Next generation biomaterials

Wood-to-Energy Value Chain Analysis

Prepared for the Energy Efficiency & Conservation Authority

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Prepared for
The Energy Efficiency and Conservation Authority

WOOD-TO-ENERGY
VALUE CHAIN ANALYSIS

Submitted by
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EXECUTIVE SUMMARY

EECA has secured funds strategically targeted at enabling the Government to achieve the bioenergy targets in the NZ Energy Efficiency and Conservation Strategy. The targets are aimed at using an additional 7 petajoules per year of forest residues for energy and an additional 3.5 petajoules per year of energy from biomass in the residential and commercial sectors by 2025.

The aim of the present study is to identify areas in the wood-to-energy value chain, specifically for heat, where EECA funding will have the highest impact on future development of the bioenergy market.

This study has concentrated on the use of forest residues for heat in industries outside the wood processing industry market, such as dairy factories, meat processors etc. These industries represent a significant heat demand. Presently, very little forest residues are used outside the wood processing industry and this study is aimed at identifying the barriers, and approaches to overcome these. The three main barriers identified in this study are:

- Fuel quality (low fuel quality, low energy density, variable particle size)
- Security of supply
- Distance from forest

For forest-residue-derived fuels to be attractive to industries outside the wood processing industry fuel quality must be of a high standard and supply must be guaranteed. Low-quality fuel increases the cost of on-site equipment for storage, automatic feeding, and combustion, thus raising the cost of energy. The non-wood processing industry is also unlikely to want the additional site footprint or to develop the required expertise to use a low-quality fuel. In addition, industries outside the wood processing industry considering investing in biomass heat plants also see securing a guaranteed supply of low-cost fuel as a major problem. This is due to the tenuous links between forest owner, fuel processor, supplier, and consumer. Finally, the vast majority of industrial users are located a considerable distance from forests, and the relatively high cost of transporting low energy density fuel makes the use of forest residues economically unattractive.

Through this study, fuel upgrading has been evaluated as an approach to overcome all three of the above barriers. Fuel upgrading examples are:

- screening fuel for contamination and particle size;
- drying;
- production of a uniform, flowable, wood chip;
- production of an industrial grade wood pellet;
- and a liquid bio-oil via fast pyrolysis.

Fuel upgrading adds more value to the end user and so the fuel will command a higher price (such as with the price of gas compared to coal). This higher value should flow down the value chain, resulting in greater return to the forest owner. Increasing the return to the forest owner is likely to be the only viable approach to securing longer-term supply contracts. In addition, if fuel upgrading involves energy densification, then the cost of transportation per unit energy decreases enabling forest residues to supply a much wider market.

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AIM

The aim of the study is to identify areas in the wood-to-energy value chain, from forest residues to heat, where EECA funding will have the highest impact on future development of the bioenergy market.

RATIONALE

EECA has secured funds strategically targeted at enabling the Government to achieve the bioenergy targets in the NZ Energy Efficiency and Conservation Strategy. The targets are aimed at using an additional 7 petajoules per year (PJ/y) of forest residues for energy and an additional 3.5 PJ/y of energy from biomass in the residential and commercial sectors by 2025 (EECA, 2007).

Extraction of forest residues for heat has been initiated by a number of players in the industry. However, there are still a number of barriers to overcome to achieve a higher uptake, especially outside the wood-processing industry. Some barriers have already been identified under the Engineering Solutions Phase 1 project, resulting in work underway in the Engineering Solutions Phase 2 project.

EECA is particularly interested in identifying key areas where investment will have the highest impact or, in other words:

- What and where are the barriers?
- How important are they?
- How much will it cost to eliminate or reduce them?

BACKGROUND

The forest residue resource has only been extracted for commercial energy use in New Zealand in the last few years. The resource is geographically dispersed and has low energy density, making it expensive to extract. Other issues such as fuel variability and supply security have made the introduction to the energy market difficult. The increasing price of coal and natural gas in the last few years has made forest residue more cost competitive. Governmental initiatives are also supporting development opportunities in the renewable energy sector. Additionally, technology development over the last decade has made the use of forest residue practical and economic in specific cases.

Over the last decade forest residues have been used increasingly by the wood processing industry. Flexible solutions, such as hogged fuel, have been developed. These flexible solutions, however, have created a fuel of varying quality. To date only the wood processing industry has been able to use variable quality fuels since they already handle their own on-site residues.

In the past, the close relationship between forest owners and wood processing industries has made it possible to develop an “informal” market between the forest residue owner and the end user. The relationship was also important because the end user, the wood processing industry, required security of supply. The use of forest residues as industrial wood fuel rose from almost nil in 2000 to 50-100,000 tonnes in 2003 and to an estimated 100-150,000 tonnes in 2007. The estimated volume available annually is around 1 million tonnes of forest residues on the landing sites and 700,000 tonnes of residues on the more easily accessible cutover (Hall, 2008). To achieve the 7 PJ/y target in the energy strategy, 700,000 tonnes should be extracted per year – a five-fold increase over present use.

The wood processing industry presently covers approximately 85% of their heat demand with wood biomass (EECA, 2007). It is therefore expected that much of the additional 7PJ/y of forest residues will be used outside the traditional wood processing industry. Increased use requires that other industries, such as dairy processing factories, become new end users.

This report is the first phase in a study to identify areas in the wood-to-energy value chain specifically for heat, where EECA funding will have the highest impact on future development of the bioenergy market. The first phase is focused on the wood-to-energy value chain with the non-wood-processing industry as end users. It is proposed that a second phase considers the value chain for the wood processing industry as end user. This second phase must consider the more complicated possibility of wood processors using low-value forest residues for heat and upgrading their higher-value processing residues for fuel for residential and commercial users. This second phase will address the second target of the New Zealand Energy Efficiency and Conservation Strategy (EECA 2007).

CASE STUDY: DAIRY INDUSTRY

In order to consider the possibility of forest residue use outside the wood processing industry, we have chosen the dairy industry as a case study. In particular, we have chosen to consider Fonterra's dairy factories. Fonterra has 24 dairy factories throughout New Zealand, processing 14 billion litres of milk per year. The combined steam demand at these sites is 6 million tonnes annually, or 15 PJ/y (Process Developments Ltd, 2007). The heat demand at these sites is met by coal or gas boilers. The EECA Heat Plant Database shows a 40:60 split between coal and gas.

