Storage Guidelines
for
Wood Residues
for
Bioenergy

SCION
Next generation biomaterials

EECA
Energy Efficiency and Conservation Authority
Te Tari Tiaki Pūngao

Prepared by

Peter Hall
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For

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Summary

Forestry and wood processing residues are a potentially significant source of bio-energy fuels.

For a variety of reasons storage of these materials prior to utilisation is often necessary. The storage of comminuted (chipped, hogged, shredded or reduced to small particle size by other means (sawing or sanding)) biomass, particularly fresh (green) material such as logging residues can lead to degradation of the fuel due to biological and thermo-chemical processes.

Factors that significantly affect the incidence and rate of degradation are; the moisture content and composition of the material, the particle or piece size, the size and shape of the storage pile, air flow through the pile and the length of the storage period.

A review of literature is summarised here to describe the processes that can improve or degrade the fuel and recommendations are made on fuel storage strategies.

Risk factors identified that promote degradation are:
- moisture content of comminuted residues between 25% and 50% wet basis
- pile heights of over 6 m
- storage of comminuted residues for long periods

Recommended strategies to avoid risk of degradation are:
- minimise length of storage period for comminuted residues
- store residues in uncomminuted form where possible
- reduce pile size (height especially)
- for long periods of storage; dry the material before storage and keep it under non-contact cover

Comminution of the residues substantially changes the storage properties, generally for the worse; hence comminution should be delayed as long as is practically possible.

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Introduction

A key issue in the use of wood residues as bioenergy fuels is storage of the fuel before it is used. Some of the issues within this are how long, where and in what form to store the residues. These are complex issues as the wood residues used as bioenergy come in a variety of forms and from a range of sources and locations. Before it can be used it often has to be aggregated and homogenised.

These guidelines will address the major sources of wood residues that are likely to be used and then outline some of the issues relating to these residues. Some of the fuels are similar and can be handled in the same way, some are quite different in their nature and composition, and subsequently require some special treatment in terms of how they are stored.

There are some fundamental principles that apply to any woody biomass fuel, these are:

- minimising moisture content is the most significant factor (Nurmi 2000) as moisture content determines the net calorific value of the fuel.

- long periods of storage of comminuted fuels should be avoided, in order to minimise dry matter losses and wetting of the feedstock from fungal and bacterial microbial activity, respiration of live tissue and rainfall.

Moisture content of woody residues can be manipulated to some extent by the organisation of the delivery system, particularly the timing of the comminution, and the length of the storage period prior to comminution, including cases where the residue is still in large pieces (Hall 2000).

Long term storage of comminuted woody biomass can lead to significant dry matter losses, reductions in net energy content, pile fires and respiratory problems amongst workers involved in fuel handling (caused by fungal spores) (Nurmi 1995, Thornqvist 1987, Thornqvist and Jirjis 1990).

The decomposition of woody biomass converts the wood into water, CO_2 and heat. None of these are desirable in the pile or the environment (CO_2) so the fuels and piles of residues should be managed to minimise these.

Whilst the avoidance of large-scale long-term storage of residues is the obvious course of action, there are issues that dictate that some storage is necessary; principally that the production of the residues may be out of step with the demand for the fuel. Many fuel users also carry a small stockpile of fuel to avoid overly frequent delivery, and fuel producers need to have a stockpile of material in order to be able to meet unplanned customer demand. There is often a need to have a stock/surge pile to allow for disruptions in the supply chain.

During the storage of the residues there will be effects on the total energy content of the piles. This is the net effect of changes in moisture content and any dry matter losses.

For example:

- if a pile has a significant drop in moisture content with minor dry matter losses the total energy in the pile increases slightly,
- however, if the pile has no moisture content change and significant dry matter loss then the total energy will decrease substantially.

In-forest residues

In-forest residues consist of clear-fell logging residues, production thinning residues and waste thinning residues. All these sources are comprised of stem wood, branches and needles often with a proportion of dirt contamination, which should be minimised as much as possible.

<u>Landing residues</u>

Figure 1 - Pile of stem-to-log processing waste at a logging landing, mix of branches, heads, stem off-cuts and needles (Mechanised processing).

	Wood	Bark	Needles	Soil
Comminuted	80.7	18.4	0.3	0.6
Raw Residue	81.7	17.6	0.4	0.3

Table 1 – Percentage composition of landing residues, (Hall 2000)

The largest and most accessible sources of in-forest residue come from the clear-fell logging residues. This material occurs at two locations, at landings (roadside) (Figure 1) and at the stump (cutover) (Figure 7). This material is a mixture of wood, bark and needles (Table 1).

When this material is “green” immediately after harvesting the moisture content (MC) is likely to be around 55% MC wet basis (wb) and could be as high as 60% MC wb (Figure 2), (Hall 2000).

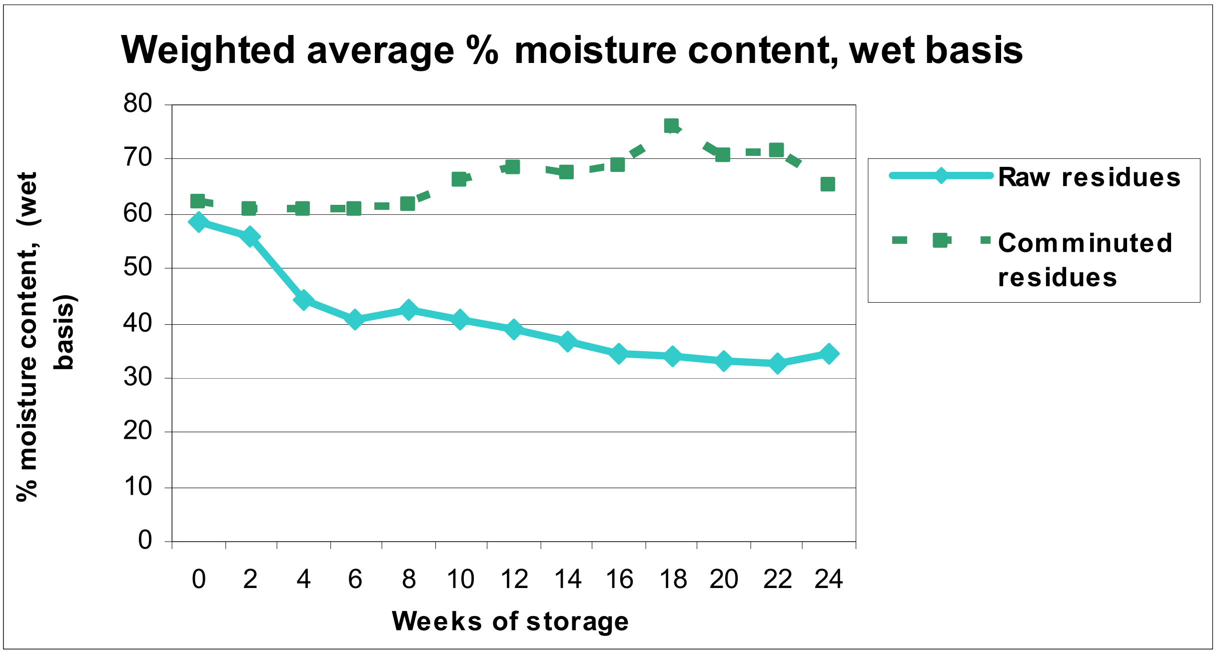

Figure 2 – Changes in moisture content over time in stored residues

Stem to log processing residues produced at a logging landing (Kinleith Forest) which were stored in two forms (comminuted and unprocessed pile) and tested for changes in moisture content showed that the comminuted residues absorbed moisture and the unprocessed or raw residues dried (Figure 2).

