TECHNICAL GUIDE **9.0**

Good Practice Guide
Production of wood fuel from forest landings

Wood fuel is a clean and renewable energy source. Burning wood fuel has a low net greenhouse effect as the CO_2 given off is absorbed by the growth of the next crop. Wood fuel is playing an increasingly important role in generating energy.

Wood fuel includes any woody biomass suitable for energy production, such as branches, bark and stem wood. The focus of these guidelines is on residues from landings – currently the largest unused source of woody biomass.

Aimed at experienced forestry contractors, this guide outlines proven methods for extracting wood fuel from forest landings.

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1. Introduction to wood fuel opportunities

Wood fuel is a clean and renewable energy source. Burning wood fuel has a low net greenhouse effect as the carbon dioxide given off is absorbed by the growth of the next crop. As fossil fuels become increasingly expensive, wood fuel is playing an important role in generating energy.

This guide provides good practice guidelines for the production of wood fuel from forest landings. Aimed at experienced forestry contractors, it outlines proven methods for effectively extracting wood fuel from landings.

Figure 1: A loader on a landing putting logs onto a truck.

Figure 2: A skidder pulling stems to the landing.

Figure 3: A pile of residues pushed to the edge of the landing.

Wood fuel includes any woody biomass suitable for energy production, such as branches, bark and stem wood. The focus of these guidelines is on residues from landings, as this is currently the largest unused source of woody biomass.

In our plantation forests, trees are grown to maximise the volume of high quality wood, such as veneer and structural logs (Figure 1). Lower quality wood may be used for pulping or fibre board. Wood 'residue' is what remains after those log products are produced. Depending on the harvesting system, a portion of these residues will be left on the cutover, but a considerable volume is often extracted to a landing (Figure 2).

About 20 million cubic metres (m^3) of wood is harvested in New Zealand each year. Wood residues created at forest landings during logging range from 1-17% of that total volume.

How these residues are managed depends on the volume and type of wood fuel and the specifics of the landing site and its operational constraints. Residues may be simply pushed into a pile on the edge of the landing (Figure 3), or they may be extracted and processed for use as wood fuel.

It is estimated that more than one million m^3 of wood residues are produced on forest landings annually. As the forest estate matures, that volume will increase over the next 10 to 15 years. About 25% (250,000 tonnes) of easily-accessed residues was used in 2009, leaving at least 750,000m^3 per annum still available for use as wood fuel.

Wood fuel can take on many forms for domestic, commercial and industrial purposes. Firewood is a well recognised wood fuel. Hog fuel has long been used for large industrial boilers. New markets are developing for chips that can be used in higher efficiency boilers. Residues can also be ground up and pressed into pellets for residential heating.

In many European countries the wood fuel market is well developed, with forest owners and contractors geared to meet the rising demand (Figure 4). However, much of this demand is based on government subsidies for renewable energy. Contractors in New Zealand need to understand the conditions under which they can be as successful.

This good practice guide provides some guidelines for wood fuel suppliers and contractors who are interested in buying woody biomass from forest growers and processing it into wood fuel. It also provides information to forest owners or managers regarding integrating wood fuel production with current harvesting from forest landings.

Topics covered include:

- hot water heaters
- the market for the fuel and options for end products
- managing wood fuel quality
- production of wood fuel and harvesting systems
- transport issues (Figure 5)
- the supply chain
- system productivity, costs and revenues.

Figure 4: A large scale European wood chipping operation working with a stack of dried logs.

Figure 5: Hog fuel being loaded into a bin-truck. Trucking can be the most expensive part of a wood fuel operation.

2. Woody biomass supply from forest landings

2.1 Introduction

Woody biomass is available from three common sources:

- forest residues: branches, tops of trees and other stem wood from harvested trees and unmerchantable trees
- wood processing residues: bark, sawdust, shavings and off-cuts from processed wood such as panel board, construction timber and furniture
- woody crop plantations: short rotation forest crops grown specifically for energy purposes.

This guide deals with the first source only – wood fuel arising from forest harvesting. It is this woody biomass which can be collected and made into a wood fuel through comminution (reduction in size through chipping, grinding or shredding).

Woody biomass from landings consists of branches, tops of trees and other stem wood from both harvested trees and trees considered unmerchantable for conventional log making. It is highly variable in size and composition (Figure 6).

These mixtures are driven by the harvesting and log making system, and the form of the tree crop (Figure 7).

Figure 6: Wood fuel on a landing – mostly tree tops and branches.

Figure 7: Log-makers measuring and cutting up stems at the landing.

Mechanised felling systems will often de-limb and top the tree at the stump and little residue will be extracted to the landing. Conversely, when felling by chainsaw on steeper terrain, it is dangerous to de-limb and top trees so in this harvesting system a large amount of residue will be extracted to the landing. Harvesting contractors will often leave most of the residue at the stump as they are only paid for the merchantable wood they produce.

The following table provides a quick guide as to the volume of residue you may expect, relative to the total volume of timber harvested. These figures refer to wood fuels from radiata pine harvest (about 90% of New Zealand's plantation forest resource).

Table 1: Type of harvest and influence on quantity of residue available

	Stem	Branch
Ground-based (mechanised felling)	4-6%	up to 1%
Yarder-based (manual felling)	5-8%	1-4%

Both the competence of the log-makers and the type of log-making influences the outcome:

- good log-making » less residue
- poor log-making » more residue
- manual processing » less residue
- mechanised log-making » more residue.

Volumes from other crops will differ notably, for example Douglas fir generally has very low volumes of branches at landings, due to the brittle branches being snapped off during felling and extraction. Eucalyptus harvest, in comparison, has a high proportion of branch content due to their large-diameter, resilient branches.

A useful tool that can help calculate the expected volume of landing residue from a harvest can be found on the bioenergy website at www.bkc.co.nz

2.2 Stem wood piece size

A key consideration in targeting material to collect and process is the size of the pieces. There is a large variation in the individual sizes of landing residue pieces, ranging from slovens typically less than 0.6m length to large-diameter off-cuts of 2-3 metres length to short small-diameter tops (Figure 8).

Figure 8: Stem wood at a large landing, interspersed with plenty of fines (especially bark) is typical of a secondary processing yard.

From a database of 4,385 individual stem wood sections from typical harvesting operations, it was found that;

- more than a third of the volume (36%) was in the largest 10% of pieces
- two-thirds (66%) was in the largest 25% of pieces; and
- 80% was in the largest 40% of pieces.

The vast majority consisted of pieces of less than 0.10m^3.

However, this distribution can vary greatly depending on the type of harvest and processing operation. Within the limitations of the machinery, larger volume pieces will considerably increase productivity. Collecting small diameter or short length pieces will consume a lot of time and money but not deliver much volume.

For example, a sloven of 0.2m length and a diameter of 30cm has a volume of just 0.014m^3. If we assume a delivered price of $40 per m^3, the cost to pick it up, process and transport it must not exceed $0.57.

2.3 Extracting residues from the cutover

Figure 9: A wind-throw stand that has been shovelled back to the roadside for further processing.

A considerable volume of residues may be left on the cutover after harvest, depending on the system used. These residues are widely dispersed and typically require considerable effort to pull back to the landing. In many cases this will not be profitable unless the market value of wood fuel changes dramatically.

Some scenarios may allow for a cost-effective extraction from the cutover. For example, some companies will use an excavator with a root rake to windrow the cutover to improve planting conditions. At little extra cost it may be possible to extract some of the cutover residue to the landing or roadside.

Or, in another example, in a stand that has been wind-damaged, the harvest contractor may be engaged to do a salvage cut, whereby they will sort through the fallen trees and cut and extract only the higher value sawlogs. This may leave a large volume of smaller trees or logs that can be 'shovel-logged' cost-effectively to the landing (Figure 9).

Figure 10: The 'bundler' unit mounted on a forwarder frame can move through the cutover, picking up branch size residue and compressing them into bundles.

Figure 11: An in-forest bundler chipping operation at a central processing yard.

Figure 12: The in-forest chipper mounted on a forwarder base.

While some machines are not likely to be cost-effective in the New Zealand context, it should be noted that many European countries have invested greatly in the development of wood fuel production machinery. One example is the biomass bundler which is used extensively in Scandinavia (Figure 10).

The benefit of this system is that the bundles can be readily transported like logs on a standard log truck, or the bundles comminuted to improve machine productivity compared to the comminution of loose slash (Figure 11).

A second machine used in Europe is the in-forest chipper, which is also mounted on a forwarder (Figure 12). It chips the slash as it moves through the forest stand and can empty its integrated 20m^3 capacity container either into set-out bins or onto the ground. It can also chip directly to ground which can reduce fire or biotic risks.

2.4 Recommendations

You should consider the tree crop and the harvesting method when assessing whether to collect the woody biomass residue from landings.

Use the tools provided to calculate the expected volume of landing residue from a harvest.

You will also need to consider the range of piece sizes at any given landing and develop a recovery strategy that will give you the best return on your machine time.

3. Wood fuel markets and end products

3.1 Introduction

Converting wood into usable energy can be useful for domestic, commercial and industrial heating as well as other uses. Understanding the customers' requirements is critical. Types of wood fuel include: wood pellets, wood chips, firewood, hog fuel and bin wood.

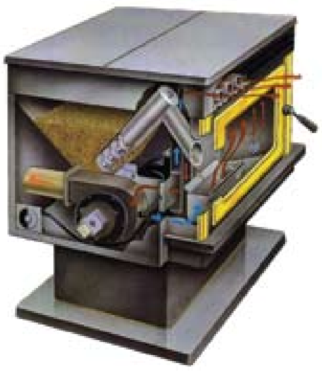

Figure 13: Highly efficient and low emission commercial and residential heating plants running on either wood pellets or chips are now commonly available.

3.2 Domestic and commercial heating

In many parts of New Zealand open fires are being replaced by wood and wood pellet burners for heating which, as well as being up to 86% efficient, are clean burning with low air pollution emissions (Figure 13). Many public and commercial buildings are converting from coal or oil-fired boilers to efficient wood chip or wood pellet burners.

3.3 Industrial heat

Wood-fired boilers and heat plants that produce either hot water or steam typically provide around 1 to 10 megawatts in heating capacity, and are common in the wood processing industry. The steam can be used for drying and processing as well as for electricity production via a steam turbine. With larger units, co-generation of electricity and heat via a steam turbine is possible and is referred to as a combined heat and power (CHP) plant. Improvements in efficiency are ongoing, and include cleaner-burning boilers, reduced handling costs and reduced problems with ash deposits. In Europe the ash is being sold as an agricultural fertiliser and considered a by-product of value.

3.4 Other uses

A variety of other wood energy conversion processes are being evaluated, including chemical processes to produce organic oils and gases, as well as liquid fuels for transport such as ethanol or bio-diesel. None of these projects are yet at the commercial stage in New Zealand, but many have been demonstrated to work overseas.