The reasons for dairy factories to convert from fossil fuels to renewable fuels such as woody biomass are twofold. Firstly, there are strong international drivers from export markets for the dairy industry to reduce its greenhouse gas footprint; and secondly, the NZ Emission Trading Scheme is likely to increase the price of fossil fuels on top of recent gas price increases (MfE, 2007). For example, a carbon charge of \$20 tCO_2-e will increase the price of coal by 30-40% and that of gas by 10%. Use of fuel derived from forest residues is therefore an important possibility for dairy factories.

Currently, however, there are no dairy factories using forest-residue-derived fuel for their heat demand (Mallinson, 2007). Barriers to use of fuels derived from forest residues for process heat at dairy factories are:

- **Low fuel quality**
  Generally, if the fuel quality is low or variable a more sophisticated control and feeding system is required for a boiler, which increases the cost of the system. A low-quality fuel, such as hog fuel, is also likely to be undesirable to dairy factories due to additional expertise and land required to deal with the fuel. For example, dairy factories with coal or gas boilers do not usually have the space to accommodate the fuel stockpiles typically required for hog fuel. The location of wood residue stockpiles close to dairy factories is also undesirable because the stock piles host insect populations which can contaminate the air intake systems to hygiene areas and dryers within the dairy factories (Process Developments Ltd, 2007).

- **Security of supply**
  This has been identified as one of the key barriers to forest-residue-derived fuels. The milk supplied from surrounding dairy farms must be processed immediately, so factories cannot afford to lose processing capacity during the dairy season. Historically there has been a strong relationship, including ownership or co-ownership, between the forest owners and the wood processing industry. This has enabled a measure of security of supply between the

forest owner and the heat plant owner at a wood processing site. In the case of a dairy factory there is no such connection.

- **Distance from forest**
  Figure 1 shows the 24 Fonterra dairy factories overlaid on a map of the current plantation forest estate. Obviously a number of factories are a large distance from a forest and the supply of forest derived fuel will be more costly for these sites. This is likely to be a barrier for a number of industrial sites.

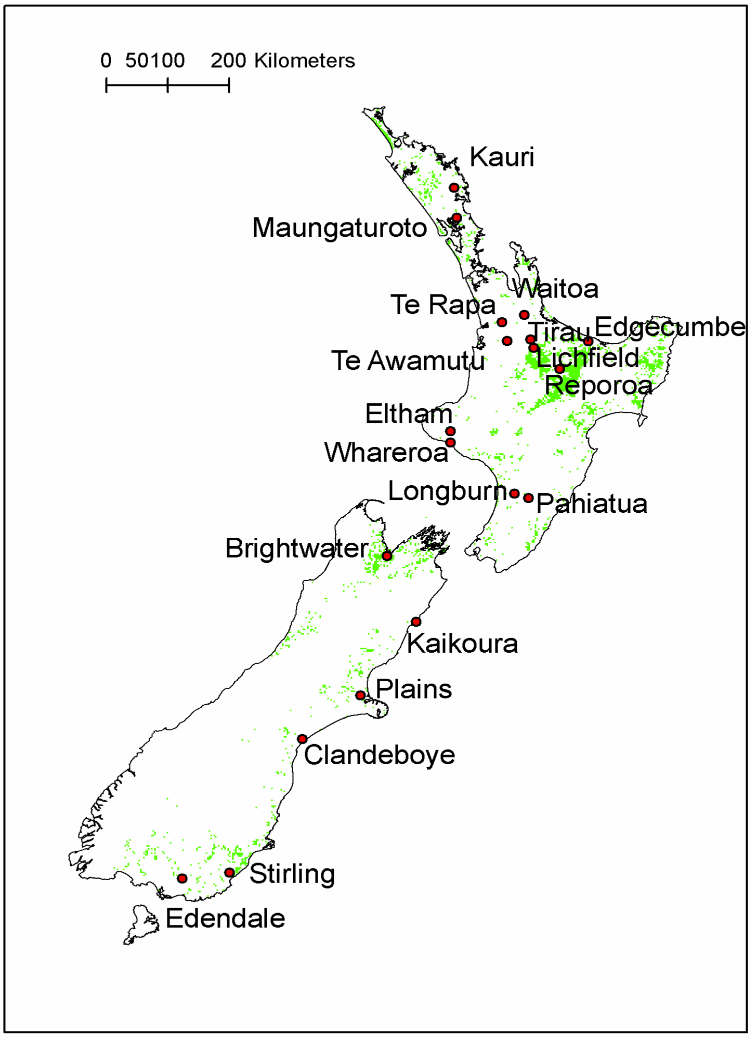


Figure 1: Fonterra dairy factories in relation to plantation forests

WOOD-TO-ENERGY VALUE CHAIN

In order to understand how some of the above barriers could be addressed it is necessary to consider the whole wood-to-energy value chain. The wood-to-energy value chain is, in the present study, defined as starting with landing and cutover residue extraction in the forest through to final use as heat. The analysis carried out is very specific to the New Zealand situation. It covers, in particular, the New Zealand radiata pine plantation forest, which comprises 90% of the plantation forest area in New Zealand. Residue production in other species of plantation forest, for example Douglas-fir and eucalypts, will be different in composition and volume and is not analysed in this study.

New wood fuel market

To achieve the aim of using forest residues in the non-wood-processing industry requires a new relationship to be created between the wood fuel processor and the new end user. To this end, it is useful to consider the different perspectives of stakeholders in this new market.

Dairy factory end-user perspective

The dairy factory end user is interested in buying a fuel which can be used to meet a heat demand. The dairy factory has a steam demand, which is delivered by a boiler. The boiler type defines the fuel requirements going into the boiler feeding system. The boiler is required to run “hassle free”, as it is critical the factory gets steam on demand. This sets a demand on the feeding system, which has to be able to feed the system consistently. Trouble-free fuel feeding for the boiler requires high-quality, consistent fuel. These requirements for fuel quality and security of supply continue on down the value chain.

