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Environmental Inventory of Three Common New Zealand Composite Sheet Materials – A Preliminary Study

R. A. Jaques

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READERSHIP

This report is intended for environmental engineers, building technologists and environmental researchers.

ENVIRONMENTAL INVENTORY OF THREE COMMON NEW ZEALAND COMPOSITE SHEET MATERIALS – A PRELIMINARY STUDY

BRANZ Study Report No. SR 115 (2004) **Roman Jaques**

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KEYWORDS

Composite sheet manufacture, engineering board environmental profiling, life-cycle analysis, environmental profile, life-cycle inventory, timber products eco-profile

ABSTRACT

A truncated life-cycle inventory study of the three common types of New Zealand-produced wood-fibre-based composite boards – fibre cement board, medium density fibre-board and plywood sheeting – was conducted. An examination of the three composite boards – from raw material acquisition through to the finished product on the factory floor – was made. The environmental aspects investigated were: energy and material inputs, and discharges to air, land and water. An environmental profile was derived, listing all the major inputs and outputs in the production of 1 kg or 1 tonne of respective composite board. Research guidelines, in terms of the analysis scope, data sources and standard conventions, were supplied by a Canadian study.

Information was mainly sourced through plant-specific surveys (i.e. actual industry data) carried out in New Zealand for the years 2000-2001, with this data being supplemented by compatible international environmental profiles and industry contacts. The exception to this was fibre cement board, for which most of the information was derived from a comprehensive Australian life-cycle inventory study conducted in 1999 by the associated company of New Zealand's only national producer.

The environmental inventories/profiles established in this BRANZ study should be considered to be indicative and preliminary because of the incomplete dataset (necessitating many assumptions), and the undetermined accuracy in the resource-use reporting by the mills. Environmental profile comparisons are made with similar studies conducted in Australia and Canada where possible, but only tentative conclusions can be made because of the incomplete dataset and the differing methodology and time periods in which the surveys were carried out.

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1. INTRODUCTION

This research provides up-to-date environmental inventory data associated with the manufacture of a major building sheet material – composite boards. The object of this research was to "*develop environmental life-cycle impact data for (fibre-based) composite boards… and provide a report outlining the…approach to be used with the currently available New Zealand-specific information".* A life-cycle-based study was conducted on the following wood-fibre based composite board products:

- plywood
- medium density fibre board (MDF)
- fibre-cement board

These three wood-based composite board products were chosen as they are commonly used and form the basis of most other wood fibre board types (such as laminated veneer lumber, fibre-board and hardboard). Thus, from plywood; LVL manufacture can be derived; likewise, from MDF; particle board, hardboard and soft-board can be derived. Fibre cement board is the exception, having a more unique production process.

This research supports a long-term goal to assist the development of a scientifically sound basis for determining the environmental impact (associated with resource use and emissions) of building materials. Details from this type of study can be expanded to allow both the building industry and the consumer to select building materials that result in reduced environmental impact.

This report adds to the series of BRANZ studies examining environmental inventories/profiles of common building materials – with the previous including cement (Jaques, 1998), sawn timber (Gifford et al, 1998), structural and non-structural concrete (Jaques, 2002), steel (Jaques, 2002), and aluminium (Jaques, in draft).

2. BACKGROUND

2.1 Life-cycle analysis

The methodology used for this research report is based on life-cycle analysis (LCA) (Forintek, 1993a), which is a means of identifying the complete environmental impacts caused by a product. The overall goal of using LCA is to reduce the environmental impact of a product or component, by providing as complete a picture as possible of the inputs and outputs resulting from the manufacture and use of a product. LCA usually comprises four inter-related components: 'scoping', 'inventory', 'impact assessment', and 'improvement analyses'. This composite board study focuses almost entirely on the inventory stage, which is the data-intensive sub-process of LCA that quantifies the inputs and outputs that occur over the life-cycle of a product. This process is commonly termed life-cycle inventory (LCI) or environmental profiling. The inputs and outputs quantified include: raw materials, solid wastes, emissions to the atmosphere and liquid effluents.

In this BRANZ study the inventory will be restricted to only the first three stages of the life-cycle, in keeping with the other BRANZ environmental inventory profiles conducted. These three stages, and their implications for composite boards, are:

1. 'raw' material extraction/collection, i.e. growing of timber and the manufacture of resins
2. 'raw' material transportation, i.e. to the mills, nationally and/or internationally
3. product manufacture, i.e. the combining of the 'raw' materials - mechanically, thermally and chemically.

2.2 Research approach

This research was a collaborative effort between Forest Research Ltd and BRANZ Ltd. Forest Research Ltd was employed for its extensive knowledge, expertise and contacts in the timber/composite-board industry.

In December 2001 and January 2002 nine New Zealand composite board manufacturers were approached and asked specifics about their resource use. In all, four plywood plants, four medium density fibre-board plants and one fibre-cement board plant were requested to provide resource-use information on their respective operations (refer Appendices A and B). The questionnaire required information on: process details, material composition, raw material sources, energy use, water use and disposal, environmental controls, solid waste outputs, co-product output and possible future upgrades. Once surveys were returned, a 'virtual' (i.e. a composite) mill was constructed, based on the most common operations inputs/outputs while protecting confidentialities.

In the development of LCI for composite boards, each of the process stages (i.e. raw material extraction, transportation to mill and final processing) and resource type (i.e. energy, water materials) were analysed separately. Each of the three main board types was investigated under the following headings (in order):

- Introduction
- Raw material requirements
- Manufacture
- Energy use
- Water use
- Discharges to air
- Discharges to land
- Future improvements
- Overall environmental inventory/profile
- International comparison.

This report finishes with conclusions and recommendations for further research.

2.3 Methodology

GENERAL

Setting boundary conditions in an LCA is problematic at best (LeVan, 1996). As for the previous BRANZ study reports, the methodology used is based on that established in Canada by Forintek Canada Corporation in the early '90s. The Forintek Canada Corporation project "*Building Materials in the Context of Sustainable Development*" (Forintek, 1993 and Forintek, 1993a) developed out of a research-based alliance of public, private and academic institutions that wanted to make available environmental data on common construction materials (Meil and Trusty, 1996). The project was prompted by unsubstantiated claims promoting the environmental benefits of using timber (over other) alternatives in construction. It was recognised there was a need to carry out objective, scientifically based analyses of all building materials, to achieve a fair comparison based on the life-cycle-based approach. The Forintek project resulted in one of the definitive LCA-based works, and was chosen as a model for this BRANZ study due to its transparency and objectivity.

Forintek's (1993) level of analysis, scope, systems boundaries and standard conventions were all adopted for use in this BRANZ study. An overview of this methodological approach can be found in previous BRANZ research reports (Jaques, 1999 and Jaques, 2001), and consequently that material has not been duplicated in this report. However, some salient issues that are specific to composite boards are:

- Wastes from thinning operations during forestry management (e.g. pruning during growing, and de-limbing during tree extraction) are outside this study's boundary, so are not included within the final environmental profile

- All wood products are reported in oven-dry tonnes (ODT) unless otherwise stated, to maintain comparability with previous BRANZ reports and to ensure comparability with non-wood building materials

- Density: one cubic metre of green (roundwood) is estimated to weigh 1000kg; and the calorific value of sawdust is assumed to be 8 MJ/kg at a 50% moisture content.

- As in the Forintek study (1993) "*During analysis raw material input streams were kept separate and later combined to arrive at a final product. Where adhesives comprise 5% or less than the total product weight, these amounts have been added to the final product: i.e., a product containing 1% adhesive by weight would have a final oven-dry weight of 1.01 tonnes".*

- For purchased energy, the actual gross energy used at the mill is reported, with no allowances for production and delivery losses in the transportation of that energy type to the manufacturer

- For process heat energy converted on site via the burning of wood waste (hogfuel), allowances are made for boiler efficiencies – which were all assumed to be 70%.

- Where the production processes result in one or more co-products (i.e. in the manufacture of structural timber, pulp chips used for paper manufacture are being produced), only the impacts directly associated with lumber manufacture are attributed to it. These impacts are allocated on a weight basis.

- The fossil fuel feedstock used in the production of PF (phenol formaldehyde) and UF (urea formaldehyde), such as natural gas and petroleum, account for a substantial part of the total embodied energy of the resin. As these feedstocks are not transformed via combustion, they do not create any air emissions directly. By convention (Forintek, 1993), feedstock-related combustion atmospheric emissions are not accounted for, although their energy contributions are. To quote Forintek (1993) "…*the inclusion of feedstock energy in this analysis only reflects the additional draw-down of our limited fossil fuel resources*"

CARBON AND ENERGY ACCOUNTING

Environmentally profiling timber-based composite boards show some unique features when compared to other construction materials, in terms of their:

- ability to absorb CO_2 a major greenhouse gas, while growing
- use of process waste materials (such as bark, off-cuts and sawdust) for fuel input, during their manufacturing process.

The way these issues are addressed can have implications for the resulting energy and emission intensity figures within the environmental profiles. Somewhat surprisingly, given this significance, neither of these issues have been standardized internationally. For example, in terms of:

- **Carbon accounting –** both the Australian (Frick and Cottier, 1999) and UK (Howard et al., 1999) methodologies recognise timber as being quickly renewable and recyclable. Thus, no CO_2 emissions result from timber scrap that is burnt for fueling timber processing, as the fuel doesn't contribute to the build-up of CO_2 in the atmosphere. Forintek Canada (1993) takes the contrary approach and includes emissions from biofuels when determining environmental profiles, and excludes the CO_2 stored from planting to harvesting.

- **Energy accounting –** Forintek Canada (Forintek, 1993) takes into account the energy converted on site via the burning of biofuel (i.e. hogfuel), with the gross energy use being stated throughout the report. However, there has been a trend in the more recent international LCI-based studies to regard renewable fuels as not contributing to fossil fuel depletion, so they are not accounted for. This reflects the constant re-evaluation and movement of system boundaries in embodied energy analysis (Shipworth, 2002).

For this BRANZ study, hog fuel energy and CO_2 contributions from the burning of scrap will be included separately for the sake of completion, to assist future work in this area in case there is a shift in the methodological approach. However, CO_2 sequestered during timber growth which ends up as part of the composite board is not accounted for in this study. It is estimated to be around 0.53 kg carbon/kg of lumber (Baines, 1993), so can easily be subtracted from the reported emissions in the boards' environmental profiles.

2.4 Industry issues

2.4.1 Forestry establishment, silviculture and harvesting

For each of the composite boards, an important material contributor is timber. The environmental-related inputs/outputs associated with the growing of this timber are accounted for in this BRANZ study. A previous study (Forest Research, 1998) was employed as the basis for deriving these resource requirements, using industry energy analysis from 1995–1997. Although the Forest Research inventory study was for the manufacture of sawn lumber, much of the forestry establishment and management data is generic in nature, being suitable for application in this study. Thus, the same forestry establishment and management figures were used for all the three composite board types examined in this study – fibre cement, plywood and medium density fibre board.

For the Forest Research study (1998), the energy, resource and emission information is based on a 'typical' central North Island Pinus Radiata plantation, using the most common current management regimes and harvesting systems. The assumptions made as part of the artificially constructed 'typical' plant include:

- the previous land use was for plantation forests (rather than new-cleared land)
- the site was chemically and mechanically prepared
- pruning, but no production thinning
- harvesting was carried out with mechanical ground based machinery
- the travel distance to each composite-board mill is 50km, by diesel truck
- a minimal amount of processing is carried out, i.e. only debarking and chipping.