A wood gasification system is also being developed by researchers. The woody biomass is turned into a mix of hydrogen, methane, carbon monoxide and other gases, which can then be used to generate electricity by powering gas turbines or modified internal combustion engines. Limitations at present include high costs and challenges in producing sufficiently clean wood gas.

3.5 Meeting customer demand

Wood fuel users are the first step in the supply chain. Customers wanting wood fuel, including the wood processing industry, buy wood fuel from contractors. Understanding the needs of the local users in terms of the type, size and quality of the fuel they require, and the price implications, is critical.

To date many woody biomass recovery systems have failed to fully satisfy the needs of the consumer. This can sometimes be due to contractors or management not recognising the consumer's real requirements.

A market demand-driven supply chain is needed, whereby high quality and high value wood fuel is demanded by the customer and the system is adjusted to create benefits for both contractors and forest owners (Figure 14).

Ideal Consumer Situation

Supply of consistent, suitable product.
Payment that correlates to quality and energy content of product.

Ideal Contractor Situation

Large amounts of uncontaminated material made available for comminution.
Integrated into forest management.
Revenue incentives to produce high quality fuel.

Ideal Forest Owner Situation

Well-organised wood fuel recovery integrated into regular forest management activity.
Consistent revenue from wood fuel recovery from forest.
Maximise positive benefits (improved planting, reduced fire risk etc).

Figure 14: A supply chain model where product demand drives the value of the wood fuel higher.

The production system must be matched to local demand. There may be a large resource to process, but a limited market for the product. Knowing your customers' needs in terms of volume, delivery and storage is important.

For example, some customers may have seasonal variations in demand for product. Schools, for example, have only a seasonal demand for fuel. Knowing their on-site storage capacity is critical: will they need daily, weekly or monthly delivery? Many small users will be unable to have a large fuel stockpile on site.

Consumer requirements as to the form of the fuel will also vary. Typically these will include the categories detailed below: wood pellets; wood chips; firewood; hog fuel; or bin wood.

3.6 Wood pellets

Wood pellets (Figure 15) are high quality wood fuels made from compressed sawdust and/or wood-shavings. They can be burned in highly efficient heaters and boilers. Because the particulate emissions are extremely low, pellet burners can meet the new air emission limits being set for many urban areas.

Figure 15: A sample of wood pellets.

There are currently no standards in New Zealand for pellet specifications, however, the Bioenergy Association of New Zealand has produced the Wood Fuel Classification Guidelines (2009). Specifications for wood pellets put forward by two local bodies include:

- fines: 1% maximum through a 3mm screen
- bulk density: > 640kg/m^3
- size: 10mm diameter maximum, 10 to 38mm in length
- ash content: 1% maximum (oven dry basis)
- moisture content: 4-8% (MCwb)
- energy content: 18-20GJ/tonne minimum

3.7 Wood chips for fuel

Chipping is also a common method of converting woody biomass into a wood fuel product (Figure 16). Some boiler systems require a chip product rather than a hogged fuel, where the wood is ground (beaten and abraded) into a coarse shredded product, as the feed systems can clog on the longer strands often present in hog fuel.

Chipping is much more sensitive to dirt contamination than hogging, as the processing involves cutting the wood with knives that revolve at high speed either on a drum or a disc. These knives are easily damaged by stones and can go dull very quickly if the wood being processed is dirty, affecting chipper productivity, fuel consumption and chip quality.

Figure 16: A sample of wood chips.

3.8 Firewood

While firewood operations (Figure 17) have a long tradition in New Zealand, not many forestry companies or harvesting contractors have integrated it into their regular forest operations. Councils with air quality standards may dictate that no firewood is to be used unless the moisture content wet basis (MCwb) is less than 30%. This not only provides for greater efficiency in burning, but also for reduced emissions.

Figure 17: Firewood stacked for in-forest drying.

3.9 Hog fuel

Currently the most common form of woody biomass processing is hogging (Figure 18). This is mainly due to it being the lowest cost, and most robust, comminution option available. The size of the end product can be adjusted by altering the screens on the hogger.

Figure 18: Shredded wood fuel.

3.10 Bin wood

Larger users of wood fuel often have their own on-site processing capacity to convert wood residues into a boiler fuel, or can hire it in. This may mean that some buyers will accept wood fuel from landings in an unprocessed form as ‘bin wood’. This is generally limited to stem wood material (Figure 19), but can include residues from branches.

Figure 19: Bin wood piled on a landing.

Note the variation in piece sizes in the landing residues shown in Figure 19. The large sections on the lower right are typical of the off-cuts arising from log-making. They are significant in terms of volume, and limiting in that they often need either a large machine for processing, or a two-stage treatment to split them into smaller sections before chipping/hogging.

3.11 Recommendations

You need to understand your customer’s fuel requirements and the implications for your operations. In particular, you should consider:

- the type of fuel
- the quality
- the size
- the price.

4. Managing wood fuel quality

4.1 Introduction

When considering using wood as a fuel, there are a number of key factors that the buyer will consider including;

- moisture content
- dirt and ash content
- bark content
- leaf and needle content
- other contaminants (plastics and metal).

These factors are all important as they affect the fuel value of the material (energy content per tonne or cubic metre). They will also affect its potential end uses and wood to energy conversion costs, for example the cost of disposing of ash, considering both volume and contamination factors.

In New Zealand there are no product quality regulations that standardise wood fuel properties. There is, however, a new set of Wood Fuel Classification Guidelines (2009) produced by the Bioenergy Association of NZ which can be found on both their website (www.bioenergy.co.nz) and at the Bioenergy Knowledge Centre (www.bkc.co.nz).

4.2 Moisture content

The water content of biomass can be a major problem. A wet log looks very much like a dry one, so one can't judge 'by eye'. Wood and other biomass is never bone dry, and water content goes up and down with ambient conditions (such as humidity and temperature).

Moisture content (MC) can be reported on a % wet basis (MCwb), but also on a % dry basis (MCdb). For MCwb the equation is:

MCwb= water in sample (kg) / total sample (kg)

For example, when a tree is cut down the total weight of the stem is measured in 'green tonnes'. For NZ pine, a green tonne will have about 440kg of wood and 560kg of water. The moisture content on a wet basis (MCwb) is then 56%.

Moisture content on a dry basis is the relative amount of moisture compared to dry wood.

MCdb= water in sample (kg) / wood in sample (kg)

For the example above this would be 560kgs/440kgs = 127% moisture content on a dry basis.

For very dry wood the difference is not very great. For example, a tonne of well dried firewood that has a MCwb of 10% (i.e. 100kg of water and 900kg of wood), has a MCdb of 11%.

These two standards can cause a lot of confusion. Remember to check what moisture content is being referred to. For simplicity, this guide uses only moisture content (wet basis) or MCwb.

The moisture content of the wood has a direct effect on the fuel value of the material. Figure 20 shows the change in energy content per tonne, by MCwb. The equation for this chart is:

Energy (GJ/t) = 18.9 - 0.213*MCwb

This was derived from wood energy data (*van Loo and Koppejan, 2008*). Specific energy content calculators are available on the Bioenergy Knowledge Centre website (www.bkc.co.nz).

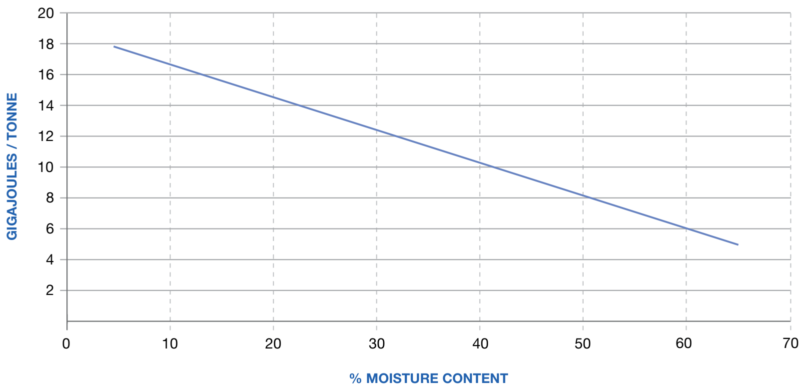

Figure 20: Reducing energy value of wood fuel with increasing moisture content (% wet basis)

It is important to understand this relationship between moisture content and energy value from two perspectives:

- suitability to the fuel buyer's needs (energy content)
- the impact of moisture on weight and cost of production.

The needs of end users in terms of moisture content of wood fuels will vary with the type of plant that is using the fuel.

Freshly harvested (green) wood is typically about 55-60% MCwb. Large industrial boilers such as those at pulp mills will take fresh or green wood up to 60% MCwb (they prefer 45% to 55%), but above this point the wood fuel has unstable combustion properties and may not maintain combustion without an additional fuel source (coal, gas or dry wood).

Many medium-sized or smaller boilers operate best on wood fuel in the 30%-40% range, and will not operate efficiently on wetter material. Self starting (auto-ignition) boilers require fuel that is less than 30% MCwb, otherwise they will not ignite. Using a fuel with a higher moisture content than the boiler was designed for will reduce its output capacity.

Drying of the wood fuel is therefore an advantage in terms of fuel quality and marketability. Fuel drying can be achieved with either unprocessed (raw) or processed (comminuted) wood fuel.

A number of studies in New Zealand on drying radiata pine have shown that in good conditions it is possible to reduce moisture content relatively quickly. The main climate factors that dictate good drying include high air temperature, low humidity, good pile airflow and wind. The main storage consideration is stacking, or at least piling the wood. This reduces the amount of wood in ground contact and the impact of rainfall. Wood spread out and in contact with the ground does not dry as well as stacked or piled material.

A study done in conjunction with the development of these guidelines tested the difference in drying rates between small and large diameter logs, as well as splitting the large logs and covering the small logs (*Visser et al, 2010*). The study conditions were very favourable to drying (summertime, low humidity and windy). The wood was neatly stacked and cut into relatively short (2m) lengths. Results showed drying to less than 30% in only 16 weeks (Figure 21).

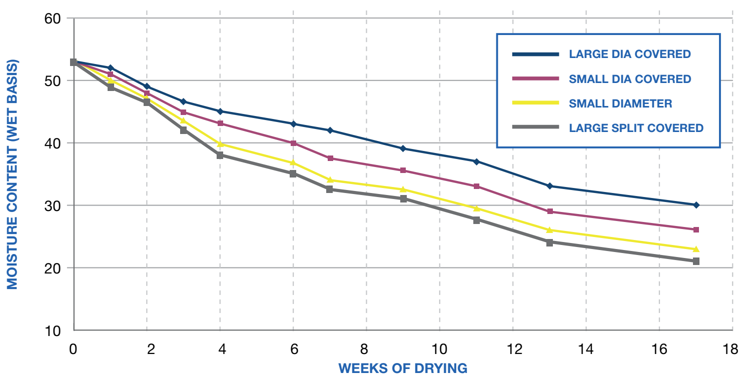

Figure 21. Results from a three-month drying trial in Mosgiel.

