Techno-economic analysis of producing engineered and thermally modified products from specialty wood species

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EXECUTIVE SUMMARY

This report covers an analysis of making a range of engineered and modified wood products from non-radiata species. The products and wood species considered were:

- Non-durable eucalypt peeled veneer
- Non-durable eucalypt sliced veneer
- Non-durable eucalypt CLT
- Non-durable eucalypt glulam beams
- Non-durable eucalypt OSB
- Non-durable eucalypt LVL
- Thermally modified cypress
- Douglas-fir CLT
- Douglas-fir LVL
- Douglas-fir glulam

The techno-economic analysis of these options was done using the WoodScape model with new products added and updated log prices (Douglas-fir, Eucalyptus and Cypress) as required.

Initially individual processes were assessed separately to determine their viability. Where a process looked to have reasonable financial returns the opportunities to cluster or co-locate complimentary processes were considered.

The highest ROCE, at 29.6%, was from the thermally modified Cypress. Other financially viable options included peeled Eucalyptus veneers (24%) and OSB (17.7%). It should be noted that these Eucalypt based operations take very different log grades as feedstocks and could be complimentary to each other in terms of utilising a tree crop.

The area of forest required to grow sufficient biomass to service the processing plants assessed are outlined below. The first table below shows the area of forest required to supply processes taking logs and the second for those taking lumber from a sawmill.

Process	Peeled Veneers	Sliced Veneers	Euc. LVL	D-fir LVL	OSB
Volume in m^3	27,000	35,000	55,000	46,000	172,000
Form in	Logs	Logs	Logs	Logs	Logs
% of crop*	53%	53%	64%	53%	100%
Volume of harvest required m^3	50,943	66,038	85,938	86,792	172,000
Ha per annum	71	92	119	98	367
Total ha	1,910	2,476	3,223	4,876	5,501

*This figure does not include any loss of logs to splitting. For peeler logs this can be as high as 50% of the logs becoming unsuitable for peeling. This implies that the area of forest required to meet the peeler volume demand could be much greater (as much as twice) with the split logs being suitable for sawing.

Process	TMW Cypress	Euc. CLT	D-fir CLT	Euc. Glulam	D-fir Glulam
Volume in m^3	9,225	35,000	35,000	10,000	10,000
Form in	Lumber	Lumber	Lumber	Lumber	Lumber
% of crop	23%	29%	29%	29%	29%
Volume of harvest required m^3	40,109	120,690	120,690	34,483	34,483
Ha per annum	75	168	136	48	48
Total ha	2,999	4,526*	6,780*	1,293	1,937**

*Area would double to get CLT plants with ROCE of ~20%
**Area would need to double to get sufficient material for a Douglas-fir glulam plant with a ROCE of 25%.

Clusters
The opportunity identified for clustering of processes was based on non-durable Eucalypts with a combination of veneers and OSB being produced. This option would allow the use of the whole tree, with the better-quality logs from the lower stem being made into veneers and the upper stem logs going to OSB. Some of the residues from the veneer plant could be used as feedstock in the OSB process.

The ROCE of a cluster of non-durable Eucalypt veneers and OSB was estimated to be 20.6%. The scale of this operation was a combined log intake of 286,000 m^3 per annum, with residues from the veneer mill being used in the OSB plant.

A cluster of a sawmill and a CLT plant was considered for both Eucalyptus and Douglas-fir. The Eucalyptus options was more attractive with a ROCE of around 22% compared to Douglas-fir at 8.5%.

A supply chain based on a *Eucalyptus fastigata* forest resource, taking all the logs (including chip grade logs) and processing the saw logs into a mix of CLT and chip and including a profit margin for forest growers, and contractors involved in the roading, harvesting and transport of logs was able to produce logs at cost less than current market prices and had a processing cluster that had a ROCE of around 21%.

INTRODUCTION

The potential of non-radiata trees species for making a range of engineered wood products (EWP) has been established from a technical perspective, with CLT, LVL, and Glulam made from species such as Douglas-fir, *Eucalyptus fastigata* and *Eucalyptus nitens*.

There is interest within Specialty Wood Products Research Partnership (SWP RP) to extend previous work to better understand the kinds of conditions that would be required to make these SWP processes profitable (size of planting, scale of processing plant, log prices, product prices etc.) and to generate data that could be used in the development of regional strategies.

This study includes extending the WoodScape model to include new processing technologies for non-durable Eucalypts, Douglas-fir and cypresses. This allows analysis of financial metrics of these processes and determination of log prices and product prices that would make these options viable.

Part of the work will be looking at what scale of operation is required to make these operations financially viable, and what area of forest is required to support a plant of that scale. Within any forest a range of logs will be produced, including those that are not suitable for EWP, some analysis of the use of this material for reconstituted products (OSB) in cluster of wood processing operations was assessed.

Financial metrics used were return on capital employed (ROCE) and internal rate of return (IRR).

OBJECTIVES

The objectives of this work are to provide technoeconomic analysis of a range of engineered wood products made from Douglas-fir and non-durable Eucalyptus species (*E. nitens* and *E. fastigata*) as well as thermally modified cypress. The full list of products and species is:

- Non-durable eucalypt peeled veneer
- Non-durable eucalypt sliced veneer
- Non-durable eucalypt CLT
- Non-durable eucalypt glulam beams
- Non-durable eucalypt OSB
- Non-durable eucalypt LVL
- Thermally modified cypress
- Douglas-fir CLT
- Douglas-fir LVL
- Douglas-fir glulam

Glossary

CLT	cross laminated timber
EWP	engineered wood products
Glulam	glue laminated (typically beams joists etc.)
IRR	internal rate of return
Led	large end diameter
LVL	laminated veneer lumber
m^3	cubic metre
odt	oven dry tonne
OSB	oriented strand board
ROCE	return on capital employed
Sed	small end diameter
TEA	techno-economic analysis
TMW	thermally modified wood

METHODS

The WoodScape model (Jack et al, 2013) was used as the base model for the techno-economic modelling. There were 10 new technology variants added to the model. The basic templates for most of these technologies (CLT, Glulam, OSB, LVL, veneers and thermally modified wood (TMW)) were already in the model. These templates were copied and modified to allow for the new log and product prices to be used.

Log prices for Douglas-fir, Cypresses and Eucalypts (Appendices 1 to 3 respectively) were obtained from a range of sources including contacts in the New Zealand forest industry, New Zealand Farm Forestry Association, New Zealand forest industry newsletters and online searching.

