Integrating biomass recovery operations into commercial timber harvesting: the New Zealand situation.

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Abstract

In most countries biomass recovery from existing timber harvesting operations is recognised as an important component of any bio-energy program. At present, there are very few biomass recovery operations in New Zealand, despite the very large amount of residue generated by large-scale harvesting operations in plantation forests. Much of this residue is readily available post-harvest at landings, with a major concern being the contamination. Currently, residue constitutes a problem for both processing as well as the subsequent planting. A research project has commenced to help assess what an optimal residue recovery system may be. The paper considers what strategy could be employed to successfully integrate biomass recovery into NZ logging operations, with the integration of biomass recovery into the harvesting operation being key. Based on both international literature as well as extensive field visits three favourable options are established. Productivity and cost estimates are provided: with both the post-harvest residue recovery from the landing using a tub grinder, as well as using off-road trucks to transport the residues to a secondary landing for comminution estimated at 34 NZ$/ton. Whereas the post-harvest option provides for easier logistics, the concurrent recovery option will yield both greater quantity as well as quality biomass. Using a bundler to accumulate slash, and then comminute at the power plant is expected to increase the cost to 44 NZ$/ton. Finally, limitation and future research considerations are also discussed.

Introduction

In most countries biomass recovery from existing timber harvesting operations is recognised as an important component of any bio-energy program. Biomass recovery adds to the complexity of forestry operations, but also offers opportunities to increase efficiency, raise value recovery and reduce harvesting and management costs (Björheden 2000). At present, there are very few biomass recovery operations in New Zealand, despite the very large amount of residue generated by large-scale harvesting operations in plantation forests. These present a concentrated opportunity for low-cost biomass recovery.

Ninety-five percent of NZ plantation forests (Pinus radiata and Douglas Fir) are grown on a rotation that targets recovery of veneer, clear wood and or sawlogs. Potential residue recovery as a by-product is therefore very much secondary to the main harvest, which generates the largest revenue. Nearly all operations are whole-tree extraction, where trees are generally processed at the landing or eventually also at a central processing yard. Regardless of the site of processing, logging residue constitutes hindrance to harvesting and processing, as well as the subsequent restoration activities (Figure 1). Therefore biomass recovery also offers an important benefit in terms of easier operation and forest management.

Figure 1: Typical yarder landing showing the biomass discarded 'over the side'. Such biomass piles are becoming larger as the market for pulpwood decreases

A number of woody biomass studies have already been carried out in NZ to help define the problem and opportunity (i.e. Jack and Nielsen 2008; Hall and Evanson 2007; Hall et al. 2001; Kimberly and Manley 2006). The NZ government is trying to promote biomass use through targeted subsidies; for forestry mainly in the form of a 40% capital subsidy on equipment (EECA 2008). To develop a biomass recovery industry, contractors should have access to detailed operational information about machines and systems that are most cost effective.

A project has commenced at the University of Canterbury, funded by the Energy, Efficiency and Conservation Authority (EECA) that aims to determine such cost-effective biomass recovery systems through a series of intensive field studies, as well as the development of a set of Biomass Recovery Guide for Contractors.

Internationally, the biomass 'industry' is quickly developing with new machinery and new systems continually becoming available. The general goal of this paper is: 1) consider strategy options for integrating biomass recovery into forest operations; 2) to present different options for recovering the logging residue; 3) to provide a reasoned estimate of the recovery cost for each option; 4) to indicate the technical limitations of these systems; 5) to address the gaps in our knowledge of these systems, and especially the uncertainties about their transfer to NZ conditions, pointing the direction of future research on the subject.

1. Biomass Recovery Strategy

Currently, there are no product subsidies or any form of renewable energy guarantee. A biomass recovery industry cannot succeed without being integrated into the forest industry as a whole. The first step of this project was to review international literature that would help develop a strategy that may strengthen a newly developing market in NZ:

1. Combining roundwood and energy wood production optimisation: An integrated approach to full tree utilisation revenues and processing costs. At the moment we

refer to biomass waste or residue, but in fact it is a commercial by-product. This allows us to consider higher efficiency value chain systems such as whole-tree chipping for lower quality trees.