An obvious result was that smaller diameter logs dried faster than large diameter logs. However, covering the stacks was in fact detrimental as it reduced both wind (pile airflow) and sun-assisted drying (Figure 22). This is consistent with other studies that show that covering wood fuel is only beneficial in winter, or in areas with high rainfall. Covering piles where the material has been chipped or hogged can be beneficial.

In general, these results were similar to other drying trials: in Kinleith the wood dried to below 35% in 16 weeks (*Hall, 2000*); in Wellington, moisture content dropped to 35% to 40% over a period of two to three months in summer and 40% to 45% in winter *(NZCEC, 2009*); in Dunedin billet logs (1 to 3m long) dried from 58% moisture content to 35% in four to six months (*Forest Environments Ltd, 2009*).

The results also showed that splitting large wood accelerates the drying. For this trial the wood was split using an excavator with a ripping tine, as shown in Figure 23.

While this splitting was effective for drying, the additional cost was estimated to be $15/tonne. There are new purpose-built splitting heads and the one shown in Figure 24 is being used in Italy on large diameter pine. It can split and stack at the same time, and the cost is approximately $5-8/tonne. The cost of splitting needs to be balanced against the benefits obtained from the drying for each site under consideration.

Hogged or chipped material in a pile dries very little as exposure to sun and wind is limited to only the outside layer. It can absorb moisture from rainfall and become wetter (*Hall 2000, Scion 2009a*). Hogged or chipped material will dry, but only if it is under cover and adequate airflow is provided for. Very large piles can self-heat and dry, but this process is driven by the microbial breakdown of the wood. A decomposing pile may end up drier, but it will always have less energy in it.

A key point to remember is that as the material dries the energy content per tonne increases, and the weight reduces (i.e. less tonnes). For example, a 25-tonne payload of green wood fuel (MCwb = 55%, 7GJ/tonne) delivers 175GJ of energy. A lower weight load of 20 tonnes of drier wood (MCwb = 30%, 12.5GJ/tonne) delivers 250GJ of energy. It is the energy content of the wood fuel that is being delivered, not the weight in tonnes, that should be important to both the contractor and the wood buyer.

Figure 22: A large stack of wood fuel that has been set out for drying. This material will be chipped to produce a higher quality wood fuel.

Figure 23: An excavator splitting logs prior to stacking to improve drying.

Figure 24: Splitting head from Italy suitable for large diameter pine.

4.3 Dirt and ash content

Dirt has no fuel value and if fed into a boiler it becomes ash which, as well as being abrasive, is problematic for most in-feed systems. Normal ash contents of clean wood fuels are low, between 0.5% and 2%. Most boilers can cope with ash contents higher than this but excessive ash causes a number of problems:

- lower energy content per tonne of in-feed material
- reduced boiler output
- higher ash volumes to be disposed of
- more boiler and fuel feed wear and maintenance.

There are cases where wood fuel from landing residues has produced ash content up to 10%. Subtracting the ash percentage from clean fuel, this indicates that about 9% of the purchased wood fuel being fed into the boiler is producing no energy. Some boilers and stoves specify certain ash limits for their fuel.
Wear and tear on grates from gravel and rocks is a particular problem. Some Regional Plans also specify ash content limits on solid fuels. The impact of ash content on fuel energy values should be reflected in the price paid.

Figure 25: A 20 tonne excavator 'sieving' out biomass that was pushed off the landing during harvesting operations. Here the operator had to work three or four hours to extract 20 tonne of contaminated wood fuel.

Minimising ash content due to dirt contamination is therefore a priority. The way the raw material is handled on the landing has a direct effect on the amount of dirt in a pile of landing residues. If the material is pushed around the landing surface with the blade of a loader, especially in wet conditions, inevitably there will be a lot of dirt mixed in with the wood. The wood then has to be picked out of the dirt, but some dirt will inevitably be stuck to the wood (Figure 25).

Figure 26: A root-rake that is mounted on an excavator base so the operator can shake out contaminates and under-sized wood residues.

Loader operators can have a positive impact, in the amount of care they take to avoid including dirt in the material picked up. Where dirt has been mixed in a pile, operators can reduce this by shaking the material as they move and load it. Some wood fuel contractors use modified grapples and saw heads to aid this process (Figure 26).

4.4 Bark content

Bark is usually present in wood fuels produced on forest landings. Harvesting systems that use mechanised processing will typically remove much of the bark from the stem, whereas with manual processing most bark will stay on. Drying or additional handling of the wood will also cause bark to drop off.

Bark is combustible and depending on the end-use may be an acceptable component of the wood fuel. Small amounts of bark are also acceptable in many conversion processes, but the end user requirements must be understood. For example, if the end use is making premium wood pellets then bark content must be minimised. According to the Wood Fuel Classification Guidelines (2009) produced by the Bioenergy Association of New Zealand, wood chips must have <2% bark content.

4.5 Needle content

Needle content should be minimised in wood fuels for a number of reasons. Needles have comparatively high nitrogen content. This means that they have value in the forest as a nutrient for the next tree crop, and they will also have high NOx emissions when combusted. High needle content will also lead to higher ash content in the fuel, due to the high mineral concentrations in the needles.

Needle content of wood fuels from radiata pine harvest typically tends to be low. However, with some low stocked or highly malformed stands, there can be high volumes of branch and needle material.

Needle content can be minimised by:

- removing the small needle-bearing branches from the material being processed
- allowing the branches to dry for four to six months prior to collection, at which point the needles are likely to either have fallen off or to fall off during handling.

4.6 Other contaminants

It is not uncommon to find non-wood contaminants in a fuel pile. Typically these are metal and plastic items from logging operations such as spray cans, chainsaw chains, wire rope, plastic wrapping, and packaging. Other items that have been found include: clothing, chaps, helmets, spanners, wedges, axes and track plates.

These items can cause many problems during subsequent processing. Even very small pieces of metal can have a very destructive effect on processing machinery, such as chipper knives. Any large piece of metal inadvertently fed into a comminution machine can cause many hours of lost production and high maintenance costs, so it is absolutely critical that these materials do not end up in the raw material pile. One exception is smaller metal items such as nails in pallets, which can pass through most hoggers without much impact. Material with nails is not suitable for chipping.

Most plastic material will pass through the processing machines without causing much damage. However, the plastic is then mixed in with the wood fuel and will enter the combustion or conversion system. In combustion the presence of plastic can cause emission problems. In gasification or pyrolysis processes plastics may interfere with the conversion process.

The presence of contaminants such as plastic in a fuel also affects the ash and what it can be used for. If the intention is to return the ash to the forest or use it as a fertiliser, contamination with plastics and treated wood must be avoided.

4.7 Screening and grading

All wood fuel products can be screened after comminution to remove over- and under-sized particles as well as dirt and stones. In some cases the screening can create multiple products with different uses and values. Screening can range from very simple systems (Figure 26) to more complex machines with multiple grates to optimise wood fuel sizes.

For some boiler plants the particle size and size distribution is critical, and screening is needed to get the hogged or chipped fuel to the required specification.

Figure 26: A simple screen used to limit undersize firewood and help remove any dirt contamination.

Screening can have a significant impact on the dirt/ash content of a fuel. For example, a chipped fuel product may have 3-4% ash in the larger particle size chip, but 20-40% ash in the very fine material (less than 3mm). The material <3mm should only be a very small proportion of the total volume (less than 1%). Therefore screening and removing the very fine material may remove only 1% of the fuel but 6-10% of the ash.

Screening is not without its costs, and this option needs to be considered carefully. However, removal of very fine material can have a significant effect on fuel quality, both in terms of the ash content and combustion characteristics. Fuels with very diverse particle sizes are difficult to combust efficiently as a system designed to burn chip size material will have an airflow that is likely to blow fine particles out of the combustion zone into the flue before it is completely combusted, causing emission issues.

4.8 Recommendations

The fuel value and potential uses of wood fuel are affected by the content of moisture, dirt and ash, bark, leaves and needles and contaminants. The content of biomass can be a major problem and needs to be carefully assessed.

Considering handling options and minimising dirt contamination should be a priority. Bark and needle content and other contaminants should also be minimised if possible. Stacking and drying wood fuel can improve fuel quality and marketability. Splitting large wood can accelerate drying but adds costs. Screening also has costs but its advantages should be considered.

5. Wood fuel production machinery

5.1 Introduction

The choice of comminution machinery should be driven by:

- properties of the in-feed raw material (piece size and piece size distribution, contamination of raw material, especially dirt)
- the suitability of processing equipment
- the scale of operation
- operational factors
- demands of the fuel end users (product type, size and size distribution).

5.2 Suitability of processing equipment

The key to a successful wood fuel harvesting system is that it is well designed and fits with the material to be handled. The comminution machine must be suitable for the majority of the in-feed raw material.

This is critical. Smaller machines may be cheaper to buy and run but may not be able to cope with the larger pieces of woody biomass, especially larger diameter stemwood sections. Production is lower if they are consistently processing material at their upper size limit.

In New Zealand the larger pieces often form a significant part of the volume, so a machine capable of taking these is preferable. Larger machines may need to be considered or some pre-processing of the larger pieces may be an option.

If there are a significant number of ‘oversize’ sections in the raw material, but insufficient total volume to warrant use of a large machine, a two-stage processing system may be viable where the larger pieces are split into smaller pieces before being fed into a medium size chipper or hogger. Splitting can be achieved using an excavator fitted with a purpose built splitting head or jaws, but you can also use a spike or ripper tine for smaller volumes.

5.3 Scale of operation

Larger chippers and hoggers that are able to cope with almost any sized material are expensive to buy and run. While they have higher throughput, they must be able to work close to capacity in order to minimise operating costs. A key consideration is whether the throughput capacity of the chipper or hogger matches the supply of raw material and the demand for product.

The best type of system will depend on the volume of residue to process. This can be estimated by looking at harvesting crew daily production and the crop characteristics (high or low percentage of residues).

An estimate of the amount of wood fuel produced daily and the area needed to store it can be derived from Table 2, which is based on average wood fuel volume of 5% of extracted volume and pile heights limited to 6m.

Table 2: Daily volume (solid wood and pile volume) of wood fuel on varying rates of log production

Daily Harvest Volume (m^3)	Daily Wood Fuel Volume (m^3)	Pile Volume (m^3)	Pile Height (m)	Pile Area (m^2)
100	5	20	4.5	13
200	10	40	5.5	22
400	20	80	6.0	40
800	40	160	6.0	80

For a wood fuel production operation to be viable, it needs to be producing sufficient volume to optimise machine use, minimise production costs, and be balanced with market demand.

Some previous studies have suggested the scale of work required is in the order of 40-50,000 green tonnes per annum to make it viable to invest in a hogger capable of processing logging residues. Other studies have suggested that a volume of at least 15,000 cubic metres per annum of solid wood is necessary to justify equipment purchase *(Forest Environments Ltd, 2009)*. At 6% woody biomass from landings this is equivalent to an annual harvest of minimum 250,000m^3. Smaller volume operations may be viable, but with equipment that is hired in as required, or a premium paid based on low utilisation.

