Transport Guidelines
for
Wood Residue
for
Bio-fuels

SCION
Next generation biomaterials

EECA
Energy Efficiency and Conservation Authority
Te Tari Tiaki Pūngao

Prepared by

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For

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Summary

In any system for delivering wood residue as bio-fuels from forests or wood processing sites, transport is a key factor and contributes significant cost. Transport cost as a percentage of delivered cost can vary from ~12% (5 km haul) to ~60% (150 km haul) depending on the transport distance. Optimising transport systems on medium (50 km) to long (100 km) haul transport is therefore critical to minimising costs.

The type of transport has close interactions with the fuel source and residue type, the site where the fuel is used and any processing steps that are introduced along the way. Careful design of the transport system including the truck, specification and configuration is essential in order to maximise the efficiency of the transport operations.

For most wood residues in New Zealand the principal form of transport will be by truck due to current infrastructure and resource location combined with the need to keep handling to a minimum. Rail transport will only be viable for longer distances, or where there is a good existing fit between resource, rail infrastructure and end-use.

Design of the transport system including the loading and unloading requirements will vary with the type of residue to be transported.

Many of the wood residues have low bulk density and poor handling characteristics making the system design decisions critical to the efficiency, not only of the transport but the whole fuel delivery system.

Fundamental to optimising transport efficiency is maximising the payload, especially over longer transport distances. Design of the transport system must consider the design of the trucks, with the intent of minimising the trucks tare weight and maximising load space within the operational constraints of the specific site being considered and the vehicle mass and dimension regulations.

Key areas are:

- Maximising payload (weight, volume or energy)
- Optimising utilisation
- Minimising costs

The issue of payload needs to be considered bearing in mind the impact of dry material on load weight. For woody biomass, a dry load is effectively a light load and measures other than weight may need to considered, these are:

- Volume
- Energy

Payment by volume is only suitable for homogenous fuels, where truck load volume is known and used consistently.

Introduction

Transportation of wood residues is one part of a biomass harvesting system. Along with harvesting, extraction, comminution (e.g. chipping, hogging, shredding or other size reduction processing), storage and utilisation, transportation forms the supply chain in a biomass fuel delivery system. All parts interact to a greater or lesser extent. The harvesting must occur first, and the utilisation last, but the order of the steps in between can vary depending on the site-specific conditions that the system is designed for (Hankin and Mitchell 1994). Deciding on the order of storage, comminution and transport is key to optimising the delivery system, as this will determine the form (e.g. harvesting residues, bales/bundles, hogged wood or chip) that the residue will be transported in, and to an extent, its moisture content and energy content.

In New Zealand the transport of logs from forests is dominated by road transport on trucks. There are a few exceptions where rail and barging are used but the nature of the resource and the infrastructure dictate that for the foreseeable future, trucks will remain the principal form of log transport. Forest residues will also be transported by truck for the same reasons. The exceptions to this would be the two large Kraft pulp mills in the central North Island (Kinleith and Kawerau), which are served by rail.

In most cases, once a load (of any kind) is placed on a truck it is unlikely that it will be transferred to rail due to the handling costs involved, which negate any gain in cost per unit of distance unless the rail transport distance is long. The most notable exception to this in New Zealand is the Murupara railhead where large volumes of logs are transferred from truck to train for transport to Kawerau and Port of Tauranga. The use of rail transport is considered to be cost competitive for moving large volumes of material for distances in excess of 100 to 130 km (Adler 1985). As the cost of trucking rises with increasing Road User Charges (RUC), fuel prices and wages this distance may reduce, but is dependent on rail infrastructure being available.

The majority of wood residues to be transported will be carried by truck, as they will be produced at diverse sites, many of which are currently not serviced by rail. The question is, what sort of truck is used to carry what form of residues?

Truck configurations are many and varied (Figure 1) and careful consideration of options is required to optimise transport costs.

Transport Guidelines

Transport Principles

Current road transport laws in New Zealand limit the maximum size and weight of trucks. Within these rules it is important that the trucks carry the maximum possible payload (weight, volume or energy) in order to minimise transport costs. Transport costs can be a significant proportion of the delivered cost of a biomass fuel. Depending on the one way transport distance it can be as high as 60% (150 km), and is unlikely to be below 10%, even on very short lead distances.

Whether a truck bulks out (runs out of volume before maximum payload is reached), or weighs out (reaches maximum payload before the truck is full), depends on the density of the material being transported. Ideally trucks should weigh-out with every load, otherwise their capacity is being under utilised. To achieve this, denser loads are preferable. The load density (ratio of solid material to air space) of wood residues can be increased by compaction in some cases. However, sometimes the cost of achieving a denser load may out-weigh the benefits and the limiting factor becomes the maximum possible volume. For transport of low density materials such as dry wood chip where compaction is difficult and may lead to unloading issues, specialist high volume trucks are required.

In New Zealand, most transport of forest products is paid for on a per tonne-kilometre basis. In this situation maximising the tonnes carted per trip is a critical factor (Wylie 1998). The density of the fuel (tonnes of dry matter per cubic metre) and the payload of the trucks are fundamental to getting the most cost efficient transport.

A further consideration with transporting wood residues is that the product being carried is energy and that the energy content per unit of weight rises as moisture content (and weight per unit of volume) 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 mass (weight) and moisture content are used to determine the energy content of the load and payment is made for the material on this basis (Hall 2008 a & b).

System integration

When designing a fuel harvesting and delivery system, transport is an important consideration, but it must not be examined in isolation from other parts of the system with which it interacts.

For example: Power stations may demand high standards for their fuel, including particle size and size distribution as well as moisture content. Particle size and size distribution would be easier to control with centralised chipping as opposed to mobile or semi-mobile chipping operations. There may also be benefits in terms of reduced costs in the supply chain from centralised processing (Hunter et al. 1999). However, the decision on whether to comminute before or after transport needs to be considered carefully along with other transport factors, as comminuted fuels may be less sensitive to the effects of transport distance than raw residues in some cases (Spinelli, 2009, Hudson and Hudson 1999). The higher chipping cost of in-forest chipping may be off set by greater transport efficiency if transport distances are over 50km. The costs and benefits of when to comminute must also be examined, comminution in-forest is more expensive than at a central processing facility (Andersson 1999). Due to economies of scale and the power source and design of the equipment. In some cases the higher transport costs of the raw residues can be offset by lower costs elsewhere in the system (lower chipping costs) as the raw residues can be well compacted with the correct loading and handling system (Andersson 1999, Hudson and Hudson 1999).

In Sweden there has been a move away from in-forest chipping systems to transporting baled residues, as it is easier to store, handle and transport than the raw residues and chipping costs are lower at the mill (Norden 1995). It is also possible to regard the baled residues (which contain a mix of stem and branch residues) as a mixed product load (energy and chip wood) (Norden 1995). The material can be separated into its different components during processing at the power plant, with the higher value pulp grade chip material being sold off separately from the energy grade material. Integrating the harvesting of wood fuel products with the harvesting of conventional products is regarded as essential to the economic viability of wood fuel harvesting (Hudson and Hudson 1999, Bjorheden 1999).

Transport Regulations

When a single factor such as transport contributes a significant proportion of the total delivered cost, it is important that it be examined carefully in order to minimise its impact. In order to do this, the limits of what is potentially possible have to be defined. Fundamental to this are the weight and dimension limits imposed on truck operators by law (Table 1) and what size of vehicle can be built within these (Table 2, Figure 1).