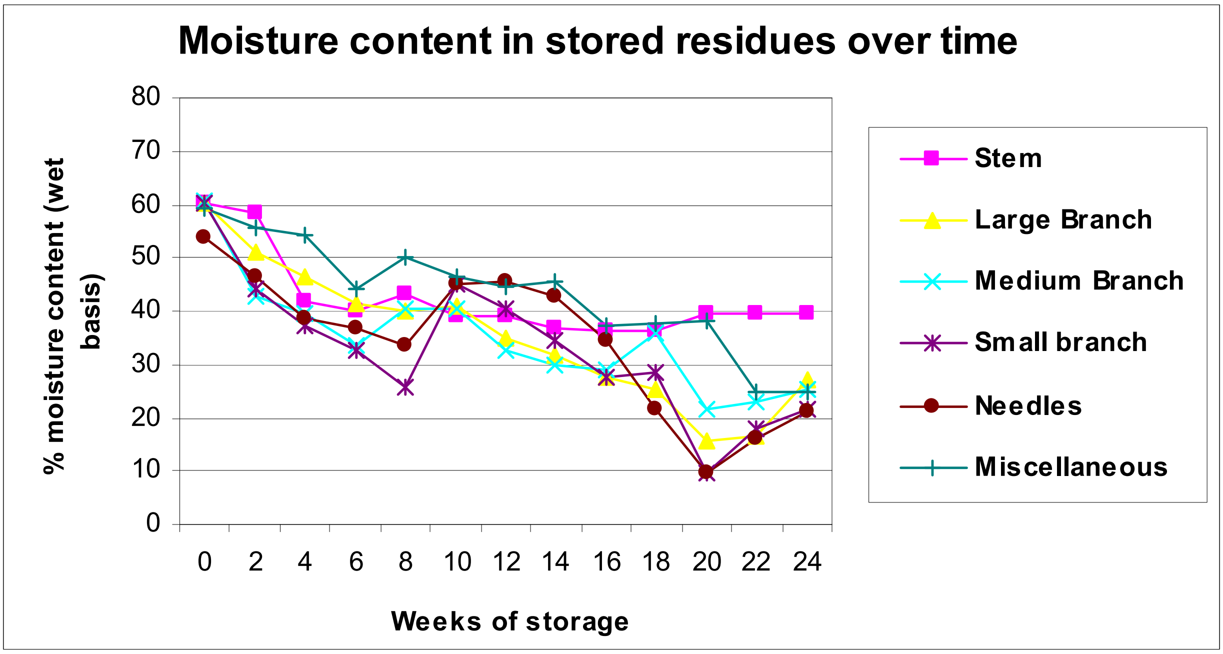

Figure 3 – Changes in residue moisture content by component.

The smaller diameter components (branches) of the residues dried more than the larger diameter stem wood sections (Figure 3). The miscellaneous material is a mixture of loose bark, small pieces of broken wood, sawdust, cones and needles.

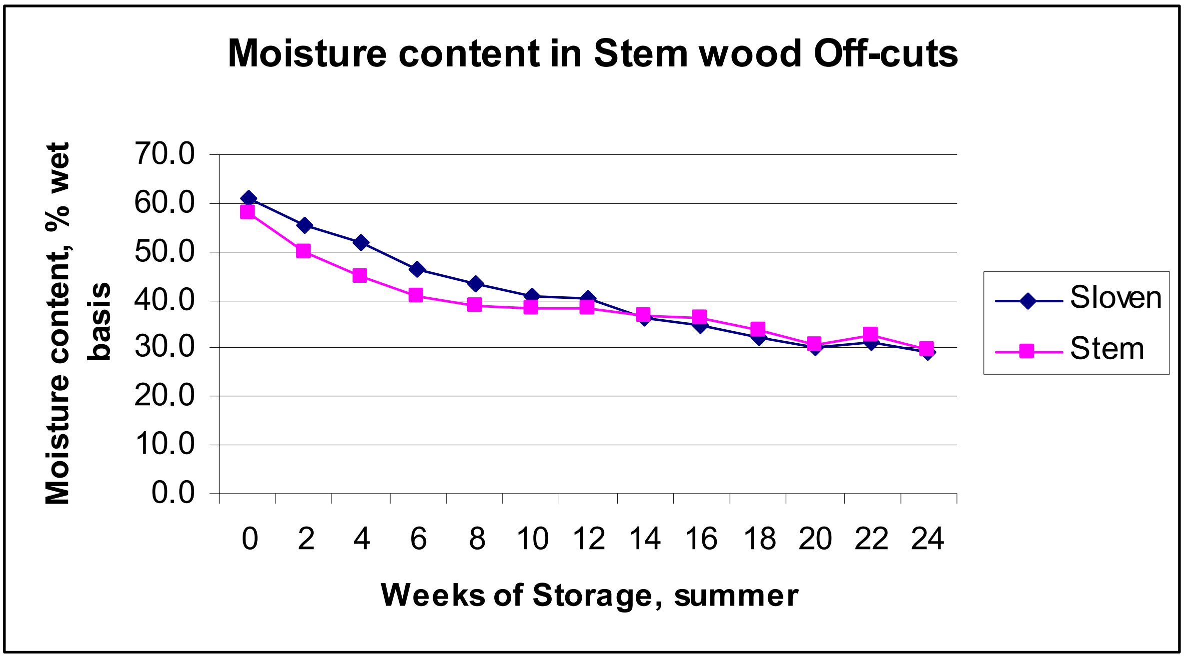

Figure – 4. Moisture content change in sloven and stem sections stored in exposed conditions

The data presented in Figure 4 shows the maximum likely amount of drying from larger pieces of logging residues such as slovens and other stem wood off-cuts. This material was stored as individual pieces, with no ground contact. They dried from ~ 60% MC wb to ~ 30% MC wb over 24 weeks in summer. Stem sections in the residue pile, at the same site dried to 40% MC wb over the same period.