2.4.2 Transportation

Transportation modes and distances for raw materials can vary considerably between composite board plants. For this BRANZ study, an average distance–travelled figure was calculated according to the most likely mode of transport for each particular plant, with a simple average (by composite board type) taken. From this information, the atmospheric emissions could be calculated knowing the emission rate by fuel type (refer Table 17). Atmospheric emissions associated with transporting the 'raw' materials, as well as their transport to the mill are included. No allowances have been made for post-mill delivery of timber product to the retailer/wholesaler.

2.4.3 Production fuel changes

The composite board industry continuously invests in technical development for improving the production processes and, in particular, changes in fuel use. These fuel use changes are very price sensitive due to the availability of alternative fuel types and their significance in terms of bottom-line costs (Nielsen, 2002).

A change in the principal fuel type is motivated mainly by the dramatic changes in harvest volumes (both in the short and medium term) with the industry expanding in response to the growth in available fuel sources. This industry characteristic has implications also for the adoption of improved efficiencies, as a changing industry is more likely to respond to production-related technical advancements by implementing the newest available technology (Nielsen, 2002). This makes predicting even short-term production trends (in terms of fuel mix/emission rates/energy efficiencies) problematic due to the uncertainties. For example, natural gas is predicted to almost double in price over the next five to 10 years. This will undoubtedly change the fuel mix patterns considerably. What fuel type that change will be to, however, is unknown.

2.4.4 Pollution abatement

ASH (Most of this section is adapted from Nielsen, 2002)

It is recognised that the heat requirement for drying/pressing/curing of composite sheet materials is its largest energy burden. The bulk of this process heat in New Zealand is sourced from the burning of biofuel (hogfuel), i.e. off-cuts, sawdust, and bark. Although essentially a 'free fuel', biofuel does not come without an assortment of pollutants – the chief of which is ash. The ash content in pure wood is very low and mostly contains nutrients. The ash content is proportional to the contamination of the wood with soil and dust. However, the chemical content of ash is dependent on the temperature and efficiency reached in the combustion zone. If the combustion process is not highly efficient, the ash will contain significant amounts of unburned carbon.

Ash from timber mills is commonly divided into two types – flyash and bottom ash. Flyash is produced from the flue gases while bottom ash is produced from the grate. The ratio of the two ash types produced is dependent on the combustion technologies. Typically, the fly ash: bottom ash ratio will be about 1:4.

The chemical character of the two ash products is very different. The simplest differentiator is that fly ash is soluble in water whereas bottom ash is not. As any heavy metals in the ash tend to be in the fly ash, this has important implications for its handling. Fly ash's environmental burden is somewhat mitigated as it also has the highest nutrient value.

There was conflicting New Zealand data on the amount of wood ash (whether fly or bottom) generated for the various mill types. Overseas figures (Anderson and Tillman, 1977) estimated that **1.1% (by weight) of all wood waste burned becomes boiler (i.e. bottom) ash**. This figure was applied to this study report.

PARTICULATES

Particulates are part of the fly ash which escapes the cleaning processes applied to the flue gases, due to their small particle size. Particulates are characterised by their size. The largest, which is larger than 10 microns, is called 'dust'. The smaller sized is called PM_{10} and has a diameter of smaller than 10 microns. The smallest, $PM_{2.5}$, has a diameter of less than 2.5 microns. At present, most filtering/cleaning technologies are effective only for PM_{10} or larger particulates.

Although there are a wide variety of systems to remove particulates from the stack gases, very little information was able to be sourced in New Zealand. It is estimated that **0.7 g/MJ of particulates is emitted on average**, in the burning of industrial wood waste (Environment Canada, 1990). Following Forintek's lead, it was estimated that the particulate recovery for New Zealand softwood (such as *Pinus Radiata*) is in the order of 80% of the unabated particulate discharge.

WATER DEMAND

The production of composite boards is heavily reliant on water use for the washing of chips, conditioning of wood and wood steaming. The majority of water used in the production of composite boards is for steam energy required as part of the drying of wood fibre (Forintek, 1993). This steam is often condensed and returned to be recycled or off-gassed as water vapour. Post-use treatment and disposal/reuse of mill water varies greatly between mills and mill-types in New Zealand. The most common practice (by composite board type) will be considered to be reflective of the board type addressed.

ADHESIVE USE

There are a variety of formaldehyde-based resins (i.e. bonding agents) used in the production of composite boards. The selection of bonding agent for plywood has considerable significance as the adhesive properties will influence its performance and therefore its suitability (TRADA, 1981). For externally-used plywood, which needs to have a high resistance to moisture/water, phenol formaldehyde (PF) is used. For internally-used MDF, a less durable (and cheaper to manufacture) resin is suitable – urea formaldehyde (UF).

PF resins have high strength properties with the required durability characteristics – being more durable than the wood itself. PF resins are immune to micro-organism attack and are very resistant to common solvents, wood preservatives, flame-retardant chemicals and most acids (TRADA, 1981). Phenol used in New Zealand plywood manufacture is imported from Melbourne, while all urea for MDF board is manufactured in New Zealand (Anthony, 2002).

PF and UF atmospheric emissions were calculated separately, based on New Zealand-sourced industry data as well as Forintek data. In the calculation of each resin's atmospheric emissions, contributions from both national and international transportation energy use were examined. The mix ratios of the component parts of the resins (i.e. phenol, urea and formaldehyde) were estimated as the actual figures are confidential to industry, and the emissions derived accordingly.

In the manufacture of formaldehyde, New Zealand plants have to comply with emission standards which require a threshold of a maximum of 1 kg/hr formaldehyde (Anthony, 2002). These threshold emission levels are well above actual (plant) emission levels, which are estimated to be only **0.01 kg/tonne formaldehyde produced**. For more details on the manufacture of PF and UF, refer to Appendix D.

2.5 Terms and definitions

The following terms and abbreviations were used in the study:

Co-product – When the manufacturing process produces more than one product (i.e. in addition to the primary product). When this extra product has an economic value, it is referred to as the co-product. All resource inputs associated with this co-product are usually subtracted from the primary products inventory on a *weight* basis.

Feedstock – the combustion heat (energy) of raw material inputs which are not used as an energy source (ISO, 1997), for example the petroleum products used in plastics.

Green – wet or freshly-cut timber. For *Pinus Radiata*, it is expected to have moisture content when green of around 50%. Note that wet wood = oven dry wood content + moisture content.

MC – moisture content. When referred to on an oven-dry basis, it is kg moisture/kg oven-dry wood.

OD – oven dry; an expression used in the timber industry to describe when wood has had all the moisture removed. This is the most common basis for measuring wood mass or wood energy content (Baines, 1993)

ODT – Oven dry tonnes. See OD.

Roundwood – logs recently cut ready for processing, which still have their bark on.

Hogfuel – timber off-cuts, sawdust, chip and bark usually used as a fuel source in the production of a variety of timber-based products. The terms hog-fuel and bio-fuel are used interchangeably in this report.

3. NEW ZEALAND COMPOSITE BOARD INDUSTRY

New Zealand produces approximately 2.3 million cubic metres of wood-based composite products for many construction-related purposes (Page, 2002). The production, consumption, export and import figures for the three major composite board types are briefly overviewed. The majority of the figures are for the 2000/2001 year, based on an annual survey, sourced from the Ministry of Agriculture and Forestry's (MAF's) Statistics Section (available online through www.maf.govt.nz/statistics/). The exception to this is the fibre cement board figures, which are estimates (Page, 2002).

MAF divides the composite board types in the following manner:

- **Plywood**, which includes laminated veneer lumber (LVL) as well as plywood production.
- **Fibreboard**, which includes hardboard, soft board and medium density fibreboard (MDF).
- **Particleboard**, which includes particleboard, tri-board and strand-board (not dealt with here).

Note that these generic groups cannot be broken down further due to confidentialities (e.g., sometimes there are only a few producers of a particular product). Although the MAF groupings don't correspond exactly to the investigated BRANZ board types, they are useful for indicative purposes.

PLYWOOD

Total 'plywood' production (as defined by MAF) for the year ended 31st March 2001 was 243,702 cubic metres. This quantity of plywood was produced by six mills, having an installed capacity of 320,000 cubic metres of plywood per year, based on the established number of working hours per working day of each mill at 31 March 2001. The main export markets were Japan and Australia.

FIBREBOARD (MDF)

Total 'fibreboard' production (as defined by MAF) for the March 2001 year was 801,493 cubic metres (or 574,416 tonnes). This quantity of fibreboard was produced by six mills, having an installed capacity to produce an estimated 940,000 cubic metres (or 670,000 tonnes) of fibreboard per year, based on the established number of working hours per working day of each mill at 31 March 2001. The main export markets were USA and Japan.

Table 1: New Zealand composite board production and consumption statistics

NEW ZEALAND COMPOSITE BOARDS PRODUCTION AND CONSUMPTION (in m^3, for year ending 31 March 2000)					
BOARD TYPE	Production	Imports	Exports	Apparent consumption per 1000 capita	Apparent consumption per 1000 capita (five year moving mean)
Plywood	239,947	7,430	108,394	36	24
Fibreboard (MDF)	744,879	6,808	588,780	43	55

Notes:

1. No account is taken of changes in stock levels.
2. Imports and exports are for years ended 30th June.

3. Year-to-year changes in the derived series 'Apparent consumption' need to be interpreted carefully as the effects of increased capacity becoming available and shipping movements may considerably alter the Apparent consumption levels. Follow-on effects may still be present in the next time period. A better appreciation of the trend is given by the consumption per capita (five-year moving average) series.

FIBRE CEMENT BOARD (FCB)

BRANZ in-house sourcing of FCB production figures were used, as no MAF figures were available (Page, 2002). It is estimated that for the year ending December 2001, a total of 1.6 million m^2 of FCB board was used nationally, covering all types of construction[1]. The most recent New Zealand production and import figures were 341,000 m^2 and 456,000 m^2, for the June 1998 to July 1999 year, respectively.

[1] *This figure includes an estimate for non-consented work as well as for consented work.*

4. FIBRE CEMENT BOARD

4.1 Introduction

Fibre cement board (fcb) is imported into New Zealand from several countries, including Australia, China, Indonesia, Malaysia, Chile, Belgium and the United Kingdom (Burnett, 2001). However, the sole New Zealand manufacturer, James Hardie New Zealand, remains the largest supplier to the domestic market by quite a margin (Trevethick, 2002), estimated to be around 85% of national consumption (Page, 2002).

Little New Zealand-specific information was able to be sourced on James Hardie New Zealand production, being the only national producer in a highly competitive industry (Trevethick, 2002). As a result of the sensitivity of resource information, much of the relevant data has been sourced off-shore; using comparable manufacturing processes. The bulk of the off-shore data is sourced from a comprehensive Australian LCI study conducted by James Hardie (Australia) in 1999. Although the scope of the Australian study is slightly more inclusive than BRANZ's[2], the extra resource contributions are known to be very small, and thus can be disregarded.

The justification of using the 1999 James Hardie (Australia) LCI study as 'typical' of New Zealand's operations is based on the following assumptions:

- The manufacture (processing) of fcb in Australia is similar to that in New Zealand (see Trevethick, 2002).
- Being the single largest national supplier, a detailed assessment of its operations is likely to be of most relevance.
- The James Hardie (Australia) operation is a fair representation of off-shore fcb manufacturing plants exporting to New Zealand.

4.2 Background

The James Hardie Australia (JHA) environmental profile was conducted on a variety of fcb and sheet products manufactured at its New South Wales (Rosehill) plant (Frick and Cottier, 1999). The majority of its inventory database (which makes up its environmental profile) is sourced directly from the component suppliers. Thus, the downstream environmental effects of the manufacture of each of its individual components (such as cement and cellulose fibre) have been captured also. Where this was not possible, average data was obtained; either from the SimaPro Life-cycle Inventory database (SimaPro, 1998), or from literature reviews (Frick and Cottier, 1999, and Frick 2002).