Forest manager and wood fuel producer perspective

The perspective from the wood fuel producer is very different. In the traditional supply chain, forest residue is extracted from the forest, comminuted (mechanical reduction in particle size), stored and transported to the end-user site. The key driver in the past has been to deliver a wood fuel as cheaply as possible. In this case the receiving system and boiler feeding system have been designed to handle the wood fuel delivered from the forest. Furthermore, boiler systems with cyclone and bag filters, for example, have been designed to convert a non-homogenous fuel.

From the perspective of the forest manager, forest residues are a waste product following the harvesting a more valuable log product. The harvesting of logs is tied to the fluctuating international log price, so production of residues is not guaranteed. With the low return from residues there is very little incentive for forest managers to manage their forest to accommodate a secure supply of residues. There is also little incentive to inform wood-fuel producers of future harvest plans so that longer-term contracts can be put in place. In fact, this information is often commercially sensitive.

It is clear there are major differences between how the end user, the fuel supplier, and the forest manager see the wood-to-energy value chain. These perspectives will need to be addressed in establishing such a market.

VALUE CHAIN ANALYSIS

In this section five possible wood-to-energy value chains are considered. These chains represent a broad range of possible options for utilising forest residues for heat in dairy factories and other industrial sites.

In the first two chains, landing residues are comminuted in-forest and then transported to a dairy factory. In these cases, the comminuting process can be either hogging (producing hogged fuel) or chipping (producing chipped fuel). The third wood-to-energy value chain is based on bundling cutover residues and transporting the bundles on logging trucks to a comminuting plant on the end-user site. The fourth value chain converts the forest residues into a dense wood pellet, which is then transported to the end user. The fifth value chain processes forest residues into a bio-oil, which is then transported and used as boiler fuel for heat by the end user.

It is often useful to consider two separate parts of the chain in isolation: the “end-user value chain” consisting of the part of the chain occurring on site at the industrial site; and the “fuel-supply chain” the part of the chain from forest through to fuel delivery to the end user.

The five wood-to-energy value chains are further analysed below, with the aim of understanding the cost structure of each value chain and comparing the overall costs. The analysis presented here is based on models of plant, transport, and equipment costs (Hall, 2008). Regional variability of costs is critical. The numbers given here are generic and therefore only intended as a guide. Any commercial business opportunity needs to be analysed with specific data for a particular location.

For consistency, a total transport distance of 100km was considered in all value chains. Potential loss of biomass in the supply chain has been taken into account. In addition, it is assumed that the forest residues are purchased for a fee of $5/t (5 dollars per tonne). This is a fee that is presently charged in some cases. It is likely that as the wood fuel market develops forest owners will seek a higher fee. This is discussed in more detail in the conclusions of this report. Other general assumptions are described in the Appendix.

Hogging value chain

In this chain, landing residues are hogged in-forest and then transported to a dairy factory where they are burnt in a boiler for heat. This value chain represents the present standard process for extracting forest residues for heat. This value chain is based on the use of a mobile hogger on a large, in-forest landing site. The landing site is assumed to have sufficient area for a hogger and for turning a truck and trailer unit. Residues from surrounding landing sites are transported (first-stage transport) via a bin truck to the large site for processing and loading onto a truck. The truck then transports (second-stage transport) the residues to a dairy factory heat plant where they are stored for later use.

The total cost of delivered heat in this case is $13/GJ. A breakdown of the cost of delivered heat in terms of the various components is shown in Figure 2. Sixty-two percent of the cost is associated with the fuel supply portion of the chain. Costs in dollars per tonne are shown in Table 1 for reference.

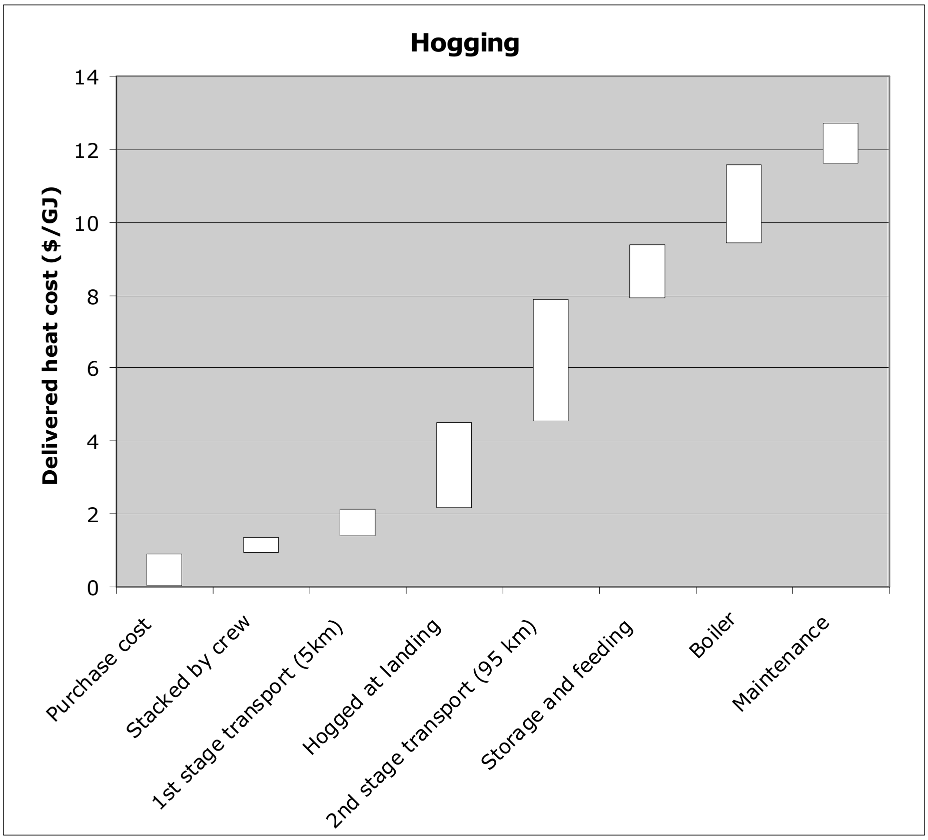


Figure 2: Hogging value chain – delivered heat cost

Assumptions behind this analysis are detailed in the Appendix.