2. Integration of the biomass recovery system into the harvesting operation. Tend to focus on post-harvest biomass recovery, but have not considered to volume losses associated with pushing this material off the landing, and then pulling it back on.
3. Payment (or at least evaluation) by mass and moisture content, and or energy content of product. We tend to base our evaluation on green tons, resulting in very low quality biomass being delivered. We need to focus on product value depending on end-use.
4. Differing volumes of residues depending on harvesting and landing configuration. With a number of operations now two-staging, or processing at a CPY, we need to recognise the impact on not just the changing volume, but also the raw material type. For example, at a CPY the residue is primarily in the form of short but large diameter off-cuts and bark.
5. Drying effect – quality of fuel and optimisation of transportation. Transportation of dryer biomass has clear advantages in terms of return, but dry biomass is (more) difficult to comminute, and there is also an energy loss associated with natural decomposition that are not well understood.

2. Residue recovery options

The recovery of logging residue can be carried out with a number of different systems, depending on where the residue is made available and on whether the current operation planning can be aptly modified. While large volumes of biomass are also left on the cut-over, the focus is on landing because its disposal is particularly problematic, and there is a much higher potential for cost-effective recovery.

Concerning place, this residue can be recovered at:

- the conventional landing (skid),
- a 'superskid', which is a processing area that services a number of smaller landings (typically called 'pads') to concentrate the log-making, cross-cutting, sorting and loading activities, whereby stems are often forwarded off-road by a two-stage type machine
- at a larger central processing yard (CPY), with more automated processing, whereby stems are transported by either off-road, or on-road trucks.

CPYs are still relatively rare. The sheer volume of biomass that is generated at CPYs, and their convenient location close to a mill, means that these residues are already being recovered by a permanent, or semi-permanent comminution machine on-site (Figure 2).

Figure 2: Tub grinder working at the CPY in Kawerau. This CPY processes over 500,000 m3 of wood annually

Recovery from conventional landings and super-skids is the key issue. The options available depend on whether it can be performed concurrently with the main harvesting operation, or post-harvest. Recovering logging residue post-harvest is perhaps simpler to organize, but presents important disadvantages related to the contamination of the residue and the difficulty in reaching it. Normally, operators use a skidder or a bulldozer to push the residue off the landing, or throw off-cuts off the landing with the loader. Regardless of the technique, the result is very similar: the residue gets contaminated, entangled and difficult to reach. As a consequence, the eventual recovery operation will need to include an excavator (or bulldozer?) for retrieving the residue back onto the landing. Furthermore, the entangled and dispersed residue is likely to decrease the productivity of retrieval, making it comparatively expensive. The repeated handling of the residue is likely to cause a high incidence of breakage and contamination, both of which favour the use of a sturdy tub-grinder, one of the few machines capable of comminuting contaminated short-wood.

These disadvantages can be largely avoided if the residue is salvaged as harvesting progresses, which has already been demonstrated as a more effective strategy (Grushecky et al. 2007). This requires a higher planning effort, since the main harvest operation will need to adapted and accommodate the concurrent recovery activity. As loader and dozer operators already spend much time and effort trying to get rid of the residue, perhaps a convenient trade-off could be eventually worked out. If biomass recovery is concurrent with the main harvest, different options can be explored:

1) adding a chipper to the operation and chip the residue as it reaches the landing (Westbrook et al. 2007). The chip can be blown directly into chipper vans or in roll-on roll-off containers, or it can be discharged onto the ground for later reloading;
2) move the residue to a separate collection point – possibly an older landing located nearby. Residue can be stored from multiple landings, and eventually chipped and delivered by an industrial operation, when the storage site contains enough material to justify it, and when this material is dry enough to provide a high-quality fuel (Ranta and Rinne 2006);
3) use a truck-mounted bundler that will move between multiple active landings. It will compact and stack the accumulated residue for later collection and transport by standard

log trucks to the user plant (Johansson et al. 2006, Stampfer and Kanzian, 2006). In this respect, it is important to consider the quality of the residue to be processed: most commercial bundlers may have considerable difficulty in manufacturing coherent bundles from a residue composed mainly of short wood pieces, especially if a comparably large amount of branch material is not available. In this case, it may be worth checking the performance of new "compaction box" bundler prototypes, recently appeared in Sweden (Lindroos et al. 2008).