In all, James Hardie (Australia) environmentally profiled five sheet and board materials – 6 mm Villaboard, 4.5 mm Hardiflex Sheet, 9 mm Compressed Sheet, 7.5 mm Hardiplank Board, and 9 mm PrimeLine Board, as part of its LCI. For this research report, only the most common sheet – the 6 mm Villaboard (i.e. the generic '6mm fibre cement board') is being profiled, and will be compared to the Australian environmental profile.

The bulk of the energy-related New Zealand fcb process information is sourced from the James Hardie Australia study. This includes: refinery steam requirements, electrical processing energy requirements, and other miscellaneous processes. However, where possible, New Zealand data supplements Australian figures. The main example of this is the contributions of New Zealand-produced pulp and cement.

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[2] *The Australian study uses a 'cradle-to-installation on-site' boundary, rather than this study's 'cradle-to-manufacturing gate' boundary*

4.3 Raw material requirements

The New Zealand generic 6mm fibre-cement board is composed of the following components:

- Cellulose fibre – unbleached plantation *Pinus Radiata*
- Ordinary Portland cement (OPC)
- Ground sand or quartz rock (silica)
- Small amounts of additives as required (such as minerals or alumina)
- Water

The percentage composition figures of those ingredients (rather than what is finally created in the sheet) are shown in Table 2. The fibre-cement sheets final density is approximately 1600 kg/m^2 (Frick and Cottier, 1999). The proportions are approximate, being distilled from a variety of sources which cannot be named to protect confidentialities.

Table 2: Raw material proportions for New Zealand fibre cement board

Typical 6mm fibre cement board composition (Source: various)	
Raw material	**Percentage composition** (by weight)
Sand (silica)	45
Portland Cement	40
Cellulose Fibre (pulp)	10
Alumina	5
Water (assume dry weight)	0
TOTAL	**100**

It was estimated that during the manufacturing process, 30% of each of the contributing 'raw' materials ends up as waste, whether in the form of autoclave dry scrap, fine solids, process sludge or other wastes. This estimated percentage reflects JHA operations (see Section 4.8).

4.4 Manufacture

The following process description represents what 'typically' occurs in a fibre-cement plant. James Hardie New Zealand has indicated that this process description is a "fair indication" of what happens (Trevethick, 2002).

The manufacture of fibre-cement board consists of several processes:

1. ***Sourcing:*** *The 'raw' materials – cement, silica sand (which has been graded and ground in a ball mill), cellulose (in the form of a cube), water and other additives – are sourced, mainly nationally.*
2. ***Mixing:*** *The raw materials are mixed into a slurry which is stored in an agitator chest and further diluted with water.*
3. ***Forming:*** *The slurry runs into a sieve drum-sheeting machine. The rotating drum above the slurry mixture slowly picks up material, and removes the moisture by vacuum dewatering.*

Once a predetermined thickness is achieved on the drum, the mat/board is laid out onto a continuous conveyor.

4. ***Curing:*** *Boards are steam cured in a steam chamber then de-stacked and dried in the autoclave for approximately 24 hours.*
5. ***Finishing:*** *Boards are then sorted, face sanded if required, and raw sheet edges trimmed, using water jets, template stamps or circular knives.*
6. ***Storing:*** *Boards are then labelled, stacked with spacers, set aside, and stored before being packaged and transported out*

Figure 1 displays the 'typical' fcb manufacturing process schematically. As can be seen, the process is quite straightforward.

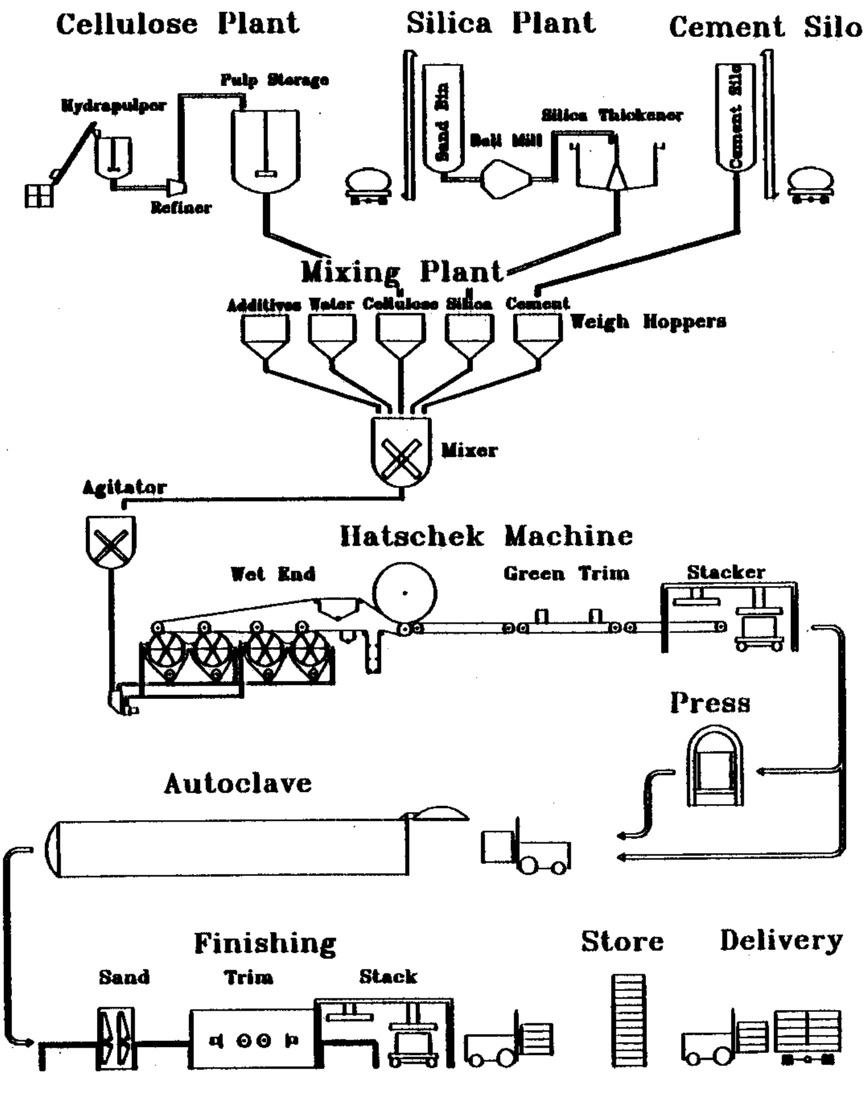

Figure 1: Fibre-cement sheet manufacture (the Hatschek process)
(source: Frick and Cottier, 1999)

4.5 Energy use

4.5.1 Introduction

When examining energy use, the focus was on which process inputs – whether it be 'raw material' or production-related – were the most energy intensive. The JHA LCI study calculated the embodied energy of 6mm fibre cement board (termed 'Villaboard^{TM}') to be 4.8 MJ/kg (based on a board density of 1594 kg/m^3). The energy process contributions to the total energy requirements are listed in Table 3.

Table 3: James Hardie Australia fibre cement sheet embodied energy

(after Frick and Cottier, 1999)

Process input	6 mm Villaboard^{TM} sheet (%)	6 mm Villaboard^{TM} sheet (MJ/m^2)
Additives	2.9	1.3
Cement	27.4	12.6
Cellulose fibre	13.2	6.1
Electrical energy	17.4	8.0
Other process inputs	4.2	1.9
Refinery steam	24.5	11.2
Sand	8.0	3.7
Solid waste transport	2.4	1.1
TOTAL	**100**	**45.9**

Using Table 3 as a guide, it can be seen that the five most significant contributors to the fcb embodied energy are: cement, refinery steam, electrical energy, cellulose fibre and sand. Together, these process inputs account for more than 90% of fcb's total embodied energy. Given that similar production processes are used in the manufacture of New Zealand fcb, these process inputs have been classified as 'key inputs' and given special attention when deriving their New Zealand-specific contributions.

4.5.2 Key inputs

CEMENT

Embodied energy figures derived for cement were based on a previous New Zealand concrete LCI study, carried out using 1999 figures (Jaques, 2001). The concrete study updated and extended an earlier BRANZ study on the environmental burdens of cement, which in turn was based on energy and material flows from the 1995 year.

Type GP (i.e. general purpose) cement is assumed to be used for fibre cement board manufactured in New Zealand having an approximate composition of: 76% limestone, 19% clay, and 5% gypsum. This composition reflects 'current' industry practice (i.e., as of 1999), where natural mineral 'fillers' (in this case extra limestone) are accounted for. The extraction, transportation and processing of these 'raw' materials result in an embodied energy figure of **4.52 MJ/kg for cement**[3].

[3] *Note that this embodied energy figure is significantly smaller than what would be expected using NZ-average technology, due to the way waste oil is accounted for under Forintek methodology. Forintek considers that previously used oil burnt in an industrial process is 'free input'.*

REFINERY STEAM

Refinery steam, required for high-temperature fcb processing, is assumed to be made from 100% renewable biofuel in New Zealand. This is seen to be a fair representation by experts (Gifford, 2002). The embodied energy related to its production – i.e. that associated with forest establishment, harvesting transport and the minimal plant processing – is included. These contributing biofuel energy intensities are quantified in Table 4.

Table 4: Energy requirements for the production of 1 kg of woodchip biofuel
(after Forest Research, 2002)

STAGE	Petrol (MJ/kg)	Diesel (MJ/kg)	Oil (MJ/kg)	Electricity (MJ/kg)
Forest establishment and harvesting	0.005	0.218	0.007	0.000
Transport (50 km)	0.000	0.065	0.000	0.000
Minimal processing	0.000	0.017	0.000	0.002
TOTAL (gross) …	**0.005**	**0.300**	**0.007**	**0.002**

Note on Table 4

In deriving the energy flows associated with the manufacture of wood chip, the following assumptions (as mentioned in 2.3) were applied (Nielsen, 2002). In deriving the refinery steam energy-related requirements, the amount of biomass necessary was estimated in the following manner:

> It takes 1.176 MJ/kg of refinery steam per kg of finished fibre cement board (from James Hardies Australia, 2002), and 2.8 MJ of steam energy is derived from each kg of (wet) biofuel. Thus, 0.42 kg of biofuel is necessary for each kg of finished fibre cement board.

CELLULOSE FIBRE (PULP)

Unbleached cellulose fibre ('pulp') for fibre cement board manufacture is purpose-made in the Tasman mill at Kawerau, and is named 'Tasman Fibre Cement Pulp'. For confidentiality reasons, no specific information on its production could be sourced. Pulps major components are cellulose, lignin, hemicellulose and water. It has a density of around 700 kg/m^3 (at a moisture content of 20%). It is transported about 400km from the Tasman mill to the cement board manufacturing plant in Penrose, Auckland. It is thought that the fcb-specific pulp is mechanically, rather than chemically produced (Gifford, 2002), which has significant implications for the processing energy content. Using the Forest Research industry survey figures from the 1995–1997 period (Forest Research, 1998), the total embodied energy required was found to be 14.9 MJ/m^2 of 6 mm board.

4.5.3 Secondary material inputs

According to James Hardie Australia (Cottier, 2001), the additives cited in its LCI paper are confidential, but are just 'natural minerals'. For this BRANZ study, these minerals are assumed to be an equal amount of clay and alumina. The clay is assumed to be mechanically extracted using diesel machinery and used unprocessed. The amount of energy required is based on a general industry figure for mining and quarrying, equating to **0.074 MJ/kg of the clay mineral** (Alcorn, 1996). The alumina is assumed to be mined at Weipa and refined at Gladstone, with the same requirements (at **108.7 MJ/kg per tonne of alumina**[4],) as established in a parallel study on aluminium production (Jaques, 2004).