Product prices were obtained from a range of sources including online searching, retailer price lists, Scion industry contacts and in some cases the prices were linked to the existing WoodScape price data which for some products are benchmarked to radiata prices (CLT, OSB) or to product specifications (LVL).

Prices for new equipment added to the processing options (e.g., veneer slicers) were sourced from online searches and equipment suppliers.

With the base data in the WoodScape model established, prices for logs and products were manipulated to get a ROCE of >20%. Then, other parameters such as plant scale and capital costs were also adjusted, in order to find a scale of operations that worked for the baseline prices for logs and products.

The mix of log grades produced from a stand were derived from the Douglas-fir and *Eucalyptus fastigata* calculators (Knowles 2007, van der Colf and Kimberley 2013) respectively.

The forest area required to supply a viable processing operation was derived from a combination of the volume by grade data and the demand for a financially viable operation or cluster of operations.

RESULTS

Techno-economic analysis

Veneers
A small radiata sliced veneer mill was used as a base case. The scale of this operation was 15,000 m^3 of veneers, produced from 35,000 m^3 of P2 grade logs in. The price of the P2 logs was set at \$151 per m^3. The price of the dried veneers was \$607 per m^3. At these prices the ROCE of the operation was -4.7%. In order to make the operation viable the veneer price had to be increased to \$727 per m^3, an increase of 20%.

Two options for producing veneers from Eucalyptus logs were considered. For an operation to be considered as an attractive investment the ROCE should be over 20%.

Non-durable eucalypt veneer - peeled
For peeled veneers with a yield of 55% 15,000 m^3 of dried veneers were produced from 27,000 m^3 of log in. Based on log price of \$169 per m^3 for high quality Eucalypt logs and a product price of \$833 per m^3 this standalone operation was estimated to have the following financial metrics;
ROCE; 24.0%
IRR; 13.4%
ROCE sensitivity to product and log price;

- for a 5%+/- change in product price the ROCE would change by 9.3%+/-.
- for a 5%+/- change in log price the ROCE would change by 2.9%+/-.

The ROCE was over 20% at this scale. Doubling the size of the mill only increased to ROCE by 2.1 %. A very large mill, in the order of 100,000 m^3 per annum of log intake would be required to get the ROCE above 20%.

Non-durable eucalypt veneer - sliced
For sliced veneers with a product yield of 43%, 15,000 m^3 of dried veneers were produced from 35,000 m^3 of logs. Based on log price of \$169 per m^3 for high quality Eucalypt logs and a product price of \$833 per m^3 this standalone operation was estimated to have the following financial metrics;
ROCE 13.4%
IRR 10.0%

ROCE sensitivity to product and log price;

- for a 5% +/- change in product price the ROCE would change by 7.8%+/-.
- for a 5% +/- change in log price the ROCE would change by 2.7%+/-.

A smaller mill (half size) had a ROCE of 4.5%. Doubling the size of the mill only increased the ROCE by 2.1%. To get to a ROCE of 20% the mill would need to have a production capacity of at least 60,000 m^3 per annum.

CLT
Non-durable eucalypt CLT
For CLT made from Eucalyptus lumber with a product yield of 85%, 35,000m^3 lumber in gives 30,000m^3 of CLT. Based on a lumber price of \$750 per m^3 and a product price of \$1,790 per m^3 this operation (standalone) was estimated to have the following financial metrics;
ROCE 17.3%
IRR 9.3%

ROCE sensitivity to product and log price;

- for a 5% +/- change in product price the ROCE would change by 3.3% +/-.
- for a 5% +/- change in log price the ROCE would change by 1.7% +/-.

Doubling the size of the mill would give a ROCE of just over 20%

Douglas-fir CLT
Douglas-fir lumber to CLT at the same scale as the Eucalyptus operation (35,000 m^3 in, product out 30,000 m^3) was also assessed. Based on a lumber price of $400 per m^3 and a product price of $1228 per m^3 this operation had financial metrics of;
ROCE 12.4%
IRR 5.8%

ROCE sensitivity to product and log price;
- for a 5%+/- change in product price the ROCE would change by 2.0%+/-.
- for a 5%+/- change in log price the ROCE would change by 0.9%+/-.

Increasing product price to $1350 / m^3 gave a ROCE of 20.8%

Doubling the size of the mill would give a ROCE of just under 20%

<u>Glulam</u>
Non-durable eucalypt glulam beams
For Glulam made from small knot Eucalypt lumber (10,000 m^3 lumber in) at 75% yield there was 7,500m^3 product out. Based on lumber prices of $750 per m^3 and glulam prices of $2,370 per m^3 the financial metrics were;
ROCE 22.0%
IRR 12.4%
ROCE sensitivity to product and log price;
- for a 5%+/- change in product price the ROCE would change by = 2.7%+/-.
- for a 5%+/- change in log price the ROCE would change by = 1.2%+/-.

The ROCE is over 20% at this scale.

Douglas-fir glulam
For Glulam made from small knot Douglas-fir lumber at 75% yield of product and 10,125 m^3 of lumber in there was 7,500 m^3 of product out. Based on lumber prices of $400 per m^3 and glulam product prices of $1,555 per m^3 the financial metrics were;
ROCE 14.9%
IRR 7.7%

ROCE sensitivity to product and log price;
- for a 5%+/- change in product price the ROCE would change by 1.8%+/-. For example, if the product price was $1,780 per m^3 then the ROCE would be around 20%.
- for a 5%+/- change in log price the ROCE would change by 0.7%.

If the scale of the mill is doubled the ROCE was estimated at just under 20%

<u>LVL</u>

The variations in the price for LVL are based on the expected higher stiffness (GPa) performance of the eucalypt LVL.

Non-durable eucalypt LVL
For a plant making LVL with log in at 55,000 m^3 per annum and product out at 30,000m^3 per annum (conversion 60%), with log price at $169 per m^3 and product price of $1,050 per m^3 the financial metrics were estimated at;
ROCE 9.2%
IRR 2.9%

ROCE sensitivity to product and log price;

- for a 5%+/- change in product price ROCE would change by 2.0%+/-.
- for a 5%+/- change in log price ROCE would change by 0.6%+/-.

If the product price was $1,350 per m^3 then the ROCE would be around 20.8%

Upscaling had minimal effect on ROCE.

Douglas-fir LVL
For a mill making Douglas-fir LVL from lumber at 46,000 m^3 in product out 30,000 the ROCE was -15.3% and IRR could not be calculated. The product price was $597 per m^3 and the log price was $151 per m^3.

