shareholders.
- Accys has opened a new office in Dallas, TX and reports staff number in the order of 75 people.
- Accys is also pursuing opportunities to acetylate fibres and enter the fibreboard market.

In summary, Accys has raised a tremendous amount of capital to fund the development and growth on acetylated wood and their Accoya® brand. They are positioning themselves to take aggressively the product to market through engineering advancements in their processing plant allied with market and brand positioning to attract licensees. There are some doubts around the level of capital required
by a licensee to build an acetylation plant and the final product cost in the market place. With the “war chest” available to Accys, they have time to improve both these economic drivers through even more innovation in their processing operations.

3.2 Furfurylation
Furfurylation of wood involves the pressure impregnation of wood with a water based solution of furfuryl alcohol followed by curing with steam and conventional drying. Conventional pressure cylinders and wood kilns as used in the wood products industry can be used. The final wood product is dark in colour but has enhanced stability and durability properties. Furfuryl alcohol is derived from corn cobs or sugar cane residues providing a good environmental story.

The principles of forming furanic polymers were reported in the 1920s and early attempts at wood furfurylation commenced in the 1950s. It wasn’t until some further developmental work was completed at the University of New Brunswick in the 1990s that commercialisation of the technology was able to be considered. Wood products produced from furfurylated wood are sold today by Kebony ASA (previously Wood Polymer Technologies ASA) out of Norway. See www.kebony.com and www.kebonyproducts.com.

Kebony ASA ("Kebony")
- Kebony produces furfurylated wood products branded as Kebony (K30 and K100). The product is dark in colour and its primary markets are exterior – cladding, decking, roofing, panels as well as interior flooring.
- Current species being treated include beech, pine sapwood, maple and Scots pine.
- Kebony has a stated vision to be a “category killer” through a three-fold strategy of branding/marketing; establishing a showcase plant and developing a profitable and scalable business model through licensing its production technology.
- Kebony is privately held and in 2007 received financing of 235 million NOK (approximately NZ$64 million). This has provided funding to complete a dedicated production facility with a capacity of 26,000m³ per annum due to be operational in October 2008.
- The current organization, including production staff, numbers over 40 people.
Kebony has received significant and much-needed funding in 2007 that has taken it from a niche Scandinavian technology to a point where it can become a truly global business and compete in the exterior market segments with Titan Wood. They have a clear objective to be the category leader for modified wood.

![Kebony process for furfurylation of wood](Image)

### Figure 2. Kebony process for furfurylation of wood

3.3 **Wood hardening i.e. Indurite™ and its derivatives**

New Zealand Forest Research Institute (now Scion) developed and patented, in the early 1990s, a wood hardening technology they called Indurite™. The technology involves pressure impregnation of starch and a cross-linking chemical using traditional pressure treatment equipment following by curing/drying using a traditional wood drying kiln. This results in a densified and hardened wood product through a polymerization reaction that results in chemical bonding with the cell wall. Dyes can be added to the formulation to impart various colours. The product was developed principally for the interior market with the key segments being flooring and furniture due to enhancements in hardness, stability and machineability.

The original patents are today controlled by a company called Indurite plc (see [www.indurite.com](http://www.indurite.com)) whose sole licensee appears to be Osmose UK (see [www.osmose.co.uk](http://www.osmose.co.uk)). By all accounts there has been little take-up of the original technology through sub-licensing by Osmose UK. However, the author is aware of at least three companies using technologies related to Indurite™ to produce a wood hardened and coloured product for interior markets. All three companies have production facilities and have a branded product that is commercially available.
**Fibre7 Limited** ([www.fibre7.com](http://www.fibre7.com))

- Original commercialiser of the Indurite™ technology via company called Pacific Hardwood Industrees.
- Now using a different formulation
- Production plant in Tauranga with drying/curing outsourced
- Hardened wood product branded as Lignia™
- Business privately owned by UK interests
- Business model appears to be to produce and sell Lignia™ wood products as opposed to licensing production technology.

**EverTech LLC** ([www.alowood.com](http://www.alowood.com))

- Developed own patented, wood hardening formulation
- Starch-based formulation like Indurite™ technology but uses different cross-linker that is formaldehyde free
- Production plant in Washington State with treating and drying facilities on-site, plus chemical formulation plant
- Hardened wood product branded as Alowood; hardening formulation branded as Everdex
- Parent company is Verdant Wood Technologies ([www.verdantwoodtechnologies.com](http://www.verdantwoodtechnologies.com)) which is made up principally of three separate businesses
  - Chemco – fire retardant treating of wood products
  - TrueLog – firelogs made via an impregnation process
  - EverTech – wood hardening technology
- Business privately owned by US interests
- Business model is to sell chemical formulation to licensees globally.