[4] *excluding bulk freight transport to New Zealand*

4.5.4 Energy use summary table

Table 5 summarises both the key and the secondary energy requirements associated with the manufacture of fcb in New Zealand. Any process input that is not accounted for in the key or secondary sections are assumed to have the same embodied energy value as for the corresponding Australian process input.

Table 5: Summary of 'typical' New Zealand fibre cement board embodied energy requirements

Embodied energy requirements for 1 kg of fibre cement board		
Process input	**MJ/m^2 of finished product**	**MJ/t of finished product**
Alumina*	0.13	14
Cement	19.7	2,056
Clay	1.3	139
Electrical energy*	8.0	835
Other process inputs*	1.9	202
Pulp	14.9	1,560
Refinery steam*	1.3	132
Silica	2.2	225
Solid waste transportation*	1.1	115
TOTAL	**50.5**	**5,277**

Notes on Table 5

1. A star (*) indicates that this figure is wholly derived from overseas sources.
2. Electrical energy refers to that required for the fcb manufacture only.
3. Note that if the energy associated with biofuel is included (in the manufacture of 'refinery steam') an extra 8 MJ/m^2 for fcb is required.

As can be seen from comparing Table 3 and Table 5, the total embodied energy of the New Zealand-made fcb is similar (but larger than) the Australian figure. The most significant differences are the cement, refinery steam and cellulose fibre figures. However, this observation can only be made tentatively, given the many assumptions in trying to establish New Zealand's fcb mix design. Especially problematic is that assumptions had to be made for the most energy intensive process inputs – electrical energy, cellulose fibre and refinery steam. However, at this time, this is the best information available.

4.6 Water resource depletion

Little New Zealand-specific information on water requirements was available for either the major raw material ingredients or the manufacturing of the fcb. Water requirements in the manufacture of fcb are all sourced entirely from the JHA document (Frick and Cottier, 1999). In the making of one square metre of fcb, it was estimated that 101.7 litres of water is required using cradle-to-the-gate assessment. This equates to 10.6 litres of water per kg of fcb, based on a board density of 1594 kg/m3.

Analysis shows that cellulose pulp manufacture is the major influence on water usage attributable to fibre cement products (Frick and Cottier, 1999), accounting for up to 60% of all water requirements, based on an average over all the fcb products. Sand mining (at up to 22%), the manufacturing process of fcb itself (at 14%), and cement manufacture (at up to 8%) are the next three large water consumers. Table 6 converts these averaged percentages into litres per kg of finished fcb product.

Table 6: Water usage by process type for fibre cement board
(after Frick and Cottier, 1999)

Process type	Percentage[5]	Litres water per kg of fcb product
Cellulose pulp	58	6.15
sand mining	22	2.33
Fibre cement processing	14	1.48
Cement manufacture	6	0.64
TOTAL	**100**	**10.6**

4.7 Discharges to air

Air pollutants are calculated directly from the fuel usage attributable to each stage of fcb manufacture, up to the 'factory gate'. Where applied, emission reduction technology (e.g. environmental control in the form of fume hoods, particulate filters etc) is accounted for.

Table 7 shows the various major atmospheric pollutants for the finished fibre cement board. Although not shown within that table, the primary processing stage was the main contributor for atmospheric pollutants. Two processes in particular – cement and pulp manufacture – were responsible for the largest (absolute) contributions. The manufacture of cement was responsible for the bulk of the CO_2 and particulate[6] emissions, while the manufacture of pulp was responsible for the bulk of the rest of the pollutants accounted for in Table 7.

Table 7: Main air pollutants in the production of fibre cement board

AIR EMISSIONS		
Pollutant	**kg/t of fibre cement board**	**kg/m^2 of fibre cement board**
CO_2	542	5.180
VOCs	2.31	0.022
CH_4	0.35	0.003
NO_x	36.3	0.347
CO	2.02	0.019
SO_2	2.96	0.028
Particulates	0.72	0.007

4.8 Discharges to land

A lack of New Zealand-specific data necessitated the use of the JHA study for all solid waste information for fcb. Despite recycling efforts, solid waste totalling about 300 kg per tonne of fcb product is generated during manufacture of fcb. This is thought to represent between 32% and 42%[7] of the overall solid waste generated when considered from cradle-to-gate, with cement being responsible for the majority of the 'raw material' solid wastes. Overall, the solid waste emissions for the production of 6mm fcb are estimated to be 6.8 kg/m^2. For a breakdown of all the contributing solid wastes for 6mm fibre cement board, refer to Table 8.

[5] Note that these percentages are average figures for all the fcb types, rather than just for 6 mm Villaboard.
[6] In this case, cement kiln dust. This figure is taken from Forintek (1993), as no New Zealand figure could be sourced.
[7] The range accounts for the various types (and therefore composition or mix-design) of fcb assessed, under the JHA LCI.

Table 8: Solid wastes from all contributors to fibre cement production
(source: Frick and Cottier, 1999)

WASTE MATERIAL	kg of waste/tonne fcb	Percentage contribution
Non-autoclave dry scrap	76	11
Fine solids (surface finishing)	48	7
Process sludge	36	5
Other process wastes	140	20
Raw material contributions	414	57
TOTAL	**714**	**100**

Notes on Table 8:

1. 'Other process wastes' includes felts, sanding belts, timber scrap, packaging wastes, synthetic bulk bags, paper, empty drums and cans etc.
2. Non-autoclave dry scrap includes reject sheets, interleaves etc.
3. The 'raw material contributions' figure is a 'best guess' as the actual number is confidential. However, it is likely to be at the lower end of the 32% to 42% range, since it is a simpler product (comprising of fewer additives) compared to the other composites.

4.9 Future improvements in the FCB industry

As for the previous sections, the JHA operations at the NSW Rosehill plant in Australia are assumed to be representative of James Hardies operation in Penrose, Auckland and representative of other operations. This section, to a large extent, has closely followed the Frick and Cottier study (1999).

On general environmental stewardship issues:

JHA is continually implementing programmes addressing its resource use in the areas of:

- Water and resource conservation
- Energy consumption and management
- Use of renewable resources as raw materials
- Avoidance of damaging materials
- Waste minimisation by recycling of process materials
- Pollution reduction and protection of the natural environment.

On raw material inputs:

Within the manufacturing process, James Hardie is attempting to recycle as much of the waste products as are practical. This includes: recycling some of the waste mix slurry back into the fresh fibre-cement mixes; the recycling of the process water and the recycling of oil, packaging, steel consumables and scrap green sheets.

On treatment of effluent:

A new biological wastewater treatment plant was recently installed which enables the process water to be recycled further and also treats the effluent to a much higher quality than was previously (pre 1999) being discharged.

On solid waste emissions:

Dust is mechanically collected and treated with water and binders (emulsifiers) during transport and disposal. Silica dust is contained when milled with a continuous aqueous slurry. Potential uses of dry fibre-cement solid waste, such as scrap and fine particles, are being investigated by JHA. Recycling of post consumer fibre-cement waste in the manufacture of new fibre cement products is not possible at this time because of coating (paint and other surface finishes) contamination. There is some potential for post-consumer product use in crushed concrete road base, low-strength recycled concrete, or as a soil conditioner.

4.10 FCB environmental inventory

Table 8 combines the results from the previous sub-sections to obtain an environmental inventory for the production of one tonne of New Zealand produced fcb. These figures include all the manufacturing stages (from cradle-to-factory gate), all transportation (from raw material extraction to plants, as well as between plant transportation) and feedstock energy contributions. This inventory was largely based on Australian data with many assumptions, so should be seen as a preliminary result only.

Table 9: Resource inventory for 1 metric tonne of finished fibre cement board

For 1 tonne of fibre cement board		
INPUTS		
Material inputs	**Quantity**	**units**
Alumina	33	kg
Cellulose	130	kg
Cement	455	kg
Chemicals (incl. fertilizer)	31	mg
Gypsum	37	kg
Limestone	611	kg
Silica	1,125	kg
Water	15,063	kg
Energy inputs	**Quantity**	**units**
Material contribution	5,162	MJ
Manufacturing	5,750	MJ
Solid waste transportion	115	MJ
TOTAL	*11,027*	*MJ*

For 1 tonne of fibre cement board		
OUTPUTS		
Solid emissions	**Quantity**	**units**
Ash (all)	1.0	kg
(Bauxite residue)	50	kg
Solid wastes (general)	1,133	kg
Air emissions	**Quantity**	**units**
CH_4	346	g
CO	2.0	kg
CO_2	542	kg
Dust	4.8	kg
Formaldehyde	14	mg
HCl	716	mg
NO_x	36.3	kg
PAH	4.6	mg
SO_2	3.0	kg
Water emissions	**Quantity**	**units**
Acids as H+	564	mg
BODs	21	mg
Cl-	983	mg
Dissolved organics	296	mg
Dissolved solids	5,214	mg
Fluoride	594	mg
Metallic irons	72	mg
Oil	39	g
Sulphate	3,531	mg
Suspended solids	3,465	mg
Waste w+M39ater	13,617	kg

Note on Table 9

1. Items which are bracketed are only included for completion sake, as they fall outside the defined LCI boundary limit, as defined by Forintek (1993).

4.11 International comparison

Since most of the information was sourced from Australia, comparative analysis was not performed.

5. PLYWOOD

5.1 Introduction

Very little resource-related information could be gained from the plywood industry (mills), with some of the forms being returned only partially complete. Often there were conflicts with information both between and within mills, making comprehension and amalgamation difficult. As a result, this section of the report should be regarded as strictly "preliminary" with further investigation to be carried out.

For the purposes of this study, a 'typical' mill is derived, which means that no one particular mill is exactly represented. Where there was a conflict/disagreement in a particular process, the most common operation is used – for example, not all plywood manufacturers use PF resin as their resin of choice, but this was the preferred resin overall and, therefore, the one chosen for analysis in this study.

The following assumptions were made as part of the resin analysis:

- all of New Zealand-used phenol formaldehyde resin (PF) for plywood manufacture is made in one of New Zealand's four PF plants
- each plywood plant gets its resin from its closest manufacturer
- the manufacture of phenol in Australia is assumed to be the same as for Canada.

As mentioned in section 2.4.1, the Forest Research study carried out in 1998 was used as the basis for the information on forestry establishment, silviculture and harvesting for this resource study.

5.2 Raw material requirements

Plywood has a density of 400 kg/m^3.

1 OD tonne of roundwood (i.e. timber log with bark still on) yields:

0.57 ODT of plywood
0.24 ODT of co-product
0.19 ODT of bio-fuel

The gross roundwood required per ODT of plywood
= 1/0.57 = 1.75 ODT of roundwood

The composition of 1 ODT of ply is:
98% timber (which has a density of 400 kg/m^3)
2% phenol formaldehyde resin (which has a density of 1300 kg/m^3)

The PF resin has an approximate P:F ratio is 0.4:0.6. (The actual ratio is confidential to the manufacturer). The manufacture of the resin includes herbicides, pesticides and fertilisers used during forest establishment (Gifford et al, 1998). For a complete list of these additives used, see Appendix 5 in the Gifford et al report (1998).

5.3 Manufacture

The manufacture of plywood from Pinus Radiata veneer bonded with (phenol formaldehyde) resin adhesive consists of six processes:

1. **Timber selection:** Straight and mostly defect-free Pinus Radiata timber is selected and transported to the mill. Logs undergo conditioning in hot water or steam to improve the quality of the peeled veneer and to decrease the energy demand.

2. **Peeling:** logs are debarked and then sawn to pre-determined lengths – usually about 100mm longer than the size of veneer to be produced. The log is then peeled using a large rotary lathe that produces a continuous ribbon of veneer of a consistent thickness (from 1mm-4mm).The veneer ribbon passes through a clipper which cuts it to a predetermined sheet size and is then stacked ready for drying.