Chipping value chain

In this chain, landing residues are first transported to a central processing yard (CPY) where they are chipped before being transported to a dairy factory where they are burnt in a boiler for heat. This value chain is based on the use of a stationary electric chipper operating at a large CPY. Residues from surrounding landing sites are transported (first-stage transport) via a bin truck to the CPY for processing and loading onto a truck. The truck then transports (second-stage transport) the residues to a dairy factory heat plant where they are stored for later use. The chipping value chain differs from the hogging chain in two ways. First, the processing of the fuel is done at a CPY with a stationary chipper. The cheaper processing cost afforded by a stationary system is offset by the higher first-stage transport costs. Secondly, the chipper will be producing a more uniform and higher quality fuel which leads to a reduction in end-user costs.

The total cost of delivered heat in this case is $10/GJ. A breakdown of the cost of delivered heat in terms of the various components is shown in Figure 3. Sixty-four percent of the cost is associated with the fuel supply portion of the chain. Costs in dollars per tonne are shown in Table 1 for reference.

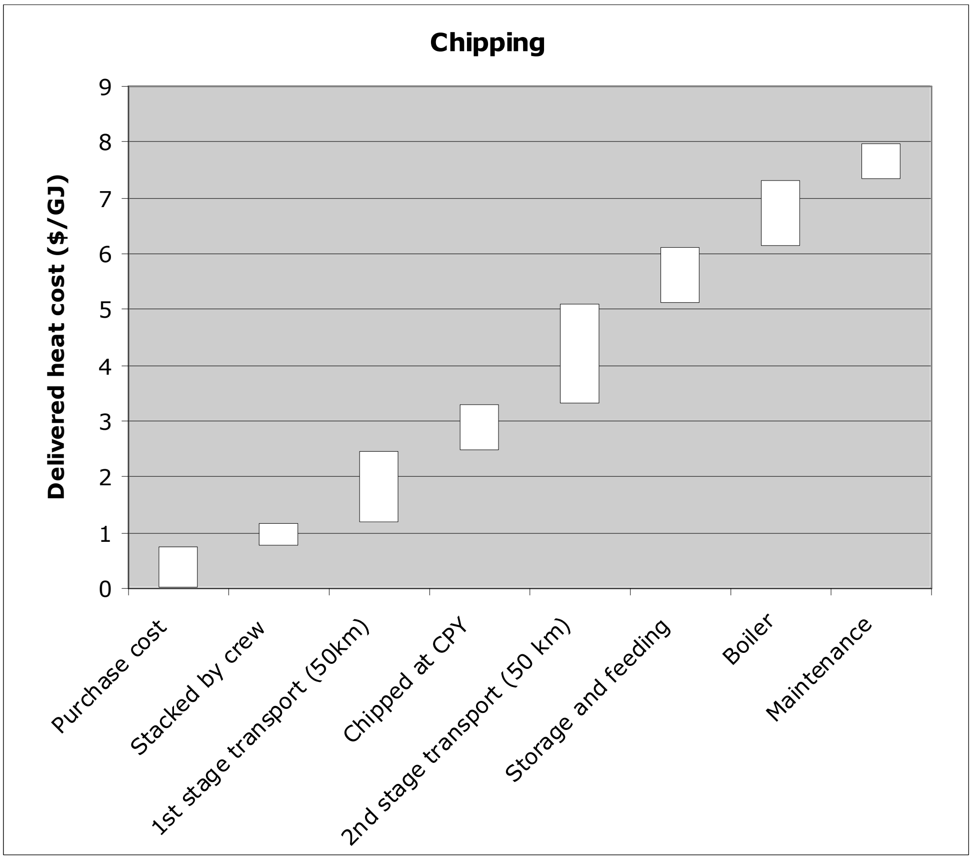
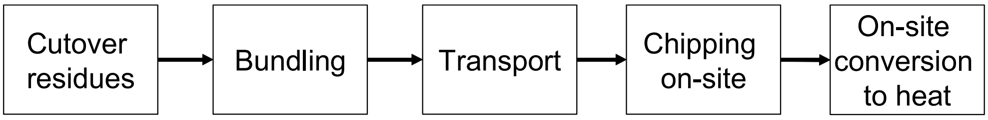


Figure 3: Chipping value chain – delivered heat cost

Assumptions behind this analysis are detailed in the Appendix.

Bundling value chain



In this chain, cutover residues are processed into log-like bundles and extracted to landing sites where they are optionally stored in bundle form to dry, then loaded onto standard logging trucks. These bundles are then transported directly to a dairy factory site where they are chipped and stored before being burnt in a boiler for heat. This value chain is based on the use of bundling technology, which makes branch-like material from the cutover into easily transported bundles. These bundles are transported to a landing site using a forwarder and loaded onto a standard logging truck, which reduces the cost of transport. The fuel produced in this chain is likely to be drier than hog fuel, but not a clean as the chipping value chain due to additional branch and bark material. The bundling value chain differs from the first two value chains in that cutover residues are used instead of landing residues and allows access to greater volumes of residues. However, there is a cost associated with recovering the material to a landing site.

The total cost of delivered heat in this case is $10/GJ. A breakdown of the cost of delivered heat in terms of the various components is shown in Figure 4. Sixty-two percent of the cost is associated with the fuel supply portion of the chain, even though processing is done on site. Costs in dollars per tonne are shown in Table 1 for reference.