3. Influencing factors

A number of factors will affect the feasibility and the results that can be obtained from each alternative option. In particular: the amount of biomass available at each landing, and its accumulation rate; the space available at the landing; the distance of the eventual collection point; the size and the form of the residue.

Typical productivity for NZ operations range from 200 to over 400 tons per day. Significant amounts of branch and top wood is left on the cutover as a consequence of felling and dragging breakage. However, the NZ value recovery (log-making) procedure produces larger volumes of mid-stem off-cuts. The estimated biomass to log weight ratio is about 1:10 (Hall 1994). The residue produced by the average operation would amount to about one to two truckloads per day, which is too limited for justifying the presence of a full-scale chipping operation concurrent to the harvesting operation. This restricts the choice to either a smaller stand-by chipping set up, or to concentration at a separate storage point, with or without bundling.

A survey of NZ landings showed that the average period of use varies between one and 12 weeks, with a median value of 3 weeks (Visser et al. 2009). This would correspond to the accumulation of 15-25 truckloads (about 375-625 t) of biomass per landing at the end of the harvest. Conversely, a super-skid may be in operation for 3-6 months and can accumulate over 10,000 tons of residues.

Exploring the option of stacking the residue on the landing, we can calculate the space this would take up, if properly stacked. Assuming 100 kg m^{-3} as the bulk density of loose logging residue, the 400 tonnes accumulated at a landing would represent 4,000 m^3, and organized in 3 m tall stacks (considering 3 m as the maximum height at which a loader can comfortably stack such material) would occupy a surface of 1,200 m^2. The landing survey indicates that the average landing area in excess of 4,000 m^2. Such surface could easily accommodate the biomass stack, the chipping operation and the transport vehicle, but only after the main harvest operation has been completed and the equipment relocated to a new site. Therefore, both space requirements and accumulation rate prevent the set up of an industrial chipping operation alongside the main harvest rig, whereas the utilization of old landings as biomass storage and processing sites seem feasible.

Distances between the landings in the same forest were also measured in the landing survey. As the large plantation forest mature evenly, it is not uncommon to have 3 or 4 operations working in close proximity. The distance between active and inactive sites can range between few hundredths meters and few kilometres, so that a collection point can generally be found within 2-3 km from any of the other landings – active or inactive. Hence, loose residue could be moved at a comparatively low cost, even if its low bulk density does not allow utilizing the full payload capacity of the transportation vehicles. Such short distance makes bundling redundant, unless the purpose of bundling is actually to allow storage at the original landing and direct transportation to the end user. In this case bundling could still make sense, as it would allow for using a highly efficient stationary chipper at the user plant. Bundles could be removed by standard log trucks every time a full load is ready, or they could be stored at the landing, since their bulk density is 3 to 4 times higher than that of loose residue (Spinelli and Magagnotti 2009) and therefore the 3-m stack coming from a single landing would occupy between 300 and 400 m^2. With its average gross productivity of 7 tons per hour (Kanzian 2005), a truck mounted bundler could serve 2 operations working in the same forest. Covering a third and/or fourth operation may require longer shifts. Such machines often work double shift in their Nordic countries of origin (Kärhä and Vartiamäki 2006).