3. **Drying and clipping:** The wet veneer is fed through a continuous drier. The veneer emerges from it with a specific moisture content (between 4% and 8%). Veneer is visually graded and stacked according to grade and passed to the jointing section.

4. **Grading:** The dried and clipped veneer is sorted into face or core veneers. Any surface defects may be repaired.

5. **Jointing and bonding**: The narrower widths of dried veneer may be edge-jointed by gluing, taping or stitching to form standard pile sizes. If log-grain jointing is required, scarf joints are used. The veneers are then sorted, ready for gluing. Assemblies of veneer are made using veneers laid up alternately. Grain orientation is aligned according to the desired end product requirements, making a sandwich.

6. **Pressing and finishing**: The veneer lay-ups are then assembled in packs, and pressed together in carefully monitored cold and hot presses. After unloading, the boards are cooled, trimmed and sanded. The boards are then inspected (where a grading check is performed) and packed, ready for shipment.

5.4 Energy use

Energy demand for plywood production varies by mill, due to differing sawing equipment, boiler efficiencies, peelers and conditioners and basic mix design transport roundwood (roadside to mill) requirements and forestry management.

ROUNDWOOD-RELATED

It is estimated by Forest Research (2002), that it takes 0.295 MJ/kg to plant, manage, harvest and transport 1 kg of timber (assuming a moisture content of 50%). Thus, when OD, this equates to 0.59 MJ/kg.

Gross roundwood delivered energy (net of co-product production) becomes:

= 1.75 ODT x 0.59 MJ/kg x (1 – 0.24)
= 0.78 MJ/kg

PLY MANUFACTURING–RELATED

Substantial process heat is required for steam energy in plywood manufacture. Approximately 95% of the total energy is required for heat processing (refer Table 10).

Table 10: Percentage of energy for plywood, by manufacturing stage only

PLYWOOD Manufacturing Sub-processes	Mechanical	Heat
Debarking	*1.2*	
Preheating of logs		*16.2*
Log peeling	*2.1*	
Drying timber		*68.5*
Clipping and cutting	*0.4*	
Hot processing		*10.1*
Cooling, trimming and finishing	*1.4*	
TOTAL PERCENTAGE	**5**	**95**

The gross energy input for manufacturing is 10.66 MJ/kg, of which the bulk of the contribution is made up of biomass. This embodied energy figure is calculated by dividing the gross energy input (551 TJ) by the gross output (of approximately 51 kt). Biomass contributions were calculated assuming that it is derived mainly from bio-energy produced internally (rather than from externally purchased) as part of mill operations. In New Zealand, approximately 53% of the gross process heat energy consumed by plywood mills is derived from bio-energy. This energy is supplemented by other fuels as necessary (mostly in the form of natural gas). A breakdown of fuels (by type and by mill) is not shown to protect confidentialities.

Accounting for co-product energy, this is reduced to:

= 10.66 MJ/kg x 0.76
= 8.10 MJ/kg.

PHENOL FORMALDEHYDE–RELATED

PF is known to have a high embodied energy content. Forintek (1993) estimates that PF resin has an embodied energy of approximately 87 MJ/kg, of which 60% is said to be attributable to feedstock energy. For the purposes of this report, New Zealand embodied energy figures were assumed to be the same. In addition to manufacturing energy, both international transportation (from Melbourne) and national transportation (by diesel truck) was accounted for. Transportation adds another 0.30 MJ/kg to the manufacturing energy intensity. Thus, the total embodied energy for New Zealand-made **PF is 87.3 MJ/kg**. Refer to Table 17 for energy intensity by mode of transport.

Allowing for the percentage contribution of PF resin as a proportion of OD weight in ply, gives:

= 87.3 MJ/kg x 2% of OD weight
= 1.75 MJ/kg (i.e. 16% of the total embodied energy)

Thus, the total embodied energy associated with the production of PLYWOOD becomes:
= 0.78 + 8.10 + 1.75 MJ
= 10.63 MJ/kg.

5.5 Water resource depletion

Water is required for nursery irrigation (see FRI report) as well as during ply manufacture. The manufacturing process water demand is for log conditioning prior to initial peeling and steam generation for the drying and pressing of the wood fibre. The water use for nursery irrigation is estimated to be 0.64 litres per ODT ply. It seems that no water monitoring is performed in the plywood mills surveyed. Some water recycling is carried out. This water is either treated before going into the waste water system or used on-site for secondary purposes, depending on its original use. The assumption is made that the water management in New Zealand mills is similar to that operating in Canada, in that all steam is returned to be recycled with conditioning water ponds only losing water through evaporation. Thus, no major effluent discharges result from the manufacture of plywood.

5.6 Discharges to air

Table 11 shows the atmospheric emissions, by production stage, for plywood production. Air pollutants are calculated directly from the fuel usage attributable to each stage of plywood manufacture, up to the 'factory gate'. Where applied, emission reduction technology (e.g. environmental control in the form of fume hoods, particulate filters etc) is accounted for. For atmospheric emissions by fuel type, refer to Table 17.

Table 11: Emissions for plywood, by stage

Pollutant	Silviculture & transport	PF manufac. & transport	PLY Manufacture	TOTAL (incl biofuel)	TOTAL (excl. biofuel)
	……………………g pollutant/t PLY…………………..				
CO_2	26,750	29,533	428,363	**484,645**	**201,705**
CH_4	6	1	184	**191**	**132**
NOx	266	38	1,766	**2,070**	**690**
CO	204	9	273	**486**	**86**
SO_2	43	26	307	**376**	**213**
VOCs	5	47	488	**541**	**431**

5.7 Discharges to land

HOGFUEL

The major solid wastes from plywood manufacture all result from the burning of hogfuel at the mill. These hogfuel-related wastes are:

- unused hogfuel which has not been processed on site
- ash from the burning of hogfuel
- particulates (primarily fly-ash and unburned carbon).

It is estimated that the hogfuel utilisation for plywood processing is around 76% or 0.25 kg of the 0.33 kg of hogfuel produced per kg of plywood. Thus, the net solid waste per kg of finished ply is 0.33 – 0.25 = 0.08 kg.

ASH

It is estimated that 1.1% by weight of all wood waste burned becomes boiler ash (Anderson and Tillman, 1977). Thus, the burning of 0.19 kg of hogfuel produces 0.002 g ash. Although ash can be used as a soil fertiliser, mention was only made of it being landfill in the survey. This is more expensive and less environmentally beneficial than using it as a soil conditioner.

PARTICULATES

There are numerous systems currently available to effectively remove particulates from stack gases. From the plywood survey responses it cannot be established whether particulate filters and control systems are commonly used. Thus, a figure of 0.7076 g/MJ (Forintek, 1993) was applied. The final destination of these particulates is, if they are filtered, most likely to be landfilled.

Summary of manufacture-related wastes

Per kg of finished product:

Gross input	= 1.75 kg
Net Input	= 1.33 kg (net of co-product contribution)

Net solid waste (g) per kg of finished product

Unused hogfuel	= 80 g
Ash	= 2g
Particulates	= 4 g
TOTAL	**86 g**

5.8 Future improvements

No specific plans to upgrade/modernise the 'typical' mill operations were mentioned in the questionnaire replies.

5.9 Plywood environmental inventory

Table 12 combines the results from the previous sections to obtain an environmental inventory for the production of one kg of New Zealand produced plywood. These figures include all the manufacturing stages (from cradle-to-factory gate) and all transportation (from raw material extraction to plants, as well as between plant transportation). This inventory should be seen as preliminary only, due to the heavy reliance on overseas figures for solid and liquid emissions.

Table 12: Resource inventory for 1 metric tonne of finished plywood

For 1 kg of plywood – INPUTS		
Material inputs	**Quantity**	**units**
Roundwood	1.75	kg
Phenol formaldehyde	20	g
Water	*not monitored*	litres
Hogfuel	0.33	kg
Fertiliser	0.24	g
Chemicals	0.05	g
Energy inputs	**Quantity**	**units**
For silviculture and transport	0.78	MJ/kg
For PF resin manu.	1.75	MJ/kg
Manu. (excl. biofuel)	8.10	MJ/kg
Manu. (incl. biofuel)	11.60	MJ/kg
TOTAL (excl.biofuel)	22.23	MJ/kg
TOTAL (incl.biofuel)	14.13	MJ/kg

For 1 kg of plywood – OUTPUTS		
Solid emissions	**Quantity**	**units**
Ash	2	g
Unused Hogfuel	80	g
Particulates	2	g
Air emissions	**Quantity**	**units**
CO	486	mg
CH_4	191	mg
CO_2 (excl. biofuel)	202	g
CO_2 (incl. biofuel)	485	g
NO_x	2070	mg
SO_2	376	mg
VOCs	541	mg
Water emissions	**Quantity**	**units**
Waste water	1	millilitres

5.10 International comparison

Key input and output parameters are examined only in this comparison. Note that for the Canadian figures, an underestimation in the air emissions is reported due to the electricity emission figures being excluded. Thus, only preliminary values are given.

In terms of atmospheric emissions:

The Canadian figures (Forintek, 1993) for CO_2 (at 587 g/kg including biofuel), CO (at 986 mg/kg) and VOC (at 549 mg/kg), are all higher than the comparable New Zealand figures. However, it is unknown if either of these figures are significantly higher, given the uncertainties inherent in LCI studies.

In terms of energy inputs:

The Canadian figures for both the manufacturing only stage (at 8.83 MJ/kg) and the production of the adhesive (at 1.56 MJ/kg) are both very similar to the New Zealand figures.

In terms of solid wastes produced:

The Canadian figures for unused hogfuel (at 60 g) are lower than the New Zealand figures. The ash and particulate emissions (at 5 g) are higher.

6. MEDIUM DENSITY FIBRE BOARD

6.1 Introduction

New Zealand has three dedicated MDF plants – Nelson Pine Industries, Canterbury Timber Products and Fletcher Wood panels. A fourth facility – Juken Nissho's Triboard plant at Kaitaia manufactures a smaller amount of MDF. Once again, a 'virtual' mill was built based on the questionnaire responses, with the most common operation being used when there were conflicting results. The same silviculture figures and assumptions were applied here also.

It should be noted that the raw material for MDF manufacture can have a variety of sources, including chipped waste from a plywood industry sawmill. Thus, plywood production may actually be viewed as a 'co-product' from another process, as the manufacturing process results in two or more economic products. For this study, the raw material for MDF board is all assumed to be from non-waste sources.

6.2 Raw material requirements

MDF board has a density of 700 kg/m^3.

1 OD tonne of roundwood (i.e. log with bark still on) yields:

0.94 ODT of MDF board[8]
0.06 ODT of bio-fuel (i.e. hogfuel, in the form of bark, sawdust etc)

The gross roundwood required per ODT of MDF board

= 1/0.94 = 1.1 ODT of roundwood.

The composition of 1 ODT of MDF board is:

91% timber
9% urea formaldehyde resin (which has a density of 1300 kg/m^3)
plus trace amounts of paraffin wax.

UF resin has an approximate ratio of 1:1. (Actual ratio is confidential to the manufacturer). The manufacture of the resin is outlined in Appendix D.

6.3 Manufacture

The manufacture of MDF from woodchip feedstock consists of seven processes:

1. **Chipping screening and washing.** Oversized chips are screened out. Chips are washed to remove contaminants. Chips are dewatered using a screw drainer.

2. **Steaming, digesting and refining.** Chips are steamed and then fed into a digester where they are softened and refined. Paraffin wax is added before the fibre is dried. A mixture of condensed urea-formaldehyde resin and water is injected into the mixture with the Urea Formaldehyde resin being added to the blow line.