ROCE sensitivity to product and log price;
- for a 5%+/- change in product price ROCE would change by 1.2% +/-.
- for a 5%+/- change in log price ROCE would change by 0.9% +/-.

A substantially higher product price at $1,500 per m^3 would be required to give a ROCE of around 20%.

Upscaling has minimal effect on ROCE.

<u>OSB</u>
Non-durable eucalypt OSB
The plant size for making OSB out of Eucalypts was based on the existing mills size in the WoodScape model. This had log in at 172,000 m^3 per annum and product out of 100,000m^3 (conversion factor of 58%). OSB was priced at $480 per m^3 and the logs at $65 per m^3. The financial metrics for this plant were;
ROCE 17.7%
IRR 9.7%
ROCE sensitivity to product and log price;
- for a change in product price of 5%+/- the ROCE will change by 4.4%+/-.
- for a log price changes of 5% +/- will change the ROCE by +/- 0.5%.

Log price at $57 (similar to radiata pulp log price = ROCE of 20.4%).

Doubling the size of the plant would give a ROCE of around 27.6%.

<u>Thermally modified wood</u>
Thermally modified cypress cladding
Cypress lumber intake 9,224 m^3, product out 9,040 m^3
ROCE 29.6%
IRR 16.3%
Product price at $978 / m^3, feedstock (sawn and kiln dried cypress lumber) in at $578 per m^3

ROCE sensitivity to product and log price;
- for a 5%+/- change in product price the ROCE will change by +/-8%.
- or a 5%+/- change in log price the ROCE will change by +/-5%.

<u>Summary of processing options data</u>

The results outlined above are summarised in Table 1 and Figure 1 below.

Table 1 – Summary of processing options results

	Log in, m^3 p.a.	Product out, m^3 p.a.	Log price, \$ per m^3	Product price, \$ per m^3	ROCE %	IRR %
Non-durable eucalypt peeled veneer	27,000	15,000	$169	$833	24.0	13.4
Non-durable eucalypt sliced veneer	35,000	15,000	$169	$833	13.4	10.0
Non-durable eucalypt CLT	35,000	30,000	$750	$1,790	17.3	9.3
Non-durable eucalypt glulam beams	10,000	7,500	$750	$2,370	22.0	12.4
Non-durable eucalypt OSB	172,000	100,000	$65	$480	17.7	9.7
Non-durable eucalypt LVL	55,000	30,000	$169	$1,050	9.2	2.9
Thermally modified cypress	9,224	9,040	$578	$978	29.6	16.3
Douglas-fir CLT	35,000	30,000	$400	$1,228	12.4	5.8
Douglas-fir LVL	46,000	30,000	$151	$597	-15.3	-
Douglas-fir glulam	10,125	7,500	$400	$1,555	14.9	7.7

Commented [ML1]: Log or lumber in

Commented [PH2R1]: As labelled, logs and product (which is not lumber)

Commented [ML3]: Log or lumber price

Commented [PH4R3]: See above

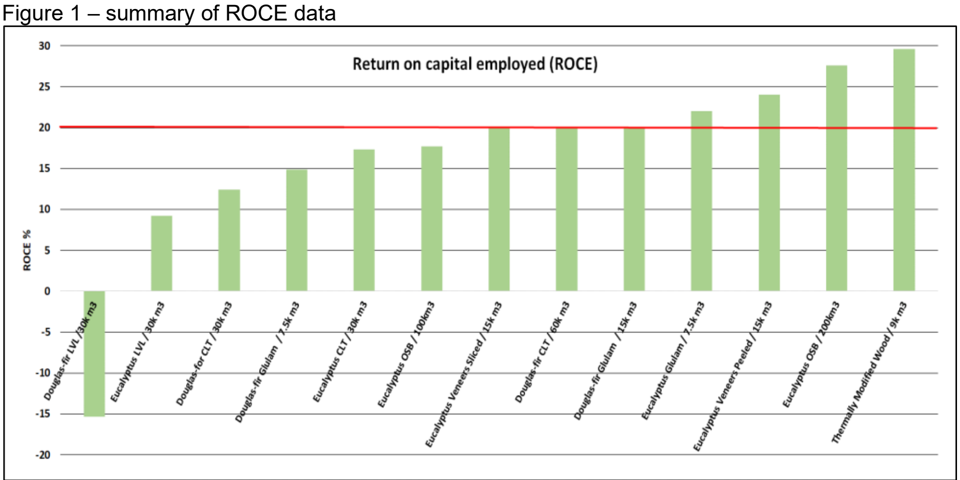
Commented [ML5]: 2020 prices - Stora CLT landed in Australia for circa AU\$800/m3 and in Auckland for circa AU\$750/m3. The numbers in the table seem high?

Commented [PH6R5]: Prices were derived from a variety of sources. Online, local merchants and literature. Radiata CLT came out at around \$1270 to \$1280 per m3. There is apparently a premium for a denser stiffer product. If you have prices for Euc CLT it would good the cross check.

If the CLT price goes down substantially (from \$1790 to \$1270) then the ROCE of the plant drops down to 1%.

The ROCE figures in Figure 1 include larger plant scales that allow some processes to get to a ROCE of 20%.

Figure 1 – summary of ROCE data



<u>Area of forest required to support various processing plants</u>

The assumptions behind the estimates of forest area required to support a processing plant of various sizes varies with the type of product being made. For example, veneers require logs with a minimum SED of 300mm and small knots. For some mills a maximum led of 600 mm is an upper limit. Typically, these would be grown on longer rotations and the regime would involve a thinning.

For OSB the log diameter is not of as much significance and much of the feedstock for OSB is pulp grade logs with SEDs of 100 to 150mm. These can be grown at high stockings and on shorter rotations. This means greater area is required for growing veneer grade logs (per 1,000m^3) – as only some of the crop would be suitable for veneer processing.

The assessment of area required is also dependant on whether the process is taking logs or lumber as the feedstocks. The veneer, LVL and OSB processes (Table 2) are taking logs. The TMW, CLT and Glulam operations (Table 3) are taking lumber from a sawing operation so the losses in those operations have to be taken into consideration.

The area of forest required in Tables 2 and 3 are based on NZ average yields. They do not account for degrade of logs due to end splits making them unsuitable for peeling. If splitting is factored in the area of forest may increase substantially, doubling in the worst-case scenario).

