Wooden It
Wood processing guidance

Douglas-fir Processing Opportunities

Douglas-fir Strategy

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EXECUTIVE SUMMARY

Douglas-fir, as the second most widely grown exotic species in New Zealand, has an important role in New Zealand forestry and all wood consuming industries. Its greatest asset lies in its structural properties and these have been put to good use in New Zealand over many decades. This study investigates and evaluates some of the more attractive options for bringing Douglas-fir to the market.

Douglas-fir has advantages over the most widely planted exotic species in New Zealand, Pinus radiata, in its physical properties of stability, stiffness, natural durability, and strength to weight ratio. In qualities such as machinability, brittleness on nailing - both products of the large difference between early-wood and late-wood densities - and time to maturity it is less attractive than P. radiata.

In reaction to leaky home experiences in the late 20th century, the New Zealand building code was changed to eliminate the use of any untreated softwoods in normal construction. However, in 2011 D-fir’s natural resistance to wetting and associated decay mechanisms was again recognised by an amendment to the building code allowing its use in indoor areas, but in the meantime kiln dried and treated radiata had moved in to occupy the niche that Douglas-fir had enjoyed. In most cases now Douglas-fir is graded the same way as radiata and marketed alongside it where, perhaps its stiffness advantages are not leveraged as effectively as they could be.

Of the options available for the use of Douglas-fir logs the least-cost lowest-risk option is that of exporting whole logs. Douglas-fir logs command a premium over radiata logs in the markets they are traded.

Sawmilling and marketing structural wood alongside radiata requires a lot of capital and must bear a higher log cost driven by log export prices. On the face of it, sawmilling Douglas-fir has little economic attraction unless the product goes into specialty markets or has value added by further processing.

Opportunities to add value by further processing already exist in the form of engineered wood products including glue laminated products, mass timber products like cross-laminated timber, and developing technology like optimised engineered lumber (OEL^{TM}) products. All these processes are capable of differentiating Douglas-fir by making use of its inherent strengths.

INTRODUCTION

This report is the second part of a three-stage project to develop a regional processing strategy for Douglas-fir (D-fir).

> Stage one – Characterisation of the resource, used MPI data and grower/mangers' comments to describe the regional and age class distribution of the D-fir resource.
>
> Stage two – will investigate processing options ranging from, exporting raw logs to such recent technologies as Cross laminated timber (CLT) and Optimised Engineered Wood (OEL^{TM}). Stage two will consider such things as
>
> capital requirement,
> scale economics,
> production costs,
> the physical suitability for Douglas-fir,
> market opportunities and profitability for each option.
>
> Stage three will combine the information from the previous two stages to identify which process approaches are likely to be more successful in each region.

D-fir has been recognised to have advantages over radiata in stability (Sargent & Durbin, 2019), stiffness (Bier,1988, *rev, Britton*, 1999), limited natural durability (NZ Building code, April 2011 para 3.2.2.2), and weight/strength ratio, with disadvantages in brittleness and quality of machine finish.

These characteristics meant that in the 1970s to 1990s, when kiln dried pine was not so widely available, D-fir was used in roof trusses, wall frames, and solid or laminated beams. During this era natural wood wall panelling and exposed beams were fashionable, and D-fir was popular in these uses because its colour and early/latewood contrasts were seen as attractive and natural wood finishes do not highlight machining irregularities as much as smooth paint finishes do.

There is still some demand for large cross sections for beams and lintels, and for boards for wall lining, however it is difficult to differentiate D-fir from radiata in uses such as wall frames and trusses (personal communication, various, 2020).

There is a small demand from those seeking to use untreated timber in their buildings and for some horticultural uses where treated wood is undesirable (Grant Hagan, Dave Butler Red Stag, personal communication, 2020) but it is currently regarded as an alternative to KD radiata rather than a more attractive substitute.

It has been used and tested more recently in cross laminated timber (CLT) and optimised engineered (OEL) products and proves to be as effective as kiln dried radiata in these roles. With a few exceptions there seems to be little or no effort to differentiate it from KD radiata based on its stability or stiffness qualities.