3. **Fibre drying.** Drying relies upon a laminar mass flow with heat and moisture transfer between fibre and the surrounding air. A cyclone stack at the end of the drying line removes the hot moist air.

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[8] *Note that since most logs are mechanically harvested, they have less bark on them and therefore require less debarking.*

4. **Forming.** The fibre is fluidised by air to ensure even distribution and is ultimately formed on to a moving wire screen from which the transport air is removed by means of vacuum boxes located beneath the screen. A scalper then removes the top part of the mat.

5. **Pre-pressing**. The fibre mat now has a density of about 25 kg/m^3. Continuous presses reduce the mat's former thickness by two-thirds. The edges are trimmed.

6. **Pressing**. The fibre mat is further densified and heated to set the resin using a press. The pressures and time in the press are dependent on the thickness and density profile of the final product.

7. **Finishing.** The boards are cooled or conditioned. After two to three days, they are sanded to remove 0.5 to 1 mm of pre-cure, then graded, cut to size and packed for transport.

6.4 Energy use

ROUNDWOOD-RELATED

It is estimated by Forest Research (2002), that it takes 0.295 MJ/kg to plant, manage, harvest and transport 1 kg of timber (based on moisture content of 50%). Thus, when OD, this equates to 0.59 MJ/kg.

Gross roundwood delivered energy, net of co-product production becomes:

= 1.1 ODT x 0.59 MJ/kg
= 0.65 MJ/kg

MDF MANUFACTURING RELATED

Substantial process heat is required for steam energy in MDF manufacture. It was calculated that approximately 8% of the total manufacturing energy is required for heat processing (refer Table 13).

Table 13: Manufacturing stage percentage energy requirements for MDF

MDF manufacturing sub-processes	Mechanical	Heat
Debarking of logs	0.3	
Chip preparation	0.8	
Chip refining	30.5	
Formation of mat		49.2
Pressing	7.7	
Conditioning, trimming		3.8
Steam		7.8
TOTAL PERCENTAGE	**39**	**61**

The energy requirement for manufacturing is represented in Table 14. As can be seen, the final embodied energy content is dependent on the UF contribution which, although only making up 8% of the final OD weight, is responsible for over half (at 55%) of the embodied energy content.

Table 14: Embodied energy, by stage for MDF board

STAGE	MJ/kg	%
Silviculture + transportortation	0.31	3
UF resin contribution	6.26	55
Manufacturing Process	4.73	42
TOTAL	**11.30**	**100**

6.5 Water resource depletion

As for plywood, water is required for nursery irrigation as well as for the manufacturing process. Some water recycling is carried out. Waste water is primarily from chip washing and is treated post use, using various methods. Very little (if any) monitoring is conducted by industry. Total water use is estimated to be 0.64 litres per ODT MDF (for nursery irrigation) and 1.6 litres per OD kg MDF (for the manufacturing process only), giving a total water use **of 1.6 litres of water per OD tonne** of finished MDF.

6.6 Discharges to air

As for plywood, air pollutants are calculated directly from the fuel usage attributable to each stage of MDF board manufacture, up to the 'factory gate'. Where applied, emission reduction technology (e.g. environmental control in the form of fume hoods, particulate filters etc) is accounted for. For atmospheric emissions by fuel type, refer to Appendix C. Table 15 shows the various major atmospheric pollutants for the finished MDF board. As can be seen, the manufacturing stage at the mill is by far the most polluting.

Table 15: Emissions for MDF board, by stage

Pollutant	Silviculture & transport	UF manufact. & transport	MDF Manufacture	TOTAL (incl. biofuel)	TOTAL (excl. biofuel)
	………………….……….g pollutant/t MDF……….……..………….				
CO_2	21,400	1,118	339,245	**361,763**	**143,183**
CH_4	5	0	69	**74**	**30**
NOx	245	10	671	**926**	**260**
CO	188	5	66	**260**	**432**
SO_2	40	3	111	**154**	**66**
VOCs	5	3	147	**155**	**48**

6.7 Discharges to land

Waste from the scalper and mat lay-up trimmings is recycled back into the production line. Waste from sanding and post-sanding trimmings is used as bio-fuel. As for the previous section on plywood, the significant solid wastes from MDF-board production at the mill all result from the burning of hogfuel. These hogfuel-related wastes are:

- unused hogfuel which has not been processed on site
- ash from the burning of hogfuel
- particulates (primarily fly-ash and unburnt carbon).

HOGFUEL

Not all hogfuel is burnt, due to various inefficiencies. It is estimated that the hogfuel utilisation for MDF is around 76% or 0.05 kg of the 0.06 kg of hogfuel produced per kg of MDF. Thus, the net solid waste (g) per kg of finished MDF is 0.06 – 0.05 = 0.01 kg.

ASH

It is estimated that 1.1% by weight of all wood waste burned becomes boiler ash (Anderson and Tillman, 1977). Thus, the burning of 0.06 kg of hogfuel produces 0.001 g ash.

PARTICULATES

As for plywood, it appears from the survey responses that particulate filters and control systems are not commonly used in MDF manufacture, so the full amount – estimated to be 0.7076 g/MJ – is applied. It is unknown what the final destination of these particulates is, but most likely they are landfilled.

Summary of manufacture-related wastes

Net solid waste (g) per kg of finished product

Unused hogfuel	= 10 g
Ash	= 0.001g
Particulates	= 2 g
TOTAL	**12 g**

6.8 Future improvements

No specific plans to upgrade/modernise MDF plant operations were mentioned in the questionnaires.

6.9 MDF environmental inventory

Table 16 combines the results from the previous sections to obtain an environmental inventory for the production of one kg of New Zealand-produced medium density fibre board. These figures include all the manufacturing stages (from cradle-to-factory gate) and all transportation (from raw material extraction to plants, as well as between plant transportation). This inventory should be seen as preliminary only, due to the heavy reliance on overseas data for the solid and liquid emissions.

Table 16: Resource inventory for 1 kg of medium density fibre (MDF) board

For 1 kg of MDF board		
INPUTS		
Material inputs	**Quantity**	**units**
Roundwood	1.1	kg
Urea formaldehyde	90	g
Water	1.6	litres
Hogfuel	0.07	kg
Fertiliser	0.20	g
Chemicals	0.04	g
Energy inputs	**Quantity**	**units**
For silviculture and transport	0.31	MJ/kg
For UF resin manu.	6.26	MJ/kg
Manu. (excl. biofuel)	4.73	MJ/kg
Manu. (incl. biofuel)	6.34	MJ/kg
TOTAL (excl.biofuel)	11.3	MJ/kg
TOTAL (incl.biofuel)	12.9	MJ/kg

For 1 kg of MDF board		
OUTPUTS		
Solid emissions	**Quantity**	**units**
Ash	1	mg
Unused hogfuel	10	g
Particulates	2	g
Air emissions	**Quantity**	**units**
CO	260	mg
CH_4	74	mg
CO_2 (excl. biofuel)	362	g
CO_2 (incl. biofuel)	626	g
NO_x	926	mg
SO_2	154	mg
VOCs	155	mg
Water emissions	**Quantity**	**units**
Waste water	1.6	litres

6.10 International comparison

No comparative figures could be sourced for this board type.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The following conclusions can be drawn; regarding the cradle-to-gate assessment of three New Zealand produced wood-fibre based composite boards:

For fibre cement board:

The figures derived for the New Zealand-used (if not produced) fcb is a 'best guess' only, since many assumptions were necessary as very little information could gained on the:

- basic product composition (or mix design)
- contributing 'raw material' suppliers – especially the 'pulp' manufacture
- actual fcb manufacturing process.

The difficulty gaining information is reflective of the competitive nature of the industry. The bulk of the inventory information was sourced from James Hardie Australia operations, who independently undertook an extensive LCI study (in 1999) of its own. Assuming that James Hardie Australia operations are reflective of those carried out by its New Zealand operations, the following conclusions can be drawn:

- The largest contributors to the total embodied energy are: cement (at 19.3 MJ/m^2 of fcb), pulp (at 14.9 MJ/m^2) and electrical energy required for fcb manufacturing process (at 8.0 MJ/m^2 of fcb). The overall (total) embodied energy is 50.5 MJ/m^2 (or 5.28 MJ/kg) of finished fcb sheet.
- In terms of air pollutants, the manufacture of cement was responsible for the bulk of the total CO_2 (at 542 kg/t of fcb) and particulate emissions (at 0.72 kg/t fcb). The next largest emission to air was NO_x at 2.31 kg/t of fcb.
- In terms of waste materials, the main contributors were in the manufacture of the 'raw material inputs' (at 414 kg/tonne of fcb) and '(non)autoclave dry scrap', which includes reject sheets, interleaves etc (at 76 kg/tonne of fcb).

For plywood:

A good response (in terms of survey response numbers) from the plywood manufacturers mean that the figures gained for New Zealand operations can viewed with some degree of certainty. The following conclusions can be drawn for New Zealand-produced ply:

- The largest contributors to the total embodied energy are: timber drying (at 65% of the manufacturing energy), of which 53% was made up from biofuel contributions. The overall (total) embodied energy is 10.63 MJ/kg of finished plywood sheet.
- In terms of air pollutants, the manufacturing process was responsible for the bulk of the total CO_2 emissions (at 485 g/kg of plywood). The next largest emission to air was CO at 2.1 mg/kg of plywood.
- In terms of solid waste materials, all the contributors were generated as a result of the burning of biofuels. The main solid waste was unused hogfuel, from burning inefficiencies (at 80g/kg plywood followed by ash and particulates (both at 2 g/kg plywood).

For MDF board:

Few MDF manufacturers responded to the BRANZ LCI questionnaire which means that the figures gained for New Zealand operations must be viewed with some uncertainty.

- The largest contributor to the total embodied energy is the formation of the mat which accounts for nearly 50% of the manufacturing stage process; followed by the chip refining stage, at approximately 30% of the manufacturing process. The overall (total) embodied energy is 11.3 MJ/kg of finished mdf board.

- In terms of air pollutants, the manufacturing process was responsible for the bulk of the total CO_2 emissions (at 339 g/kg of plywood). The next largest emission to air was NO_x at 926 mg/kg of plywood.

- In terms of solid waste materials, all the contributors were generated as a result of the burning of biofuels. The main solid waste was unused hogfuel, from burning inefficiencies (at 10g/kg plywood) followed by particulates (at 2 g/kg of mdf) and ash (at 1 mg/kg mdf).

An environmental inventory table for all the major inputs and outputs related to the production of one tonne of mdf is summarised in Table 16.

General

A limited comparative study was conducted on two board types, for which similar resource information was available. The two board types were fibre cement and plywood. It was found that for

- **fibre cement board**, there was a close correlation between the (independently sourced) New Zealand resource-related input/output figures, and those sourced from a recent (1999) Australian-specific industry study
- **plywood**, there was a close correlation between the New Zealand figures and those sourced from a Canadian study performed in 1993, for the major resource-related inputs/outputs.

7.2 Recommendations

There are a few issues that need resolving before the LCI data set obtained here can be further developed into impact assessment models which can be applied to the building industry. These include:

- A definitive answer on how carbon sequestering is dealt with in timber products, i.e. for both bio-fuels as well as the carbon stored in longer lasting timber. New Zealand working groups addressing climate change are currently addressing this, and will have to be watched closely if life-cycle assessment and its associated applications are to gain wider acceptance.
- Likewise, a definitive answer is needed on how biofuels emissions (produced during their incineration) are to be accounted for. This is especially important for the timber industry, given the large percentage of biofuels used as part of its normal operations.

A suggested best medium-term move is to follow the Australian lead in this area, which would sit well with New Zealand and Australia’s Standard integration.