Table 1 – Summary of Transport regulations (see Figure 1 for truck configuration diagram)

Truck configuration	Gross vehicle weight	Length	Width	Height *
Truck Only (6x4)	22.4 t	12.6 m	2.5 m	4.25 m
Truck and 4 axle trailer***	44 t	22 m (11.5 m**)	2.5 m	4.25 m
Truck and 3 axle trailer	42 t	22 m	2.5 m	4.25 m
Semi trailer (3 axle)	39 t	18 m	2.5 m	4.25 m
B train****	44 t	22 m	2.5 m	4.25 m
A train	39 t	22 m	2.5 m	4.25 m

* Maximum height includes all load, load restraints, covers, fittings and attachments.
** Maximum length of truck in truck and trailer configuration
*** Only if tandem drive or twin-steer
**** Only if tandem drive

Within these broad rules are limits on axle spacings and weights, truck and trailer lengths and overhang. For full details on weight limits for different configurations, and exceptions and variations, see:
www.landtransport.govt.nz/rules/vehicle-dimensions-and-mass-2002.html#4
www.landtransport.govt.nz/factsheets/13.html

Truck Dimensions

Table 2 – Load space dimensions for some common residue truck configurations

Truck Type	Truck				Trailer				Total Volume
	Length	Width	Height	Volume	Length	Width	Height †	Volume	
Chip*	5.8 m	2.3 m	2.3 m	30.6 m³	9.5 m	2.3 m	2.3 m	50.2 m³	80.6 m³
Chip* large	5.8 m	2.35 m	2.8 m	38.1 m³	9.5 m	2.35 m	2.8 m	62.5 m³	100.6 m³
Bin**	5.6 m	2.3 m	2.3 m	29.6 m³	8.3 m	2.3 m	2.3 m	43.9 m³	73.5 m³
Bin** large	5.6 m	2.3 m	2.7 m	34.8 m³	8.3 m	2.3 m	2.7 m	51.5 m³	86.3 m³
Semi Bin	-	-	-	-	9.6 m	2.3 m	2.3 m ***	62.0 m³ ****	62.0 m³

* truck and trailer unit
** truck and trailer unit
*** height tapers down around hitch point and fifth wheel
**** volume calculated from example trailer including taper
† height of sides from deck up, that is load space only not total truck height

Actual truck dimensions may vary, and have slightly larger load spaces in some instances (for example chip trucks of up to 100 m^3). The volumes in Table 2 do not allow for loading over the height of the sides, which can occur with some loads, as long as the total height does not exceed 4.25 m.

The load space within the dimension limits of a log truck whilst not physically bound are nonetheless present, and are of a similar size to a bin truck (~70 to 75 m^3). This volume is relevant to the cartage of baled logging residues.

After the size and weight of the trucks have been determined, the possible load densities have to be assessed. These are given as likely ranges (Table 3) due to the variation inherent in biomass fuels.

For trucks designed to carry low density loads such as dry chipped or hogged wood, maximum load space height may increase and overall load space length could be increased for truck and trailer combinations. A very high volume vehicle could have a load space of up to 115 m^3.

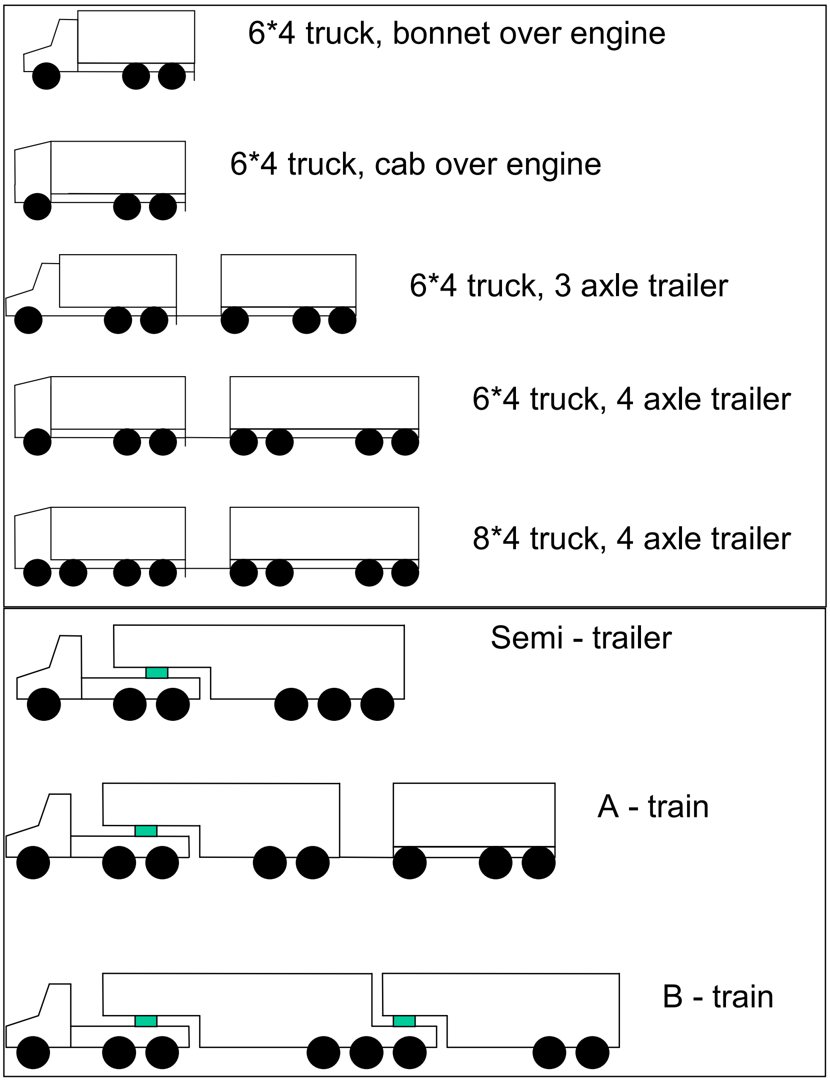

Figure 1 – Common truck configurations (not to scale)

Wood Residue types

Wood residues come in a wide variety of forms, from short sections of stem wood to sawdust. These materials have very different properties for loading and load densities (Table 3) (Bjorheden 1990, Hall 2002 unpublished data, Pettersson and Nordfjell 2007). The density of a load of residue can be defined by what proportion of the load volume is airspace, and what is solid material.

Table 3 - Typical residue densities (%)

Residue type	% density Loose	% density Compacted
Branch material	20 – 25	40 - 45
Stem sections*	30 – 35	30 - 35
Chip	30 – 35	35 - 40
Logs	60 – 70	60 - 70
Bin wood **	40 – 45	40 - 45
Residue bales	n. a.	50 - 70
Landing Residue ***	25 – 35	40 - 45
Hog	30 – 40	35 - 45
Sawdust	37 – 42	40 - 45

% density = (solid volume / bulk volume)*100

* even length sections of stem with branches on

** stem sections of uneven length (<3.7 m), no branches

*** mixture of stem wood and branches of uneven size distribution

Load Optimisation

From the information in Tables 1, 2 and 3 it is possible to calculate the density required to gain maximum payload for different vehicles allowing for variation in moisture content (mc)(Table 4).

Table 4 - Load densities required to weigh-out for biomass with varying moisture contents

Truck type	Tare tonnes	GVM tonnes	Pay Load tonnes	Truck Vol. m^3	Load Vol.* m^3	Required density by % moisture content (mc), (wet basis)					
						58% mc	**56% mc**	**48% mc**	**40% mc**	**35% mc**	**30% mc**
Chip	15.5	44	28.5	80.6	98	29.1	30.3	36.4	41.6	44.8	48.5
Bin	20.0	44	24.0	73.5	89	26.9	28.0	33.6	38.4	41.3	44.8
Semi	19.0	39	20.0	62.0	73	27.4	28.6	34.3	39.1	42.1	45.7
Residue bales (Log truck & trailer)	16.5	44	27.5	~68 to 70	~70 to ~75	weigh -out	weigh -out	weigh -out	weigh -out	weigh -out	52%

* difference between the truck volume and the load volume is an allowance for stacking material higher than the side of the truck and restraining it. Calculation of over height volume (ohV):

ohV = (π * Length * Width * Height) / 6, *where H is 0.4 m.*

GVM = gross vehicle mass (or weight)

The truck and trailer units will have a load space of approximately 80 to 100 m^3 (Table 2) and total load volume of ~110 m^3, which allows for stacking over the sides of the truck and tie-down compaction. Loose landing residues have a stacked density of between 20% and 30%, and this density can be improved in the truck by using the loader to crush and compact the load. The load can be stacked over the height of the truck sides then restrained and compressed by ratchet tie-downs. The load density can be expected to improve by up to 40% to 45% density, depending on the type of residues and the loader. Independent knuckle boom loaders have a greater capacity to compact the load than a truck fitted with a self-loading crane and can improve load density by up to 57% in branch residue (Norden 1993, Andersson 1995a). The self-loading cranes also increase the tare weight of the trucks by up to 2.5 tonnes, lowering the potential payload by the same amount. However, the decision to self load will be driven by other factors as well, including the viability of having an independent loader on site to service the trucks. The ability to substantially compact pine residues is supported by other studies which have found that residue density can be increased significantly by loader compaction and tie-downs (Silversides and Moodie 1985). In some cases the residue density can be doubled, from 20% to 25 % up to 40% to 50% (Danielsson et al. 1977).