Physical Properties of D-fir

> "Because of its good strength and stability New Zealand grown Douglas-fir is primarily suited for use as a structural and framing timber. It has greater fibre length than radiata pine and a major advantage is that wood density and strength do not decrease near the pith, allowing framing timber to be sawn from much smaller logs including thinnings. When used above ground it does not need to be treated with preservative, so it can be sold to the end-user straight off the saw. Douglas-fir timber has a low moisture content and dries with little distortion. As well as its suitability for light timber framing, it is valued for internal exposed post and beam construction" (FRI Bulletin, 124/14, 1994).

> "Unlike radiata pine, there is a clear distinction between the density of wood laid down in autumn (latewood) and wood deposited in spring/summer (earlywood). Within each growth ring, the latewood band is very hard and dense, and the earlywood is very soft. This sharp contrast determines much of Douglas-fir's virtues and failings. Given New Zealand's rapid growth rates- with wide growth rings as a result- the high-density areas are clearly visible in finished timber. This may sometimes look attractive, particularly in combination with the rich red colour of the heartwood, but it is very difficult to create a smooth finish- and it is also problematic to achieve consistent results when staining, gluing, painting or varnishing. For these reasons, therefore, New Zealand-grown Douglas-fir is not a preferred timber for the "appearance grade" market. Radiata pine, with its even texture, is more suitable for this purpose. Within each growth ring, dark bands of very dense wood are laid down in autumn, contrasting with lighter bands of soft earlywood (P. De La Mare) But the very features that make Douglas-fir unsuitable for appearance-grade products also confer an advantage for structural grades. Concentration of a high proportion of wood material in latewood bands creates structures that enhance strength for a given weight- the same principle is used in modern engineering designs. Yet for the lamination ("sandwich") effect to operate well there must be several growth rings in any cross-section of wood. This means that Douglas-fir is not favoured for small items or detailed mouldings - the risks of encountering a patch of substandard earlywood is too high. (Maclaren, FRI Bulletin, 237 2009, p.19).

Strength and stiffness properties of D-fir

In D-fir "Branch size and wood density have been shown to be the most important factors influencing timber stiffness and strength - especially the former. (FRI Bulletin, 237, p. 20).

Branch Diameter (mm)	Wood density required (kg/m^3)
64	559
51	488
38	417
25	347
13	276

Table 1: Wood density required to achieve stiffness of 5.5kPa at given branch size in D-fir. (FRI Bulletin, 237- Maclaren, 2009).

From analysis of short clear samples, D-fir exhibits a significantly smaller within-tree variability in strength and stiffness characteristics than P radiata.

> "Expressed as coefficient of variance between small clear specimens from the same radial position (growth ring), the variation ranged from 8% to 32% for P. radiata and from 7% to 13% for Douglas fir." (Hanson, Knowles, Walford, n.d.).

Durability

As a refractory species, D-fir cannot be treated with preservatives in the same way as radiata and other pines. However, in the untreated state it has a reasonable resistance to common decay mechanisms if it is kept dry or experiences only rare wetting in service. D-fir ….

> “would need to be submerged in water for four days to absorb enough water to reach a decay level of moisture” (FRI bulletin 237, 2009, p23).

The innate resistance to wetting and decay means that the building code now allows its use for building components in weather-protected areas.

Table 2 shows the results of a test conducted at FRI stress testing and assessing the appearance of boards exposed in the open for two years.

Treatment	Failure rate (No boards failure deflection test)	Condition score (1=Poor, 10=Good)
H1.2 treated radiata pine	None	10.0
Untreated Douglas-fir heartwood	None	7.4
Untreated Douglas-fir sapwood	2/33	5.4
Untreated radiata heartwood	13/23	2.3
Untreated radiata sapwood	23/23	0.1

Table 2: Douglas-fir versus radiata pine timber- durability after 2 years (FRI bulletin 237, 2009, p23)

Under the auspices of SWP, SCION has put some Douglas-fir samples through the thermal modification process in order to determine if its durability can be enhanced in this way. The samples were installed in SCION’s fungus cellar in June 2018 to begin the three-year trial. Thermal modification has proven to be successful in increasing durability and stability in timber from many other species and the outlook for D-fir is optimistic (Sargent, 2018).