Commented [ML7]: I don't think we should down play the importance of log splitting

Commented [PH8R7]: I don't think it is being down played – quite clearly stating that its an issue and could be substantial.

Table 2 – forest area required to supply veneer LVL and OSB mills

Process	**Peeled Veneers**	**Sliced Veneers**	**Euc LVL**	**D fir LVL**	**OSB**
Volume in	27,000	35,000	55,000	46,000	172,000
Feedstock, form in	Logs	Logs	Logs	Logs	Logs
% of crop	53%	53%	64%	53%	100%
Volume of harvest required	50,943	66,038	85,938	86,792	172,000
Ha per annum	71	92	119	98	367
Total ha **(Total ha with worst case splitting)**	1,910 (3820)	2,476	3,223	4,876	5,501

Table 3 – forest area required to supply TMW, CLT and Glulam operations

Process	**TMW Cypress**	**Euc CLT**	**D fir CLT**	**Euc Glulam**	**D fir Glulam**
Volume in	9,225	35,000	35,000	10,000	10,000
Feedstock, form in	Lumber	Lumber	Lumber	Lumber	Lumber
% of crop	23%	29%	29%	29%	29%
Volume of harvest required	40,109	120,690	120,690	34,483	34,483
Ha per annum	75	168	136	48	48
Total ha	2,999	4,526*	6,780*	1,293	1,937**

*Area would double to get CLT plants with ROCE of ~20%
**Area would need to double to get sufficient material for a Douglas-fir glulam plant with a ROCE of 25%

The growth rates of the various tree species vary from region to region and the impact of this is shown in Tables 4 and 5.

The only regions with sufficient resource to support mills with demands of greater than 30,000 m^3 per annum are the Central North Island and Southland / Clutha (Appendix 7). In most other regions the supply is small and erratic and would require a sustained planting programme over several decades to build a resource.

Table 4 – area (ha) of forest required by region for log-based processes

	Peeled Veneers*	Sliced Veneers	Eucalypt LVL	D fir LVL	OSB
Northland	1,424	1,846	2,402	3,635	4,101
Auckland	1,869	2,423	3,153	4,770	5,382
Waikato	2,170	2,813	3,661	5,539	6,249
Bay of Plenty	2,143	2,778	3,615	5,469	6,171
Gisborne	2,903	3,763	4,897	7,409	8,359
Hawkes Bay	2,376	3,080	4,008	6,064	6,841
Taranaki	2,426	3,145	4,093	6,192	6,986
Manawatu-Wanganui	2,485	3,222	4,192	6,343	7,156
Wellington	2,109	2,733	3,557	5,382	6,072
Nelson	1,835	2,378	3,095	4,683	5,283
Marlborough	2,013	2,609	3,395	5,137	5,796
Canterbury	1,431	1,855	2,414	3,652	4,120
West Coast	1,718	2,228	2,899	4,386	4,948
Otago	2,054	2,662	3,465	5,242	5,914
Southland	2,088	2,707	3,522	5,330	6,013

*These areas could double if there is significant splitting in the peeler grade logs post-harvest and prior to processing

The areas presented in Table 5 are larger as they allow for the processing losses associated with a sawmill which will be required to produce the lumber that would go into these processes.

Table 5 – area (ha) of forest required by lumber-based processing

	TMW Cypress	Euc CLT	D fir CLT	Euc Glulam	D fir Glulam
Northland	3,311	6,072	9,096	1,735	2,599
Auckland	2,523	4,626	6,930	1,322	1,980
Waikato	2,173	3,984	5,968	1,138	1,705
Bay of Plenty	2,200	4,035	6,045	1,153	1,727
Gisborne	1,624	2,979	4,462	851	1,275
Hawkes Bay	1,985	3,639	5,452	1,040	1,558
Taranaki	1,943	3,564	5,339	1,018	1,525
Manawatu-Wanganui	1,897	3,479	5,212	994	1,489
Wellington	2,236	4,100	6,143	1,172	1,755
Nelson	2,570	4,712	7,060	1,346	2,017
Marlborough	2,343	4,296	6,435	1,227	1,839
Canterbury	3,295	6,043	9,052	1,726	2,586
West Coast	2,744	5,031	7,538	1,438	2,154
Otago	2,296	4,210	6,307	1,203	1,802
Southland	2,258	4,141	6,203	1,183	1,772

Addition to existing processes and clustering of processes

With the variation in processes within a species type there is potential to look at the clustering of processes (e. g, Eucalyptus sawmill with CLT and Glulam). There is also the potential to consider the addition of a process to an existing mill (e. g., adding a small veneer mill to a sawmill). However, sawmilling of these species did not give ROCE's that were attractive and whilst adding CLT operations improves this, different processing routes are better.

Addition to existing processes
A small veneer slicer could be added to an existing sawmill, potentially with modest outlay. A flitch slicer can be bought for around NZ$60,000. Installed with appropriate infrastructure this cost might be in the order of $200,000 when a shed and materials handling equipment is included. The current WoodScape model has a small sawmill in it. Using current log and product prices it would have a ROCE of around 5.4% if running on Douglas-fir.

Adding the option of making veneers from a small proportion of its production (10%) would enhance the ROCE to around 10%. This operation would require a forest area of around 4,600ha (Table 6) to support it (based on national average yields). However, the sawmill is less attractive than a veneer mill so having a veneer only mill makes more sense.

Table 6 – log volume and forest area required to support a small Eucalypt saw and veneer mill

Process	**Lumber + Veneers.**
Volume in m^3	65,000
Feedstock, form in	Logs
% of crop	53%
Volume of harvest required m3	122,642
Ha per annum	170
Total ha	**4,599**