In a small trial in New Zealand of 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 ratchet load restraints, the density rose to 45%.

In order to maximise the payload of a truck and trailer with green residues (58% moisture content and assuming a solid 1 m^3 = 1 tonne) a load density of 26.9% is required (Table 4). If the residues have been stored and air dried the moisture content may be as low as 30%, in which case a load density of 44.8% (Figure 2) would be required to get a maximum payload (24 tonnes). This would increase delivered energy from 163 GJ to 306 GJ per load.

From these figures it can be seen that in most cases, with good loading and compaction the bin truck and trailer configuration should be able to meet the goal of maximising its payload in most situations where typical landing residues are being transported.

The uncompacted load densities of chipped and hogged material are around 40% for chip and 36% for hogged material. This gives a volume of ~2.5 m^3 of chip for a solid cubic metre of wood for chip and ~2.7 to 2.8 m^3 of hog fuel for a solid cubic metre of wood. The weight of the material will vary with moisture content (Figure 2).

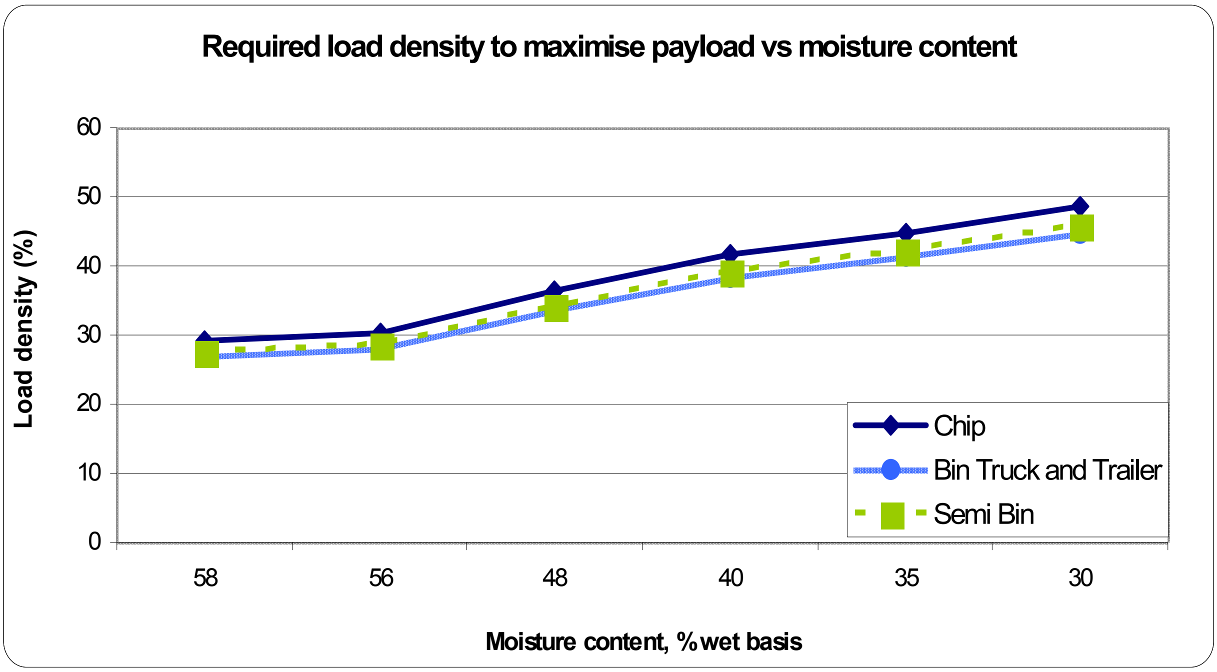

Figure 2 – Load density required to achieve maximum payloads at different moisture contents

The amount of compaction required to get to maximum payload depends on the moisture content of the residue. If landing residues are assumed to a have a density of 30% when piled without compaction then at a moisture content of 40% a compaction ratio of 1.28 is required and at a moisture content of 35% the required compaction ratio rises to 1.38. From previous studies in New Zealand it has been found that piled landing residues will dry to approximately 35% moisture content (Hall 2000).

The baled residues, which are expected to have a density of at least 50%, would weigh-out at the higher moisture contents. At a moisture content of 30%, the density of the bales would need to be 52%. At lower moisture contents (such as 25%), which are possible with extended summer drying, bale densities of 56% to 60% would be required.

Ultimately the costs of wood residue transportation are a function of haul distance, material bulk density, moisture content, truck capacity (weight and volume) and truck utilisation (Stokes and McDonald 1994).

Set-out bins

A variation on the truck and trailer / tip bin configuration is the use of set-out bins (Figure 3). In this configuration empty bins are dropped at the landing site and left to be filled, and full ones are lifted onto the truck or trailer by a hydraulic arm that is integral to the truck. The bins can be filled with either unprocessed or comminuted residues.

Figure 3 - set-out bins (left) and hook truck and trailer (right)

Bins can be used with a truck, semi-trailer or truck and trailer configuration. The advantages are:

- minimised handling
- easier bin filling/loading
- rapid loading of bin to truck
- good truck utilisation
- convenient residue storage at landings

Disadvantages can be:

- reduced truck payload due to the bin and hook construction
- higher capital cost for truck purchase truck costs

In-forest residues

In-forest residues that are produced as a by-product of logging operations occur at two distinct locations. Some occurs at the stump and some is created at landings. At either location the material will vary in its composition depending on the crop and the harvesting system used, but in most cases it will have a mixture of stem wood, bark, branches and needles.

The density and moisture content of this material varies with its composition and how long it has been in storage. How this material is most efficiently transported is affected by these factors.

A further issue is the accessibility of the residues. Much of the harvested area in New Zealand is on steep land. The access roads are often steep and most have metal surfaces. Some truck configurations are not suitable for use on the steeper lower quality roads that occur in some forests. An example would be a high volume B-train attempting to work on narrow winding roads with steep adverse grades on a gravel surface.

Thought and planning are required when configuring a residue transport system. Specifically what truck configuration will work best on the road network specific to the site where the residues are being collected. For example, the type of truck that could be used on Kaingaroa's easy terrain and off-highway network would potentially be quite different to that used to visit small forests in Coromandel hill country.

Landing residues

The residues at landings can vary substantially from site to site in their composition. Some have a high proportion of branch material and some are almost exclusively short sections of stem wood (Figure 4). The majority will be somewhere in between and will contain stem wood, branches and bark. The bulk of the solid wood content of residues will be short sections of stem wood.

Figure 4 – landing residues from different crops, left - farm forestry block with many edge trees; right – highly stocked stand in a large forest estate

Landing residues can be transported in its raw form (loose or baled), or it can be comminuted on-site and transported as chipped or hogged material. The decision on whether to comminute before or after transport is an economic one, and is affected by factors other than just transport efficiency. However, the residue density will affect this decision. A compromise is a two-stage option where residues in raw form are transported to a central point (initial transport), residues are then comminuted prior to transport to a point of use (second transport). The use of two staging with intermediate processing needs to be looked at very carefully in terms of its costs and benefits, as it adds handling.