Some suppliers advertise an H1.2 treated D-fir product for sale in the New Zealand market.

Utility

(Machinablity, gluability etc.)

The large density variation between earlywood and latewood within a single growth ring presents several difficulties when using D-fir.

> “…..It also makes the wood more likely to split when, for example, nailing near the end of a board; it makes the species (when fast-grown) inferior for peeling for plywood or veneer; it makes the wood more splinter-prone- these splinters even reduce the value for some pulpwood markets.” (FRI Bulletin 237, 2009, p 19).

All processors who use D-fir for glued products – glue-laminated beams, CLT, and OEL – express satisfaction with how D-fir glues and presses and note no difference between the performance of D-fir and that of other timbers.

The difficulty associated with peeling D-fir for veneer means it is seldom, if ever, used for products such as ply and LVL in New Zealand. It is also difficult to trace mills in the US that are still peeling Oregon for veneer. It is reasonably easy to locate suppliers of quarter-sawn (probably sliced) D-fir veneer, but I have not managed to trace a single supplier of rotary-cut D-fir veneer.

Performance (stability)

Green D-fir moves much less on drying than does green radiata pine. For this reason, in the 1970s, 80s and 90s when it was still common to build wall frames and roof trusses with green timber, D-fir was often preferred over radiata.

D-fir also exhibits very low variation in wood properties from the bark to the pith so, although shrinkage figures are similar to those for radiata, there is likely to much less differential shrinkage within a single piece leading to less shape distortion.

> Degradation following drying is an issue, but not to the same extent as radiata pine. Spiral grain, longitudinal shrinkage and compression wood are less common. Twisting, crook and spring (mostly caused by grain deviation around knots) are the most likely problems, but - unlike radiata pine - there are few complications resulting from the presence of pith in a piece of timber. Any warping will most likely occur in the initial two months of drying, after which it is a very stable timber. (FRI bulletin 237, 2009,
>
> Shrinkage in Douglas-fir (Table 6) is slightly higher than for radiata pine, but Douglas-fir is more stable in response to changes in humidity. (Cown, 1992, cited in FRI Bulletin 124/14).

Processes considered

We investigated a number of the processing opportunities available for D-fir in the following section. For each we will discuss,

- capital set-up cost,
- cost of production,
- market opportunities and competitive environment.

Direct export of raw logs

Capital requirement:

Log export infrastructure is already established in most major New Zealand ports and there are many companies ready and willing to help forest growers into the raw log export market. This means there is no need for extra capital outlay to export raw logs.

Scale economics:

The existence of so many export options means that there are many opportunities to consolidate logs from several sources into economic shipping parcels and specialists in this work in most log broking companies. Therefore, small wood lots can be sold at good prices into export shipments.

Production Costs:

Compared to other options considered, direct export has the lowest post harvest cost associated with it.

Physical Suitability:

There is plenty of demand for D-fir logs in Japan and the logs stack at least as well as radiata in a ship.

Market opportunities and profitability.

D-fir usually enjoys a premium over radiata in the log export markets for several reasons including the perception that scaling method appears to deliver more wood than is invoiced. D-fir substitutes U.S Oregon in the Japanese market so is tallied the same way.

> "The United States market still uses "board feet" as determined by the complicated Scribner Log Scale, and the log export market uses an estimate of volume based on the equally confusing Japanese Agricultural Standard UAS). (FRI Bulletin 237, 2009)."

This remains the case and gives D-fir an advantage over radiata in most markets. "D-fir consistently commands a premium over radiata and demand for D-fir holds as markets soften " (Andy Easton TPT, personal communication,2020).

Years of access to D-fir logs from the US have sustained an appetite for these logs in Asia, and New Zealand sourced logs help feed this demand.