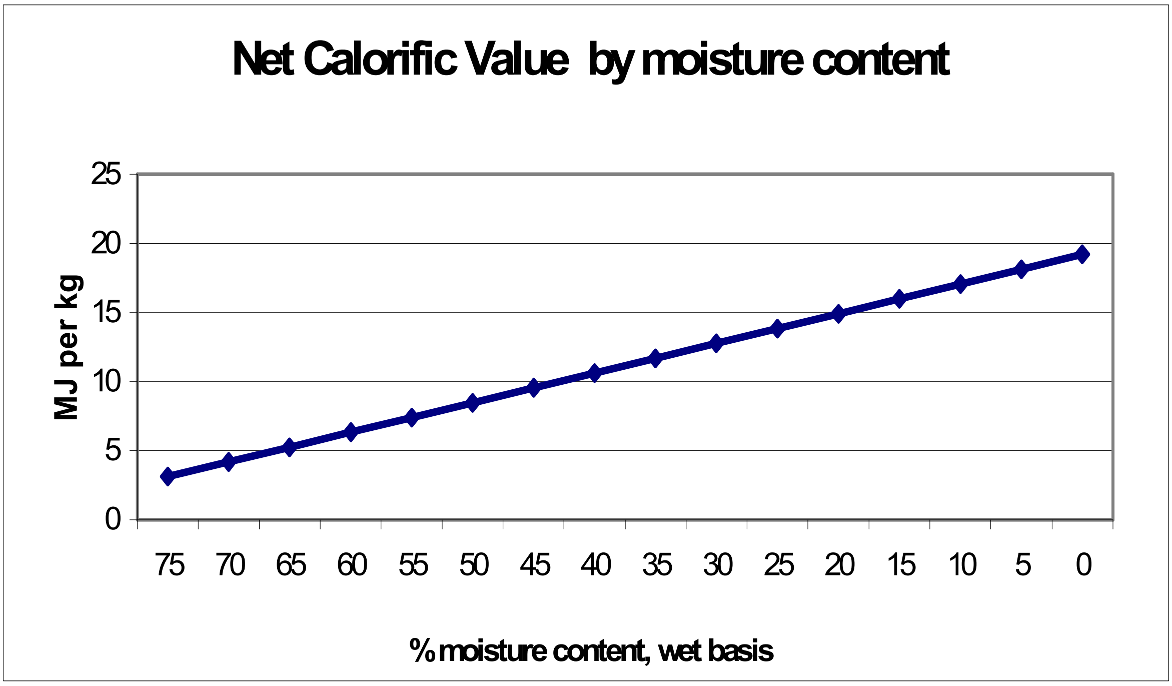

Figure 5 – change in net calorific value by moisture content (radiata pine)

The net calorific value (NCV), presented (Figure 5) here as megajoules per kilogram (MJ/kg), of a wood fuel is determined by its moisture content; the higher the moisture content the lower the NCV.

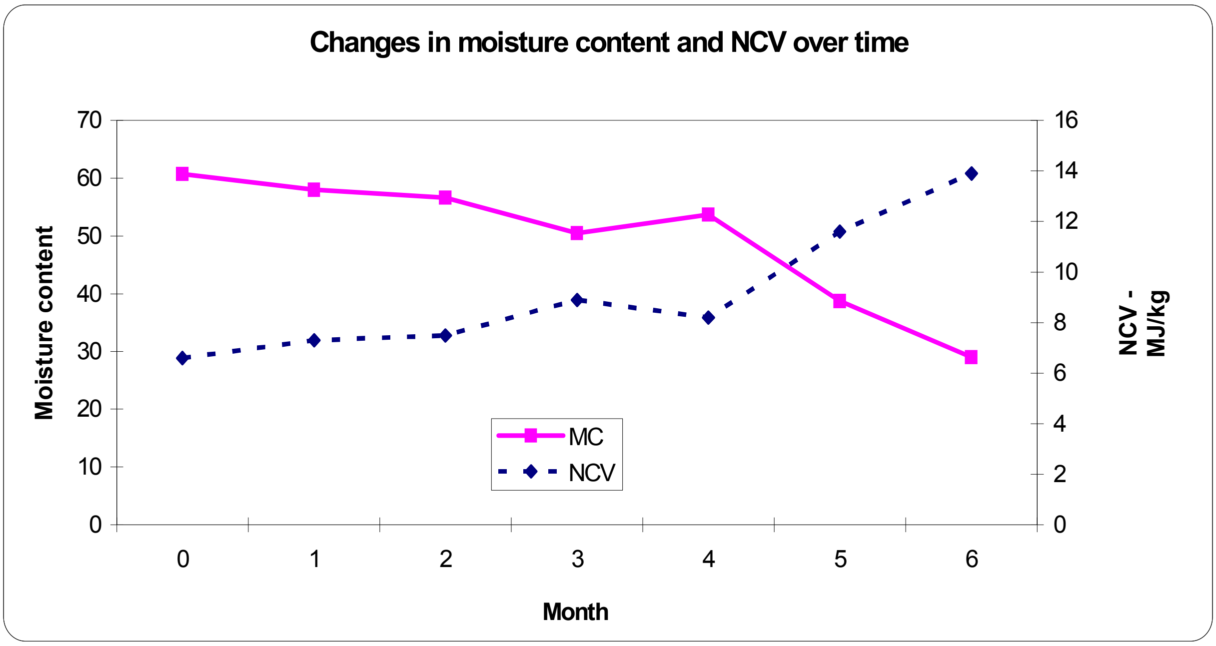

Figure 6 – NCV (right hand scale) and moisture content (left hand scale) of unprocessed landing residues over storage time

The data in Figure 6 shows that the NCV of the fuel improves with age, especially during summer months (5 and 6). In this study (Hall 2000), the NCV increased from around 6 MJ/kg to nearly 14 MJ/kg. This improves fuel quality and its potential value, but it must be remembered that due to the moisture loss there are less tonnes (mass) of fuel.

In New Zealand, the logging systems generally produce stem-to-log processing residues on landings and super-skids (effectively at roadside) at a rate of approximately 4% of the total extracted volume (this can vary substantially, from 1% to 12% depending on the crop type and log-making system). Much of this material is simply abandoned to rot. If this material is to be used as a fuel source it would be best left to dry for 6 to 8 months, as this substantially improves its fuel value.

If it is not possible to leave the residue in the forest, storing it as uncomminuted chunks for as long as possible is desirable, as it improves the NCV (due to drying) and avoids the problems associated with storing comminuted fuels.

Wood fuels stored as large pieces do not generally suffer the problems of dry matter losses, pile heating and increase in moisture content to the extent that comminuted fuels do. Landing residues stored in raw form tend to lose moisture over time. If they do not contain a lot of loose bark particles pile heating will be unlikely to occur. Dry matter losses will be minor, at less than 1 % per month. The exception is very large piles of landing residues (for example at super skids) where loose bark is a significant component of the pile, along with the large pieces of stem wood. These piles can have high levels of self heating.

Cutover residues

Figure 7 – Cutover logging residues, fresh on left, aged on right.