The most likely truck configuration to be used to transport comminuted material over long distances (>50 km) on-highway is a chip style truck and trailer. Chip trucks (Figure 5, left) have greater load space and lighter tare weights but may not be robust enough to cope with the potentially damaging nature of the loading and compaction of stem wood residues. If raw residues are to be transported, trucks with heavy duty bins are required (Figure 4, right). The development of slash bales allows the use of log trucks.

Figure 5 – Chip truck (left) and bin truck (right)

Landing residues that are comprised of mostly stem sections can not be compacted to any significant extent, but have a reasonable maximum achievable load (packing) density (40% to 45%). Maximum pay-loads will be able to be achieved with all but very dry material if the material is loaded well (maximising the packing or load density). The load density is affected by the skill of the loader operator and the visibility available to accurately place the material in the load space. Loading with independent excavators can cause difficulties with visibility inside the bin or load space, and guidance of the loader driver by someone able to observe externally can be helpful. Another option is small closed circuit video cameras, mounted on the excavator boom, linked with a small screen inside the excavator cab. Very small cameras and screens are now available and may cost in the order of $3000 to purchase and install. Self loading cranes mounted on the truck give the crane operator superior visibility of the trucks load space, allowing accurate placement of the log sections or residues, leading to greater packing and load density.

For residues from sites with very high branch content it may be difficult to get a maximum payload with any truck if the material is dry. The smaller diameter branches tend to dry more than stem wood in summer and may dry to as low as 20% mc (wet basis) if stored for a period of 4 to 6 months in dry conditions. Branch residues have a low natural pile density and although it can be compacted by a factor of up to 55% it may still give a load weight less than the maximum legal limit. In this case there is little that can be done to improve the potential pay-load, as even using chip trucks carrying comminuted material will not give a maximum legal load, due to the low moisture content. Where dry material is being carried, payment by volume or energy content of the load may be appropriate.

In overseas studies, bales of forest residue have been reported as having densities from 50 to 60%. The weight of the residue bales or bundles will depend on the moisture content of the material, which will affect the load weight. The baling of the residue creates compressed residue logs that can be loaded and transported with the existing logging equipment.

Cutover residues

Cutover residues (Figure 6) that are best suited for recovery are those from forests harvested off slopes of less than 20º. Residues on steeper slopes are theoretically accessible, but currently (2009) they cannot be recovered economically.

Figure 6 – Cutover residues; aged and dry (left), fresh and green, (right).

The cutover residues generally have a higher content of branches and needles than the landing residues (Hall 2002) but the majority of the volume is still in short sections of stem wood. These stem wood pieces are created by felling breakage. The residues are distributed across the cutover, at an average volume of anywhere between 30 m³ to 70 m³ per hectare. Density at individual points on the cutover may range from 0 (on tracks) to 200 m³ per hectare (in gully bottoms). When harvesting this material, ideally only the large pieces of stem residue will be collected, along with some attached branches and branches from accumulations of residue material (for example branch piles from mechanised delimbing).

Collection of small diameter branches, bark, needles and widely scattered residues is uneconomic and also undesirable for site nutrition reasons.

The stem wood and large branch material can be salvaged to, and stockpiled at, roadside. It will air dry at either location. If left spread on the cutover residue will dry slightly faster to a lower moisture content than residues stockpiled at roadside. The recovery of this residue to roadside can be considered as a primary transport operation.

There are four commonly used options for this primary transport (Figure 7):

- some form of off-road bin truck or a tractor/trailer (or skidder), which requires a separate loader (photo a)
- forwarder (self loading crane) (photo b)
- chipper forwarder (self loading crane) (photo c)
- residue baler and forwarder (self loading crane) (photo d) +(photo b)

Photo a

Photo b


Photo c


Photo d

Figure 7 – Some cutover residue transport and harvest options

Chipper forwarders (photo c) are used in Scandinavia and have been unsuccessfully trialled in New Zealand. It is a very expensive operation, as chipper productivity is low, and this practice is unlikely to occur in New Zealand in the foreseeable future.

The use of forwarders (photo b), or off-highway bin trailers towed by a skidder (photo a), are both viable options for cutover residue recovery depending on the demand for fuel. The advantage of the bin trailer is that it can unload quickly by tipping, speeding up the work cycle. However it does require two machines and operators.

Balers (sometimes called bundlers) are becoming more common in Scandinavia and Europe and are a means of taking a mix of branches and small diameter short length stem sections and creating a uniform product sometimes called a compressed residue log that can be easily forwarded, loaded, transported and chipped with existing equipment used for logs. The balers are typically mounted on a large forwarder and have self loading crane. The bales are left on the cutover, for transport to the roadside with a separate forwarder.

Once delivered to the roadside, cutover residues material can be treated in much the same way as the landing residues, although it will generally have a slightly lower density due to its higher branch content. It is likely that it will be harder to achieve a maximum payload with cutover residues due to their lower density and greater propensity to air dry to a lower moisture content. However, the transport system used for uncomminuted landing residues will be similar for cutover residue, unless in-forest chipping is being used. If in-forest chipping is used then chip trucks are a better option as they have a greater volume capacity. The decision to move to in-forest chipping will in part be affected by costs other than transport, although transport cost will be a major consideration.

In some cases baling of residues can be effective as it condenses the residues and simplifies the handling and transport system (Anderson 1995b). Based on current costs baling does not have major benefits over other options in most situations (Hunter et al. 1999). Whether baling is effective will depend on the residues; where there is a high proportion of stem wood present, it will be difficult to improve the density of the residues sufficiently enough to justify the cost. However, where the residues are predominantly branch material with a small amount of small diameter stem wood, baling may have advantages, particularly where long (>100 km) transport distances are involved. Bales can be transported in log trucks and trains.

Baling also fits well with larger-scale operations where centralised chipping or hogging occurs.

Wood processing residues

Figure 8 – Wood processing residues; hogged residues (left), chipper fines (right)

Wood processing residues (Figure 8) come in a wide variety of forms; bark, sawdust, sander dust, shavings, sawmill dockings and trim from reconstituted panel products. The most commonly available are bark and sawdust and to a lesser extent shavings. They have a wide range of moisture contents and densities. As these materials are typically already comminuted, they are suitable for bulk transport including bulk loading and tip unloading. The optimal configuration for transporting this material is generally in the largest volume truck available (chip trucks).

It is common practice to build loads in chip trucks over the height of the sides of the truck and then cover the load with a tarpaulin. This effectively increases the volume available for loading (Table 4). The load will settle during transport, by 3% to 5% over distances of 10 to 50 km depending on road conditions and travel speed (Giselrud 1976).

The density of uncompacted wood chips is commonly between 30% and 35%. Bark will tend to be slightly denser and hog fuel slightly less but with more variation (dependent on how it is produced).

The lowest density processing residues are dry shavings with an uncompacted density of less than 10%. Compaction of this material is essential to achieve an economic load, although this material is frequently very dry (10 - 20% moisture content) and so has high energy content compared to other residues on unit of weight basis. Unloading the compacted shavings may present some issues with binding and hang-up of part of the load within the truck when tip-unloading and some assistance (loaders/chains) may be required to assist the unloading.

Costs

The benefit of carrying dry wood is that although it may weigh less, the energy content, in gigajoules (GJ) will rise for the same volume (Figure 9). This highlights the need for those involved in transport of wood residues for fuel to consider not just the weight and solid content of the load but the effect of moisture content on the total net energy content.