Finally, the size and shape of the residue can impose significant constraints on the technology used for recovery and processing. A significant proportion of the residue accumulated at NZ landings consists of slovens and offcuts, whose large diameter may prevent the use of light chippers, thus precluding the standby chipper option. The short length of these pieces also requires that the infeed opening of any equipment used for processing them is fitted with an extended lower lip or table, and favours the use of tub-grinders. Bundling is also possible, on condition that there is enough branch and top material to build coherent packs. For this same reason, it is advisable to manufacture short bundles, with a length between 2.5 and 3 m.

Based on these considerations, we remain with three options for recovering logging residue from NZ landings, and namely:

Option I - Retrieving the residue post-harvest with an excavator, and process it with a mobile tub-grinder; transporting hog-fuel to the user plant with chip vans;

Option II - Moving the residue to a nearby collection point using a truck with a large-size bin, while the main harvest proceeds (no need for pushing the residue off the landing); chipping the residue at the collection point when enough residue has been accumulated to justify an industrial chipping operation; transporting chips to the end user with chip vans;

Option III - Bundling the residue at regular intervals as the main harvest proceeds; transporting the bundles to the user plant with standard log trucks; chipping at the plant with a stationary chipper. Again, this option is limited to those cases where residue includes a significant amount of slash, to fill up the space between log offcuts and build a coherent bundle.

4. Productivity and cost

Note: All costs are in New Zealand dollars, whereby 1 NZ$ is approximately 0.5 Euro.

It is important to try and estimate a rough landing-to-boiler cost for the different options, in order to assess their feasibility. In the absence of proper experimental data, such comparisons are not conclusive, and should rather be taken as a general indication. Such estimates should be transparent, thus enabling readers to substitute their own figures and repeat the calculations as more detailed information becomes available.

Table 1 shows the estimated machine rates for the range of equipment considered in our study. Such rates have been obtained with the method described by Miyata (1980). The basic operating cost has also been increased by 25 % to account for overheads, relocation and profit. The rates shown in the table do not include labour costs, that have been added separately, at a rate of 20 $/h for the forest machine operators and 14 $/h for the truck drivers. The resulting figures are compatible with those reported by Forme (2008), which however only provides information for the loader, but not comminution, bundling and transport machinery.

Table 1 – *Machine rates and calculation assumptions (excluding operator)*

Machine		Loader	Mobile grinder	Mobile chipper	Stationary chipper	Bundler	Truck-loader	Truck-trailer	Chipvan
Investment	$	300,000	800,000	800,000	700,000	850,000	300,000	350,000	320,000
Service life	yrs	5	5	5	7	5	5	5	5
Usage	h / yr	1750	1750	1750	2000	1750	1750	1750	1750
Fixed cost	$ yr^{-1}	64,320	171,520	171,520	124,400	182,240	64,320	75,040	68,608
Variable cost	$ / SMH	29.3	101.6	96.7	55.8	38.9	29.3	32.0	25.8
Total cost	$ / SMH	83	249	243	148	179	83	94	81
Total cost	$ / 8h	661	1996	1947	1180	1430	661	749	650

Productivity estimates are somewhat more complex, but can be obtained from relevant literature.

Concerning Option I, the operation may consist of three units: a 350 kW mobile tub-grinder and two 20-t excavators, one for retrieving the residue and the other for feeding the grinder. The productivity of such operation is limited by the grinder, and is in the range of 20 tonnes per scheduled machine hour (SMH), all delays included. Such figure is slightly lower than that presented by Hall and Evanson (2007), but is taken as a conservative estimate of long-term productivity, meant to include operational, mechanical and personnel downtime. Thus, processing the 400 t available at the average landing will take approximately 20 hours. Residue retrieval may proceed twice as fast, taking 7-8 hours per landing (Hall 1993), also because the excavator only needs to treat part of the biomass – that at and over the landing edge.

The excavator can be equipped with a second clam bucket for loading trucks. This way, the grinder can dump the hog fuel on the ground when no trucks are available, dramatically reducing the large operational delays that cripple the efficiency of roadside chipping operations (Spinelli and Visser 2009; Stampfer and Kanzian 2006). In this specific case, discharge on the ground is unlikely to increase significantly the contamination of an already contaminated fuel, and the 4% losses indicated by Hall (2008) might be reduced when dealing with large quantities. Overall, this operation requires two operators – one on each loader.