Logging also produces woody residues on the cutover (Figure 7). This material is similar to that found at the landings although, depending on the harvest system used, it will have a higher branch and needle content. On sites that have flat to rolling terrain, this material is relatively easy to access and could also be part of a biomass fuel resource. If left on the cutover for a period of months after felling, these residues dry out (Figure 8), lose their needles (Figure 9) and do not suffer significant dry matter loss in the first 6 months after felling (Figure 10).

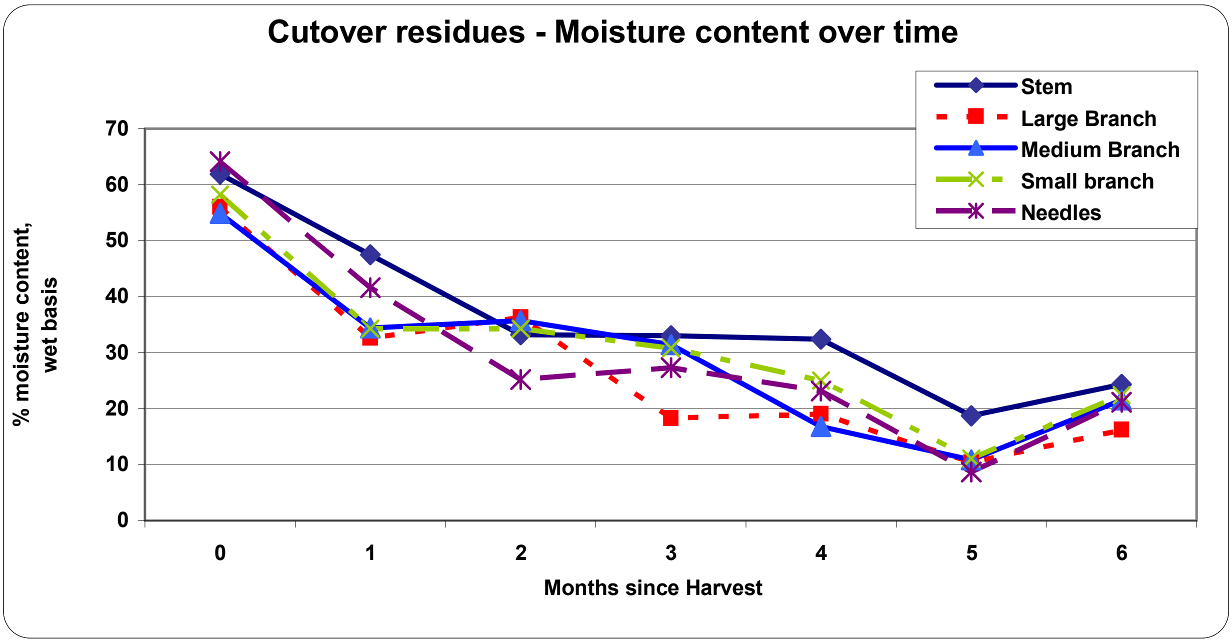

Figure 8 – Changes in percent moisture content (wet basis) over time

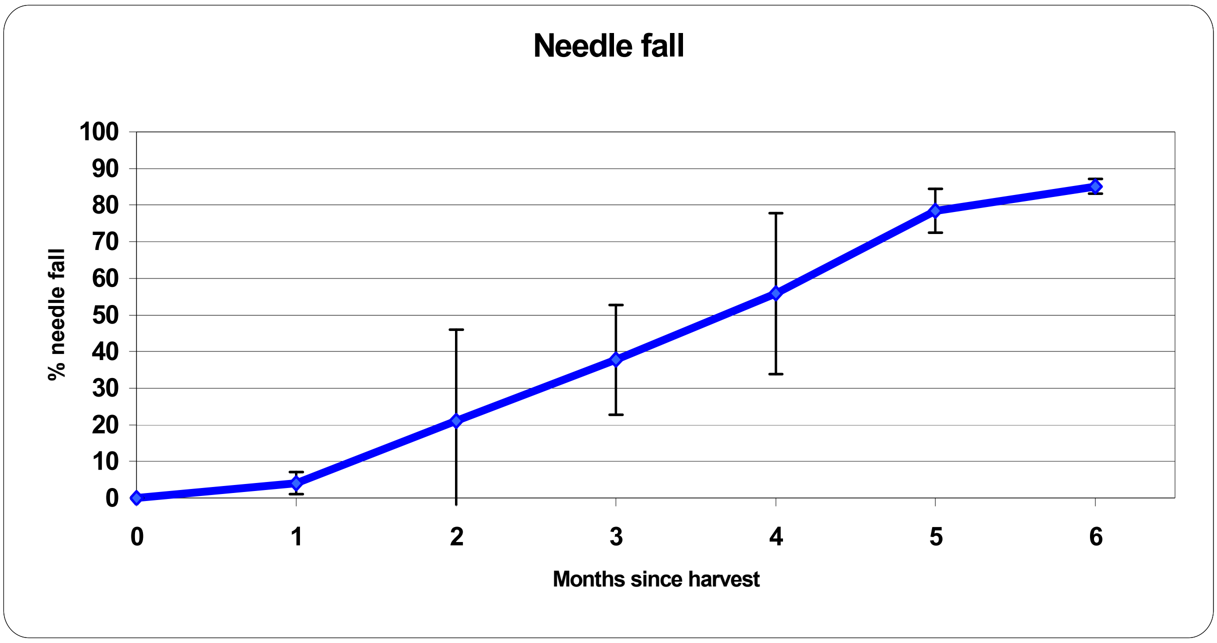

Figure 9 – Percent needle fall since harvest over time

Removal of the needles from the fuel is desirable from two perspectives. The needles contain high concentrations of macro-nutrients such as Nitrogen, which are beneficial to the nutrient status of the site for the next rotation. The needles can also be a problem if they form a significant proportion of the fuel as the more needles (and nitrogen) in the fuel, the higher the NOX emissions will be during combustion. High needle content will also lead to higher ash content in the fuel due to the high mineral concentrations in the needles.