5.4 Operational factors

There are four main types of comminution equipment for the production of wood fuels:

- chippers (high speed cutting)
- hoggers (high speed grinding and tearing)
- shredders (low speed tearing)
- firewood splitters.

Variables to be considered in the choice of equipment include:

- **Configuration.** Options include: drop feed or side feed; integral loader or by separate loader; direct control or remote control.
- **Size of machine and capacity.** Some models of whole tree chipper are very large (8.0-12.0m long and 3.0-5.0m wide) handling trees up to 91cm diameter.
- **Mobility.** Units range from wheeled and semi-trailer-mounted to self-propelled tracked units. Size of equipment also affects the ability to operate on individual landings or whether it is better to be semi-fixed at one processing site.
- **Operating safety.** In some situations projectiles exiting the machine is an issue. Machines must be adequately screened and guarded or placed at a safe distance from other work areas.
- **Fuel efficiency.** Large capacity mobile chippers and hoggers are driven by large diesel engines (300-800kW) with large fuel consumption. Fuel efficiency is affected by factors such as rate of feed, delays and running at less than capacity. For machines that are fixed, or likely to be working on a site with a power supply, the use of electric motors which are cheaper to operate is an option.
- **Repair and maintenance.** With all comminution machinery, repair and maintenance of items, such as knives that need to be sharpened or replaced regularly, is a significant cost. As with all equipment, maintenance needs to be managed to minimise the impact on productivity. The accessibility of the knives, the ease of changing, cost of replacements and the potential to sharpen or reface in-situ are all factors that need to be considered.
- **Robustness.** All comminution machinery is vulnerable to catastrophic damage from non-wood contaminants. Disc chippers may suffer major production losses simply from a single very dirty log or a few embedded stones. Low speed shredders are the least vulnerable to contaminant damage.

5.5 Chippers

Chippers, especially disc chippers, are designed to produce chips which meet the specifications required by the pulp industry. These specifications may not be necessary or suitable for wood fuel uses.

All chippers have a high velocity of discharge, which means that the chips can be directed and ‘blown’ into a waiting chip truck.

5.5.1 Disc chipper

Disc chippers are commonly used in the pulp industry. They produce a high quality product that is specifically designed as a pulp feedstock. They can also be used to produce wood fuels, but they require the raw material to be clean and in stem sections of at least one metre in length.

Most disc chippers do not cope well with short length material (<1m) as the short sections can bounce and turn, resulting in jamming or chipping along the grain as opposed to across it, causing chip quality and size issues.

Disc chippers are available in all sizes and configurations from large, fixed electric-powered chippers at pulp mills to mobile chippers mounted on track bases (Figure 28) to semi-trailer-mounted units to small (45kW) hand-fed units that handle a maximum 15cm diameter tree, and can be towed behind a utility vehicle (Figure 29).

Figure 27: A disc chipping blade.

Figure 28: Morbank Typhoon disc chipper working in pine thinning.

Figure 29: Small trailer-mounted disc chipper.

5.5.2 Drum chipper

Drum chippers (Figure 30) are more suitable for chipping logging residues for wood fuels than disc chippers as they take a variety of sizes and shapes of raw material without affecting processing and product quality.

They will typically not produce pulp quality chip, but will produce wood fuel chip. Knives can be either fixed (Figure 31) or swing-type.

Most of these machines can also be fitted with a self-feeding crane/grapple. Or they can be fed by independent machine, where the loader driver controls the hogger or chipper via remote control. A potential issue with integral loader booms is their limited reach (Figure 32). This means another machine is required to bring in-feed material to the chipper or it needs to move more frequently.

Figure 30: Semi-trailer-mounted drum chipper.

Figure 31: Fixed knives on a drum chipper. The alignment is critical to good operations.

Figure 32: A small but efficient chipper that is powered by the PTO of an agricultural tractor. These systems are relatively cheap to run but limited in the maximum diameter they can cope with.

5.6 Hoggers

Hoggers, including drum hoggers, tub grinders, horizontal disc hoggers and vertical disc hoggers, are much more able to cope with dirt contamination than chippers, as the knives on the drum are more like hammers (and can be either fixed or swing type), and are designed to tear pieces of the raw material rather than cut or slice them. Due to the high speed rotation of the knives, contamination of the in-feed material should still be minimised, and any contaminants will end up in the fuel.

The hogger's design, where the wood fuel goes through a screen before it is discharged, means the velocity of the discharge is low, and the out-feed is by a belt. This means the material cannot be blown into a truck from any distance, but the truck must park next to or under the discharge belt for direct loading.

In many cases the discharge belts are not of sufficient height to load over the side of a high volume truck and so the material is discharged onto the ground and then handled again to get into the trucks. This option can lead to between 4% and 12% of the processed volume being left on the ground, and it can be a source of dirt contamination in delivered wood fuel.

5.6.1 Drum hoggers

As most hoggers are fed by separate loader, the engine, in-feed deck, hogger and track drive are often remotely controlled by the loader operator. Some European models can be truck mounted for ease of relocation (Figure 33).

Figure 33: A truck mounted Starchl hogger working with landing slash.

Figure 34: Horizontally-mounted hammers inside a tub grinder.

Figure 35: Large tub grinder.

5.6.2 Tub grinders

Tub grinders (Figure 34) have a drum with fixed or swing hammers mounted horizontally in the bottom of the tub (in line with the engine drive shaft). The tub rotates, dragging material past the hogging drum/screen.

Tub grinders work best when the drum is at least half full, as the weight of the material presses the material at the bottom against the hogger drum. If the drum becomes empty, the hammers can catch loose chunks of wood and eject them over the side of the tub. In some cases a moveable cover may be required to stop too much material being thrown from the tub.

All tub grinders feed 100% of the contaminants to the cutting mechanism, and then they force it between the hammers and screens until it is finally forced through the screen holes. High wear is inevitable and screen blow-outs are common.

Tub grinders come in a range of sizes which will depend on the in-feed material.

5.6.3 Horizontal disc hoggers

Horizontal disc hoggers are sometimes known as Universal Refiners (after the Universal Refiner Corporation, an equipment manufacturer) or Universal Refiner clones (Figure 36). They have a configuration where the hogger disc is flat in the bottom of the hopper (which is fixed) and the disc oscillates around the bottom of the tub as it spins. The drive mechanism is complex.

Figure 36: The Ripper: a horizontal disc hogger.

When a fresh load of material is fed in it is constantly agitated, breaking loose dirt, sand and rock that can exit the machine without contacting the cutter disc. The cutting action does not force the material against an anvil or against the screens. The cutter disc and cutter blades travel at about half the speed of the hammer tips in a tub grinder, therefore damage and wear is less.

Horizontal disc and tub grinder-type machines both have a high in-feed height as the material must go in over the top of the sides of the tub.

5.6.4 Vertical disc hoggers

Figure 37: WoodWeta vertical disc hogger with Trommel pre-screen.

The WoodWeta is like a drum or trommel screen and a hogger built into one machine (Figure 37). The dynamic screening action of the trommel screen on the WoodWeta, which is inside the covered body of the machine, has a double function: it removes dirt and fines before the raw material gets to the hogger disc, reducing wear and dirt content in the fuel; and it moves the raw material to and around the hogger disc.

Figure 38: Crambo high torque low speed shredder.

5.7 Shredders

The third type of comminution machine is the low speed high torque shredder (Figure 38). In these machines the knives contact the wood at much lower speeds (30 rpm as opposed to 300 to 600 rpm). Slow-running screws with shredding tools shred all types of woody biomass and minimise fine particle and dust emissions. Due to the configuration of the shredder, the material produced tends to be longer and more splintered, but this also depends on the type of raw material and the screen size. Replacing the screen baskets can change the product from course shredded to fine shredded wood fuel.

Many modern comminution machines have a pressure sensor in the drive system so that if the knives are pulling a hard object into the machine (such as a large piece of metal) the drive reverses and pushes the object out. The operator can then stop the machine and remove the object.

5.8 Firewood splitters

Commercial scale firewood operations are often located near to market (i.e. near an urban area), but also can be located in the forest. There are many makes and models of firewood splitters available, with various levels of automation. This includes firewood machines designed and built by contractors themselves to reduce capital outlay (Figure 39).

The maximum log diameter will be limited by the firewood machines' cut-off saw and splitting frame (Figure 40). Small diameter radiata pine is not preferred because of the very high moisture content.

Figure 39: A 'self-made' in-forest firewood machine.

Figure 40: Splitting frame on a firewood machine.

5.9 Recommendations

There are many different equipment options. Contractors selecting equipment should:

- know the requirements of the purchasers
- know the type of raw material being dealt with
- ensure the chipper or hogger is large enough for the material being chipped (minimum 7.5kW power per centimetre of wood diameter)
- maximise comminution equipment productivity
- ensure the chipper or hogger has the mobility required for the situation. Track-mounted or truck-mounted chippers are more mobile than trailer-towed units.
- minimise delays caused by other operational constraints (such as wood supply and machine moving).

6. Wood fuel transportation

6.1 Introduction

Transportation is a key component to a viable wood fuel production delivery system. The transport of both raw woody biomass to the processing operation and the second stage transport of wood fuel product to the end user is a significant proportion of the total delivered cost of the fuel. Maximising load density and gains in transport efficiency will therefore have a marked impact on total cost.

Figure 41: Chipping directly into a set-out bin. This can be effective when cleaning up multiple landings as the trucking and comminution operation is de-coupled.

There are many options available. Where it is viable, the chipper or hogger should load directly into trucks as this will improve recovery and efficiency and reduce cost. In most cases, the comminution machines have out-feed chutes or conveyers that are capable of loading directly into or over the top of truck trailers. By feeding from the hogger directly into the truck, a separate loading cost and loss of materials during handling is eliminated; this can potentially reduce costs by 10% (Figure 41).

The system must be designed to optimise transport, especially where haul distances are long. This includes having purpose-built trucks which are robust and high volume and having loads of sufficient density for the truck to be able to reach its maximum gross vehicle mass (GVM) thus maximising its payload in addition to its volume.

In some operations where the moisture content is high the transport operations will have high payloads. If they are paid by the tonne, this is highly advantageous to the truck operator, but the fuel purchaser is disadvantaged by paying for the delivered weight that is water, not fuel.

Comminuted fuels may be less sensitive to the effects of transport distance than raw residues. Therefore the decision whether to process wood fuels before or after transport needs to be considered carefully along with other factors. For more information on transport options refer to the Transport Guidelines for Wood Residues for Bioenergy *(Scion, 2009b)*.

6.2 Transport options

There may be limits on the truck design that can be used, for example some chip truck and trailer units are not suitable for steep, winding, narrow forest roads and small landings with limited turning space.