The addition of thermally modified wood to a small cypress milling operation would likely add value given the high ROCE of this option. To be assured of sufficient supply to a mill, a planted resource of around 2,500 ha is required. The only regions that are close to this is the West Coast of the South Island, with nearly 4,500 ha. The majority of this is in the Westland District (the southernmost part of the West Coast). The distribution of plantings is highly uneven with no plantings noted in the last 10 years and the bulk (3,851 ha) of the plantings being between 11 and 25 years old. There are other resources that are in the order of 1,000 ha in the Central North Island and Otago / Southland. The CNI resource is largely in the Rotorua, Kawerau and Taupo districts and is unevenly spread over time. The southern resource is mostly in Southland and Clutha Districts, with the majority on Clutha. The distribution over time is more even although there is a large drop in area of plantings of age 1 to 5. The Otago / Southland has potential for a cypress based thermally modified wood operation, but increased plantings would be required to continue supply in the long term. The West Coast has a substantial area of cypress plantings with resource potentially available for around 25 years but would require new plantings to support a processor in the longer term. Data on Cypress volumes projected to be available based on the National Exotic Forest Description (MPI 2021) and the yield tables provided by MPI for Cypress species are shown in Appendix 6. The impact of going to a smaller TMW plant was estimated. Halving the size of the plant, making 4,500 m^3 per annum reduced the ROCE to around 12%. This is important as anecdotally there are major issues with the form and quality of the West Coast cypress resource. Some of the stands are on shallow soils and there has been substantial amount of toppling resulting in trees and logs with sweep (Patrick Milne per comm.). Subsequently yields of sawmill suitable log grades from the stand may be low (20%) (Alan Laurie Pers. comm). Further, the yields of lumber from these logs may also be modest (~45%) as the crop is reported as having heavy branching, bark encased knots, canker and some trees with centre rot. Some of the crop will be mill-able, but the amount of mill-able wood available from the West Coast cypress plantations may be much less than the area and yield tables indicate.

Clustering of new processes
For radiata pine there are established markets for lower grade material such as pulp logs and residues. That is not necessarily the case for other species, so processing options for lower grade logs and residues need to be considered. In order to encourage the planting of a forest estate, utilisation of the entire crop would be preferable. A cluster of processes that would take the majority of the logs produced is therefore desirable, because it shouldn't be assumed that there are existing markets for every grade of log. From the analysis above a potential cluster would be based

on a non-durable Eucalypt resource and make both veneers and OSB (Table 7). To match the scale of the OSB operation the veneer operation is increased substantially in size (from 27,000 m^3 of logs per annum to 162,0000 m^3 per annum). Some of the processing loss from the veneer mill could be used in the OSB plant as feedstock. The initial incomplete peelings (called round-up or fish-tails) would be suitable. This would help balance the demands with the log supply, where a forest producing logs suitable for veneers would also produce logs that are only suitable for processes such as chip, or OSB.

Table 7 – clustered processing option.

Product	**Log Input, m^3 p. a.**	**Residual input, m^3 p.a.**	**Product out**	**Capex, $ / M**	**ROCE %**	**Capital Weighted ROCE %**
Eucalypt veneers	162,000	-	100,000	$48.0M	24.0	
Eucalypt OSB	124,000	48,000	100,000	$53.7M	17.7	
	286,000			$101.7		**20.6**

The cluster above would take around 286,000 m^3 per annum, with 57% being good quality logs going into veneers and 43% being lower quality logs going into OSB. Around 28% of the feedstock going into the OSB mill would be residuals from the veneer mill.

The area of forest required to support such a mill would be 398 ha per annum of harvest from an estate of 10,746 ha. It would be challenging to achieve this scale of operations in the short term based on existing resources.

A more conventional approach to processing would be to start with a sawmill and add engineered wood products such as CLT and/or glue-laminated beams (Glulam).

A Eucalyptus sawmill on its own is not particularly attractive with a ROCE of around 5 to 6%, adding a Eucalyptus based CLT plant, which has a much higher capital cost and a much higher ROCE gives a capital weighted ROCE of 22 to 23%. The CLT plant needs the sawmill to make the lumber that it uses as its feedstock. The intake of this cluster would be around 67,000 m^3 per annum, which allowing for a proportion (30%) of the crop being unsuitable for sawmilling means an annual harvest of 100,000 m^3. The area required to supply this would be in the order of 142 ha per annum or 3,900 ha of forest in total. This scale of cluster could be viable in both the CNI and Southland / Clutha based on the existing resources and continued plantings of either *Eucalyptus nitens* in the Southland and *Eucalyptus fastigata* in the CNI.

Whilst the addition of a CLT plant to a Douglas-fir sawmill also improves the overall ROCE, the result (ROCE of 8.5%) is not sufficient make this option attractive as an investment. If this approach was taken it would require the harvest from around 75 ha per annum, with the estate required being in the order of 3,000 ha. There is sufficient existing Douglas-fir estate to allow this to occur in the Central North Island, likely centred on the Taupo District. However, the longevity of this is dependent on future plantings Douglas-fir, which have been at lower levels in the past 5 years than they have been historically. The Canterbury region centred in the Hurunui District also has an existing estate sufficient to supply a processing operation of this scale. Clutha and Southland Districts also have more than sufficient resource to supply such an operation with further.

In all cases the long term (beyond 40 years) supply of Douglas-fir is dependent on supplies of this species continuing. The supply chain for such an operation is well established with the main question to answered being the use of the chip grade logs from both clear fell and production thinning. A potential outlet for this material in all regions is the growing demand for woody biomass as fuel which will be required to displace coal in industrial process heat. This is a particular issue in the South Island as there is no reticulated natural gas supply. The costs of electricity and gas for heat will be higher than the price of energy derived from pulp logs, assuming current price for pulp logs ($55 to $57 per green tonne).

Supply Chain analysis of the Eucalyptus based sawmill / CLT / hardwood chip option

Growing (including harvesting and transport)
The area of forest required to maintain a continuous supply of logs would be around 150 ha per annum for *E. fastigata* in the CNI and 175 ha for *E. nitens* in the South Island. The regimes are different, and the rotation lengths are 27 and 20 respectively, but the area required (rounded off) is similar with *E. fastigata* requiring a total estate of 4050 ha and the *E. nitens* option requiring 3500 ha.

Growing costs

E. nitens	20-year rotation; $71 /m^3
E. fastigata	27-year rotation; $69 /m^3

Profit margin built into growing costs = 6%

Roading costs
Roading on a typical site with no existing forestry roading infrastructure (including landings) will cost around $7.00 per m^3.

Harvesting costs
Both crops were assumed to be grown on steeper terrain with hauler logging required, estimated to cost $45 per m^3.

Transport costs
Transport costs were assumed to be $21 per m^3 for an average transport distance of 90km (one-way forest to mill).

Total delivered log costs (average)

E. nitens;	$144 per m^3.
E. fastigata;	$142 per m^3.

The log prices used (Appendix 3) and the splits of log products from the *E. fastigata* growth modelling indicates that the combined growing, harvesting and transport operations can be completed with all parties making a profit.

Not all the logs are suitable for sawmilling, some (25%) are chip logs and sell for around $65 per tonne which is less than the cost of production but covers the costs of harvesting and transport.