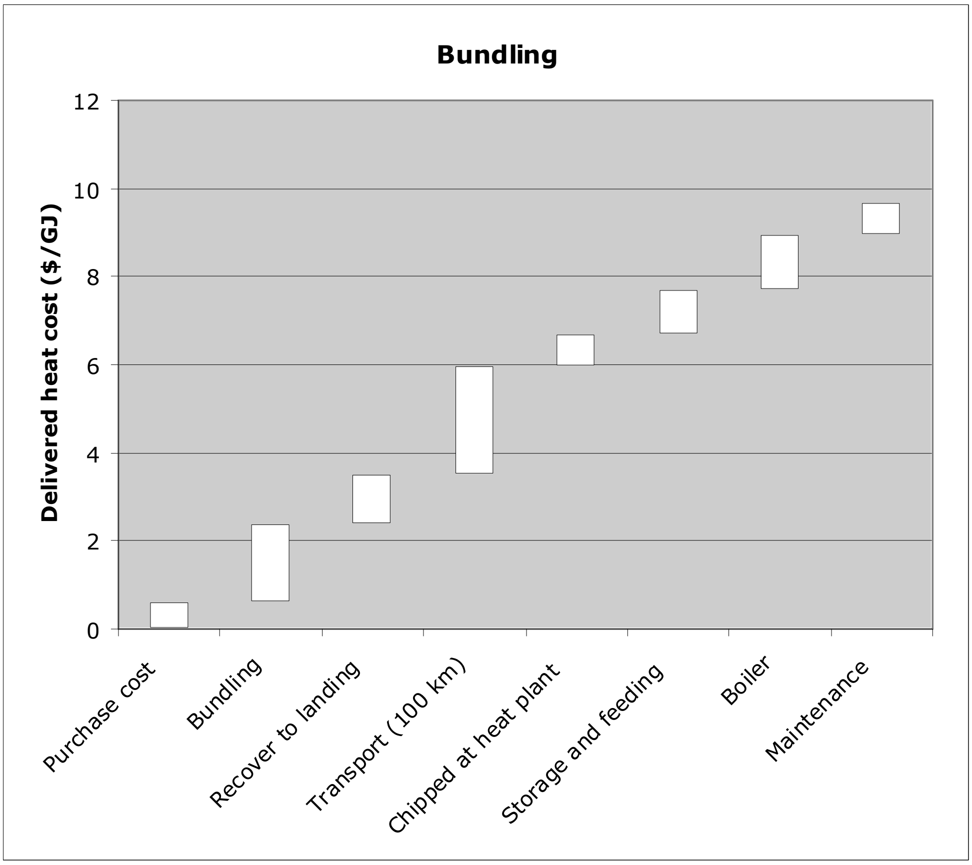
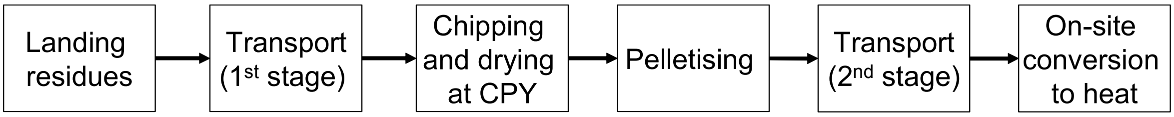


Figure 4: Bundling value chain – delivered heat cost

Assumptions behind this analysis are detailed in the Appendix.

Wood pellets value chain



In this value chain, landing residues are transported (first-stage transport) to a CPY where they are cleaned, chipped, hammer milled, dried and pelletised. The pellets are then transported (second-stage transport) to the dairy factory where they are stored before being burnt in a boiler for process steam. This value chain is based on the use of a wood pellet plant to upgrade the fuel. To make wood pellets from forest residue requires comminuting the material to a particle size of less than one millimetre and drying to at least 15% moisture content (wet basis) prior to the press. Pellets produced from forest residue are likely to be of lower quality than wood pellets made from wood-processing residue. For example, they are likely to have higher ash content due to bark and other contaminants. These pellets could be referred to as an industrial-grade pellet. In comparison to the chains considered so far, this chain contains much more fuel processing. This greater processing is more costly but leads to a higher-quality fuel that can reduce transport and heat plant costs.

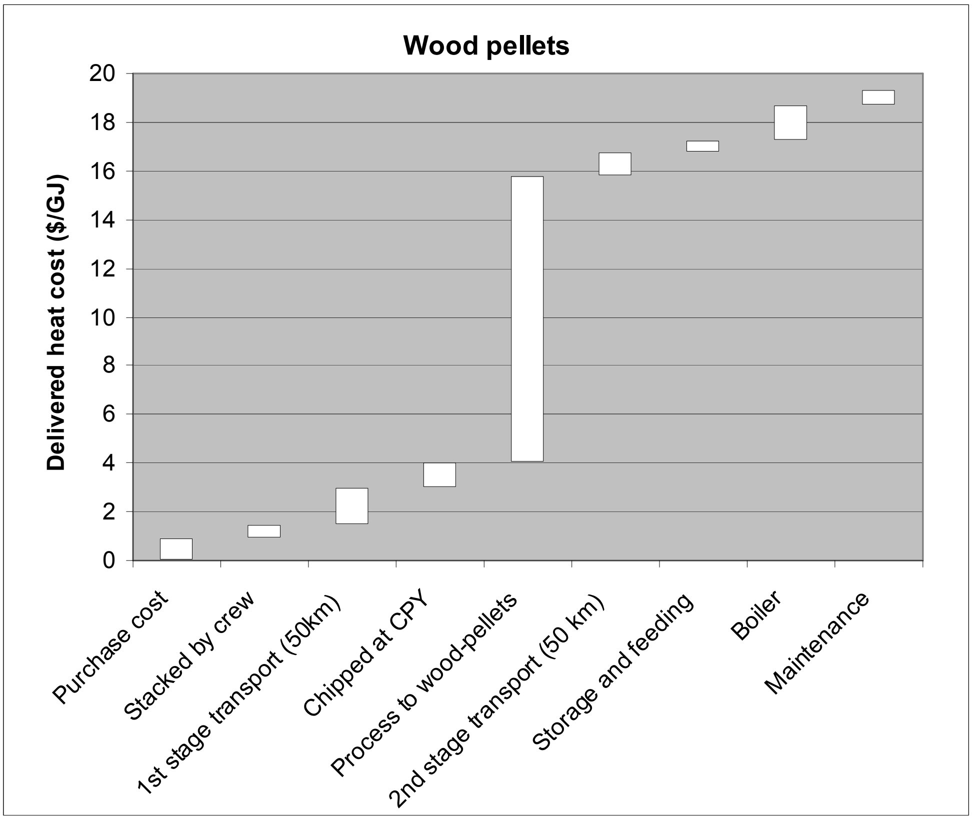
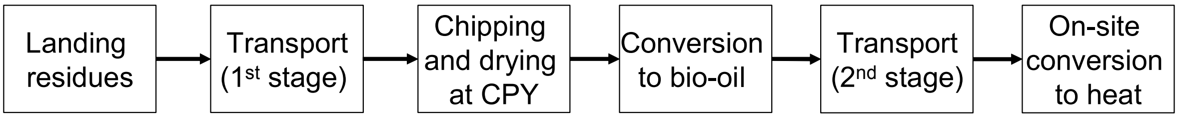


Figure 5: Wood-pellets value chain – delivered heat cost

Assumptions behind this analysis are detailed in the Appendix.

