Chapter

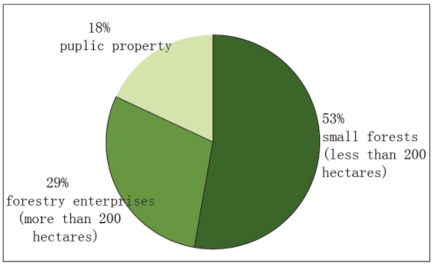
Overview of Forestry, and Wood Fuel Supply Chains

2

2.1. Austria

2.1.1. Forestry and Wood Fuel Supply and Use

Austrian forests cover an area of 3.96 mio hectares, which is 47.2% of Austria's total land area. 82% of the forests are privately owned. In total there are about 170,000 different forest owners (Figure 1).



	Forest owners
under 2 ha	80,000
2 to under 5 ha	60,000
5 to under 20 ha	57,000
20 to under 50 ha	12,000
50 to under 200 ha	4,300
200 ha and more	1,300

Figure 1. Diversification of forest owners in Austria (BIOENERGY 2020+)

A sharp increase in Austrian industry's demand for wood, and in particular the rising need of biomass plant operators for wood as fuel, has led to a fundamental transformation of the timber market from a buyer's to a seller's market. New marketing opportunities in terms of a range of wood as energy products, combined with an efficient way of harvesting, have opened up a new economic prosperity for the forestry industry.

Forest Energy in Austria

The energetic utilisation of solid biomass has a long tradition in Austria and it is still a very important factor within the renewable energy sector. The consumption of final energy from solid biofuels increased from 142 PJ for 2007 to 174 PJ for 2012. The consumption of wood chips has increased steadily since the beginning of the 1980s. In 2012 wood chip consumption was 80 PJ and thus exceeded the consumption of wood logs at 70 PJ. The very well documented wood pellet market developed at an annual growth rate between 30 and 40% until 2006. This development then stopped due to a supply shortage which resulted in a substantive price rise. The production capacity of

21 Austria pellet manufacturers then expanded to 1.25 million tons a year and this resulted in a market recovery. Pellet production in Austria was around 13.6 PJ (800,000 t) in 2012. Fuels from solid biomass contributed to a CO_2 reduction of almost 9.8 million tons for 2012. The whole sector of solid biofuels accounted for a total turnover of 1,304 billion Euros and 12,748 job positions.

The market for biomass boilers increased steadily from 2000 until 2006. A market break of more than 60% occurred in 2007 with low prices for heating oil and the above-mentioned supply shortage of pellets. In 2008 the sales figures again reached the level of 2006 (Figure 2). A slight reduction of about 4% in the sale of pellet boilers was documented in 2010, and the sector of wood log boilers suffered a substantial market break due to the economic and financial crisis. In 2012 the market for pellet boilers was growing again with a 15% increase of sales.

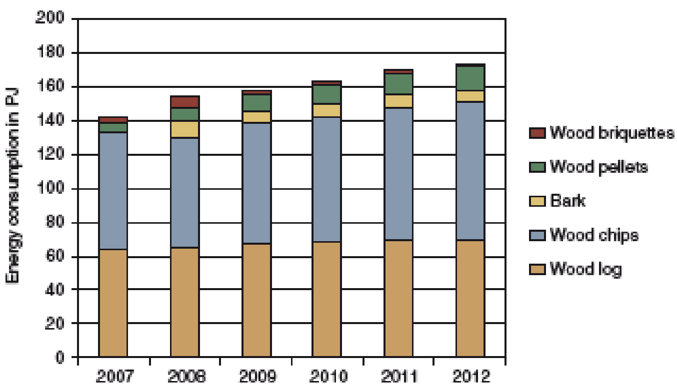


Figure 2. Market development of different biomass fuel types from 2007 to 2012 in Austria (BIOENERGY 2020+)

In 2012, on the Austrian market, 12,076 pellet boilers, 6,887 wood log boilers and 4,264 wood chip boilers were sold, representing the entire range of biomass boilers. Furthermore 2,857 pellet stoves, 9,155 cooking stoves and 20,244 wood log stoves were sold. Austrian biomass boiler manufactures typically export approximately 70% of their production. In Germany, for instance, two out of three installed biomass boilers are of Austrian origin. Germany and Italy are the biggest export markets for Austrian companies. The biomass boiler and stove sector achieved a turnover of 1,247 Mio Euro in 2012. This resulted in a total number of 5,871 jobs. Research efforts are currently focused on the extension of the power range, further reduction of emissions, optimisation of systems and combined systems, annual efficiency improvement and in the development of market-ready small-scale and micro CHP systems.