Sawmilling

Products

Framing
Large beams/ lintels/ posts
Laminate/ remanufacturing feedstock
Packaging and industrial

Capital requirement

Sawmill capital costs vary relative to the volume processed and the level of technology employed. As a rule, investing more capital in capacity and advanced technology will reduce operating costs and increase value recovered. So, the amount spent putting a mill together is governed by the resource available to process and the products the mill is aiming to cut.

There is usually a range of used sawmill equipment available globally that, carefully selected, could go some way to reducing the capital input required to build a mill, however, the sawing equipment itself usually represents a smaller part of the overall cost of establishing a new sawmill.
Indicative capital costs include around $NZ100million for a sawmill capable of cutting 400,000-500,000 m^3 product p.a., excluding buildings. It is unlikely that any region in New Zealand could support such a mill on a diet of D-fir alone.

At the other end of the range a new "Super Saver" log line capable of producing 40,000 m^3 p.a. would cost $NZ15 million. This capacity can be doubled with addition of one more machine centre for around $1.5 million (Skookum Technology Ltd).

Production costs

D-fir has an advantage over radiata in that, the ability to recover high structural value from the centre of the log and from juvenile wood (upper logs and thinnings) means there is smaller volume of low-value arising products to deal with. These arising products not only reduce the average value return-to-log, but in many cases accrue un-recoverable costs such as drying and handling, before being culled from higher grade material.

For the purpose of this report, production cost will only consider the process under discussion – in this case, sawmilling – and exclude other costs such as logs, drying, machining and transport because they are not required for some products, or may vary according to mill location.

Estimated cost for a sawmill capable of 400,000m^3 p.a. range around \$40/m^3.
For a mill producing 40,000m^3 p.a. the cost is estimated to be around \$90/m^3.

Suitability of Douglas fir

D-fir is very suitable for structural products, much of the literature describes D-fir as having higher stiffness, strength, and stability properties than other common framing timbers.

One comparison of stiffness and strength in radiata and D-fir from data collected by ENSIS in the late 1990s from batches of visually graded, KD 90x45, states…

> "For the same general location, Douglas-fir shows a higher bending stiffness (varying between 1.5 to 3 GPa) compared to the equivalent radiata pine. In general, it can be stated that for any given region Douglas-fir is typically 2 units of GPa stiffer than radiata pine. These results are consistent with other more detailed studies of individual stands of radiata pine and Douglas-fir"
> http://www.douglasfir.co.nz/_uploads/downloads/douglas-fir_strength.pdf

A comparison of D-fir and radiata data from the work of Bier (1988, rev. Britten, 1999), supports this view, and also shows that D-fir stiffness to density relationship is considerably better than that of radiata while strength to density is similar.

	MoR (MPa)	MoE (MPa)
Radiata 450-500 kg/m^3 (average 472 kg/m^3)	93.69	9510
Radiata 400-450 kg/m^3 (average 425kg/m^3)	79.36	7788
D-fir average 427kg/m^3	81.12	9159

Table 3. Relationship between density and MoR/MoE. From *Bier (1988 rev. Britten 1999)*

Market opportunities and profitability

Douglas-fir retains a special place in most structural framing markets and is preferred by some customers and for some end uses.

In New Zealand, D-fir's market position suffered because of changes to the building code introduced in 2003 in response to problems with untreated wood in leaky buildings.

In April 2011, Amendment 7 to B2/AS1 of the building code was introduced and allows for the use of untreated D-fir as an "acceptable solution" in low/moderate risk situations where it is protected from wetting and weather. This change gave the market an effective alternative to H1.2 chemically treated pine for most house framing uses. There is still no "acceptable solution" provision for use of untreated D-fir framing in commercial or multi-dwelling applications, or for that matter in mass wood products used in buildings of this nature.

There are still opportunities for large section material in lintel, beam and post applications in New Zealand and Australia and D-fir is highly regarded for these uses.
There are opportunities to sell D-fir into the market for engineered wood products such as glue-lam, CLT or OEL products.