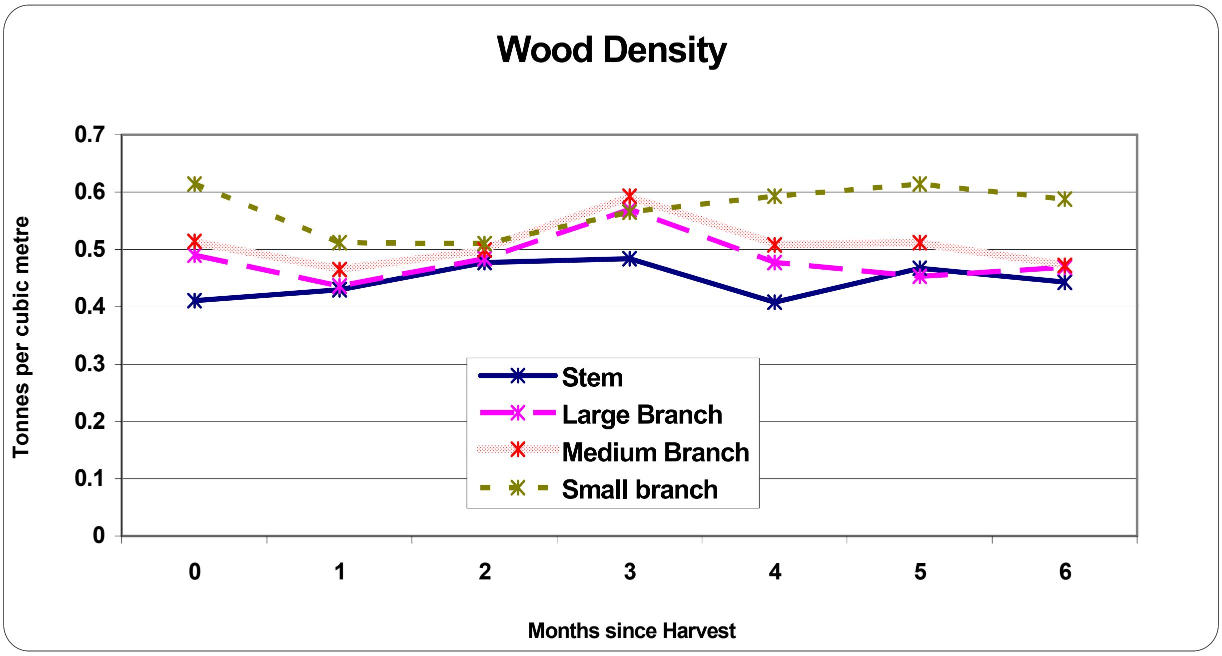

Figure 10 – Density by residue type over time

In some circumstances the in-forest residues are of such low density that some sort of compaction of them is necessary to enable efficient transport and handling. Baling or bundling of residues is now common in Scandinavia and is being considered for cutover residue handling in New Zealand. Once the residues have been baled or bundled they can be stored for periods of several months with few detrimental effects. The moisture content will drop and dry matter losses will be small (Hudson and Hudson 1999, Jirjis and Lehtikangas 1993). Recent studies (Pettersson and Nordfjell 2007) using Norway spruce logging residues in Sweden showed moisture content in stored bales of logging residues (compressed residue logs, 0.7 m diameter and 3.4 m length) dropping from ~ 50% MC wb to 40% MC wb in 6 months over winter and from ~ 50% MC wb to 20 to 30% MC wb in 6 months over summer. These drying rates are similar to landing residues in large piles. Dry matter losses ranged from 6 to 10% in the same material. Needle content can be managed by allowing the material to dry and shed needles prior to baling.

An important decision when planning to use residues for fuel is selecting a suitable storage site. It is common practice in some countries (Sweden, Finland) to stockpile cutover residues in windrows along roadsides. This material can be left to dry for several months, and has the advantage of not adding any handling. In New Zealand a similar approach could be taken with residue from skid sites, super-skids and central processing yards, as well as cutover residues extracted to roadside. Planning for siting such residue stockpiles would need to be incorporated in the harvesting plan. Stockpiled residues are best placed in windrows rather than large piles as it enhances drying and minimises dry matter losses.

Another consideration in selecting the storage site is the cost of handling the material. It may be that a secondary storage within the forest would require an extra loading and transporting stage to be added. The benefits gained from the storage have to be weighed against the costs. It may be better to stockpile at the point of use, reducing the handling costs (Serup et al. 1999). At smaller scale sites, covered storage of fuel piles would be viable.

The economic analysis of the handling and transport system needs careful examination, although the cheapest systems are often the simplest with the fewest steps and the least handling.

Baling or bundling of cutover residues and short rotation biomass is generally done to increase the density of the residues to improve transport and handling qualities. The size of the bales affects the drying rate and dry matter losses; larger bales (1.2 m diameter by 1.2 m long) have been found to have limited drying in the interior of the bale, with fungal growth and dry matter losses. However, bundles of 0.7 m diameter and 3m long were found to dry, had low dry matter losses and little fungal growth. Hence it would appear that baling, where it suits the overall objectives of the delivery system, should be in smaller diameter bales. These longer narrower bales are sometimes referred to as compressed residue logs.

The cutover residues should be left at their point of production as long as possible (up to 6 months) before any collection operation is undertaken; to enhance moisture loss and to minimise the cost per unit of delivered energy. If the residues are to be stockpiled further, they should be stored somewhere that has:

- year round all weather access
- good drainage
- no contamination sources

The contamination of fuels with dirt and gravel is a risk during in-forest handling, and it should be minimised wherever possible.

Waste thinning

Residues from waste thinning are also a potential source of biomass for fuel, albeit a relatively small one in comparison to other sources. In this case the initial storage and drying should be by leaving the stems to dry and lose needles where they are felled. This is sometimes referred to as sour-felling. Moisture loss from this can be substantial, from initial moisture contents of 55% to 60 % to 25% over 3 months (Wells and Booker 1981, Alexander 1995). The needle loss would be similar to that of the cutover residues, with further removal of needles likely during handling.

After the initial drying at the stump, or possibly in piles at the roadside, the waste thinning residues would be treated the same as any other forest based woody residue.

Wood processing residues

Wood processing residues come in a wide variety of forms and moisture contents. The material may range from 60% MC wb (green sawdust) to 10% MC wb (planer shavings from kiln dried lumber). Residues can be bark or wood and can range from large chunks (sawmill dockings) to very fine particles (sander dust).

Bark

Storage of bark for periods of more than a few days can cause significant problems. If the bark is stored long-term, the dry matter losses can be substantial; losses of up to 19% in a 6 month storage period have been recorded (Fredholm and Jirjis 1988). Other issues are acidic tannin leachate, pile heating, fungal growth and the potential for pile fires (bark has a lower ignition temperature than wood). Currently bark as a fuel is mostly used within the wood processing industry; storage issues are relatively minor as turnover is timely and volume is small scale. If bark was to be aggregated and used externally to the wood processing industry, more attention would need to be paid to managing the fuel supply chain to minimise the issues raised above.

Mixing bark with other residues, such as dry planer shavings, may mitigate some of the storage problems associated with pure bark piles (Jirjis and Lehtikangas 1992).

Sawdust

Sawdust is generally denser than other residues due to its small particle size and therefore reacts differently to external influences. Large sawdust piles do not react as much as chip piles to external weather, such as temperature and rainfall. (White et al. 1983). Depending on the rate of rainfall, the exterior of the sawdust pile can become wet to saturation point. The interior of the pile heats up and moisture content changes little. Large piles of sawdust (over 6 m) should be avoided due to the likelihood of intense internal heating. In smaller piles (< 6 m) the piles are likely to heat to around 70° to 80° C and then cool slowly over time. Keeping storage periods short will minimise dry matter losses.