The delivered wood pellets are expected to have a calorific value of 15 GJ/tonne and the total cost of delivered heat in this case is $19/GJ. A breakdown of the cost of delivered heat in terms of the various components is shown in Figure 5. In this case, 90% of the cost is associated with the fuel supply portion of the chain. Costs in $/tonne are shown in Table 1 for reference.

Bio-oil value chain



In this value chain landing residues are first transported to a CPY. At the CPY, a large-scale industrial chipper is used for the first pass comminuting, before the material is comminuted into smaller particles and converted via fast pyrolysis into bio-oil (Ringer, 2006). Drying of the feedstock is expected to be integrated with the pyrolysis plant (Hedley, 2007). The bio-oil is then transported to the dairy factory where it is stored before being burnt in an oil boiler for process steam. This value chain is based on the use of a pyrolysis plant to produce a medium energy density liquid fuel. As in the wood pellet case this chain has large processing costs. The advantage of producing a bio-oil as a fuel is cost savings in transportation and heat plant capital costs. The costs of fuel storage, feeding, and handling, and even the cost of the boiler itself, are reduced for a liquid fuel.

The delivered bio-oil is expected to have a calorific value of 18 GJ/t and the total cost of delivered heat in this case is $17/GJ. A breakdown of the cost of delivered heat in terms of the various components is shown in Figure 6. In terms of delivered heat, 93% of the cost is associated with the fuel supply portion of the chain. Costs in dollars per tonne are shown in Table 1 for reference.

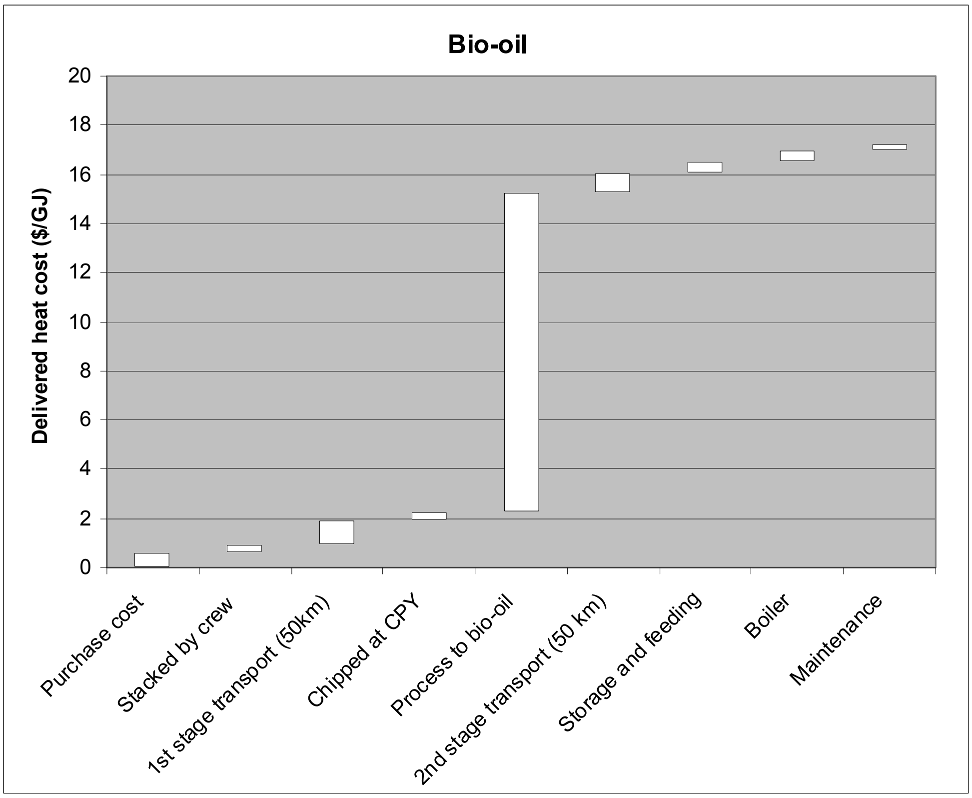


Figure 6: Bio-oil value chain – delivered heat cost

Summary of value chain analysis

Table 1 summarises the value chain analysis.

Table 1: Summary of economic analysis of the 5 wood fuel value chains

Costs	Hogging	Chipping	Bundling	Wood pellets	Bio-oil
Fuel calorific value (GJ/t)	7.36	7.36	10.35	15.00	18.00
Fuel supply chain ($/t)	46.58	36.81	55.48	213.95	259.77
Fuel supply chain ($/GJ)	6.33	5.00	5.36	14.26	14.43
End-user chain ($/t)	28.20	20.68	24.41	32.28	19.55
End-user chain ($/GJ)	3.83	2.81	2.36	2.15	1.09
Total ($/t)	74.79	57.49	79.89	246.23	279.33
Total ($/GJ heat)	12.70	9.76	9.65	19.31	17.24

The above woody biomass value chains must be considered in the context of the current fossil fuel systems. Coal presently has a cost of $6-7 per GJ of delivered fuel and natural gas $12-16 per GJ of delivered fuel. Note that these costs do not include the end-user costs. Emission trading is likely to increase the cost of these fuels. For example, a carbon charge of $\$20/\text{tCO}_2\text{-e}$

will increase the price of coal by 30-40% and that of gas by 10% (MfE, 2007). Industrial heat users presently using coal are likely to consider high-grade hog fuel and chipped fuel as possible alternatives. Industrial heat users presently using gas will demand higher fuel quality. The price that these users are willing to pay for gas reflects its value to the user. Similarly, upgraded forest fuels such as wood pellets and bio-oil approach the convenience of gas. Some of the benefits of these fuels for the end user are reflected in the reduced on-site costs estimated in the above analysis. But a similar analysis for gas and coal illustrates that this simple economic analysis has not captured all the value of these upgraded fuels. It is nonetheless clear that high-quality, clean and convenient fuels demand a premium.