In New Zealand especially, and in Australia to some extent, D-fir is often offered as an equivalent alternative to SG8 P. radiata and tends to be used mostly by those already accustomed to using it. Although there is plenty of evidence of higher stiffness in D-fir - and most promotional material mentions this - there is little evidence that this knowledge is used as an asset in the marketing of D-fir on the ground.
Most glue-lam and mass wood manufacturers spoken to, who have used D-fir have used it in exactly the same way they would P. radiata, i.e. buying SG8 to make GL8 without trying to leverage the stiffness benefits in design.

In 2019, SCION ran scenarios through their "Woodscape" modelling software in which they used the following table to generate a blended market price for the D-fir scenario. (Hall, Sargent, Riley, 2019).

Product	**% of lumber vol**	**Price ($/m^3)**	**Volume weighted price**
SG8	56	$400.00	$224.00
No 2 Framing	16	$280.00	$44.80
Merch.	13	$310.00	$40.30
Industrial	11	$220.00	$24.20
Green packaging	4	$191.26	$7.65
Total	**100**		**$340.95**

Table 4. Blended D-fir price (Hall, Sargent, Riley, 2019).

These prices are good reference points for comparison even though some markets have spiked in the last few months -the U.S. market commentator "Random Lengths" on Oct 2nd 2020, had Green D-fir listed at $US857/mbf compared to $US435 in the same week a year earlier. There may be opportunities to take advantage of this price increase in the short term, but it would be a brave company that based a business strategy on this being a sustainable position.

Scale economics

We have used the "Woodscape" blended price from Table 4 in calculating scale economics rather than more recent market prices because of extremely high prices in the current market, and because we used the composite log price for the same period from WoodScape on the other side of the equation.

Table 5. shows the gross margin calculation for the two mills identified above, using the log purchase prices and blended ex-mill sales prices from WoodScape modelling done for SWP in 2019.

Mill scenario	**40,000m^3**	**400,000m^3**
Log Cost $/m^3	192	192
Chip price ($/bdu)	45	45
Wood %	58%	58%
Chip %	25%	25%
Wood cost-chip value	311.64	311.64
Milling cost($/m^3)	90	40
Total wood cost	401.64	351.64
Blended sale price ($/m^3)	340.95	340.95
Gross margin	-15%	-3%

Table 5. Gross margin calculation based on WoodScape log and wood prices

Table 5 suggests that to be worthwhile D-fir sawmillers need access to specialist high value markets or have further value adding processes and this seems to be the case with all the D-fir sawmillers spoken to.

Glue Lamination

In the past Douglas-fir has been used for large size beams because large cross section D-fir was available from several mills in both Islands cutting 60+ year-old logs. From here a market developed for laminated beams engineered to span larger gaps than a 12x4 was appropriate for. On 9th March 2003, the Building Industry Authority issued BIA directive 23, requiring that treated timber be used for all consents issued from 1 April 2004, this directive effectively removed untreated D-fir from the available “acceptable solutions”.

In April 2011, Amendment 7 to B2/AS1 once again permitted the use of D-fir in enclosed situations with low risk of leakage. However, glue laminators spoken to state that 90% of the market is supplied with treated pine products regardless of end use.

As discussed previously, D-fir offers opportunities to design stiffer components with less wood by selecting stiffer wood. Engineer designed products such as glue-lam should be well placed to take advantage of these opportunities.

With some exceptions, those producers that are machine stress grading D-fir are largely only supplying SG8 grade and are not segregating material that could grade at SG10 or higher, so there is no ready supply of higher stress grades that would allow engineers to take advantage of the extra stiffness D-fir can offer.

Capital and Production costs

Glue lamination technology ranges from very low tech, manually loaded and unloaded clamp presses with manual glue application, to fully automated presses with very low labour requirements and glue cure accelerators such as heat or radio frequency generators. As a general rule of thumb, the more generic a product is the greater the need to reduce production costs in order to be competitive. There is a considerable opportunity in this market for bespoke solutions that while smaller in scale offer opportunities to generate more margin. These products also usually require more design and engineering cost, and products are usually priced on a cost-plus basis.

Market and profitability

The market for glue laminated products is split into two major sections.