The operator on the loader that feeds the grinder will also steer the hog through a remote control placed in the cab. The total cost of this operation is equal to 455 $/SMH, or 22.7 $/t. The hog fuel is then hauled to the plant using chip vans, with a volume capacity in the range of 90 m^3. A simple deterministic model has been developed for estimating transport productivity and cost, and is presented in Table 2. Based on this model, transport cost will amount to 11.1 $/t on the average one-way hauling distance of 40 km. For Option I, the total delivered cost will then amount to about 34 $/t (Table 3).

Table 2 – *Basic assumptions, productivity and cost of transport*

Transport option		**Hogfuel**	**Chips**	**Bundles**	**Slash**
		Basic assumptions			
Payload	t	25	27	27	8
Speed - forest road	km / h	15	15	15	15
Speed - public road	km / h	50	50	50	50
Loading	Min	50	50	40	20
Scale and unloading	Min	20	20	30	10
Delays	Min	10	10	10	5
		Productivity and cost calculation			
Turn time - 2 km	Min	-	-	-	51
Productivity	t / SMH	-	-	-	9.4
Hourly cost	$ / SMH	-	-	-	97
Unit cost	$ / t	-	-	-	10.3
Turn time - 40 km	Min	176	176	176	-
Productivity	t / SMH	8.5	9.2	9.2	-
Hourly cost	$ / SMH	95	95	108	-
Unit cost	$ / t	11.1	10.3	11.7	-

In Option II, the residue is moved to an older inactive landing using an off-road truck, equipped with large size bin and independent loader. The bin can be enlarged to a volume of 40 m^3 (2.5 x 6 x 3.2 m), which on 3-axle truck would leave just enough space for the loader. Average load, loading and unloading times, and moving speed are shown in Table 2. Assuming a one-way hauling distance of 2 km on forest road, such unit could move slightly more than 9 tons per hour, at a cost of 10.3 $/t. The material is then chipped with a powerful mobile chipper, fed by an excavator-based loader. This operation requires one worker only, since the loader operator can also steer the chipper through a remote control placed in the loader cab. Long-term chipping productivity can be estimated in the range of 25 t/SMH (Spinelli and Hartsough 2001) - slightly higher than the grinder, due to the more efficient comminuting device (Asikainen and Pulkkinen 1998). What's more, dirt-free chips will present a higher quality, possibly fetching a better price than hog fuel (Eriksson and Björheden 1989). Due to their more regular shape, chips also pack better than hogfuel and can form denser, heavier loads on the chip vans, which explains the lower transportation cost. Overall, Option II achieves almost the same financial result as option I, but offers a better product, with a potentially higher market value.

Option III is based on a truck-mounted bundler, regularly visiting active landings to pack and stack the residue. The machine is manned by one operator and can produce about 7 tonnes per hour, at a unit cost in the range of 28 $/t. The bundles are then moved directly to the user plant with a self-loading log truck, or loaded out with the regular excavator loaders used in the harvesting operation. The bundles are chipped with a stationary chipper at the plant, capable of processing about 40 t of biomass per hour (Spinelli et al. 2007). Compared to a mobile chipper, the stationary unit is more efficient and much cheaper to acquire and operate, since it does not require a carrier, runs on electric power and uses a much simpler and more durable transmission. Overall, the cost of Option III is significantly higher than that of the alternatives, due to the very high cost of bundling. This assumes that the bundler models currently on the market can handle a residue largely consisting of short, stubby elements. The future availability of new and more versatile bundling units could prove to be the simplest recovery chain to organize, requiring the addition of only one specialised unit to a conventional logging set up.