A further, more detailed process examination of New Zealand’s plant operations, in terms of solid waste (generation, use and disposal), water (use and disposal) and energy flows is necessary. At present, overseas results have been taken as being representative for operations carried out in New Zealand. In reality; this may not be the case.

The current BRANZ approach to industry information collection needs serious re-examination. Presently, it is likely that industry sees itself as having very little to gain for resource reporting of its mill operations to outside bodies, such as BRANZ. In addition, it seems that often industry does not have basic resource-use type of information on hand and does not carry out periodic monitoring and/or benchmarking as a regular practice. Although this may change with the onset of Kyoto obligations (or other forms of environmental reporting which would require only a small change to the Financial Reporting Act), win-win situations between BRANZ and industry are needed now. A solution would be to approach industry with the objective of providing it with the information it needs (post resource data collection). That is, providing it with benchmarking information (in the form of tailored auditing material etc), assisting in its own periodic resource tracking. It is likely that there is a lot of scope for process improvement and efficiencies. An auditing tool would be a useful prompt if it could highlight these process inefficiencies.

Generally, the three industry-specific resource-use forms (i.e. survey questionnaires) provided to the mills and plants were suitable for the application. However, the plywood questionnaire requires fine-tuning as it caused some confusion, most notably within the energy section.

A sensitivity analysis also needs to be conducted on plywood and MDF sheeting, due to the uncertainty and variability of the resins contained within them which have disproportionately high energy and atmospheric emission concentrations associated with them. For example, although UF resin only accounts for 9% of the total MDF board weight, it contributes to 55% of the total embodied energy of the board. It has been argued that the need for estimating this uncertainty is best addressed through the development of a fully stochastic modelling framework (Shipworth, 2002). This type of framework will be methodologically more appropriate for environmental reporting, for applications such as that required as part of Kyoto Protocol compliance. In addition, a sensitivity analysis of the implications of changing the sources of MDF raw material needs to be made. For example, what is the effect of using waste material from the plywood and saw mill industries for MDF manufacture?

Appendix A: Typical survey request form

<Date>

<Address>

Dear ___________

RE: Survey of composite board resource use

As discussed on the phone, Forest Research and the Building Research Association of New Zealand (an independent body representing the construction industry) are examining the resource use of common construction materials. The objective of this resource study is to gain estimates for all the inputs (e.g. raw material requirements, energy use, demand for water) and the outputs (e.g. solid and liquid wastes) for five composite sheet materials, namely: *Particle-board*, *Hardboard, Soft Board, Plywood*, and *Fibre Cement Sheets.*

The accumulated, **averaged** data from this study on composite boards will be used in conjunction with building design data, maintenance, durability information and economic considerations to get a better picture of a building material's overall resource use. Already, BRANZ has carried out studies on (treated and untreated) sawn lumber, structural and non-structural concrete and steel.

We would be grateful if you could fill in the following survey, for your MDF board production. Although it looks long, if you have already carried out an energy audit on your operations nearly all the information will be readily available. You are one of several similar manufacturers we are asking to complete the survey. All inventory data should be as representative as possible of the latest manufacturing techniques, with industry averages being used. The final data will be normalised by unit of output (using a unit factor of $1m^2$ area, and weighted by industry output).

We recognise that there may be sensitive resource-use information, therefore all data will be amalgamated to protect confidentialities (i.e. final resource figures will be industry-weighted averages).

If you have any questions on this survey, you can contact me at Forest Research on ph (07)3435657 or email me per.nielsen@forestresearch.co.nz. If you feel that it would be quicker to go through the questions by phone, please ring me.

We would be grateful if you could complete the survey form overleaf by February 16th, 2002.

Thank you for your participation.

Per Nielsen, PhD
Senior Energy Engineer

Appendix B: Typical questionnaire

WOOD PROCESSING SECTOR
PLYWOOD RESOURCE USE STUDY
January 2002

CONFIDENTIAL SURVEY QUESTIONNAIRE

Section 1: *General Information*

1.1 Please provide the following information on your wood processing operation or attach a business card.

Company name	
Street address	
Postal address	
Specific mill or plant name	
Contact person	
Position within company	
Phone No.	
Fax No.	
E-mail address (if applicable)	

Section 2: ***Summary of Energy Use and Wood Material Flow***

If you have information on total energy use and wood material flow for your plywood processing facility, please complete the following tables.

2.1. What is the annual total fuel/energy use at your plywood processing operation? Include only energy/fuel used directly for plywood processing activities. Exclude all transport fuel. Please complete the following table.

Fuel/energy type	**Quantity used per year**	**Units (eg kWh, m^3, or tonnes)**	**Please indicate the purpose for which the energy/fuel is used (eg sawing, drying)**
Biomass (eg wood waste)			
Electricity			
Oil/diesel			
Coal			
Natural Gas			
LPG			
Petrol			
Geothermal			
Other (please specify)			

2.2 How much liquid fuel is used for transporting plywood-related material on site?

Fuel type	**Quantity used per year**	**Units (litres, m^3)**
Oil/diesel		
LPG and CNG		
Petrol		
Other (please specify)		

2.3 What is the plywood-related fibre flow at your mill?

Bark/roundup (for energy)……………………………green tonnes per year

(for other uses) ….……………………green tonnes per year

Log input…………………………………………………m^3 or tonnes per year

Saw dust (for energy)……………………………green tonnes per year

Other wastes (for energy)……………………………green tonnes per year

(for other uses) ….…………………….…green tonnes per year

Section 3: *Energy Audits*

3.1. Does your company undertake energy audits? Yes ☐ No ☐

3.2. Are the energy audits undertaken for the entire mill? Yes☐ No ☐

3.3. Are the energy audits undertaken for selected departments? Yes☐ No ☐

3.4. If you answered yes to selected departments, which departments were included in these audits over the last 5 years?

Section 4: *Plywood Preparation*

4.1. Debarking

4.1.1. Have logs been through a mechanical debarker prior to being delivered to your wood processing site? Yes ☐ No ☐

Please indicate the approximate percentage of logs that arrive debarked ☐%

4.1.2. If logs are debarked prior to arriving at your mill, where are they debarked?

Please specify...

If all logs arrive at your mill already debarked (i.e. 100%) then go to Section 4.2. If only some of the logs arriving at your mill are already debarked (i.e. less than 100%) then go to Section 4.1.3.

4.1.3 How is bark removed from logs processed at your mill?

Please tick the appropriate box(es)

Hydraulic debarker ☐
Dry drum debarker ☐
Wet drum debarker ☐
Ring debarker ☐
Rotating cutting head (rosser head) ☐

Other (please specify) ....

4.1.4 What is the total volume of logs debarked per year?

.....................tonnes (or m^3)/year (over bark/under bark)
Delete one

©

4.1.5 How much energy is used to de-bark logs? Please complete the following table. If you don't have the figures available, please specify debarker power output and hours operated per month/year.

Energy type	Estimated total energy consumption per year	Units
Electricity		eg KWh
Other (please specify)		

4.1.6. Is the water use monitored for the debarking operation at your mill? If so, please state the amount used per year (or month).

……………………….. (litres/m^3 per month/year)
please delete as necessary

4.1.7 What is percentage of logs coming to your mill that needs to be debarked?

_____________ %

4.2 Log pre-heating

4.2.1 Do you pre-heat your logs?

4.2.2 How? (please specify) ____________________________

4.2.3 How much energy is used to pre-heat the logs?

Please complete the following table.

Energy type	Estimated total energy consumption per year	Units
Electricity		eg KWh
Other (please specify)		

4. 3 Log peeling

4.3.1 What method is used for peeling your logs?

- Large rotary lathe ………………
- Other ……………………………

4.3.2 How much energy is used to peel the logs?

Please complete the following table.

Energy type	**Estimated total energy consumption per year**	**Units**
Electricity		eg KWh
Other (please specify)		

Section 5: *Output and Composition of Plywood*

5.1 Specify the annual output

Annual Production of Plywood .... m^3/year

5.2 Please specify the typical (untreated) PLYWOOD composition and its source (as in its location). Also, please specify what the main mode of transport (eg rail, truck etc) was used to get the raw materials to the plywood mill.

TYPICAL MATERIAL COMPOSITION, SOURCE AND TRANSPORT MODE
(for interior-use/untreated plywood)

Component	Percentage of dried weight	Component source (Town)	Main transport mode (Rail, truck, ship)
Radiata Pine veneers			
Phenol- formaldehyde			
Other (specify)			
Other (specify)	TOTAL = 100%		

Section 6: *Untreated Plywood specifics*

6.1 How much energy is used for drying the peeled timber? Please indicate the types and quantity of fuel used for this purpose.

Energy type	Estimated total energy consumption per year	Units
Electricity		eg total KWh or KWh per unit of production
Thermal (Steam or oil)		eg total tonnes or tonnes per unit of production
Natural gas		E.g. MJ or litres per unit of production
Other (please specify)		

6.2 How much energy is used during the clipping/cutting to pre-determined sizes?

Energy type	Estimated total energy consumption per year	Units
Electricity		eg total KWh or KWh per unit of production
Other (please specify)		

6.3. How much energy is used during hot pressing? Please complete the following table.

Energy type	Estimated total energy consumption per year	Units
Electricity		eg total KWh or KWh per unit of production
Thermal (Steam or oil)		eg total tonnes or tonnes per unit of production
Natural gas		E.g. MJ or litres per unit of production
Other (please specify)		

6.4 How much energy is used in the cooling, trimming and panel finishing? Please complete the following table.

Energy type	Estimated total energy consumption per year	Units
Electricity		eg total KWh or KWh per unit of production
Natural gas		E.g. MJ or litres per unit of production
Other (please specify)		

BIOENERGY PRODUCTION

Section 7: *Fuel for Plywood Energy Production*

7.1. What types of wood waste fuel are burned on your site to produce energy? If you don't use any wood waste fuel, please check this box ☐ and go on to Section 9.

Otherwise, please mark the appropriate box(es) and indicate the percentage of each of the three largest fuel types.

	Estimate of quantity of fuel used (%)			
Sawdust	green	☐	dried	☐
Wood chips	green	☐		
Shavings	green	☐	dried	☐
Log off-cuts and trim	green	☐		
Bark		☐		
Peelings		☐		
Chipper rejects		☐		
Sander dust	green	☐	dried	☐
Product trim (lumber; hard, chip, particle or fibre board)		☐		
Yard scrapings		☐		

7.2. What tree species are included in the wood waste mix?

Please specify---

7.3 Please indicate where the wood waste fuel is sourced from? Indicate the percentage used from each source.

	%
On-site wood processing	☐
Purchased from an external source	☐

7.4. What is the typical fuel feed rate to your combustion plant(s)?

Boiler No 1. ---------------- tonnes (wet or dry)/hour

Boiler No 2. -----------------tonnes (wet or dry)/hour

Boiler No 3 -----------------tonnes (wet or dry)/hour

7.5 What is the annual wood fuel usage (all plants combined)

-----------------tonnes/annum

7.6 What is the installed capacity of the boilers?

--------------------------------Megawatts

Include all boiler installations on the site. ©

7.7 Do you monitor the quality of the fuel? *Please tick appropriate box.*

Yes ☐ No ☐

7.8 If so please list the parameters.

List parameters monitored……………………………………………………………………..

Section 8: *Plywood Fuel Preparation*

8.1. Is the fuel prepared in any way prior to being used in the combustion plant?

Hogged Yes ☐ No ☐

What method is used to hog fuel? ....

Screened Yes ☐ No ☐

What method is used to screen fuel? ....

Blended Yes ☐ No ☐

What method is used to blend fuels? ....

Dried Yes ☐ No ☐

What method is used to dry fuel? Include only those methods used outside the furnace.