It is important to revisit the identified barriers to uptake by non-wood-processing industries and consider whether this value chain analysis has shed any light on these problems. In this work it is claimede that upgrading can go a long way to overcoming the identified barriers of low fuel quality, security of supply, and distance from forest.

Upgrading to wood pellets and bio-oil produces high-quality, convenient and clean burning fuels that have a high value for the end user and overcome the low-quality barrier to using forest residues. High-quality chip that has been dried and had contaminants removed will likewise improve the acceptability of forest residue fuels. These upgraded fuels will have access to markets outside the traditional wood processing sector. The cost of upgrading is by far the largest cost in the wood pellet and bio-oil value chain, and an obvious area for further development. Much of this cost in the case of bio-oil comes from energy losses in the conversion process.

As discussed above, forest managers are not likely to make an effort to guarantee supply unless they are able to get a greater return for their residues. In the case of hog or chipped fuel, increasing the return to forest managers from a token $5/t to say $20/t would lead to a 20% increase in the price of delivered heat. In contrast, this increased return to forest managers would lead to only a 10% increase in the cost of delivered heat from bio-oil. The conclusion from this is that if these upgraded fuels are able to command higher prices then this value is likely to flow down the value chain to the forest manager and owner. Only once a reasonable return is made from forest residues are forest managers likely to sign long-term contracts that guarantee security of supply.

Analysis of the chains also shows that fuel upgrading reduces transport costs and means that the fuels can be transported to sites of demand further from the forests. The on-highway costs per tonne-km of all the fuels are fairly similar, however, because the wood pellets and bio-oil have double the calorific value of the lower-grade fuels the transport cost per unit of delivered heat is halved if density allows maximum payload. This increase in calorific value is mainly due to reduced moisture content so any upgrading of fuels by drying will lead to the same result. In addition, the earlier this upgrading occurs in the production chain the greater the benefits from reduced transport costs.

CONCLUSIONS

The present study has evaluated barriers for further development of the bioenergy market in New Zealand, including an evaluation of the costs and benefits analysis of five wood-fuel processing value chains. The value chains considered have non-wood processing industries as the end user. Although this study has been based on particular case studies, general conclusions can be developed from these.

Three main barriers have been identified as significant challenges for a further development of the bioenergy market in New Zealand:

- Fuel-quality upgrading
- Supply security
- Distance from forest (transport cost)

Fuel quality upgrading

The new end users for wood fuels will set higher standards for fuel quality than previously required. These new end users currently use high-grade fuels and are therefore not familiar with the low-quality fuel delivered by the wood-fuel processing industry today.

Supply security

Both the wood-fuel processing industry and the end user require significant supply security due to the high cost of capital investment. At present it is difficult for both parties to obtain longer-term fuel guarantees. This is due to a number of factors, including uncertainty about the resource availability, potential risk of missing out on future gains for the biomass owner if they sign a long-term contract now, and lack of a transparent market. Another factor which will become more significant as demand increases is reaching the limits of regional supply of forest residues.

Distance from forest

The wood-fuel processing industry is dealing with a low-energy-density forest residue resource that is dispersed over a large area. Due to its low-energy density, costs of transporting forest residues are high. This high transportation cost is a major economic barrier for future development of the bioenergy market in New Zealand. Increasing the energy density of the forest residue as close to the resource as possible not only reduces transportation costs but it also reduces end-user handling costs.

The fuel upgrading solution

Fuel upgrading has been evaluated through this study as an approach to overcome all three of the above barriers. Fuel upgrading examples are

- screening fuel for contamination and particle size;
- drying;
- production of a uniform, flowable, fuel chip;
- production of an industrial grade wood pellet;
- production of bio-oil via fast pyrolysis.

Fuel upgrading can lead to an easier fuel to handle, (i.e., a flowable solid fuel such as wood pellets or a liquid fuel) that requires less specialised equipment for storage and use and can therefore reduce the on-site cost of heat production. It is therefore of more value to the end user and will command a higher price (such as with the price of gas compared to coal). This higher value should flow down the value chain, resulting in greater return to the forest owner. Increasing the return to the forest owner is likely to be the only viable approach to securing longer-term supply contracts. In addition, if fuel upgrading involves energy densification, such as drying, contamination removal, pelletising or pyrolysis, then the cost of transportation per unit energy decreases (second-stage transportation) and the fuel can be transported greater distances economically, thus enabling forest residues to supply a much wider market.

A key aspect of a focus on fuel quality and fuel upgrading is the development of fuel quality standards or grades, in particular around moisture content, dirt content, and particle size. Fuel-quality standards, or grades, will help increase the use of bioenergy in the non-wood-processing industry for process heat as well as an emerging liquid biofuel industry.

RECOMMENDATIONS

Barriers have been evaluated for the three major stakeholders in the wood-fuel processing sector, including the forest residue owner, the wood fuel processor and the end-user. Where possible, indications of efficiency gains, cost reductions, or value gains to overcome the barriers have been given. The analysis has pointed towards the following areas to be addressed specifically.

Web-based trading/auction site for woody biomass similar to, or developed from/with, the trading site on the WasteMINZ website. This should cover all wood fuel; wood processing residue, municipal green and timber waste and forest residue. Such a site would be beneficial to all three stakeholders and will assist the development of a market.

Development of a web-site tool could be to provide indicative costs of supplying wood fuel to users in different regions throughout New Zealand now and into the future. This tool should allow the input of a purchase price for the residues to show the effect of this price on the overall costs. This information should assist the forest residue owner to price residues to meet the market. This will also assist both the end user and the fuel supplier with long-term planning.