Sawmilling
A sawmilling operation in its own right is not a particularly attractive proposition (ROCE 5 to 6%), but it is a necessary step (primary processing) in providing the raw material required for the CLT plant. The sawmill also produces chip along with the lumber. The proportion of chip was estimated to be around 25% of the log volume going into the sawmill. The sawmill chip can be sold as either hardwood export which would have a value of around $65 to $75 per green tonne on truck at the mill or as fuel into the developing solid wood fuel market (displacing coal).

CLT / Glulam
When a CLT plant is added and combined with the sawmill the cluster of the two operations taking in saw logs and selling chip and CLT is financially viable and would make a viable financial return to an investor.

Chip
A hardwood chipping operation is a viable operation in its own right, with a ROCE estimated to be 19% based on current pricing of eucalyptus chip logs and export chip. It is necessary to have an outlet for the chip logs from the forest and for the slab chip from the sawmilling. The current market price for hardwood chip is in the order of $100 per green tonne free-on-board a shipping vessel for export. The three-year average is $107 per green tonne (MPI quarterly export data). In the current

market the use of this material as a fuel in industrial process heat outside the wood processing industry is also a possibility and at $100 per tonne, the energy cost of the fuel (delivered to a user would be around $14.28 per GJ, which is higher than current prices for coal, but the influence of the price of coal as a market price setter for heat fuel is waning, with the cost of carbon rising, government policy directing process heat demand out of coal and gas supply either being unavailable (South Island) or expensive (North Island). Electricity at the very modest price of $0.05 per kWh is $13.90 per GJ. The wholesale price of electricity in 2020 was $0.112 per kWh ($31.11 per GJ) (MBIE, 2021). Natural gas prices are currently much higher than previously, with spot prices in 2020 being around $19 per GJ, compared to $9 to 10 per GJ in 2019 (MBIE, 2021).

Based on ex-mine coal prices found online ($190 per tonne) the cost of coal delivered, including the cost of around carbon at $65 per tonne would be in the order of $16.45 per GJ at a transport distance of 75km.

Supply chain summary

Based on current prices for the major inputs into a forest growing operation and the expected yields of logs, growing a *E. fastigata* crop for use as chip / CLT production is viable. The costs for logging, roading and transport reflect current prices and production and include a profit margin for the various components of the supply chain.

The sale of the two main products from the processing cluster (hardwood chip and non-durable Eucalyptus CLT) would give an overall ROCE of 16%.

CONCLUSIONS

Of the options considered the most attractive was the thermal modification of Cypress lumber.

The next most attractive non-radiata option in this study was making veneers from non-durable Eucalypts. This operation could be clustered with an OSB plant to make full use of a veneer focussed crop and utilise some of the veneer plants residues.

In order to get a scale of operations where the full tree crop could be used, an OSB plant taking in 172,000 m^3 of feedstock is required to make around 100,000 m^3 of product. The veneer mill to match this, taking the better-quality logs and producing some of the OSB feedstock from its residues was around 162,000 m^3 in, making around 100,000 m^3 of veneers.

For a cluster such as this an area of Eucalypt forest of around 11,000 ha would be required, with a harvest area of around 400 ha per annum. This is roughly the size of the *E. nitens* resource in the Southland / Clutha districts.

The options of putting CLT or Glulam alongside a Douglas-fir sawmill was not as attractive as the same approach for Eucalypts. Having a sawmill associated with a CLT plant with Eucalypts as the feedstock also appears to be a viable option.

The operating scales, ROCE's and IRR's of the full range of options considered were as outlined below.

	Log in, m^3 p.a.	**Product out, m^3 p.a.**	**Log price, \$ per m^3**	**Product price, \$ per m^3**	**ROCE %**	**IRR %**
Non-durable eucalypt peeled veneer	27,000	15,000	$169	$833	24.0	13.4
Non-durable eucalypt sliced veneer	35,000	15,000	$169	$833	13.4	10.0
Non-durable eucalypt CLT	35,000	30,000	$750	$1,790	17.3	9.3
Non-durable eucalypt glulam beams	10,000	7,500	$750	$2,370	22.0	12.4
Non-durable eucalypt OSB	172,000	100,000	$65	$480	17.7	9.7
Non-durable eucalypt LVL	55,000	30,000	$169	$1,050	9.2	2.9
Thermally modified cypress	9,224	9,040	$578	$978	29.6	16.3
Douglas-fir CLT	35,000	30,000	$400	$1,228	12.4	5.8
Douglas-fir LVL	46,000	30,000	$151	$597	-15.3	-
Douglas-fir glulam	10,125	7,500	$400	$1,555	14.9	7.7

Only some operations had ROCE's that were substantially affected by operating scale.

Looking at the full forest to product supply chain suggests that the production of chip and CLT from a eucalypt forest is financially viable.

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APPENDICES

Appendix 1: Douglas-fir log prices

Grade	Length, m	sed, mm	Max knot, cm	$/m³ delivered
Pruned 30	6.2	300	n. a.	$264
CF+	5.9 to 3.9	300	12	$151
CF-	5.9 to 3.9	180	8	$140
CM	5.9	140	8	$130
CIS	5.9	100	20	$123
Chip	3.9	70	15	$50

Appendix 2: Cypress log prices

Grade	$ per m³ delivered
P 40	$365
P 30	$180
S30	$170
S 20	$145
L	$120
Firewood	$80

Appendix 3: Eucalypt log prices

Grade	$ per m³ delivered
Eucalypt High	$169
Eucalypt Medium	$126
Eucalypt Low	$107
Chip	$65

*Note; High, Medium and low grade logs a roughly equivalent to S, A and K grades for radiata in terms of branch size and minimum log SED sizes.