An option to consider with self-loading truck and trailer units (either tipper bins or hook bins) is trans-shipping. This is where the truck drops the trailer at the closest safe point to the landing. The truck then loads up, returns to the trailer and transfers the load over. The truck then returns to the landing and loads again, picking up the trailer on its way out of the forest (Figure 43), taking a full load to the comminution site or fuel user.

Figure 42: Bin truck and trailer being loaded with ‘bin wood’.

Figure 43: A set-out semi-trailer loaded with logs to be chipped.

Figure 44: Truck and trailer for chipped and hogged material.

Figure 45: A 'possum-belly' semi-trailer such as this can be used in a set-out system.

Figure 46: Unloading a semi-trailer at a large scale CHP plant in North America.

Figure 47: Off-highway truck for accessing difficult sites.

Figure 48: This small multi-purpose truck both collects residues from active landing operations as well as delivering firewood to customers.

Large high volume truck and trailer units are a good option for long haul transport (Figure 44). The disadvantage for New Zealand is that the GVM of a semi-trailer is only 39 tonnes (but varies with axle configuration).

A large scale operation may justify purpose-designed and built equipment, for example very high volume chip liners for carrying dry chip. The truck shown in Figure 45 is a possum-belly and specifically designed to maximise the volume of chip that it can carry.

Specialised unloading facilities may also dictate the type of truck that is suitable. For example, semi-trailers are commonly used in North America, with chipping or hogging directly into the trailer and unloading using a large tipping ramp (Figure 46).

A particularly difficult site may dictate that smaller, all wheel drive, or even off-highway trucks (Figure 47) – sometimes with a self loading crane and a purpose built wood bin – are used for transporting biomass.

Another transport option is a small lower-cost multi-purpose truck, such as shown in Figure 48. This 5-tonne load capacity truck is used to collect the biomass from the landings and is also used to deliver the wood fuel (in this case firewood) to the end-user.

It can be useful to understand the transport resources and how they can be used, adapted or integrated into the wood fuel delivery system. For example, road metal trucks working on forest roading could be used to back load woody biomass or chip.

6.3 Optimising payload

Load density is a major consideration in system design and can be critical for longer haul distances. The density of a load of woody biomass or wood fuel is defined as the proportion of the load volume that is solid wood material. The typical densities of various biomass types (as % solid wood, loosely loaded) are:

- chip 40%
- hog 35-40%
- woody biomass 25-30%

Chipped and hogged materials are denser and more suitable for longer haul distances. Unprocessed biomass is slightly less dense and requires careful loading and compaction and tie-down restraints to maximise density. If the raw material includes a lot of branches and tops, compaction and restraint should be used.

The density required to gain maximum payload for different vehicle types can be calculated allowing for variation in moisture content. In order to maximise the payload of a bin truck and trailer (44 tonnes GVM, 24 tonnes payload) with green woody biomass

(58% MCwb) a load density of 27% is required. If the biomass has been stored and air dried to a moisture content of 30%, a load density of 45% would be required to achieve maximum payload. This also increases the delivered energy content of the load from about 160GJ to 300GJ.

In one trial loading and compacting radiata pine landing residues, the loose density of the residues was 28%: this rose to 34% when compacted with a loader. When more residue material was added, and further compacted with a loader and tied down with webbing straps and tensioned with ratchets, the density rose to 45%. In most cases, good loading and compaction should allow you to maximise the payload for your bin truck and trailer.

6.4 Other factors to consider

6.4.1 Tare weight

Figure 49: Stacking logs carefully into a bin provides for a loading factor of about 60%. Simply throwing in the wood fuel will only achieve a 30-40% loading factor.

Tare weight is a trade-off between durability and mass. Every 1kg of tare weight is a 1kg lower payload. It has been estimated that tare weight of many trucks could be reduced 600-700kg without compromising vehicle durability. Chip trucks can be built from light sheet aluminium or a frame supporting heavy fabric reinforced with webbing straps. Bin trucks carrying raw biomass are more likely to be built out of heavier gauge sheet steel reinforced with a steel framework. Versatility, in terms of ability to back load other materials to reduce costs (e.g. general freight, road metal, fertiliser, etc.), should also be considered.

6.4.2 Terrain, operating conditions and technology

A key factor will be what adverse grades will be encountered, loaded and unloaded, and how much power and braking will be required to maintain safe speed and control. Central tyre inflation systems (CTI) allow the driver to adjust tyre pressure while driving, according to the road surface to improve traction on steep terrain, low standard and often loosely compacted forest roads. This also extends the operating range and season, reduces downtime, tyre wear and vibration damage to the vehicle.

On-board weigh scales are useful in alleviating the problem of underweight loads (low revenue) and overweight loads (potential fines or reject loads).

6.4.3 Vehicle configuration

Trucks with cab over engine can have a higher payload and a larger load space (depending on axle configuration) than the cab behind engine configuration. Cab-over trucks can have a longer load deck by up to 1.4m, increasing potential load volume by 8-9%. Extra axles on trucks and trailers can reduce Road User Charges, but the extra axles will have a payload penalty, therefore the cost and benefits need to be assessed carefully, taking into account the operating conditions and the above factors.

6.5 Recommendations

The transport system should aim to:

- maximise energy delivered per load
- use equipment that is suitable to the site and the scale of the operation
- maximise volume if carting dry material, or maximise payload if carting green material
- minimise overall transportation and handling costs.

7. Designing the supply chain: a systems approach

7.1 Introduction

This section looks at the three locations where comminution can be undertaken – at the end user, at a central processing yard, or at the landing. It also examines the options for production systems, including integration with forest harvesting or using a post-harvest recovery system.

7.2 Processing at the end user

Chipping the raw material at the end user (such as a heat plant or further processing facility) has the advantage that the discharge can go directly into fuel storage or heat plant input, minimising handling costs, fibre loss and contamination risks. Large scale fixed location comminution machinery is typically also the lowest cost. However, this may not be a viable option for all due to space requirements for raw material storage and processing facilities. Long distance transport of low density raw material is also costly.

7.3 Chipping at a central processing yard

Figure 50: Large scale comminution operations at a CPY where stem residues are being shredded into hog fuel.

Given limits on the ability to chip at the end user or at source, a central processing yard (CPY) may be required (Figure 50). This approach will inevitably involve extra costs, such as additional transport and handling. However, efficiencies of scale over landing-based operations are usually realised, with greater volumes and more consistent production. A CPY will also typically provide good storage options.

The CPY can be a permanent or temporary site. Temporary CPY sites are likely to be located in the forest and follow the harvesting programme as it moves through the forest estate.

The CPY could be a permanent site with the ability to run fixed chippers, screens, multiple product outputs and have undercover storage. Permanent CPY sites should be located at a point central to both wood fuel end users and forests.

One example of this type of operation was the CHH Kinleith operation which collected biomass sourced from both land clearing operations and super skid harvesting operations. The biomass was stockpiled in the field and the hogger moved to the stockpiles operating at each site for 6-8 weeks. The hogger processed 300 green tonnes per day to the ground and the wood fuel was carted 60-80km to Kinleith pulp mill in open top bin trucks. Cost of the operation (wood fuel plus transport plus stumpage) was approx $40 per tonne.

In a recent study (*Forest Environments Ltd, 2009*) CPYs were determined to be the most viable option for fuel production from woody biomass from forest landings, with chipping at landing after storage and drying possible in some higher volume, easy access locations.

7.4 Chipping at landings

The processing of woody biomass at individual forest landings is an option but it has some distinct limitations. For instance, the raw material needs to be stored to reduce moisture content, and this can require a significant area (Figure 51).

If it has not been stacked on the landing, the raw material needs to be recovered from the landing surrounds at a cost (Figure 52).

Figure 51: Residue logs stacked on the landing for processing into wood fuel.

Figure 52: Typical yarder landing showing woody biomass discarded 'over the side'.

The processing equipment (chipper/hogger) must be mobile to travel from landing to landing. The volume at each landing might be in the order of 250 to 350m^3 of solid wood. For a large chipper/hogger that is only 8 to 10 hours' work meaning the machine will have to shift site every day or so, with significant production down time.

Access to landings for transporters and chip liners may also be limited, especially if raw material is stacked on the landings. As a means of improving traction and reducing their turning circle, empty logging trucks can return with their trailers up ('piggy back'). But chip trucks cannot 'piggy back' their trailers and so may be limited to a truck-only configuration for some landings, limiting their payload.

When chipping on landings it will be difficult to chip or hog directly into a truck due to limited space or placement of raw material, so discharge to ground is likely, leading to fibre loss, risk of dirt and moisture contamination, and lower production.

For these reasons, chipping at landings is often not a preferred option.

Systems that reduce the recovery and handling steps in the system are more efficient and therefore reduce costs.

7.5 Production system options

There are five main production and delivery systems or wood flows that can be used:

- Raw biomass material transported directly from forest to the end user and then processed.
- Raw biomass material transported from forest via a central yard or storage point to the end user and then processed.
- Raw material transported from forest to a central yard for processing and/or storage. Wood fuel is transported to the end user.
- Raw material processed at forest landing and wood fuel transported to a central storage yard then transported to the end user.
- Raw material processed at forest landing and wood fuel is transported directly to the end user.

Those with the least handling steps are generally the most efficient. Intermediate handling and processing often just add cost. However, the specifics of each situation, including transport distances, will determine which option is the most efficient.

There are two options for timing the collection of wood fuel from the landing:

- integration with log harvesting
- post-harvest recovery.

7.5.1 Integration with forest harvesting

Integration of wood fuel production with harvesting must cause the least possible disruption to the harvesting operation, with minimal handling and storage requirements being critical (*Visser et al, 2009*). However, the integrated collection of wood fuel can be both efficient and mutually beneficial for the logging operation. From the logging contractor's perspective, the woody biomass that accumulates as a function of harvesting must be removed at regular intervals as it interferes with log-making operations and can become a safety hazard. Instead of the logging crew moving the biomass to (or over) the edge of the landing, at little additional effort and cost the biomass can either be placed in a bin or stacked on the landing as another product.

Integration of woody biomass production with log harvesting operations has been used widely overseas and is seen as a key component of the successful use of forest biomass in New Zealand.

The aims behind it are to:

- increase volume recovery and reduce handling steps
- minimise raw material losses (waste)
- improve quality through reduced contamination
- improve storage options
- maximise utilisation of current machinery
- minimise production costs.

The volume of biomass that accumulates on a daily basis is typically too little to justify integrating a comminution machine on site. The additional machine would either require the landing size to be increased or would interfere with logging. The three remaining supply chain options can be described as:

- Load bin or truck with woody biomass as harvesting progresses / truck direct to end user / accumulate and store / hog or chip to wood fuel storage.
- Load bin or truck with woody biomass as harvesting progresses / truck to CPY / accumulate and store / truck to end user for processing.
- Load bin or truck with woody biomass as harvesting progresses / truck to CPY / accumulate and store / hog or chip at CPY / truck wood fuel to end user.

There are three alternative approaches to integrated production of woody biomass:

Figure 53: Hook bin for landing residues.

Figure 54: Set-out bins and hook truck and trailer (end loader).