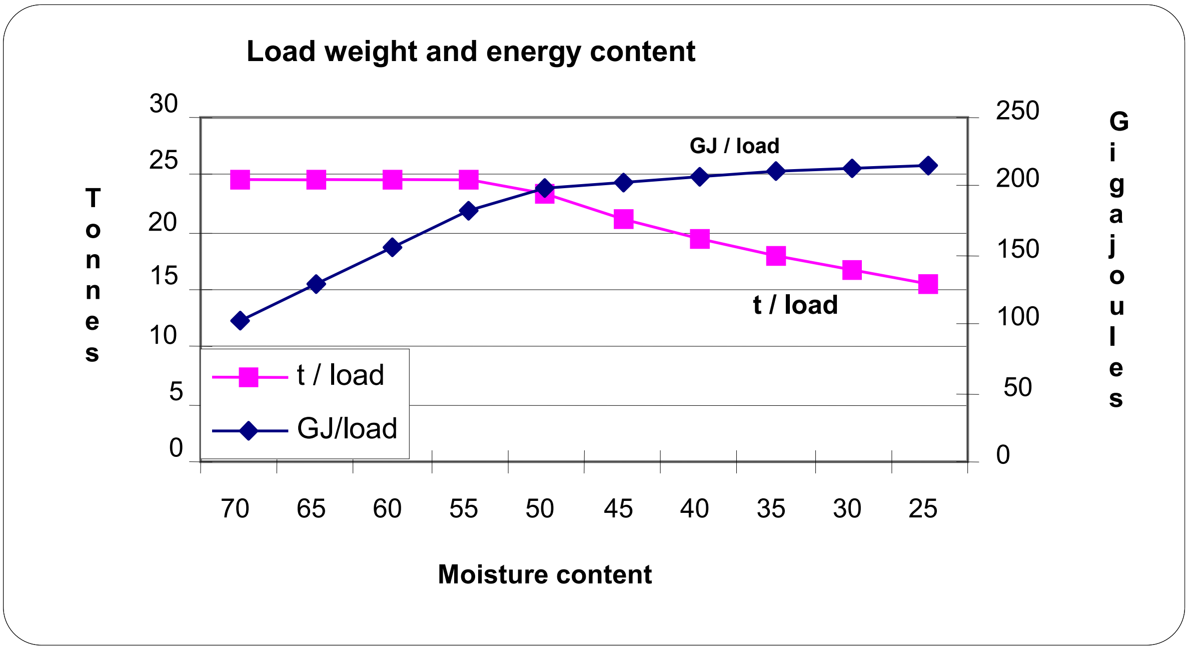

Figure 9 – Load weights and energy content at different moisture contents

The flattening of the lines in figure 9 is due to the weight and volume limits of the truck used in this example (24 tonne payload and 86 cubic metres).

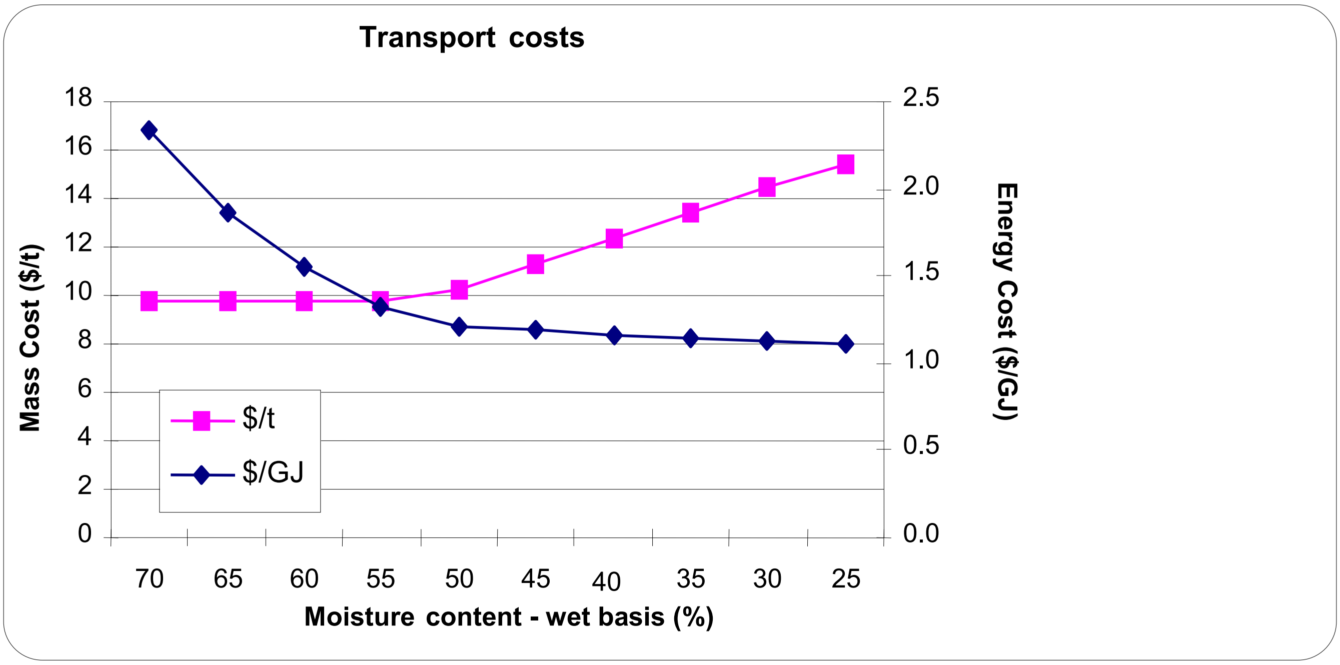

Figure 10 – Transport costs on the basis of weight and energy content at different moisture contents

As moisture content drops the cost per tonne delivered rises, but the cost per gigajoule delivered declines (Figure 10).

Payment for wood residues by energy content is common practice in Sweden and Denmark (Serup et al. 1999), where the use of wood residues for fuel is widespread. Payment by energy content is done by determining the weight of the load (weighbridge; load weight = gross weight - tare weight) and testing its moisture content. The load weight and moisture content are then used to determine the net calorific value or energy content of the load.

Net calorific value (NCV) of radiata pine wood fuel can be calculated by:
NCV (GJ/t) = (-0.2132 x moisture content (wet basis))+18.877
The energy content of the load can then be calculated by multiplying the payload weight in tonnes by the NCV in gigajoules (GJ) per tonne.

The cost of very short haulage transport (<20 km) can appear to be quite high in terms of cost per tonne-kilometre, but the total cost of transport is still very low compared with transport distances of over 50 km (Figure 11). The reason for the high rate per tonne-kilometre at short haul distances is the low utilisation of the trucks on short hauls, that is a greater proportion of their time is spent loading and unloading, with possible delays at both ends.