Development of wood-fuel grading standards; grading should be done on particle size, flow ability, ash content, moisture content and calorific value. This will establish confidence in wood fuel and enable both fuel suppliers and end users to develop a fair market price for a particular grade of fuel.

- **Forest residue owner**

  Development of a web-site tool that enables forest residue owners to understand the magnitude of their forest residue resource will assist with long-term planning for residue use.

  Preparation of a guide for harvesting operators on harvest management options for maximizing the bioenergy opportunity. Different harvesting operations have been shown to have a large impact on residue costs (van Loo, 2008). Preparing this guide will require field trials and discussions with harvesting professionals. This will help mitigate the fuel quality issues and costs related to the landing site extraction process.

- **Wood fuel processor**

  Develop and trial wood-fuel segregation and screening technologies and procedures. The purpose of this is to remove contamination and/or to grade fuel by particle size and shape.

  Develop and test in-forest fuel storage and loading systems which avoid contamination with dirt and exposure to the environment and perhaps allow air-drying for 2-3 months.

  Develop and trial compaction technologies and procedures to reduce transport costs. These will need to be feedstock specific and will depend very much on the scale of the operation.

  Develop and trial technologies that enable access to cutover residue (such as the bundler technology). Trialling of the bundler technology, for example, requires a time study including loading, transport, as well as bailer, and a drying trial. Achieving the 7PJ target will most likely require extraction of some proportion of the 700,000 tonnes of cutover residues in addition to landing residues (Hall, 2008).

  Develop technologies to produce a fuel particle that is more flowable than hog fuel or chip. For example, testing different hogger and chipper knife shapes to produce a more cube like fuel to improve fuel handling properties. This would include a study determining the ideal fuel particle size and dimensions for boilers and feed systems.

Develop a practical process to produce an industrial wood pellet from forest residues. This will require testing the pelletisation of a variety of forest residue feedstocks, accurate costing of ancillary equipment and then trialling in the field. It will also require trialling of air-drying systems to reduce the cost of production.

Develop and trial the bio-oil technology for forest residue feedstocks (Hedley, 2007). This will require testing the technology of a variety of forest residue feedstocks and then trialling in the field. Testing of the bio-oil product for its suitability for further refining should also be considered.

- **End-user**
  Develop and trial low-cost fuel storage and feeding systems designed to handle defined fuel specifications/grades.

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APPENDIX: ASSUMPTIONS

In all options boiler, storage and feeding apparatus capital costs were determined by assuming an internal rate of return on capital investments of 10% and a 10-year depreciation time. Heat plant maintenance costs were assumed to be 5% of total capital.

Additional assumptions used for the fuel supply chain are:

Residue purchase cost	$5/t
Loading losses	1%
Transportation losses	1%
Processing losses	5%
Wages	$18.00/hr
ACC	3.71%
Holidays	7.7% (4 weeks)
Fuel cost	$0.89/l (January 2007)
Interest rate	
▪ Borrow	11%
▪ Invest	7%
Productive machine hours per day	8
Shift length	10 hr
Fuel consumption (heavy machinery)	0.16 l/hr/kW

Capital costs of machines and vehicles, derived from suppliers/operators as of March 2007. Fresh, green radiata residue has approximately 56% moisture content (wet basis), likely to vary with season and location by +/- 4%. All calorific values were determined from the moisture content using the formula in van Loo and Koppejan (2008). This is the same formula used in the BKC tools.

Hogging value chain

The key assumptions for this chain are:

1st stage transport	5km
2nd stage transport	95km
Boiler size	50,000 t/y of steam
Boiler costs	$2.25M
Boiler efficiency	80%
Storage and feeding system throughput	30,000 t/y
Storage and feeding system cost	$1.5M

Chipping value chain

The key assumptions for this chain are:

First stage transport	50km
Second stage transport	50km
Boiler size	50,000 t/y of steam
Boiler costs	$1.5M
Boiler efficiency	80%
Storage and feeding system throughput	30,000 t/y
Storage and feeding system cost	$1.25M

Bundling value chain

The key assumptions for this chain are:

Transport	100km
Bundler cost	$700,000
Forwarder cost	$400,000
Delivered moisture content	40% (wet basis)
Boiler size	50,000 t/y of steam
Boiler costs	$1.9M
Boiler efficiency	80%
Storage and feeding system throughput	30,000 t/y
Storage and feeding system cost	$1.5M

It is assumed that the bundles are air dried at landing sites for two months, reducing their moisture content to 40% (wet basis).

Wood pellets value chain

The key assumptions for this chain are:

1st stage transport	50km
2nd stage transport	50km
Wood pellet plant cost (chipper, hammer mill)	$3M
Wood pellet plant throughput	30,000 t/y
Dryer	$600,000
Wood pellets calorific value	15 GJ/t
Wood pellet moisture content	10% (wet basis)
Boiler size	50,000 t/y of steam
Boiler costs	$1.5M
Boiler efficiency	85%
Storage and feeding system throughput	30,000 t/y
Storage and feeding system cost	$0.5M

In this chain it is assumed that some of the forest residue is used as fuel for drying the wood pellet feedstock. We also assume that the feedstock is dried to a moisture content of 15% (wet basis) before entering the press.

Bio-oil value chain

The key assumptions for this chain are:

First stage transport	50km
Second stage transport (bio oil tanker)	50km
Bio-oil tanker	$325k
Bio-oil tanker trailer	$100k
Total payload	23 t
Pyrolysis plant	$3M
Pyrolysis plant throughput	30,000 t/y
Pyrolysis plant operating costs	$210/t
Wood to bio-oil conversion rate (tonnes bio-oil per tonne of forest residue)	52%
Bio-oil calorific value	16.5 GJ/t (Huber, 2006)
Boiler size	50,000 t/y of steam
Boiler costs	$0.75M
Boiler efficiency	90%
Storage and feeding system throughput	30,000 t/y
Storage and feeding system cost	$0.75M

The Wood-to-bio-oil conversion rate includes drying to 10% and 70% conversion efficiency (Mohan, 2006; Huber, 2006)