- There is a section making and distributing standardised products such as door and window lintels which are commonly used and can be manufactured in standard sizes to a few specifications. To be competitive in this sector the producer needs to be efficient and cost effective.

- The other section of this market consists of bespoke engineered solutions to problems of varying complexity. Buyers in this market are looking solutions to specific engineering problems and are looking for quality of both design and production, functional reliability, and aesthetic qualities. Often wood and glue are the vehicles used to achieve a particular aesthetic effect and are an insignificant part of the price the buyer is prepared to pay.

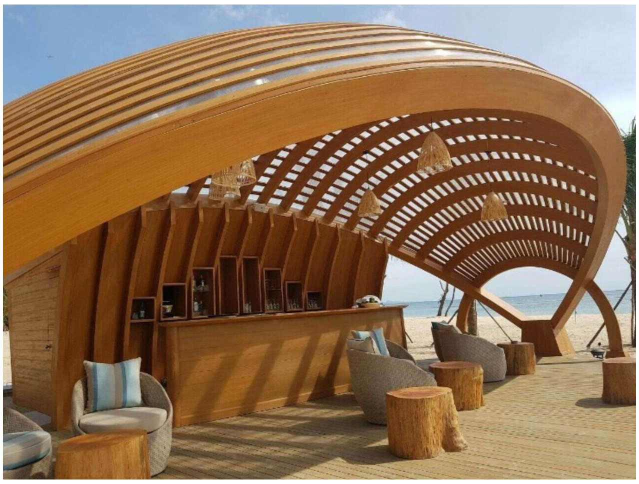


Fig1. Glue lamination used in a beach bar, Phu Quoc. Tran Duc Homes

Suitability of D-fir

The durability and stiffness characteristics discussed previously mean that D-fir is very well suited to indoor applications, especially in one off designs where stiffness characteristics could offer the opportunity to make components in smaller sections than may be the case with other woods.

It is easy to prepare for gluing and glues well with all commonly used glue formulations.

Veneer

We have not investigated options for using D-fir veneer in structural applications such as ply or LVL because this veneer is usually cut on rotary laths and the difference in early/latewood density…. “makes the species (when fast-grown) inferior for peeling for plywood or veneer” (FRI Bulletin 237, 2009).

However, there are products on the international market that use (especially quarter-sawn) D-fir veneer for its appearance characteristics. There may be opportunities available for quarter-sawn and horizontally sliced veneered products for D-fir that will increase the value of both the D-fir and the substrate. There are many products on the market consisting of high-quality veneers overlaid on low value substrates. These products have not been examined in this exercise.

Cross Laminated Timber

Cross lamination of pieces of solid wood assembled in crossed layers is a method of pre-fabricating large structural panels of solid wood. In the last 10 years it has grown in favour with those intent on using wood for the construction of multi-level buildings. Up to five or six stories the overall performance of buildings constructed this way depend on the integrity of the fastenings, after this the limiting factors are in the wood properties, especially stiffness. (Minghao Li, personal communication 23 Sept 2020).

D-fir has been successfully and regularly, used for manufacture of CLT in New Zealand since the first such commercial plant was commissioned in 2014.

Capital costs

The first CLT plant in New Zealand was built for Xlam and comprised a single vacuum press configuration. Such a press these days is has a budget cost of around $NZ3.5mill and if run, 24 hours/ 6 days a week it could be expected to produce around 15,000m^3 p.a. (R. Jack, W&R Jack, personal communication, June 2020).

At the top end of the range a large mechanical press is expected to cost around $NZ40mill and produce up to 100,000m^3 p.a. (R. Jack, personal communication, June 2020).

Operation costs

The higher capital cost option includes more automation and consequently reduces labour cost. As with glue lamination, the material costs for wood and glue remain the same for each option and the opportunities to reduce cost lie in supply chain optimisation, labour input, and material utilisation.

Material utilisation has a much greater impact in CLT than in glue-lam because of the requirement to tailor billet make-up for optimum recovery of the panels required to be cut from the billet. If this is not done well there can be a high and costly waste component.