....

Other Yes ☐ No ☐

Please list any other fuel preparation used at your site. ....

Section 9: *Furnace and Boiler System*

9.1 What is the heat transfer medium for the boilers?

Please tick the appropriate box(s).

Steam ☐
Oil ☐
Water ☐
Direct heating ☐

Other...(Please specify).

Section 10: *Energy Use*

10.1 What are the other uses for energy on-site? Please specify.

Other energy end-use ....

Other energy end-use ....

Section 11: *Environmental Controls*

Environmental controls are divided into the three following sub-sections –
11.1 The Drying Process, 11.2 The Plant Processes, and 11.3 The Hot Press Process.

11.1 The drying process

What type of air emission control system(s) is (are) used on your wood waste furnace?

Please tick the appropriate box(es).

- None ☐
- Cyclone ☐
- Wet scrubber ☐
- Bag filter ☐
- Precipitator ☐

Other (Please specify): ....

11.1.1 What parameters are specified in the resource consent which must be monitored?

Please tick the appropriate box(s).

- Particulates ☐
- Oxides of nitrogen ☐
- Sulphur dioxide ☐
- Water use ☐
- Formaldehyde ☐
- Heavy metals ☐
- VOC's ☐
- CO ☐
- Other (s) specify………………………….. ☐
- Other (s) specify…………………………. ☐

©

Please specify what your average emission concentrations were for each of the ticked parameters above, over most recently monitored period for the **drying** process. Alternatively, please supply estimations of recent emission data.

Monitored Parameter	**Concentration Levels** (Please specify units)
Particulates	
Oxides of Nitrogen	
Sulphur Dioxide	
Water Use	
Formaldehyde	
Heavy Metals	
VOC's	
Carbon Monoxide	
Other(s) please specify	
Other(s) please specify	

11.2 Environmental controls for the plant processes

What type of air emission control system(s) is (are) used on your wood waste furnace?

Please tick the appropriate box(es).

None ☐
Cyclone ☐
Wet scrubber ☐
Bag filter ☐
Precipitator ☐

Other (Please specify): ....

11.2.1 What parameters are specified in the resource consent which must be monitored?

Particulates	☐	Heavy metals	☐
Oxides of nitrogen	☐	VOC's	☐
Sulphur dioxide	☐	CO	☐
Water use	☐	Other (s) specify…………………..	☐
Formaldehyde	☐	Other (s) specify ………………….	☐

11.2.2 Please specify what your average emission concentrations were for each of the ticked parameters above, over most recently monitored period for the **plant** process. Alternatively, please supply estimations of recent emission data.

Monitored Parameter	**Concentration Levels** (Please specify units)
Particulates	
Oxides of Nitrogen	
Sulphur Dioxide	
Water Use	
Formaldehyde	
Heavy Metals	
VOC's	
Carbon Monoxide	
Other(s) please specify	
Other(s) please specify	

11.2.3. What is the total amount of ash produced per year (bottom and fly ash combined)?

Please specify in tonnes or cubic metres:______________________________ tonnes (m^3)/year
(if estimated, please state)

11.2.4 What is the proportion of bottom and fly ash disposed of?
(Please indicate the percentage of each type of ash disposed).

%

Bottom ash ☐
Fly ash ☐

11.2.5. How is ash disposed of?

Landfilled ☐
Land applied ☐

Other (Please specify) ....

11.2.6 If the ash is wetted, what happens to any liquid waste?

Please specify ....

11.3 Environmental Controls for the Hot Press

11.3.1. What type of air emission control system(s) is (are) used on your wood waste furnace?

Please tick the appropriate box(es).

None ☐
Cyclone ☐
Wet scrubber ☐
Bag filter ☐
Precipitator ☐

Other (Please specify): ....

11.3.2. What parameters are specified in the resource consent which must be monitored?

Please tick the appropriate box(s)

Particulates ☐
Oxides of nitrogen ☐
Sulphur dioxide ☐
Water use ☐
Formaldehyde ☐
Heavy metals ☐
VOC's ☐
CO ☐
Other (s) specify…………………………….. ☐
Other (s) specify….. ………………………… ☐

11.3.3 Please specify what your average emission concentrations were for each of the ticked parameters above, over most recently monitored period for the **hot press** process. Alternatively, please supply estimations of recent emission data.

Monitored Parameter	**Concentration Levels** (Please specify units)
Particulates	
Oxides of Nitrogen	
Sulphur Dioxide	
Water Use	
Formaldehyde	
Heavy Metals	
VOC's	
Carbon Monoxide	
Other(s) please specify	
Other(s) please specify	

Section 12: *Water Use*

12.1 Is the water use monitored for the **log conditioning** operation at your mill? If so, please state the amount used per year (or month).

………………………..(litres/m^3 per month/year)
please delete as necessary

12.2 Is the water use monitored for the **addition of resin** operation at your mill? If so, please state the amount used per year (or month).

………………………..(litres/m^3 per month/year)
please delete as necessary

12.3 Is the water evaporated during the **drying** operation (prior to clipping) at your mill monitored? If so, please state the amount extracted per year (or month).

………………………..(litres/m^3 per month/year)
please delete as necessary

12.5 Is water used for other operations related to PLYWOOD production that has not already been taken into consideration? If so, please state the use and its quantity.

………………………..(litres/m3 per month/year)
please delete as necessary

12.6 What happens to the water after its initial use? (i.e. is it recycled or treated in any way and how is it disposed of?).

Section 13: *Material Wastes*

13.1 Please specify, in percentages, the final destination of the following material wastes in the milling operations (or state whether recycled in-house, used as a fuel or disposed elsewhere i.e. 'other')

	Recycled	Fuel	Other	
Waste from debarking /roundup	☐	☐	☐	(%)
Sawing waste, prior to peeling	☐	☐	☐	(%)
Waste from clipping	☐	☐	☐	(%)
Waste from sanding and trimming	☐	☐	☐	(%)
Other wastes (specify)____________________	☐	☐	☐	(%)

Section 14. *Mill Modernisation and Upgrading*

14.1 Do you intend to upgrade or modernise your mill in the next 5 years? Please provide details below if they significantly impact on resource use.

Process	**Estimated date of upgrade**	**Reason(s) for upgrade (e.g. replacement or expansion)**

Section 15: *Process Description*

Please comment on whether you feel this is an accurate summary of your process operations:

The manufacture of plywood from Pinus Radiata veneer bonded with resin adhesive consists of six processes:

1. **Timber selection:** Straight and mostly defect-free Pinus Radiata timber is selected and transported to the mill. Logs undergo conditioning in hot water or steam to improve the quality of the peeled veneer and to decrease the energy demand.

2. **Peeling:** logs are debarked and then sawn to pre-determined lengths – usually about 100mm longer than the size of veneer to be produced. The log is then peeled using a large rotary lathe that produces a continuous ribbon of veneer of a consistent thickness (from 1mm – 4mm).

3. **Drying and clipping:** The wet veneer is fed through a continuous drier, which the veneer emerges from at a specific moisture content (between 4-8%). As the veneer issues from the drier it either gets cut (or clipped) to a specific press size or (if not so defect-free) cut into smaller strips that are freer from defects. The strips are then rejoined.

4. **Grading:** The dried and clipped veneer is sorted into face or core veneers. Veneers with surface defects may be repaired.

5. **Jointing and bonding**: The narrower widths of dried veneer may be edge jointed by gluing, taping or stitching to form standard pile sizes. If log-grain jointing is required, scarf joints are used. The veneers are then sorted, ready for gluing. Assemblies of veneer are made using veneers laid up alternatively, with their grains mutually perpendicular, making a sandwich.

6. **Pressing and finishing**: The veneer lay-ups are then assembled in packs and are pressed together in carefully monitored cold and hot presses. After unloading, the boards are cooled, trimmed and sanded. The boards are then inspected (where a grading check is performed) and packed, ready for shipment.

Comments

If you have any additional comments regarding the use of energy, biomass, or water at your mill, please add them here.

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Thank you for completing the questionnaire.

For further information please contact:
Per Nielsen
Forest Research
P.O. Box 3020
Rotorua
Ph. 07 343 5657
Fax. 07 343 5332
Email: per.nielsen@forestresearch.co.nz

Appendix C: Fuel-related emission factors / energy intensities

TRANSPORTATION FUELS:

Table 17: Fuel related energy emission factors (after EMR, 1990)

FUEL TYPE	CO_2	VOCs	CH_4	NO_x	CO	SO_2
	kg / GJ	*kg / TJ*	*kg / TJ*	*kg / TJ*	*kg / TJ*	*kg / TJ*
Petroleum	68	434	43	321	3805	11.7
Diesel (road)	70.7	86.9	21.7	807	443	0
Diesel (rail)	70.7	70	7.8	1400	443	0
Diesel (marine)	70.7	390	45	240	180	0
Heavy Fuel Oil (Marine)	74	360	40	200	7.4	450

PROCESS FUELS:

Table 18: Biofuel (wood waste) related energy emission factors

(after Dang, 1997 for all but biofuel figures which were sourced from Forintek, 1993).

FUEL TYPE	CO_2	VOCs	CH_4	NO_x	CO	SO_2
	kg / GJ	*kg / TJ*	*kg / TJ*	*kg / TJ*	*kg / TJ*	*kg / TJ*
Biofuel	0.815	39	8	110	11	0.2
Electricity	0.035	1	23	120	15	37
Natural Gas	0.053	5	1	250	18	0

TRANSPORTATION ENERGY INTENSITIES:

Table 19: Energy requirements by mode of transport (Forintek, 1993)

Mode	Fuel	Energy Consumed (MJ/tonne - km)
Truck	Diesel - Road	1.18
Rail	Diesel - Rail	0.49
Ship	HFO - Marine	0.12
Conveyor Belt	Electricity	0.13

Appendix D: Resin-related energy and emission estimates

Only a brief overview of the emissions resulting from the processing of the two resins is given due to the confidential nature of its manufacture. The data below was obtained from two primary sources: Forintek (1993) and Dynea (Anthony, 2002). The transportation components include transport of raw ingredients to the resin manufacturing plants as well as that to the composite board mill.

Urea Formaldehyde

Urea formaldehyde is a resin that is formed of molecules that cross link into clear, hard plastics. It is manufactured in New Zealand by four plants (Anthony, 2002). The average transportation distance and mode (assuming that each produced the same quantity) is 310km by road, and 600 by sea.

Table 20: Summary of all atmospheric emissions for the manufacture 1 tonne of UF

	CO_2	VOC	CH_4	NO_x	CO	SO_2
STAGE/UNITS	kg poll. /t	………………..g pollutant/tonne of PF………...				
Manufacturing - energy	0.062	0	0	0	3	0
Manufacturing - process	0.032	5	0	0	1	0
Transportation	12.323	28	5	110	56	34
TOTAL	**12**	**33**	**5**	**110**	**60**	**34**

Phenol Formaldehyde

Phenol formaldehyde is a resin that is formed of molecules that cross link into clear, hard plastics. It is manufactured in New Zealand by four plants, with the phenol component sourced from Melbourne, Australia. The average transportation distance and mode (assuming that each produced the same quantity) is 310km by road, and 1400km by sea.

Table 21: Summary of all atmospheric emissions for the manufacture of 1 tonne of PF

	CO_2	VOC	CH_4	NO_x	CO	SO_2
STAGE/UNITS	kg poll. /t	……………..g pollutant/tonne of PF…….………..				
Manufacturing - energy	1,445	35	31	1,822	461	1,105
Manufacturing - process	0	2,178	0	0	0	0
Transportation	32	154	17	85	3	192
TOTAL	**1,477**	**2,367**	**48**	**1,907**	**464**	**1,297**

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