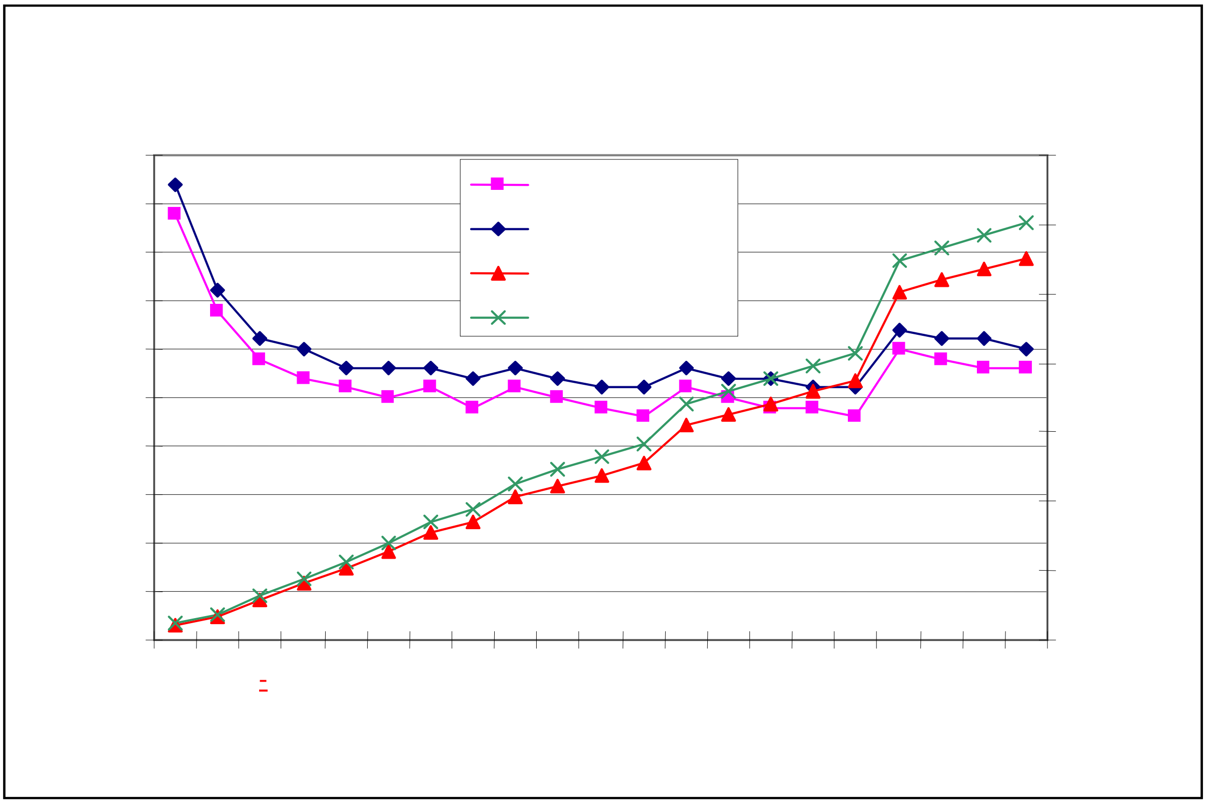

Figure 11 – Estimated total transport cost and cost per tonne-kilometre (as at March 2009, diesel (pump price of $1.01 per litre), and an alternative fuel price of $1.51 per litre

Loading and Unloading

<u>Loading</u>
The best method of loading in-forest residues will vary with the type of residues. For residues with a high percentage of branch material a grapple type loader will be suitable. For stem wood sections with lengths of 1 m to 2.5 m a grapple will also work adequately. When the length of the stem wood drops to below 1 m (such as off-cuts at a central processing yard), handling this material with grapple loaders becomes slow and ineffective. Knuckle boom operations can still be used, but the head needs to be altered or changed to either a brush grapple (wide with multiple tines), a clam bucket type arrangement or a normal bucket fitted with an opposing hydraulic thumb (Figure 12). In some cases, where the bulk of the off-cuts are very short, using a rubber-tyred front-end loader (RTFEL) fitted with a bucket and beak will be the best option. However, where an RTFEL and bucket are used care must be taken to avoid contaminating the fuel with dirt, gravel or rocks from the loading out surface.


Figure 12 – excavator bucket fitted with hydraulic thumb

When loading wood processing residues (sawdust, chip), overhead loading from bottom dump bins is possible and very fast. Where the size of the operation does not warrant the capital cost of an overhead bin the use of front-end loaders with large volume buckets is common. These machines come in a wide variety of configurations, including with a high reach boom and leading edge tipping buckets so that they can load over the sides of high volume trucks such as chip trucks. Where a high lift machine is not available a loading ramp will be needed to get the loader high enough to reach over the side of the trucks. These are not necessarily difficult or expensive to construct as the loaders can build temporary ones themselves out of dirt or in some cases out of the material being loaded (chip or bark).

Unloading

The unloading of landing residues will again depend on the nature of the residues. The loads of short stem section material can be tip-unloaded without difficulty if the truck is well designed. However, loading of landing residues that contain large amounts of branch residue and that have been compacted may not necessarily tip-unload. This material may have to be removed by a grapple loader or have some method of pre-placing a strop or chain before it is loaded to subsequently allow the load to be pulled out. The most likely option is grapple unloading. The design of the tail door of the truck is important in facilitating unloading of uncomminuted residues, with side hinged doors being preferred to a top hinged tail gate.

The unloading of bulk material such as chip, bark and sawdust can be done by tip-unloading, either onto a slab or into some form of reception bin. In some cases, part of the load can hang up in the bin during tipping, and can cause instability, especially in the trailer.

In some cases, where large volumes of material are being delivered, the power plant may install specialist facilities for unloading trucks. In the USA, where the use of semi trailers and B-trains dominate in chip transport, it is common to find trailer dumpers. That is, large hydraulic powered ramps that can lift and tip either the trailer or the entire truck and trailer (Figure 13). This means the trailer does not need its own tipping capacity, reducing tare weight. Another option, where the scale of operations does not justify the cost of a trailer dumper, is the use of semi-trailers fitted with walking floors. In these trailers the floor of the trailer is made up of independent slats that can move back and forth, shuffling the load out of the trailer (Bronson 1994).

Figure 13 – Trailer dumper (United States)

Other options include ramps that truck and trailer units can be driven up onto, and then tip out through the ramp into a receiving bin directly below (Mount Maunganui chip export facility).

The design of the truck can facilitate loading and unloading in other ways, by incorporating drop sides to improve access for grapple unloading, or the use of mesh sides to improve visibility during loading.

The speed of the loading and unloading will be affected by the design of the truck, and loading/unloading times can have a significant effect on vehicle utilisation. If time spent on loading and unloading is excessive, the number of trips a day a truck can undertake will be reduced, lowering utilisation and increasing cost.

With uncomminuted forest residues that have been compacted into a truck, tip-unloading may not be possible, and this should be considered when the entire stump to mill delivery system is being designed.

Vehicle specification

The selection of the specifications and configuration for a transport vehicle are critical factors in operating profitably (Wylie 1998).

1. Tare weight
Tare weight is a trade off between making a vehicle durable and also as light as possible. Every kilogram of tare weight is a kilogram less payload. It has been estimated (Dumbar 1994, Wylie 1998) that it may be worth spending $30 to save a kilogram of tare weight. However, a truck must also be built robust enough to cope with the environment in which it is expected to work, otherwise the repair costs and reduced service life of the vehicle will outweigh any savings. Dumbar (1994) has estimated that many trucks could be lightened by 600 to 700 kg, improving payload without compromising vehicle durability.

2. Bin construction
The type of bin fitted to a bulk cartage vehicle can vary substantially depending on the material to be carried. Chip trucks can be built from light sheet aluminium or a frame supporting heavy fabric reinforced with webbing straps, whereas trucks carrying raw residues are more likely to be built out of heavier gauge sheet steel reinforced with a steel framework. The heavier the construction of the bin, the greater the tare weight of the truck. The versatility of the vehicle also needs to be considered, in some cases the trucks may be able to be used to carry back loads of other materials (e.g. general freight, gravel, fertiliser, etc.) which can reduce costs.

3. Terrain
The key question is how much adverse grade will be encountered, loaded and unloaded, and how much power will be required to maintain a reasonable speed. The braking system is also affected by the grades to be negotiated and may dictate the need for a strong auxiliary braking system.

4. On-board scales
The use of on-board weight scales is widespread in the transport industry and is particularly useful when the material being carried is variable in its density and moisture content. It removes the guesswork from assessing load weights and will alleviate the problems of underweight loads (low revenue) and overweight loads (potentially high fines or rejected).

5. Central Tyre Inflation (CTI)
Increasingly the harvest from New Zealand's forests is from steep terrain. The surface of these roads is frequently low quality and sometimes wet. Traction, especially when towing a heavy bin trailer is likely to be a significant issue. CTI allows the driver to adjust the tyre pressure while driving and is one method of improving a vehicle's traction without major impacts on capital or operating costs (Wylie 1998). The advantages of fitting such a system are: extended operating season; extended operating range (increased adverse grade, wet, soft or loose surfaces); less time spent stuck (downtime); reduced tyre wear; and reduced vibration damage to the vehicle.

6. Cab configuration
Trucks can be built with either a flat nose (cab over engine) or a long nose (cab behind engine) configuration. Depending on the axle configuration cab over engine vehicles can have a higher payload and a larger load space than the cab behind engine configuration. The change to a cab over engine configuration can increase the length of the vehicles load deck by up to 1.4 m, increasing potential load volume by 8 to 9% (Dumbar 1994). The extra load space can be critical when carrying low density products such as dry residues.