Dockings and off-cuts

The blocky material from sawmill dockings and off-cuts is comparatively stable. In piles of this type the build up of fungal material is limited and heat is dissipated rapidly because of the large piece size (low surface area to volume ratio) and associated air-spaces (high airflow).

If stored under cover, moisture content should be stable if the material is dry , or if wet it should dry to around 25% mc wet basis. If stored outdoors, the surface of the pile will absorb rainfall, but the inner part of the pile will be stable due to the shedding of water by the outer layer of the pile. Shedding of water is dependent on the size and the shape of the pile, with larger, steeper sided piles more likely to shed water. Drying within the piles will be minimal.

Sander dust

Sander dust can be used as a fuel, but specialist equipment must be used to store and transport the material. The main users of this material are panel plants such as MDF manufacturers, where the sander dust is routinely produced as part of the production process. The dust requires specialist equipment as, due to its very small particle size and often very low moisture content, it can be highly reactive. If poorly handled, fires and occasionally explosions can occur.

Shavings

Planer shavings can be produced from both green and dried timber. Because they are very thin they can change moisture content quite rapidly, depending on the storage environment. Dry shavings absorb water rapidly if exposed to humid air. However, as long as they are stored dry, they are relatively stable. Green shavings air-dry rapidly if exposed to low humidity air. However, green shavings have the potential to deteriorate due to fungal activity, and pile heating could occur if stored for extended periods.

Short Rotation Coppice (SRC) crops

Willow and eucalypt are common species used for short rotation coppice (SRC). The material produced from SRC is suitable for storage as stacks (windrows) of stems or as bundles. When stored outdoors in this fashion willow stems lose moisture due to natural air-drying. Typically willow coppice is around 50% MC wb when harvested. When stored as windrows outdoors in a temperate climate, the moisture could be expected to drop to 20% wb or slightly less in 5 to 6 months (Gigler 2000). The dry matter losses can be expected to be small (< 1% per month) with minimal fungal growth.

Transpiration drying (sour felling) of short rotation eucalypt stems can give substantial reductions in moisture content, from 60% to 26% in 4 to 5 months (Lowe et al. 1995).

Once chipped or hogged the material from SRC will behave much the same as hogged material from other sources with similar moisture contents. That is, they are prone to pile heating, rapid dry matter losses in the early stages of storage, drying will be minimal and in some cases the material will absorb moisture.

Municipal Green Waste (MGW)

Municipal green waste (MGW) is a source of biomass with very diverse content. Some of the material is likely to come from urban forestry contractors who frequently chip to increase material bulk density. Whilst some of the material arriving at landfills will be in stem and branch form and suitable for natural air-drying as piles of raw residue, some of the material will be in a size-reduced form. Long-term storage of this material in large piles is not advisable, as it will self-heat, suffer dry matter losses and grow fungal and bacterial material. Where possible the comminuted portion of the resource of MGW material should be used as it is produced or stored in low (< 6 m high) windrows.

Horticultural residues

As with MGW, horticultural residue is likely to be very diverse in its make up, and come from a wide range of suppliers. Much of it will be small diameter sticks suitable for bundling and natural air-drying.

Demolition waste

Demolition waste is likely to be drier than most other residues as it has been either inside buildings or subject to natural air-drying before being placed in the waste stream. Given its low initial moisture content (often less than 20%) it is easier to store in comminuted form as its low moisture content inhibits the initial development of fungi and bacteria which generate heat. This material may also have been subject to chemical treatment or coating of a variety of sorts which may also inhibit micro-organisms. This treatment may also reduce its viability for use as a fuel as some chemicals also inhibit combustion or produce toxic emissions in flue gases and ash.

If the material is deemed suitable to go into the fuel stream and it is dry, it should be stored in a way that ensures that it remains dry. Contact covers such as tarpaulins are suitable for use on dry material, as there is little moisture to move up through the pile.

Storage of aggregated fuel at a heat / power plant

Given that storing logging residues in their raw form improves the quality of the fuel (lower moisture content), and that storing comminuted residues for long periods (over 4 weeks) can cause problems with dry matter loss, pile heating and moisture content increases, then it is desirable to leave the residues in the unprocessed state for as long as possible. The residues should then be comminuted as required, whilst allowing for some stockpiling of processed fuel. Comminuted residues can be stored for short periods (2 - 4weeks) with few major problems.

Piles of wood fuels should be managed on a first-in-first-out basis to minimise residence time (Bronson 1994).

Storing large volumes of comminuted woody biomass requires careful planning and management to avoid problems. Ideally wood chips should be produced on an as required basis at the heat plant (Serup et al. 1999).

Pile Heating

<u>Residue composition</u>

Piles of residue that contain high percentages of needles and bark are more at risk of self-heating then piles of clean wood chip. This is because the needles and bark are rich in nutrients that feed the initial establishment of fungi and bacteria.

A common problem for piles of comminuted wood residues is pile heating, which can lead to spontaneous combustion, causing pile fires. Once large piles are smouldering or on fire, they are difficult and expensive to extinguish. However, some initial heating is very common (and inevitable in piles of green material of more than a few cubic metres) and is not necessarily a cause for concern. In large piles intended to be stored for long periods, monitoring of temperature is essential to avoid future problems. Whole tree chips or bark piles are more prone to self-heating and self-ignition than piles of clean debarked chip (Springer 1979). Pre-storage drying is considered to be part of the least cost management of whole tree chip storage.

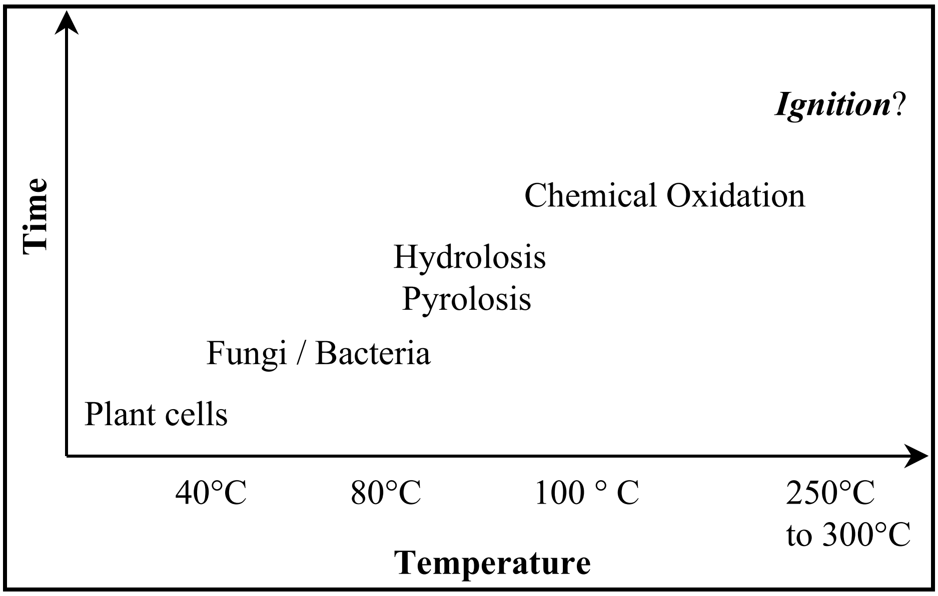

Figure 10 – Potential causes and progressions of temperature and degradation process by time in piles of comminuted wood residues.