1. Stockpile and load out as a log product

In this option, the woody biomass is treated the same as other log products, that is, it is stacked up on the landing and when a truck load is available a truck is requested and the material is loaded out. This system assumes there are sufficient suitable trucks available to remove the material on an 'as required' basis. If truck scheduling is inadequate, problems will occur. Production of the biomass material is a cost to the logging operation in terms of handling and loading and the logging contractor should be compensated for this.

2. Load to bins or set-out trailers and truck out as filled

The second option is the use of bins or set out trailers (Figure 53). This requires leaving the bin or set-out trailer at the harvesting crew and retrieving it when full and leaving another empty one with the crew.

The bins can be left singly or in pairs and retrieved using a hook system like a jumbo bin (Figure 53) or a semi trailer can be left on the landing for the crew to fill.

A study of the use of set-out bins in New Zealand (*CEC, 2009*) recommended the use of two bins delivered by truck and trailer where possible. This approach should lower cost as the machines are on site and down-time associated with moving to and from the site is minimised. Set-out bins should also lead to lower levels of dirt contamination. It is likely that the trucks would need to be fitted with central tyre inflation systems to access landings in winter or wet conditions.

The down side of the bins is that the transport system has a higher tare weight and lower payload than a conventional truck, and so is higher cost for longer haul distances.

3. Stockpile and load out using self-loading trucks

The third option is to stockpile the residues and load-out after the logging crew has left. This will only work on landings that have large storage areas for biomass, or small volumes of biomass arising.

Self-loading trucks would typically be used to pick up material from a landing after the logging crew has left, as self-loading trucks are slower in loading, and suffer from a tare weight penalty, due to the weight of the crane and stabilisers.

7.5.2 Post-harvest recovery system

With this option, storage and drying of raw material on the landing is possible, determined by timing of the recovery operation after harvesting. All wood flow options discussed earlier are available with post-harvest recovery as there is no interference to harvesting operations:

- Recover / pile on landing / truck direct to end user / hog or chip to wood fuel storage
- Recover / pile on landing / truck to CPY / hog or chip at CPY / truck wood fuel to end user
- Recover / pile on landing / hog or chip at landing / truck wood fuel via CPY or direct to end user.

There are two alternative approaches to post-harvest recovery of woody biomass: the logging crew can either stack or log the raw material prior to post-harvest recovery, or not.

Figure 55: Grapple loader feeding hogger.

On easy terrain, the raw biomass material produced during log-making is pushed off the landing regularly and the material is piled up around the edge of the landing. Salvage of the material is relatively straight-forward, as an excavator loader with a modified grapple (Figure 55) can be used to extract the material from the landing surrounds and swing/throw it towards the centre of the landing. The woody biomass will then be either loaded into a truck for transport to point of processing or piled for on-site processing.

In steep terrain, where hauler operations have not stacked or presented the raw material, salvage is often very difficult. Landing residues are frequently pushed over the side of the landing where they are difficult to access and recover (see also Figure 52). Salvage operations are sometimes used, but the proportion of the material that can be retrieved is reduced and using a heavy machine on soft soil around landing edges can be hazardous.

It is preferable to have the landing residue handled in such as way as to enable the maximum volume to be recovered and to keep the material clean.

Recommended handling methods include:

- raw material should be piled rather than pushed across the ground
- piles should be formed in a way that allows ready access and direct loading into either trucks or chippers/hoggers
- double handling should be avoided
- the area of the pile should be minimised by stacking as high as possible.

A landing servicing a harvest area of 15 hectares may have more than 7500m^3 of logs extracted, which may create about 400m^3 of woody biomass, requiring a pile of 1600m^3 in total volume. If the material was piled 6m high it would require an area of roughly 800m^2 (a circular area of 32m diameter). This is equivalent to 40% of the area of a typical cable logging landing of 50m diameter, or 2000m^2.

7.6 Recommendations

The large space requirement for storage of woody biomass restricts the usefulness of the post-harvest recovery option.

The challenges in post-harvest recovery include:

- scale (affecting fuel collection and feedstock production costs)
- steep terrain and operation on small landings (affecting mobility and processing costs)
- moisture content and timing of biomass processing (affecting energy cost in $/GJ)
- contamination (affecting fuel quality)
- trucking distances from forests to end user (affecting transport/delivery costs).

8. System productivity and costs

8.1 Introduction

The cost of operating a wood fuel production system is high and the value of the wood fuel product relatively low. A large chipper will cost upwards of $400 per hour to run, and biomass recovery operations are often plagued by delays. A clear focus on efficient and cost-effective production is essential for any successful wood fuel contractor.

Some basic principles include:

- the contractor should have a good understanding of how different site and residue characteristics affect system productivity
- detailed costings should be undertaken before an operation commences or a contract signed
- simple systems that minimise handling costs are cheaper
- systems that incorporate a drying stage will deliver cheaper energy but at a higher cost per tonne
- wood fuel production targets must be realistic and allow for adequate machine maintenance and repair time, as well as operational delay time.

For a contractor to calculate an appropriate rate for the delivery of wood fuel, they must know, or at least be able to estimate, two parameters:

- System cost ($/hour)
- System productivity (t, m^3 or GJ/hour)

Productivity is the rate at which products are produced per unit of input (often described by $ or machine hours). There are a number of published studies on recovering wood fuel from landings as well as comminution into end-products. Such studies often establish the maximum potential of a machine under a given set of conditions. As each site and system is different, a contractor needs to interpret the outcome relative to their specific conditions.

Most wood fuel delivery contracts will be negotiated as a rate ($) per unit of product delivered. The actual, or estimated, rate can be obtained by dividing the system cost by the system productivity.

For lower quality fuels (such as bin wood or hog fuel) that unit may be the weight in tonnes. With a weight-based system both supplier and purchaser are potentially disadvantaged, depending on the moisture content of the product.

For higher quality fuel (such as wood chips), where the fuel must meet specific standards, it will probably be based on volume. The volume of material (in m^3) produced over a given time period through a particular process (hogger or chipper) will be much the same, regardless of the moisture content. It also takes much the same amount of work to process (by hogger or chipper) a certain volume of woody biomass regardless of the weight of material going into the hogger.

The impact of this on production and cost is that the production rate of one cubic metre of dry biomass is about the same as that for one cubic metre of green biomass. But if paid by tonnage the return to the fuel processor will reduce as the material dries, and it will take more volume (m^3) of raw material (and more time) to make a tonne.

This highlights the need for contractors to understand the moisture content of the woody biomass, how it varies in different biomass fuels, and the cost of processing in volume terms as well as in weight terms.

8.2 Impacts on productivity

8.2.1 Utilisation

A common concept by which to measure operational efficiency is utilisation. Utilisation refers to the ratio of time a machine is actually working (productive machine hours or PMH) as a proportion of the number of hours a machine is on-site and scheduled to work (scheduled machine hours, or SMH). This ratio has a big impact on both actual production and costing.

In a well-designed logging system, machinery will typically achieve somewhere between 70-85% utilisation. For the in-forest comminution machines studied as part of this project the highest level of utilisation was only 35%.

The causes of low utilisation or, in other words, a low number of PMH, can be categorised into three types of delays (*Spinelli and Visser, 2009*): mechanical delays, operational delays and social delays.

8.2.2 Mechanical delays

Figure 57: A tub grinder opened up for maintenance on the hammers.

Mechanical delays are defined as all delays where the machine is either being repaired or maintained, i.e. the machine is not available to work (Figure 57). Biomass recovery and comminution of residues is very hard on machines. Depending on the age and type of machine, mechanical delays are typically 10-35% of the SMH. For the studies completed as part of this project, the average operational delay was 27%. In addition to the cost of non-productive time, repair and maintenance costs per annum may run between 10-35% of the new value of the machine.

8.2.3 Operational delays

Operational delays are defined as those that occur when the machines are available to work but are not producing because the machine is being delayed by other parts of the operation. An example of an operational delay may be where an excavator retrieving the residue is waiting for the harvesting crew to move. For a chipper, an example of a typical operational delay is getting the truck positioned. For trucking, a typical operational delay may be waiting to be loaded at the landing. Operational delays can often be 10-30% of a scheduled work day.

8.2.4 Social delays

Social delays are normally the shortest delays, typically in the range of 8-12% of SMH. This includes delays incurred by the operator, for example, lunch or work breaks, interaction with the forest owner, or supervision instructions. These delays are common to most operations.

8.3 Estimating productivity

Many logging systems are scheduled to operate 2,000 hours per year, achieve utilisation of 70-85%, and are costed accordingly.

Most wood fuel production contractors will not have continuous work for their machinery. Although machines at a CPY may operate multiple shifts and exceed 2,000 hours per year, many mobile machines will only have work for less than 1,000 hours per year.

For example, a large-scale chipper can produce 45 tonnes/hour when working with trees or stems. When working with typical landing residues the maximum productivity is closer to 25 tonnes/hour. If we add up the averages of the three types of delay: Mechanical (27%) + Operational (20%) + Social (8%) = 55% Total Delays. This means the machine is only operating for 45% of the scheduled time (i.e. utilisation = 45%). At 25 tonnes/PMH, the expected production for an 8 SMH day is only 90 tonnes per day.

8.4 Costing

Detailed system costings should be undertaken before any system is put in place. A useful description of costing methodology, as well as costing templates, can be found in the *Business Management for Logging handbook* (Blackburne, 2009).

Accurate costing needs to systematically account for all aspects of the operation. This will include the cost of:

- raw material (stumpage)
- machinery for extracting and piling it
- machinery for comminution
- machinery for handling and loading
- labour and vehicle costs
- storage costs
- transport of machinery
- distribution costs to customer
- operating supplies
- overheads
- profit and risk.

For costing out machinery, most costing models use the concept of fixed or variable costs. Fixed costs are those costs that do not change whether or not the machine is operating. These include interest costs, operator costs, insurance, vehicles and overheads. Variable costs are those that change with the number of hours the system is running. These include depreciation, fuel and oil costs, repairs and maintenance. This is why maximising utilisation is essential, as machines and systems have real costs even when they are not running.

A New Zealand forest consultancy surveys and updates a daily machine rate estimate book (INFORME[1]). It is designed for the logging workforce and includes loaders, excavators and labour, but does not have rate estimates on comminution machinery or transportation.

8.5 Interacting with the harvesting contractor

Logging crews typically get paid on a $ per tonne basis, which is derived from the daily cost of running the crew and the expected daily production for the specific harvest area they are working. There are clear benefits for a wood fuel production operation if the harvesting contractor stacked the residue, made an effort to keep it contaminant-free, and facilitated the collection of the residue during harvesting.

The additional work involved in collection of woody biomass could require additional machinery or could reduce daily production due to additional work for loaders. This impact should be recognised in the form of payment. Such payment could take on a number of different forms.

There are three payment options suggested, where the harvesting contractor is paid for:

- the extraction and storage of woody biomass as part of the regular logging rate
- handling and loading the residues, which is independent of the logging rate
- the increased work and volume produced, by adjusting the logging rate.