7. Vehicle Configuration (number and layout of axles)
Road user charges (RUCs) are a charge based on weight and distance and are a significant contributor to the operational costs of a highway truck (between $0.01 and $0.06 per tonne-kilometre). Fitting of extra axles to trucks and trailers can have a considerable effect on reducing RUCs, but the extra axles will have a payload penalty and the cost and benefits need to be assessed carefully on a case by case basis (Wylie 1998). This issue is complex and is best addressed with the current RUC charges and an accurate idea of what the operating conditions will be. However, in the case of chips and residues being carted from forests, the most likely choice will be either a 6 x 4 truck with a 4-axle trailer or an 8 x 4 truck with a 4-axle trailer. The class of roads the vehicle will be doing the bulk of its travelling on will also have an influence on the axle configuration to give the best overall performance. Being able to accurately estimate the operating conditions is important.

Other Issues
The in-forest conditions may dictate a two-stage transport system, with specialist off- and on-highway vehicles required.

At the time of writing (February 2009) maximum gross vehicle weights and lengths were under review. There is a possibility that larger vehicles than those in Tables 1 and 2 will be allowed on some selected major roads in the future. The impacts of changes from this review could be significant and some estimates of the effect of a potential increase in weight and volume are presented in Appendix 1.

Vehicle Utilisation

Utilisation of the truck (how much time it spends doing effective work) is affected by time spent queuing for either loading or unloading. The capacity of the loading/unloading facilities and machines must match the scheduled volume of truck capacity in order to avoid excessive waiting times for the trucks. This may entail the trucking schedule to be controlled to give staggered arrivals of trucks.

Vehicle utilisation has a direct effect on the cost of transport. As with any machinery, a truck must be working to make money and in transport where cartage is paid for by distance, or units delivered, excessive loading and unloading times can seriously affect the viability of an operation. The truck design should be such that loading and unloading are facilitated as much as possible.

The supply chain as a whole can also have an effect on vehicle efficiency, and integration of the transport with the harvesting system and its existing equipment should be considered when implementing a residue transport system.

Scale of Operations

As with any operation, what may be possible and what is viable will vary with the size of the operation (the volume of material to be shifted on both a daily and annual basis). If the operation is low volume it may not justify the cost of a specially-designed vehicle when a similar vehicle can be contracted in as required.

For large-scale operations where significant volumes of material need to be moved and at least one vehicle will be required full time, then the cost of getting a purpose built vehicle may well be justified.

Conclusions and Recommendations

Transportation is a key activity with high costs; it needs careful analysis in order to optimise the transport system efficiency.

Truck transportation of wood residues is the most likely choice given the diverse and dispersed nature of the resource, the limited rail infrastructure and the need to minimise handling.

Storage and air drying of the residues will improve the delivered energy content whilst reducing the delivered tonnage. The method of payment (by weight, volume or energy) for the transport of fuels may influence key decisions in the system design.

High volume trucks (85 to 90+ m^3 load space) will be required to reach maximum loads for the majority of the fuels under current transport regulations.

Load compaction and restraint will be necessary for loads of uncomminuted residues sourced from forest cutovers and landings that contain high proportions of branch material.

Careful consideration should be given to truck design in order to minimise tare weight and maximise payload and volume capacity. Some common truck configurations and dimensions are presented in Appendix 2.

Constraints imposed by site-specific limits must also be considered (poor road condition, remote location, bridge weight limits or height restrictions).

For comminuted residues the current state of the art chip transporters are likely to be the best truck transport option.

For uncomminuted residues in raw form (stem wood sections and branches), the use of heavy duty bins on 6 x 4 or 8 x 4 trucks with 4-axle trailers will be the most likely choice for highway transport. The truck and loading system should have the ability to compact and tie down the load, with side hinged tail doors to facilitate unloading.

For off-highway transport of raw residues (which may be applicable in some of the larger forests (e.g. Kinleith and Kaingaroa) the weight and dimension limits imposed for public highways no longer apply. The vehicles used may be over length, width, height and weight compared to a highway truck. This lifting of restrictions may mean that the optimum design is quite different. For instance, very large semi-trailers may be feasible, alone or with the use of multiple trailers (A-trains).

Baling of cutover or very branchy landing residues is possible and fits well with the current log loading and transport infrastructure. However, given the high cost of the baling machine it is likely to be limited to large scale operations.

Estimates of transport costs can be developed on the calculators provided on the Bioenergy Knowledge Centre Website, at;
http://bkc.co.nz/Portals/0/docs/tools/residue_transport_cost_calculator.html

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Appendices

Appendix 1 - Potential impacts from increased truck dimensions and mass

Currently there is a review of vehicle dimension and mass rules. One of the possible outcomes is that on some routes, there will be an increase in the maximum mass (weight) and length of heavy vehicle combinations (truck and trailers).

If the rules were altered to allow a gross combination mass of 52 tonnes for a truck and trailer, with a total length of 24 metres, this could have significant impacts on the costs of transport of biomass.

For example, a bin truck and trailer designed to carry residues could have the following dimensions, load density requirements and costs.

Tare	18.6 tonnes	GVW	52.0 tonnes
Payload	33.4 tonnes	Length	24.0 metres
Volume	116 cubic metres		

Load density required to achieve maximum payload by moisture content (wet basis)

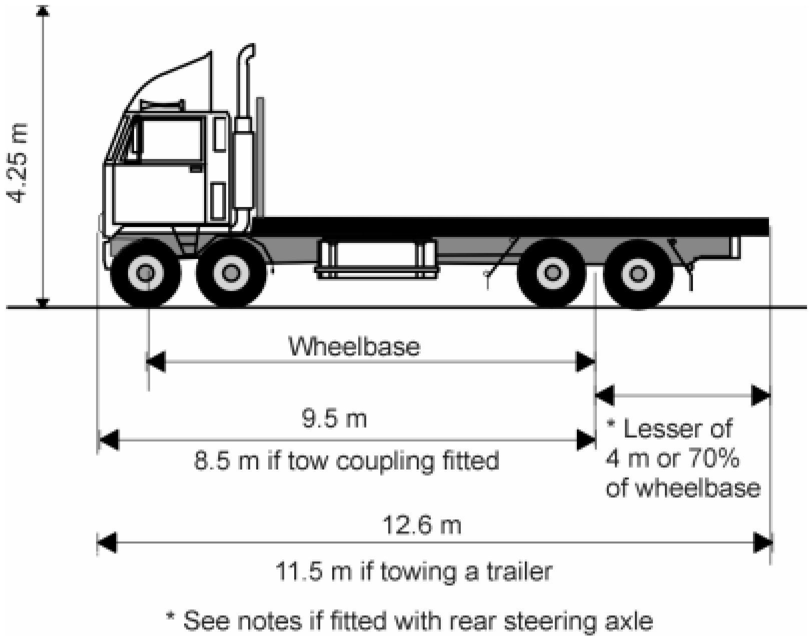
Moisture content	60%	55%	50%	40%	30%	20%
Load density (%) to weigh-out	29	30	32	36	41	47

The impact on cost is substantial, with cost reductions of ~20% possible compared to the existing vehicle limits.