When any comminuted organic matter is placed in a pile there is frequently heat generated by respiration of still live tissue and from fungal and bacterial activity (Figure 10). It is common for large piles to reach temperatures of 60°C to 70°C, just from this activity. Once the temperature goes above 70°C it is likely that pyrolysis or chemical oxidation is occurring and that the temperatures will continue to rise. If the temperature reaches the ignition point of the piled material, then a pile fire can occur, especially if the pile or parts of it are exposed to greater air flows.

The progression from stage to stage (Figure 10) is not automatic and the progression may be broken by outside intervention or by internal conditions of the pile. Initiation of heating is not always present, especially if the residues are very dry.

Ignition temperatures of organic matter vary with the material, starting at 120°C and going up to 205°C or beyond (Riggle 1996). Some bark materials are at the lower end of the range. Factors that contribute to the likelihood of a pile fire occurring are:

- pile size and shape
- material moisture content
- airflow

Very high temperatures in a pile do not necessarily mean that a fire will occur. As with any fire, oxygen needs to be present, and if it is not, then the pile will not ignite. Any production of heat indicates dry matter loss as the material in the pile is being converted to energy by biological and exothermic thermo-chemical processes.

The process of spontaneous combustion can be described as a slow thermal explosion (Armstrong 1973) where the rate of heat generated by anaerobic processes within the pile exceeds the rate of heat diffusion. When this happens, ignition can occur.

Pile size and shape

Large piles of comminuted material tend to be well-insulated in the inner part of the pile, making it difficult for any heat generated to escape. Conical piles are more prone to heating than windrows of the same volume as they have a greater mass to surface area ratio. The use of windrows with height limited to 4 m and width to 6 m will reduce the insulation effect and allow heat to escape. Few fires have been reported in piles of less than 6 m in height. Tall piles can also have a chimney effect, where the heat rises through the pile, taking moisture with it. This can lead to drying of the centre of the pile, and wetting of the outer layer, especially in the top of the heap. Generally piles of comminuted wood residues should be kept to less than 6 m in height (Bronson 1994).

Moisture content

If the residue is wet (> 45% MC wb) significant heating is unlikely and some of the heat generated will be absorbed within the pile causing evaporation of the water and subsequent cooling via the heat transfer to the atmosphere.

If the residue is dry (< 25% MC wb) heating is unlikely as live tissue will be minimal, microbial activity is inhibited by the lack of water, and the initial heat source is not present.

However, if the moisture content is between 25% and 45% MC wb there is a strong possibility that the material will self-heat.

The self-heating of the piles can cause the material in the pile to dry to some extent, depending on the conditions. Moisture content can drop by 7% in 3 to 5 weeks (Thornqvist and Jirjis 1990).

If the pile is covered with a non-contact cover, such as a roof, the moisture content can drop from 45 % to 25% in 6 months (Serup et al. 1999). If the pile is covered with a contact cover, such as tarpaulins, it will not dry out, although moisture may migrate from the centre of the pile to the upper layer (500 mm). Uncovered piles may dry, depending on the weather (rainfall, temperature and humidity), with rainfall being critical. However, the initial heating of fuel piles is generally from bacterial and fungal activity, which releases water as well as heat. The releasing of this water can increase the moisture content of some of the wood in the pile, especially in the upper layer.

Particle Size

Storage of in-forest residues in their raw form causes few storage problems and can lead to substantial fuel drying (increasing net calorific value). Comminution greatly increases the surface area to mass ratio of the material, reduces the particle size and so reduces the size of the air spaces and subsequent airflow, all of which contribute to increased microbial activity. It can in some cases increase the density of the material, depending on the residues original form.

Airflow

For the chemical oxidation process (high temperature pile self-heating) to occur some airflow must be present, but a lot of airflow will remove the heat and cool the pile.

This leads to some confusion on whether piles should be managed to get air to flow into the pile or to keep it out. If the pile is made up of small particles (sawdust or similar) then airflow will naturally be very limited and compaction of the pile and shaping it to keep wind out may be a viable option. However, compaction can lead to increased temperatures as heat dissipation is limited. Compacted piles may be hot for extended periods, but are at low risk of spontaneous ignition due to the low levels of oxygen. However, the high temperatures indicate dry matter losses.

If the particle size is larger (coarse chip or larger) then keeping air moving through the pile will probably keep it cool enough to avoid fires. However, once a pile has started to heat to temperatures of over 70°C, it is important that airflow be restricted in order to reduce the possibility of chemical oxidation, excess pile heating and spontaneous ignition.

There is also the effect of moisture to consider along with airflow. As dry or very wet materials tend not to heat up, piles with either very low moisture content or very high moisture content are suitable candidates for compaction. This is because compaction will reduce the air flow and keep additional external moisture out of the pile by limiting the ability of rain to penetrate the heap. Compaction of heaps, which restricts airflow, can be linked to reduced pile heating and lower dry matter losses (Nurmi 1999). In some cases, pile heating can dry the pile. As the pile heats, hot air moves to the top of the pile taking some moisture with it. If the hot air can exit the pile, the pile will dry to some extent. The rate of airflow is dependent on the particle size of the material in the heap and air being able to enter at the bottom of the heap. Whether the pile dries is also dependent on it not being exposed to rainfall, which replaces the moisture taken out by the hot air.

For piles of landing residues to self-heat and burn, there have to be a number of contributing factors, the piles have to be large, they have to contain some small particle size material and the air flow needs to be restricted to avoid cooling. These conditions have occurred in several cases in New Zealand where large piles of logging residues, typically created at super-skids, have heated to the point of ignition. These piles all have:

- large size and depths of several metres,
- a mix of material, including small particle size material such as bark and sawdust generated by mechanised processors,
- a layer of dirt and debris compacted on the top of the pile,
- some change in conditions that altered airflow in the pile (strong winds, machine activity in the pile, severe temperature change external to the pile (frosts).

<u>Fuel Pile Contamination</u>

By the time the fuel has been comminuted and stockpiled most contaminants should have been removed for fuel quality reasons. It is also important that particles or chunks of metals, particularly ferrous metals be kept out of the fuel pile as their presence is linked to pile fires and pockets of charring within the pile (Manssen and Walker 1979). The presence of the metals may be acting as a catalyst. However, the exact nature of the cause and process of pile fires is difficult to determine as they are self-destructive.