**Kurawood PLC** ([www.kurawood.com](http://www.kurawood.com))

- Acquired own wood hardening technology which was developed by previous investors in Pacific Hardwood Industrees
- Formulation has not been patented and is described as a proprietary mix of a vegetable oil and aminoplast.
- Production plant is in Tauranga and with drying/curing outsourced as required
- Hardened wood product branded as Vecowood®
- Kurawood listed on the London Stock Exchange’s AIM market for smaller, growing companies on 18 September, 2007. They placed 4,500,000 new Ordinary shares at £1.00 each raising £4,500,000.
- Their unaudited interim financial statements for the six months ended 31 March 2008 are available on their website and show nil revenues and current assets of £3.0 million of which cash and cash equivalents amounts to £2.8 million.
4.0 Commercial technologies: thermal modification of wood

Thermal modification of wood requires heating the wood to temperatures in excess of 180°C resulting in chemical changes to the wood cell structure that make the wood less hygroscopic (i.e. absorbs less water from air). Improvements are seen in wood stability and durability but the strength properties tend to deteriorate significantly resulting in this technology having limited applications for load-bearing, structural timber applications.

The process must occur in an inert atmosphere (free of oxygen) to avoid severe degradation or, even worse, combustion and fires! Several processes have been developed to do this and the “blanketing” media to prevent oxygen ingress include nitrogen gas, steam and hot oil.

Commercialised thermal modification processes include:
- ThermoWood® (Finnish process; see www.thermowood.fi)
- Plato®wood (Dutch process; see www.platowood.nl)
- Retification (French process; see www.retiwood.com)
- Perdure (French process; see www.perdure.com)
- Oil heat treatment (German process; http://www.menz-holz.de)

The most significant of these in recent years has been the Thermowood process and this is discussed in more detail below.

4.1 ThermoWood®

The ThermoWood® process was developed and patented by VTT Technical Research Centre of Finland. The patent is administrated by a company called Licentia Oy and it is valid in Austria, Belgium, Switzerland, Germany, Denmark, Spain, France, UK, Greece, Ireland, Italy, Holland, Portugal, Sweden, Japan, Canada and the USA. Licentia Oy has established a license agreement with the Finnish ThermoWood Association for exploitation of the patent.

The Finnish Thermowood Association was itself established in December 2000. The members are either heat treated wood producers or kiln manufacturers and include major forest and forest product corporates such as StoraEnso and Finnforest. The aim of the association is to enhance the use of heat treated wood produced by its members. It owns the registered trademark - ThermoWood® and has developed a third-party audited quality control system with a quality stamp for those producers that are signed up to the programme. Additionally, the Finnish ThermoWood Association allocates resources for topical R&D activities each year.
The Thermowood Association also completed product classification activities in 2003. Two standard treatment classes were introduced: Thermo-S and Thermo-D. The difference is reflected in the final treatment temperature such that Thermo-D, heat-treated at a higher temperature, has enhanced stability and durability performance over the Thermo-S product.

The ThermoWood® process can be divided into three main phases:

**Phase 1. Temperature increase and high-temperature drying**
Using heat and steam, the kiln temperature is raised rapidly to a level of around 100 °C. Thereafter, the temperature is increased steadily to 130 °C, during which time the high-temperature drying takes place and the moisture content in the wood decreases to nearly zero.

**Phase 2. Heat treatment**
Once high-temperature drying has taken place, the temperature inside the kiln is increased to between 185 °C and 215 °C. When the target level has been reached, the temperature remains constant for 2–3 hours depending on the end-use application.

**Phase 3. Cooling and moisture conditioning**
The final stage is to lower the temperature by using water spray systems; when the temperature has reached 80–90°C, re-wetting takes place to bring the wood moisture content to a level of 4–7%.

![ThermoWood® heat-treatment profile](image)

Figure 3. Heat-treatment profile for the ThermoWood® process

The Finnish Thermowood Association provides quite detailed production statistics on their website. These show that almost 84,000 m³ of wood was processed to ThermoWood® in 2007.
5.0 Conclusions

A broad spectrum of research into various wood modification activities was carried out in the 1990s that has lead to a number of companies being formed to spin-out these technologies.

The examples cited in this paper show that different fund-raising models have been used to raise the necessary capital to get these ventures launched. They include IPOs, angel investment, private equity and, in the case of the Finnish ThermoWood® technology, a cluster-type approach with involvement of major regional producers.

Overall, growth has been steady, if not spectacular, and it behooves “NZ Inc. Wood Processing” to maintain a watching brief of these technologies as their brand equity grows and market reach extends into Asia and North America. This is especially important as all of the wood modification technologies reviewed work well with Radiata pine as the feedstock. This is particularly true for the suite of chemical modification technologies, due to the very permeable nature of Radiata pine.

6.0 References

Most of the information presented herein is available from the various websites referenced throughout the paper. In addition, the following publications were useful.