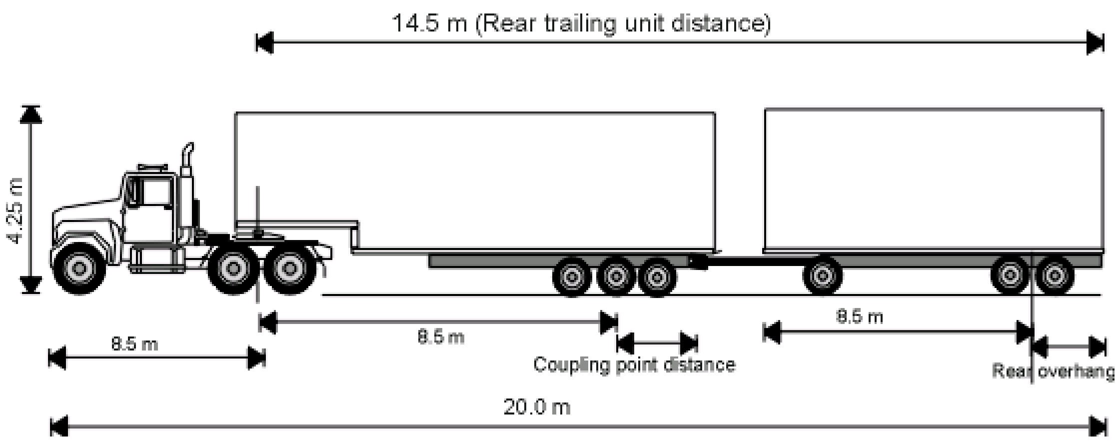
Appendix 2 - Truck Configurations & Dimension limits

Source: http://www.ltsa.govt.nz/

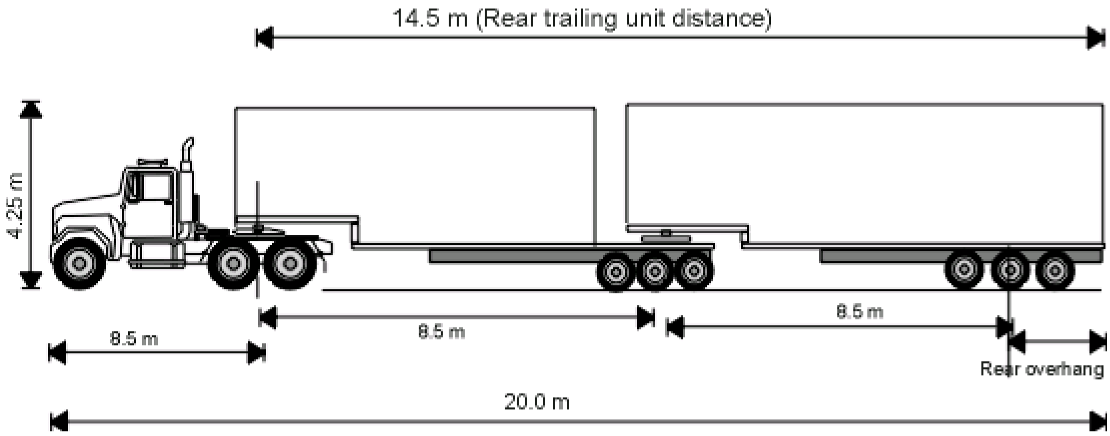
Truck



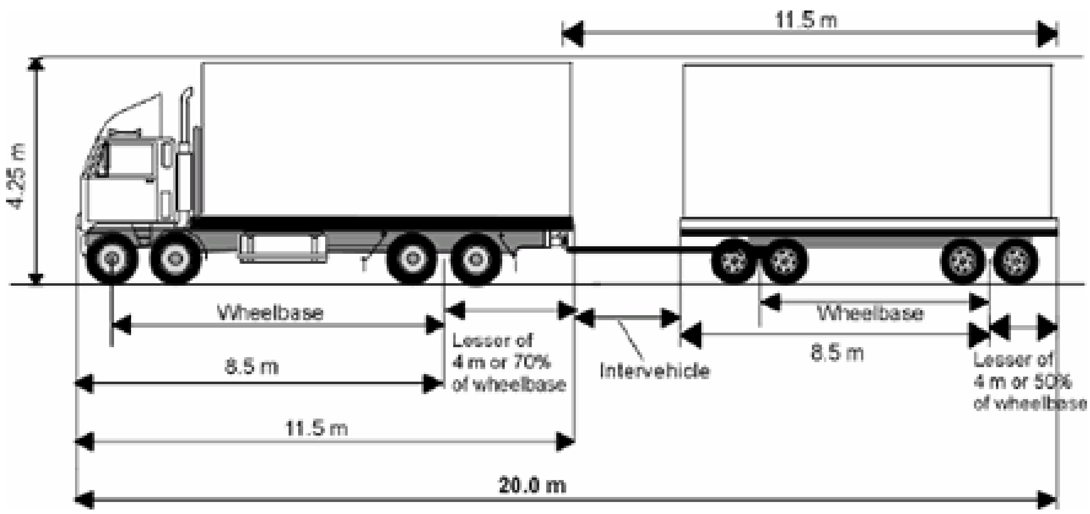
A Train



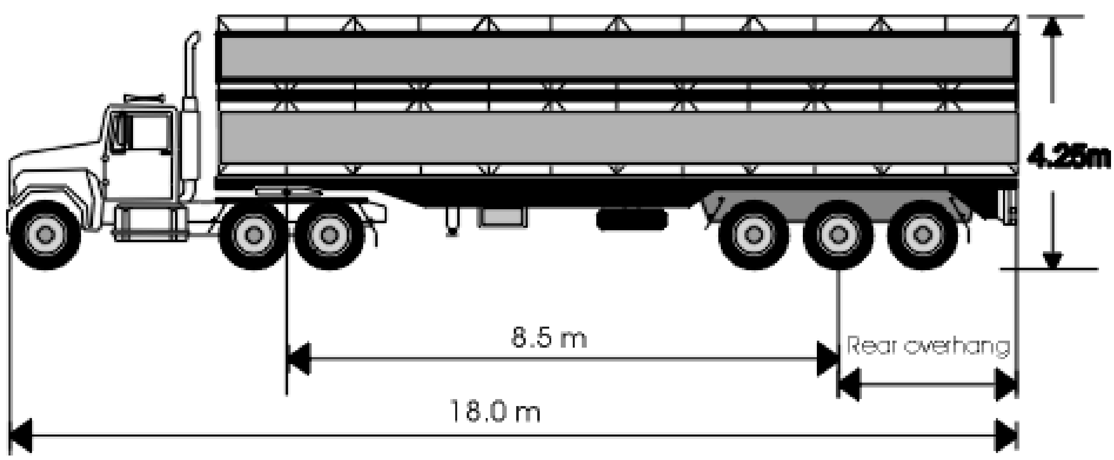
B Train



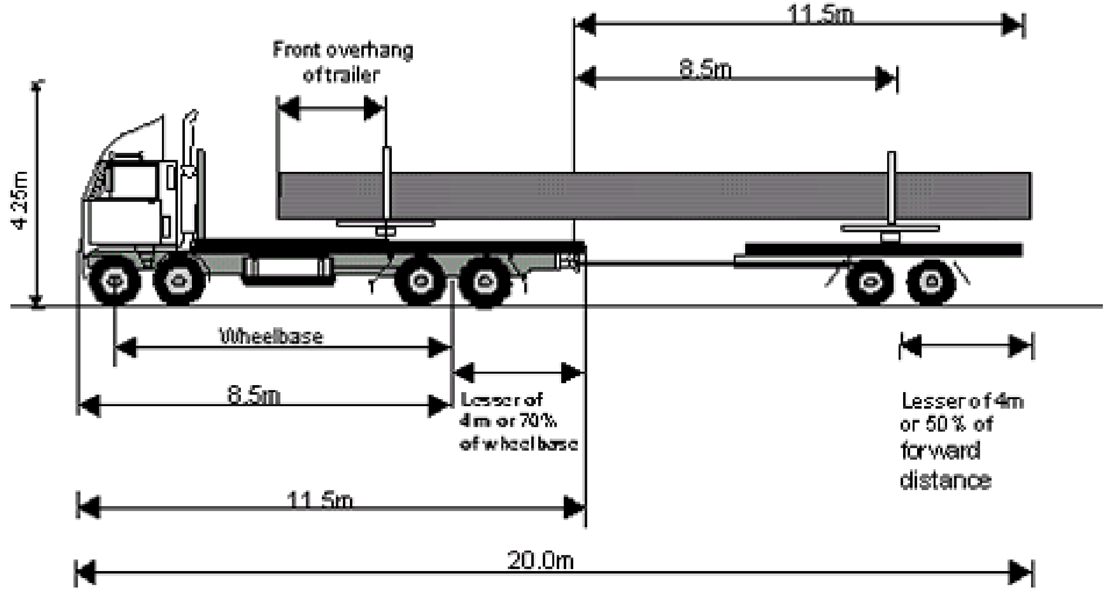
Truck and Trailer



Semi Trailer



Simple Pole Trailer



Pole Trailer