Table 3 – *Costing the three main options for the recovery of landing residue*

Operation	Option I	Option II	Option III
Moving, $ / t	-	10.3	-
Bundling, $ / t	-	-	28.4
Grinding, $ / t	22.8	-	-
Chipping, $ / t	-	13.8	-
Transporting, $ / t	11.1	10.3	11.7
Chipping, $ / t	-	-	4.2
Total	**33.9**	**34.5**	**44.4**

Superskids

The differences between a skid and a superskid is substantial, since the latter offers a larger amount of residue material, more space for accommodating processing and loading equipment, and possibly also some stationary or semi-stationary infrastructure to increase the efficiency of all operations. For example a highly efficient stationary chipper could be used for converting all residue into a higher quality and value energy co-product, turning a disposal problem into an opportunity for additional income. In this case, one can assume the same chipping cost as for Option III (stationary chipper) and the same transport cost as for Option II (chipvan), for a total delivered cost in the range of 14.5 $/t.

Once in place, the comminution line could be fed with landing residue, transported to the CPY with enlarged load space off-highway trucks, similar to those described for Option II, but with the addition of a trailer. Such units could reach a payload of 15 t, and proceed at the same 15 km/h speed as the basic truck version. Informal interviews with companies estimate the average distance between active skids and the CPY approximately 10 km. This figure has been used for calculating the turn time of an off-highway truck and trailer rig, after extending loading and unloading time proportionally to the payload increase. The resulting figure amounts to 135 minutes for a payload of 15 t. Assuming a machine rate of 100 $/SMH (operator included), the cost of delivering landing residue to the CPY is in the range of 15 $/t. Adding the 14.5 $/t previously estimated for the cost of chipping and transport to the user plant, returns a total delivered cost of 29.5 $/t, which is still very favourable.

5. Future research

Biomass residue recovery from landings is still relatively unexplored in New Zealand, and there is an urgent need for reliable information on a number of different operational aspects, including: quantity and quality of the biomass, possible markets, long-term productivity and cost of the proposed systems, and possibility for their further improvement.

Estimates presented in this paper are based either on European data, or on data obtained in NZ from comparatively short-term studies. Neither can offer an accurate prediction of long-term productivity under typical NZ conditions. It is important to validate through field trials and extended time and motion studies. In their absence it will be very difficult to develop accurate estimates of delivered costs, and to draw reliable comparisons between alternative systems.

It is also important to determine the actual amount of residue produced at typical landings, since the data available so far are based on ballpark figures - and although such methods are still acceptable and are frequently used or mentioned (Rummer 2008), they offer a very basic accuracy level.

One of the main hurdles to the development of a NZ forest energy sector is the present limited demand of wood fuel: without a market capable of absorbing significant amounts of biomass at a reasonable price, it is very unlikely that operators will develop modern and effective biomass production chains. The drivers behind the development of a forest energy sector can be many, both public and private in character (Björheden 2006), and the possible growth of bioenergy in NZ is not exclusively dependent on national policies against climate change.

Market development must proceed with product specification development, as different markets will require products with different quality. It would be important to better understand fuel quality obtained from different situations. In particular, it is important to determine the level of contamination and the moisture content of the biomass salvaged from old landings.

From a technical viewpoint, one could also explore the many variations of the main three options presented above. For instance, Option II could be made more efficient by using roll-on roll-off bins, parked at the landing and periodically recovered by a dedicated shuttle truck. This solution is likely to decrease loading time. Another example is offered by the transport of residue to CPY: in this case, the residue may consist of whole tree tops, rather than branches, slovens and offcuts. Whole tree tops could be transported with standard log trucks, and could be loaded, unloaded and chipped more efficiently. In this case, one may even explore the profitability of separating different product streams from the same tops, such as pallet logs, pulpwood, pulp chips and fuel biomass.

This report has only considered the recovery of residue accumulated at landings, excluding the cutover residue that is particularly abundant especially after a ground-based operation. The management of this residue is also expensive, since the slash is often windrowed with an excavator before establishing a new crop. Thinning operations offer a further opportunity for fibre recovery. At present, radiata plantations are generally thinned to waste. The size of cut trees is large enough to make recovery feasible.

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