Estimates for vacuum-press based operation include \$300/m^3 production costs and \$170/m^3 glue cost for a typical 3 ply billet of 90mm.

Market opportunities

Increasingly the construction industry, at all levels, is seeking solutions that are environmentally friendly and wooden products are leading the solutions with the lowest environmental impact. Innovative technologies such as CLT are at the cutting edge of alternative products for these builders. Driven by increasing environmental awareness, governments and regulatory authorities are favouring and actively supporting wood building solution to the point that some government funded projects are required to consider wood-based options in the project planning process.

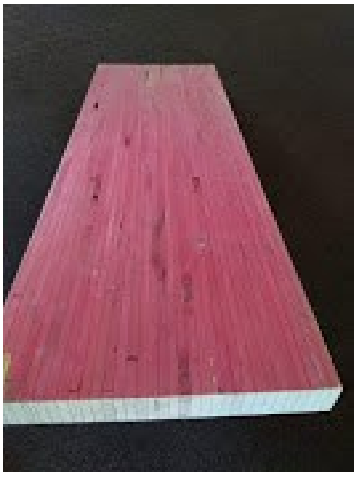
Currently all CLT used in New Zealand needs to be imported from Australia or elsewhere and the back-log of demand is considerable. Demand for this technology is overwhelming with one designer spoken to saying he is getting inquiries up to 1000m^3 of mass timber every other week.

Suitability of D-fir

Those spoken to in this industry attest that D-fir performs just as well in service as radiata, although one respondent expressed concern that D-fir appears to shrink more and produce gaps in panel faces and a sharp sounding phenomenon known as “whip cracking” as it heats and cools.
D-fir glues and presses as well as radiata and similar grade feedstock from either species will produce panels of similar performance in all respects.

Wood performance in rolling shear tests (Li, et. al., 2018) and performance of fixing systems (Li & Brown, 2019) proves to be as good as that of radiata pine.
Perhaps the last word on this subject should lie with Minghao Li who conducted many destructive tests on CLT panels and fixing systems and professes “I prefer D-fir because I think it looks better”.

Optimised Engineered Lumber



340x45 GL8 OEL

Optimised engineered lumber (OEL™) is a proprietary process for producing structural construction elements by

- cutting lower value logs into 1m lengths
- cutting laths from these logs,
- sorting and selecting the laths by grade sonically
- finger jointing similarly graded pieces
- laminating in an order that optimises strength and stiffness characteristics

The patents for this process are owned by Wood Engineering Technology Ltd (WET), which operates a trial plant in Gisborne in order to commercialise the process and develop market.

In 2016 SWP, SCION and WET combined to trial the use of wood cut from young (15-year-old) Douglas -fir thinnings (Gaunt 2016). They found that wood from such logs re-assembled in this way could yield a product that exceeded SG8 characteristic strength properties described in NZS3603.

Capital Costs

The cutting and processing technology employed in the production of OEL™ is highly automated and complex. The plant currently operating and the process itself is still in the development phase so it is difficult to establish what the final overall capital cost of a larger scale commercial plant might look like.

Operating costs

Operating costs of a developmental plant are likely to be a poor predictor of full-scale operation costs. So, we are not willing to speculate.

Market and profitability

As with capital and operating expenses, the developmental nature of current production makes it very difficult to establish consistency and surety of supply. As production stabilises and these things improve it will be easier to gauge the size and nature of market opportunities for these products. The products are certified to the grades they achieve and are ready substitutes for solid wood components currently used and are likely to have more consistency and predictability in performance.

WET's own analysis of the economics of the trial show that supplying feedstock from D-fir thinnings produced a lower cost alternative to radiata and this could give a D-fir based OEL™ product advantages over a similar product from radiata in the market, however we have not been able to independently verify the economics of this process.

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In compiling this report, I posed hundreds of questions to dozens of individuals. I am grateful for their time, the openness of their responses and their willingness to share information, and the guidance they supplied. These people included manufacturers, foresters, design engineers, researchers, technical and operations people, specifiers, machinery suppliers, sales people and plant and business managers.

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