Appendix 4: Product prices

Product	$ per m^3
Eucalypt peeled veneer	$607
Eucalypt sliced veneer	$867*
Eucalypt CLT	$1,350
Eucalypt Glulam Beams	$2,315
Eucalypt OSB	$480
Eucalypt LVL	$833
Thermally modified cypress	$1,440
Douglas-fir CLT	$1,228
Douglas-fir LVL (10)	$597
Douglas-fir Glulam Beams	$1,555

*sliced veneers adjusted based on yield basis from peeled veneer prices

Appendix 5: Veneer slicing machine

From 1.47m machine is operating
https://www.youtube.com/watch?v=89O3PPBnnb0

Crown slicing
https://www.youtube.com/watch?v=l4ewbk8q-oE

Appendix 6: Projections of Cypress volumes

	2020-2024	2025-2029	2030-2034	2035-2039	2040-2044	2045-2049	2050-2054	2055-2059	2060-2065
Northland wood supply region									
Far North District	1,888	378	2,077	5,853	4,437	283	755	-	-
Whangarei District	189	-	283	2,266	755	-	94	-	-
Kaipara District	189	-	94	189	1,888	1,982	189	-	-
Auickland Council	189	-	94	189	1,888	1,982	189	-	-
Region total	**2,454**	**378**	**2,549**	**8,496**	**8,968**	**4,248**	**1,227**	**-**	**-**
CNI Wood Supply region									
Thames-Coromand	95	48	-	95	-	-	-	-	-
Hauraki District	-	143	-	-	-	-	952	-	-
Waikato District	48	333	-	48	-	-	-	333	333
Matamata-Piako Di	-	-	-	-	-	-	-	-	-
Hamilton City	-	-	-	-	-	-	-	-	-
Tauranga District	-	-	-	-	-	-	-	-	-
Western Bay of Ple	145	1,303	72	941	1,086	3,403	-	-	-
Rotorua District	507	3,186	72	652	2,606	7,240	290	2,172	2,172
Kawerau District	-	-	-	-	-	-	-	-	-
Whakatane District	-	2,896	145	4,996	869	6,516	72	579	579
Opotiki District	-	-	-	-	-	-	145	-	-
Waipa District	-	-	-	217	-	-	-	-	-
Otorohanga Distric	-	290	-	-	-	-	-	-	-
Waitomo District	145	-	-	72	-	-	-	-	-
Ruapehu District	-	72	-	-	869	-	72	217	217
South Waikato Dist	-	217	1,086	72	-	145	434	72	72
Taupo District	-	217	217	3,475	434	11,005	14,335	2,317	2,317
Region total	**939**	**8,705**	**1,593**	**10,568**	**5,864**	**28,308**	**16,301**	**5,691**	**5,691**
East Coast wood supply region									
Gisborne District	7,168	1,946	3,379	4,096	3,277	3,277	4,608	-	-
Region total	**7,168**	**1,946**	**3,379**	**4,096**	**3,277**	**3,277**	**4,608**	**-**	**-**
Hawkes Bay wood supply region									
Wairoa District	-	-	1,436	-	11,344	646	-	-	-
Hastings District	-	144	144	431	2,226	6,318	1,436	-	-
Napier City	-	-	-	-	-	-	-	-	-
Central Hawkes Ba	144	287	-	718	-	215	-	-	-
Region total	**144**	**431**	**1,580**	**1,149**	**13,570**	**7,180**	**1,436**	**-**	**-**
Southern North Island wood supply region									
New Plymouth Dis	-	218	-	-	-	-	-	-	-
Stratford District	3,848	290	-	290	-	-	3,485	-	-
South Taranaki Dist	-	-	-	-	290	73	-	-	-
Wanganui District	436	290	-	145	1,452	6,897	581	-	-
Rangitikei District	6,316	2,178	218	871	290	1,670	182	-	-
Manawatu District	1,379	-	218	871	-	-	-	-	-
Kapiti Coast Distric	-	-	-	-	73	-	-	-	-
Upper Hutt City	726	2,904	218	-	73	-	-	-	-
Porirua City	-	-	-	-	-	-	-	-	-
Wellington City	-	-	-	-	-	-	-	-	-
Lower Hutt City	-	-	-	-	-	-	-	-	-
Palmerston North (	-	-	-	-	-	-	1,408	479	479
Tararua District	-	-	-	-	-	-	-	-	-
Masterton District	73	145	436	1,234	450	182	269	-	-
Horowhenua Distri	73	-	22	436	-	465	-	-	-
Carterton District	-	-	-	-	-	145	-	-	-
South Wairarapa D	145	-	73	290	-	145	-	-	-
Region total	**12,995**	**6,026**	**1,183**	**4,138**	**2,628**	**9,576**	**5,924**	**479**	**479**
Nelson and Marlborough wood supply region									
Tasman District	-	-	-	807	440	-	73	-	-
Nelson City	1,321	73	1,174	5,578	1,541	807	661	440	440
Marlborough Distri	-	881	1,615	3,156	3,670	3,303	1,079	367	367
Kaikoura District	147	-	-	-	587	-	-	-	-
Region total	**1,468**	**954**	**2,789**	**9,542**	**6,239**	**4,110**	**1,813**	**807**	**807**
West Coast wood supply region									
Buller District	-	1,645	-	260	-	-	-	-	-
Grey District	3,464	6,235	1,645	1,905	6,582	6,408	-	-	-
Westland District	6,235	23,555	9,526	93,095	89,977	135,269	-	-	-
Region total	**9,699**	**31,436**	**11,171**	**95,260**	**96,559**	**141,678**	**-**	**-**	**-**
Canterbury wood supply region									
Hurunui District	-	93	464	278	2,970	4,269	1,670	-	-
Waimakariri Distric	-	464	1,114	-	742	-	-	-	-
Selwyn District	278	-	10,486	3,990	-	-	-	-	-
Christchurch City	-	-	186	835	1,206	-	-	-	-
Ashburton District	-	-	557	-	186	-	-	93	93
Mackenzie District	-	650	464	650	2,042	-	-	-	-
Timaru District	-	-	557	1,485	-	371	-	-	-
Waimate District	-	538	1,670	278	464	1,299	-	-	-
Region total	**278**	**1,745**	**15,498**	**7,517**	**7,610**	**5,939**	**1,670**	**93**	**93**
Otago and Southland wood supply region									
Waitaki District	-	627	145	771	627	337	289	627	627
Queenstown-Lake	-	2,073	2,506	2,747	675	771	-	-	-
Central Otago Distr	-	-	-	-	-	-	-	-	-
Dunedin City	-	-	193	-	-	-	-	-	-
Clutha District	337	5,398	1,591	11,279	13,110	8,194	7,326	1,012	1,012
Gore District	-	-	-	-	675	-	-	-	-
Southland District	2,362	2,024	578	2,458	3,904	1,542	3,229	1,205	1,205
Invercargill City	-	-	-	-	-	-	-	-	-
Region total	**2,699**	**10,122**	**5,013**	**17,256**	**18,991**	**10,845**	**10,845**	**2,844**	**2,844**