[1] FORME Consulting Group Ltd – www.forme.co.nz

8.6 Energy content and payment

A significant issue for wood fuel contractors is the method of payment. Currently woody biomass is generally paid on a weight basis (tonnes). The wood processing industry is well equipped to pay for material by weight, as that is generally how it buys logs and pays for log transport.

One of the findings in the *FIDA Engineering Solutions Project* (Hall and Evanson, 2007) was the potential to improve the efficiency of wood fuel delivery systems by paying for the fuel by energy content rather than using the traditional weight-based systems. The basis for this is:

- Wood fuels have varying moisture content, and therefore varying energy content per tonne, creating uncertainty in the market.
- Seasonal effects, such as drying over summer, can disadvantage suppliers with a weight-based payment system as the supplier is paid less for the same volume processed and delivered.
- Buyers would also be disadvantaged by seasonal effects. Fuels produced in wet conditions are typically wetter, heavier, and have lower energy content per tonne, but with a weight-based system the buyer pays more for the same amount of energy delivered.
- The purchaser could predict how much fuel he would need to buy to drive a specific process or meet a specific energy demand.

Moving to a system that pays by energy content could lead to delivery of a better (drier and cleaner) and more consistent quality fuel, thus helping to overcome one of the barriers to increased use of wood residues as a fuel.

8.6.1 How to calculate energy content

The measurements required for a system of payment by energy content are:

- weight of the load
- moisture content.

The calculation of energy content is done by sampling the loads for moisture content and using the relationship between moisture content and energy content to derive the energy content in GJ/tonne and applying that to the weight (mass) of the individual load.

Sampling for moisture content is relatively cheap, and there are a number of methods available. Hand-held moisture meters are very quick, but not accurate on green wood. European facilities will often sample using a chainsaw with a catch bag, making multiple bore cuts into the logs to take a representative sample. These wood chips are easily weighed and dried, and reweighed to establish moisture content.

If a set price ($/GJ) is agreed for the wood fuel, sampling for moisture content can determine the price paid for the wood fuel to ensure that neither the contractor nor the customer is disadvantaged at any time.

In Appendix 1, Table 3 shows the value per tonne of wood fuel for varying moisture content, based on a fixed price per GJ of energy. In this way, a contractor can determine its break-even price for wood fuel over a range of moisture content and negotiate the price paid per GJ for the fuel.

8.6.2 Example of payment by energy content

The following example shows the impact of varying moisture content on wood fuel price if payments were based on energy content.

Firstly, the density of the woody biomass (in kg/m^3) is calculated by dividing the density of oven dry wood (440kg/m^3) by the % solid wood content of the woody biomass x 100.

Then the energy content of the woody biomass is calculated, given the moisture content of the wood (using the equation detailed earlier):

Energy (GJ/t) = 18.9 - 0.213*MCwb

At 55% MCwb, % of solid wood content is 45% or 0.45 and density of wood fuel is 978kg/m^3 (= 440 / 0.45). The energy content of the wood is 7.14GJ/tonne.

If a contracted rate of $4.50/GJ is agreed for wood fuel processing then the wood fuel price is $32.15/tonne (= 7.14GJ/t x $4.50/GJ).

If the fuel dries to 45% MCwb density reduces to 800kg/m^3 (= 440/0.55). That is, 22% more volume is required to get a tonne of wood fuel. The energy content, however, increases to 9.28GJ/tonne.

If the contractor is paid by energy content, his payment increases from $32.15 to $41.76/tonne of fuel (= 9.28GJ/t x $4.50/GJ) to cover the additional volume processed.

8.6.3 Example of payment by weight

If, however, the same contractor is paid by the tonne (at the original rate of $32.15/tonne), the contractor produces the extra volume required to make each tonne of wood fuel for no additional payment.

The rate per GJ reduces from $4.50/GJ to $3.46/GJ (= $32.15/t / 9.28GJ/t), which is effectively the same as a contracted price of $24.75 per tonne (= 7.14GJ/t x $3.46/GJ), i.e. the energy contractor is under-paid.

The fuel buyer on the other hand, receives the extra energy content of the drier wood for the same cost, effectively reducing their delivered cost from $4.50/GJ to $3.46/GJ/t.

This highlights the risk associated with paying by weight rather than energy. The variations may balance out, but if the fuel is consistently drier than the assumed average (and fuel dries out over time) the fuel producer will get paid less.

In fact, paying for wood fuel by weight acts as a disincentive for wood fuel producers (contractors) from delivering a drier, cleaner product, which is what fuel users all want.

Payment for transporting wood fuel has the same issue. The energy content per unit of weight rises as moisture content (and density) drops. Payment by delivered tonne may not be appropriate, especially for material where the moisture content is variable. Other measures (volume) are possible but unless the load volume and density are consistent, this can also lead to under- and over-payment. The best method is to pay by energy where a combination of payload (weight) and moisture content are used to determine the energy content of the load and payment is made for the material on this basis.

8.7 Recommendations

It should be noted that the bioenergy cost ($/GJ of useful energy output) is particularly sensitive to:

- wood fuel harvesting and collection costs
- moisture content
- energy content (including contamination issues)
- wood fuel production costs (including capital costs)
- transport/delivery distance, load characteristics and costs
- competition for wood fuel from fibre markets
- future climate change policy costs
- conversion efficiencies (depending on energy process).

Green woody biomass has a relatively low energy content (6-8GJ/tonne), which adds additional costs of transport, storage and handling and hence increased costs/GJ.

9. Case studies of wood fuel production systems

As part of this project, a series of case studies were completed on existing successful wood fuel contractors. The full report on the four systems can be viewed at the BKC website. A brief summary of three operations is given here, and we gratefully acknowledge the cooperation of the contractors.

9.1 Case Study 1: Hogging at a super-skid in Canterbury

Contractor: Burnside Contracting Ltd, Christchurch

Figure 58: The excavator retrieving and piling the larger residue. The pile was then hogged through the tub grinder.

This post-harvest hogging operation involved recovering biomass from old super-skids. It was a one-man operation, mainly using an excavator with a root rake, with two alterative grapples available depending on the raw material being processed. The residue was hogged by a Diamond Z tub-grinder into a hog fuel to the ground (Figure 58), and the hogger was operated remotely from the excavator. A front-end loader with bucket was used to pile the hogged material, as well as load out the trucks. The loader was operated by the truck driver. Delivery was by chip truck and trailer with a payload of 27-29 tonnes (see Figure 44). The distance to market was less than 60km from all locations.

The success of this operation was based on the very large volumes of biomass available at the old super-skids. Up to 2,000 tonnes was at individual landings, but much of it was old (>12 months) and some buried up to three metres deep.

As part of the study a comparison was made comparing the piece size distribution between hogging green and old material. The old (partially buried) material had moisture content very similar to the fresh material at 55%. The main finding was that the fresh material reduced the percentage of fines in the hog fuel. A comparison was also made with the machine hogging whole trees (clearing a shelterbelt), and this greatly improved the productivity and the utilisation of the hogging machine.

The productivity of the system ranged from about 50 to 100 tonnes per day, but the potential for the tub-grinder is far greater for more favourable conditions. System cost was estimated to range between $2,750 and $3,400, depending on the utilisation rate of the hogging machine. The average cost of recovery, hogging and transportation was calculated to be $45/tonne. This equated to $6.50/GJ.

9.2 Case study 2: Recovering wind-throw and landing residues in the Bay of Plenty for firewood

Contractor: Shane Hooker Ltd, Rotorua

Figure 59: Recovering biomass from the landing and cutover and loading it into a bin truck.

This operation focused on the recovery of larger length log residues. The market for this wood was either for subsequent chipping and pulping at a mill, or for a firewood processing plant. The distance to market ranged from 25-100km. The system consisted of a single excavator with grapple, and matched with either a bin truck (Figure 59) or a logging truck configured for short logs. The spread of the residue material meant that the majority of the time was spent shovelling either to the landing or to the roadside, and only 10-15% of the time was actually loading out the trucks.

A self-loading truck was also used depending on availability and destination (Figure 60). The average payload for the self-loading truck was 24 tonnes, only slightly higher than that achieved in the bin trucks of 23.5 tonnes.

Figure 60: Self-loading truck.

The success of the operation was based on the owner identifying, and only working on, landings where enough quality residue was present to make the move of the equipment cost-effective. The owner suggested this was at least 200 tonnes per landing.

The productivity of the system ranged from 50-75 tonnes per day. System cost was estimated to range between $1,850 and $2,175, depending on the utilisation of trucks. The average cost of recovery and transportation was calculated to be $28-32/tonne. The wind-thrown residues had dried somewhat, with an average moisture content of 45%. This equated to $3.55/GJ, but note that this price excluded the cost of comminution to either pulp chips or firewood.

9.3 Case study 3: Integrated residue recovery for firewood in Otago

Contractor: Gillion Logging Ltd, Waikouaiti

This one-person operation was integrated with the harvesting activities in the area (same contractor). It was semi-mobile and located on suitable old landings that were located near to the logging operations. It was based on a small truck frequently recovering the residues on the operational landings. However, a preference had developed for moving larger log piles from the active landings with a self-loading logging truck. The logs were stacked on the firewood landing, processed into fuel wood through the firewood machine, and then moved by conveyer directly into the small truck (Figure 61).

The firewood pieces were then tipped onto the ground for drying. After about 4-6 weeks, a second excavator was used to turn the firewood over and create a larger pile (Figure 62). This benefited the drying, and also minimised the impact of rainfall. The short truck was then used to deliver orders for firewood to residential and small commercial customers.

The basis for the success of this operation was the integration with the logging operations, good cooperation with the forest owner, and being able to deliver a high quality fuel wood into a well-established firewood market.

The average productivity of the firewood machine was just over 12 t/PMH. The optimum log diameter for the firewood machine was 50cm. At the optimum the firewood machine was able to produce 20 t/hr, with a steep decline for both smaller and larger logs (due to double handling). Loosely stacked firewood has a density factor of 0.5. The average round-trip for loading and delivery was about two hours. The cost of running this operation $1240/day, average production was about 30m^3 (15 tonnes). The moisture content of the delivered firewood was 18%, which is very low and reflects the good wood fuel drying system. This equated to $5.54/GJ delivered.

Figure 61: In-forest firewood operation in Otago.

Figure 62: Excavator with a tined bucket, used to both pile for drying, as well as load out firewood.

10. System costing examples

For larger-scale commercial operations, the following costing examples may be of interest. The costs are broken down by the steps of the operations, and the assumptions shown. Note that the raw material in each example has been given a value of $20/tonne for payment to the forest owner.

Assumptions;

Interest rates 11%, Diesel $0.98 per litre, Wages $18.00 per hour.

Forest residues without drying = 6.5GJ per tonne, 6.2GJ per m^3 of solid wood.

Distance to CPY = 10 km, transport distance for product delivery = 70 km.