<u>Leachate</u>

Whenever large piles of wood residue are stored under exposed outdoor conditions, the pile will receive some rainfall. The run-off of rainfall from the heap will contain some chemical contamination picked up from the wood. How much is picked up will vary with the particle size, moisture content, age and type of material. However, in most cases the leachate from piles of comminuted wood will contain tannins and will be acidic. This is particularly so with bark. Depending on the size and location of the storage pile and the duration of the storage, this leachate will need to be collected and treated before being discharged.

<u>Dry matter loss</u>

In any pile of comminuted residue there will be dry matter loss. This will vary with, species, material composition, moisture content and pile size. It will also vary with how the pile is managed (size, covering, etc.). Dry matter loss is caused (at least initially) by live cell activity and microbial activity, which is related to pile temperature. If the pile temperature is between 55°C and 70°C there will be substantial microbial activity and therefore substantial dry matter losses. If the temperature is lower than 30°C the losses will be small. Once the temperature goes above 70°C to 80°C the dry matter loss is from pyrolysis and chemical oxidation. There are a wide range of dry matter losses reported from a range of studies; these can be as low as 0.4 percent per month and as high as 3.6% in the first week (Thornqvist and Jirjis 1990). Figures of around 1 to 2 % per month are common (Thornqvist 1983a and 1983b, Bjorklund 1983).

The issue of dry matter loss needs to be considered when large-scale, long-term storage of biomass is being used. The costs associated with managing the pile to reduce the losses need to be compared to the cost of the dry matter loss.

Despite dry matter losses, the piles do not always end up with reduced net energy content. This is because in some cases the gain in net energy from the reduced moisture content can outweigh the dry matter losses.

General

The processes involved in spontaneous pile combustion are difficult to observe and are destructive. This means that some of the exact nature of what happens and why is not always apparent. Given that many biomass fuels fall in the range of 25 to 45% MC wb this dictates two principal courses of action:

- monitor the temperature in the pile
- keep the material turning over (first-in-first-out), the less time it’s in the pile, the less chance it has to heat up

Contact covers (tarpaulins) are not recommended for covering outdoor piles of residue that are being stored long-term. Use of contact covers can lead to:

- increases in dry matter losses
- higher moisture content in the upper layers
- lower NCV

However, contact covers can be used in the short term, especially on dry (<25% MC wb) fuel material, as they will stop rainfall entering the pile and raising the moisture content.

A higher moisture content resulting from covering an outdoor pile seems counter-intuitive. However, large piles tend to shed a great deal of rainfall even without a cover, with penetration by rain often being limited to the top 500 mm. The use of the covers on the other hand, whilst it keeps the rain off, also limits the airflow through the pile. This airflow removes moisture due to the heating of the pile, if it is stopped by the cover, the pile drying is reduced. Covering of piles should be by non-contact means if possible. Using contact covers on smaller piles (< 6 m in height) will have value, as the surface area to mass of the pile reduces the impact of the self shedding of rain (the top 500 mm is a much greater proportion of a small pile than a big one).

Forced ventilation of the piles of comminuted residues will reduce the pile temperature and inhibit fungal growth (Jirjis and Lehtikangas 1994). The particle size of the material has a significant effect on the resistance to airflow, with smaller particles being much harder to ventilate than larger ones (Nellist 1995). However, there are costs involved with forced air-drying, from the capital cost of the equipment and the energy cost of running it.

Natural air-drying is relatively cheap, as it involves only the land cost for the required storage area and the inventory cost of the material (purchase and handling costs). However, raw residues have a lower density than comminuted residues, and so will require a larger storage area for the same tonnage. The cost of this extra area depends on where the storage takes place. If the storage is along roadsides in the forest, the cost may be minimal.

If residues are stored in uncomminuted form the storage site must have all weather access, be well-drained and free from contamination such as rocks and gravel. Non-wood contaminants must be avoided as they have the potential to damage the comminution equipment.

New Development - Torrefaction

A comparatively new approach to wood fuel processing is torrefaction (in essence dry roasting) of chipped wood. This process heat treats the wood at 230°C to 300°C for a period of 20 to 30 minutes. This not only dries the wood but alters the physical and chemical structure of the wood. It becomes in effect, sterile, dry and hydrophobic, so it can be stored outdoors for long periods and it will not deteriorate or reabsorb moisture. The torrefaction process requires some energy (equivalent to about 5% of the wood being treated) but the resulting material is more energy dense, easier to store and handle, and more acceptable as a co-firing fuel in coal and lignite fired boilers. Torrefaction improves the grindability of the wood, and may allow it to be used in pulverised coal applications. This technology is still developing and further research and development is required, specific to New Zealand's feedstocks and conditions. However, it is an area worth further investigation for large-scale users of wood energy.

Recommendations & Conclusions

Woody residues should be stored in the largest piece size possible for as long as possible in order to:

- reduce the problems associated with storage of comminuted residues:
    - pile heating
    - dry matter loss
    - moisture content increase,
- take advantage of the natural air-drying that occurs when large piece size residues are stored.

These piles should not be compacted, as airflow through the pile is necessary for drying to occur.

Cutover residues should be left to dry and drop their needles before collection and removal. High levels of needle fall (>80%) should occur in ~ 5 months.

The risk of spontaneous fires in piles of comminuted residues can be mitigated by:

- having the residues dry (<20% MC wb) before comminution and piling
- limiting pile height (< 6 m)
- compaction of the pile if the material is small particle size (sawdust)
- managing air flow
- eliminating metal contamination
- keeping storage periods as short as possible
- keeping rainfall out of the pile

Dry matter losses associated with storage of comminuted residues can be minimised by:

- keeping the storage periods as short as possible

- drying the material prior to piling
- compaction
- limiting air-flow

Large piles of comminuted residues should be monitored for heat build up. Temperatures over 70°C to 80°C are a cause for concern regarding fuel degradation and present a risk of extreme pile heating.

Piles of comminuted residues should be managed on a first-in-first-out basis to minimise storage time.

Air-drying of logging residues at landings, on cutover, in bales or in stockpiles can potentially give a substantial reduction in the moisture content of the fuel. These reductions will vary with site, climate and pile structure, with small piles and windrows performing better. Drying times of ~ 6 months are suggested for spring / summer, if the harvest occurs in winter, the storage time may need to be longer - up to 9 months under exposed outdoor conditions.

Moisture content reductions are likely to be from 55% MC wb to 25% to 30% MC wb for green residues. Some dry matter loss will also occur, but this should be minimal, and may include needle fall which would enhance the fuel quality by reducing mineral content.

Storage periods for comminuted biomass for fuel should be kept to a minimum, and the material is better dried before storage. If dried, covering the material to maintain a low moisture content is desirable.

Glossary

Slovens – stem wood off-cut from the base of the tree, created when removing the uneven and torn wood from the point at which the tree was felled

Transpiration drying – felling a tree and leaving it with limbs and leaves on, at the stump, using the transpiration of the tree to draw moisture from it.

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