Appendix 7: Projections of *Eucalyptus* volumes

	2020-2024	2025-2029	2030-2034	2035-2039	2040-2044	2045-2049	2050-2054	2055-2059	2060-2065
Northland wood supply region									
Far North District	7,817	752	334	209	669	7,817	7,817	7,817	7,817
Whangarei District	4,891	-	-	-	251	4,891	4,891	4,891	4,891
Kaipara District	4,034	-	-	-	543	4,034	4,034	4,034	4,034
Eauckland Council	4,034	-	-	-	543	4,034	4,034	4,034	4,034
Region total	**20,775**	**752**	**334**	**209**	**2,006**	**20,775**	**20,775**	**20,775**	**20,775**
CNI Wood Supply region									
Thames-Coromandel D	-	-	-	-	2,006	-	-	-	-
Hauraki District	4,324	-	-	-	-	4,324	4,324	4,324	4,324
Waikato District	-	46	-	-	-	-	-	-	-
Matamata-Piako Distri	138	-	-	-	-	138	138	138	138
Hamilton City	-	-	-	-	-	-	-	-	-
Tauranga District	-	-	-	-	-	-	-	-	-
Western Bay of Plenty	-	-	-	-	-	-	-	-	-
Rotorua District	13,061	14,730	2,750	-	-	13,061	13,061	13,061	13,061
Kawerau District	7,561	-	-	-	1,080	7,561	7,561	7,561	7,561
Whakatane District	1,080	1,964	-	-	7,954	1,080	1,080	1,080	1,080
Opotiki District	7,954	10,213	3,437	-	-	7,954	7,954	7,954	7,954
Waipa District	491	-	-	-	-	491	491	491	491
Otorohanga District	-	-	-	-	-	-	-	-	-
Waitomo District	393	-	-	-	-	393	393	393	393
Ruapehu District	3,339	-	-	6,088	-	3,339	3,339	3,339	3,339
South Waikato District	295	196	3,044	295	-	295	295	295	295
Taupo District	4,517	33,486	30,147	196,105	1,571	4,517	4,517	4,517	4,517
Region total	**43,153**	**60,635**	**39,378**	**202,488**	**12,612**	**43,153**	**43,153**	**43,153**	**43,153**
East Coast wood supply region									
Gisborne District	9,809	366	183	3,660	3,257	9,809	9,809	9,809	9,809
Region total	**9,809**	**366**	**183**	**3,660**	**3,257**	**9,809**	**9,809**	**9,809**	**9,809**
Hawkes Bay wood supply region									
Wairoa District	754	4,461	262	3,018	5,543	754	754	754	754
Hastings District	1,345	-	98	6,330	820	1,345	1,345	1,345	1,345
Napier City	197	-	-	-	-	197	197	197	197
Central Hawkes Bay Di	164	131	-	7,544	853	164	164	164	164
Region total	**2,460**	**4,592**	**361**	**16,892**	**7,216**	**2,460**	**2,460**	**2,460**	**2,460**
Southern North Island wood supply region									
New Plymouth District	369	-	-	-	-	369	369	369	369
Stratford District	1,158	-	-	-	-	1,158	1,158	1,158	1,158
South Taranaki District	36	-	-	109	-	36	36	36	36
Wanganui District	-	-	-	-	-	-	-	-	-
Rangitikei District	608	109	145	217	181	608	608	608	608
Manawatu District	109	290	-	-	217	109	109	109	109
Kapiti Coast District	-	-	-	-	-	-	-	-	-
Upper Hutt City	543	-	-	-	-	543	543	543	543
Porirua City	-	-	-	-	-	-	-	-	-
Wellington City	-	-	-	-	-	-	-	-	-
Lower Hutt City	-	-	-	-	-	-	-	-	-
Palmerston North City	-	-	-	65	282	-	-	-	-
Tararua District	-	-	-	-	-	-	-	-	-
Masterton District	145	159	156	1,021	1,296	145	145	145	145
Horowhenua District	724	-	-	-	145	724	724	724	724
Carterton District	-	-	-	-	652	-	-	-	-
South Wairarapa Distri	4,742	-	-	-	-	4,742	4,742	4,742	4,742
Region total	**8,435**	**557**	**300**	**1,412**	**2,773**	**8,435**	**8,435**	**8,435**	**8,435**
Nelson and Marlborough wood supply region									
Tasman District	510	-	-	-	-	510	510	510	510
Nelson City	8,010	-	-	-	-	8,010	8,010	8,010	8,010
Marlborough District	2,490	30	840	1,410	1,710	2,490	2,490	2,490	2,490
Kaikoura District	30	-	-	-	-	30	30	30	30
Region total	**11,040**	**30**	**840**	**1,410**	**1,710**	**11,040**	**11,040**	**11,040**	**11,040**
West Coast wood supply region									
Buller District	3,550	-	-	-	-	3,550	3,550	3,550	3,550
Grey District	740	-	-	-	100	740	740	740	740
Westland District	430	-	-	-	-	430	430	430	430
Region total	**4,720**	**-**	**-**	**-**	**100**	**4,720**	**4,720**	**4,720**	**4,720**
Canterbury wood supply region									
Hurunui District	20	280	-	-	-	20	20	20	20
Waimakariri District	-	-	-	-	120	-	-	-	-
Selwyn District	980	-	-	-	-	980	980	980	980
Christchurch City	140	40	-	-	-	140	140	140	140
Ashburton District	300	-	-	-	20	300	300	300	300
Mackenzie District	200	60	-	-	-	200	200	200	200
Timaru District	-	-	-	-	-	-	-	-	-
Waimate District	40	-	-	-	-	40	40	40	40
Region total	**1,680**	**380**	**-**	**-**	**140**	**1,680**	**1,680**	**1,680**	**1,680**
Otago and Southland wood supply region									
Waitaki District	2,654	-	-	1,512	50	2,654	2,654	2,654	2,654
Queenstown-Lakes Di:	2,285	-	-	-	67	2,285	2,285	2,285	2,285
Central Otago District	-	-	-	-	-	-	-	-	-
Dunedin City	974	-	-	-	-	974	974	974	974
Clutha District	7,997	17,102	773	1,075	1,915	7,997	7,997	7,997	7,997
Gore District	9,442	470	3,259	-	1,243	9,442	9,442	9,442	9,442
Southland District	104,698	94,349	33,432	58,262	40,824	104,698	104,698	104,698	104,698
Invercargill City	-	-	-	-	-	-	-	-	-
Region total	**128,050**	**111,922**	**37,464**	**60,850**	**44,100**	**128,050**	**128,050**	**128,050**	**128,050**