1. Set-out bins / truck to CPY / hog and screen / truck to user (costs in $/tonne):

Fill bins	$3.50
Truck to CPY	$8.00
Hog + screen	$18.30 (hog to ground)
	($14.65 no screening)
Reload	$5.00
Truck to user	$14.70
Wood cost	$20.00
Total	**$69.50 per tonne**
	$10.70 per GJ

If the material is hogged directly to truck the cost would reduce slightly to $64.50 per tonne or $9.95 per GJ.

2. Set-out bins / truck to CPY / store and dry for four months / hog and screen / truck to user (costs in $/tonne):

Fill bins	$5.90
Truck to CPY	$13.50
Interest cost	$0.50 (stored material)
Hog + screen	$30.80 (hog to ground)
	$14.65 (no screening)
Reload	$8.40
Truck to user	$24.75
Wood cost	$20.00
Total	**$103.85 per tonne**
	$9.10 per GJ

The difference between example 1 and 2 is that in example 2 material has been dried. The cost per tonne rises, but cost per GJ falls. The fuel is more likely to be marketable at the lower moisture content, as it will meet the needs of a wider range of users. However, it is imperative that the dried material be sold by the energy content, not the weight.

3. Piled by logging crew / load-out / truck to user / hog to fuel pile (costs in $/tonne):

Pile	$ 2.90
Load	$ 3.50
Truck to user	$19.60
Hog to fuel pile	$14.65
Wood cost	$20.00
Total	**$60.65 per tonne**
	$9.35 per GJ

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4. Recover from landing surround / pile / load-out / transport to CPY / hog and screen / load out / transport to user

Recover	$4.20
Load	$3.50
Truck to CPY	$8.00
Hog + screen	$18.30 (hog to ground)
Load out	$5.00
Truck to user	$19.60
Wood cost	$20.00
Total	**$78.60 per tonne**
	$12.10 per GJ

For online estimates of production cost see: **http://www.bkc.co.nz**

11. Glossary of terms

Ash content	Chemical residue formed when organic compounds are burnt or decomposed; ash contains minerals, oxides, salts and metals. Wood ash is slightly alkaline.
Biomass	Widely-used term for organic material used for generating energy (e.g. grass, straw, wood).
BTF	The process of converting biomass to fuel.
Chip	Wood chips made from processing wood through a chipper.
CHP	Combined heat and power plant ('co-generation') where both heat and electricity is generated.
Comminution	Reduction in size, usually by chipping, grinding, hogging or shredding.
CPY	Central processing yard.
Cut over	Forest land where the trees have been cut down and or extracted.
Extraction	The process of removing felled trees from the cutover to the landing.
Fossil fuels	Non-renewable fuels such as coal, petrol, diesel, liquid petroleum gas and natural gas, created through geological processes over millions of years.
GJ	Gigajoule, a measure of energy content = 1 billion (109) joules or 277.8 kWh.
Green tonne	One green tonne of wood (NZ average for pine is 58% MC) yields approximately 6.5GJ of energy.
Hog fuel	Wood that has been mechanically broken down in a hogger and is suitable for burning in a large scale boiler.
Landings	Area in a forest where trees are extracted to and landed and processed into log products (also referred to as a 'skid').
Logging	Process of harvesting trees and processing them into logs, delivered to a destination.
m^3	Cubic metre, a measure of volume measuring 1.0m x 1.0m x 1.0m.
MCwb	Moisture content (wet basis) = weight of water in sample divided by the wet (green) weight.
MCdb	Moisture content (dry basis) = weight of water in sample divided by the dry weight of wood
ODT or ODMT	Oven dry (metric) tonne. One ODT of wood has 0% moisture content and yields approximately 18.9GJ.
Pellets	Wood fuel made from dried, compressed and reconstituted sawdust and wood shavings.
Semi-trailer	A trailer that has just one set of axles, and the other end a tow hitch connected to and supported by the truck.
Shovel	An excavator-base machine with a grapple that is used to 'shovel' wood in stages either into piles or to a landing.
Shredded wood	Comminuted wood that is longer and stringier than hog fuel, produced by a shredder.
Sloven	Short lengths of stem wood created when the rough end of a felled tree is cut off.
Stem wood	Wood from the bole, or the trunk, of tree.
Wood fuel	Wood products available for energy production: in the form of pellet, chip, hog fuel or firewood.
Woody biomass	Biomass resources comprising forest residues, processing residues and forest crops.

12. References

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Residue Recovery Costing Tool:
http://www.bkc.co.nz

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Wood boiler Fuel Payment by energy versus weight:
http://www.bkc.co.nz

Wood Fuel Classification Guidelines. BANZ 2009-07-22:
http://www.bkc.co.nz

13. Appendices

Appendix 1: Table for calculating wood value given energy value and moisture content

	Energy Value ($/GJ)										
Moisture Content (% w.b.)	$ 2.50	$ 3.00	$ 3.50	$ 4.00	$ 4.50	$ 5.00	$ 5.50	$ 6.00	$ 6.50	$ 7.00	$ 7.50
0	47.18	56.61	66.05	75.48	84.92	94.35	103.79	113.22	122.66	132.09	141.53
5	44.51	53.41	62.31	71.22	80.12	89.02	97.92	106.82	115.73	124.63	133.53
10	41.85	50.21	58.58	66.95	75.32	83.69	92.06	100.43	108.80	117.17	125.54
15	39.18	47.02	54.85	62.69	70.52	78.36	86.20	94.03	101.87	109.70	117.54
20	36.52	43.82	51.12	58.42	65.73	73.03	80.33	87.64	94.94	102.24	109.55
25	33.85	40.62	47.39	54.16	60.93	67.70	74.47	81.24	88.01	94.78	101.55
30	31.19	37.42	43.66	49.90	56.13	62.37	68.61	74.84	81.08	87.32	93.56
35	28.52	34.22	39.93	45.63	51.34	57.04	62.74	68.45	74.15	79.86	85.56
40	25.86	31.03	36.20	41.37	46.54	51.71	56.88	62.05	67.22	72.39	77.57
45	23.19	27.83	32.47	37.10	41.74	46.38	51.02	55.66	60.29	64.93	69.57
50	20.53	24.63	28.74	32.84	36.95	41.05	45.16	49.26	53.37	57.47	61.58
55	17.86	21.43	25.00	28.58	32.15	35.72	39.29	42.86	46.44	50.01	53.58
60	15.20	18.23	21.27	24.31	27.35	30.39	33.43	36.47	39.51	42.55	45.59
65	12.53	15.04	17.54	20.05	22.55	25.06	27.57	30.07	32.58	35.08	37.59
70	9.87	11.84	13.81	15.78	17.76	19.73	21.70	23.68	25.65	27.62	29.60
75	7.20	8.64	10.08	11.52	12.96	14.40	15.84	17.28	18.72	20.16	21.60

Table 3: Value per tonne of wood fuel for varying energy value ($/GJ) and moisture content (%).

Appendix 2: Useful industry contacts

Hogger Equipment Manufacturers

Screening & Crushing Systems Ltd (SCS)
Greywacke Road, Harewood, P O Box 6092, Christchurch 8050
Phone: (03) 359 1891
http://www.scsnz.co.nz

Woodweta, Progressive Equipment Ltd
PO Box 10040, 38c Northway Street, Te Rapa, Hamilton 3200
Phone: (07) 849 0999
http://www.woodweta.co.nz

Universal Refiner Corporation
PO Box 151 Montesano, WA 98563 USA
Toll-Free Number: (800) 277 8068
Local Number: (360) 249 4415
Fax Number: (360) 249 4773
http://www.universalrefiner.com

Morbark New Zealand
Box 1312, 27-29 Maisey Place, Rotorua 3015
Phone: (07) 348 0356
Fax: (07) 346 3433
http://www.morbark.com

Wood Pellet Manufacturers

Golden Strand Ltd
74 Patiki Road, Avondale, Auckland
Phone: (09) 828 8948

Wood Pellet Fuels
364 Lumsden Rd, Ohinewai
Phone: (09) 236 0075
Physical address of mill:
Lumsden Rd, Ohinewai, Huntly

Firelogs (NZ) Ltd
PO Box 2401, Stortford Lodge, Hastings
Phone: (06) 879 8151
Physical address of mill:
Manchester Street, Flaxmere

Natures Flame
PO Box 11-259, Christchurch
Phone: 0800 735 538
Phone: (03) 342 9920
Physical address of mill: Vaughan Rd, Rotorua
Physical address of mill: Hoskins Rd, Rolleston

Southern Wood Pellets
Phone: (03) 235 8424
207 Branxholme-Makarewa Rd, Branxholme, Invercargill

14.3 Energy Contractor Contacts

Burnside Contractors
Christchurch
Contact: John Taylor
Phone: 027 432 9930

Central Wood Recyclers Ltd
Tokoroa
Contact: Noel Richmond
Phone: 027 481 3140

Ernslaw Bio-Energy
Central Otago
Contact: Murray Cowan
Phone: 021 393 141

Materials Processing Ltd
Hamilton
Contact: Peter Frederickson
Phone: (07) 823 0086

Plateau Bark Ltd
Kawerau
Contact: Terry Robinson
Phone: 027 270 9647

Shane Hooker Ltd
Rotorua
Contract: Shane Hooker
Phone: (07) 345 7729

Wholesale Landscapes Ltd
Nelson
Contact: Ferg Brewerton
Phone: (03) 547 5300

For further information:

There are several valuable sources of information for wood energy training, education and research in New Zealand. These include:

FITEC (the forestry industry training organisation) - www.fitec.org.nz

Future Forests Research - www.ffr.co.nz

New Zealand School of Forestry (UC) - www.forestry.ac.nz

Scion Research - www.scionresearch.com

Waiariki Institute of Technology - www.forestryschool.ac.nz

For further general information about the forestry industry in New Zealand and best practice, see:

Environmental Code of Practice - www.fitec.org.nz/COP/Part1.htm

Forest Industry Contractors Association - www.fica.org.nz

Ministry of Agriculture and Forestry - www.maf.govt.nz/forestry

New Zealand Forest Owners Association - www.nzfoa.org.nz

New Zealand Institute of Forestry - www.nzif.org.nz

Sources of general information for business may also be useful, which can be accessed via the Biz service website (www.nzte.govt.nz/biz) and www.business.govt.nz. Business advice for Maori can be found at www.tpk.govt.nz/en/services/business

This guide was developed by Rien Visser, University of Canterbury; Peter Hall, Scion; and Keith Raymond, Raymond Management Services Limited.

EECA Business thanks the authors and other contributors for their input.

For more information contact The Energy Efficiency and Conservation Authority:

EECA HEAD OFFICE:
PO Box 388, Wellington, (04) 470 2200

EECA AUCKLAND:
PO Box 37444, Parnell, Auckland, (09) 377 5328

EECA CHRISTCHURCH:
PO Box 13983, Christchurch, (03) 353 9280

www.eecabusiness.govt.nz

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