2.1.2. Harvesting Technologies Including Chipping and Drying

2.1.2.1. Felling

Figure 3. Felling technologies, chain saw – harvester (LK Niederösterreich)

In recent years several new technologies for wood harvesting have been developed. Depending on the forest area, slope of ground, and soil conditions, but also on log dimension and the species of wood, the exploitation of wood is feasible and economically reasonable. In Figure 3 we can see different felling technologies. Depending on the rate of mechanisation, the costs for harvesting will decrease due to current high productivity of harvesters and forwarders, and high personnel costs. A fully mechanised harvesting chain is often not possible, however.

2.1.2.2. Forwarding

The technology used by many farmers has for many years simply been a tractor with a winch (Figure 4), due to such a system's low costs and wide range of utilisation possibilities. Investing in a tractor with a winch amounts to 2,000–8,000 €. The operating cost of the machine is approximately 2.5 €/hour.

Figure 4. Tractor forest trailer and tractor with winch/skidder (LK Niederösterreich)

A truck operated cable crane with mobile tower yarder is particularly suitable for mountainous regions.
invest: 300,000–540,000 €
machine costs 120 €/hour

A cable crane with mobile tower yarder is particularly suitable for mountainous regions.
invest: 40,000 €–70,000 €
machine costs 17 €/hour

Figure 5. Cable crane solutions for mountain regions (LK Niederösterreich, www.afo.eu.com)

Over the last 10 years forest trailers equipped with cranes have become more and more popular in Austria. The equipment can be used for transport of logs, branches and other forest material. The costs compare to those of a forwarder on a level which makes this investment reasonable for private forest owners. In the case of smaller private forest owners, this trailer is often used in a community. Some farmers share this forestry equipment with other farmers/ forest owners to balance the high investment costs and low capacity of utilisation. Large forest owners in mountainous regions use cable cranes for wood transport (Figure 5). This machinery is highly complex, and can only be used by forestry specialists.

Figure 6. Forwarder (Erwin Rotheneder, LK Niederösterreich, www.afo.eu.com)

The newest and most highly developed system is that of the forwarder (Figure 6). The harvester and forwarder system comes from Scandinavian countries. For several years this technology has also been used in forest areas in Austria, especially by large forest owners, associative forest management communities and harvesting companies. The investment costs for a forwarder are 180,000–290,000 €. The operational costs are about 40–65 €/hour. Their high productivity and a very high technical level are responsible for the success of these machines in Austria.

2.1.2.3. Chipping

The cost of the chipping process decreases according to the size of the chipper used. Small and medium scale chippers are used by farmers and forest owners for the production of wood chips for their own purposes, and to deliver wood chips to local district heating plants. Such farmers and forest owners are often organised and share the machine. Large scale chippers are used in wood chip production companies. The costs of production per m^3 are lower but the frame conditions for utilisation are different. A minimum quantity of raw material (transport costs for the chipper) is needed, and during the chipping season machinery is not always available, the chipper needs enough space for manipulation of a large machine and the logistics are more complicated (requiring a high quantity of material in a short time, 2–3 tractors with trailers depending on transport distance).

2.1.3. Storage and Transport Logistics

Wood logs and wood chips can be transported by tractors, trucks and trailers (Figure 7). Wood chips are by-products of sawmills or are made from small-sized wood and logging residues. As the water content limits storage stability, a drying phase of several months is necessary. After this the wood is chipped, either directly in the forest or at a central chipping place (Figure 8). Careful processing and drying enable optimal storage and trouble-free operation of heating systems. Quality criteria for wood chips are standardised, e.g. in the European standard CEN/TS 14961, and in the Austrian standard ÖNORM M 7133. According to the Austrian standard, wood chips with a water content of up to 30% are stable in storage.

Figure 7. Transport of log wood and wood chips with tractor, truck and trailer (Erwin Rotheneder, LK Niederösterreich)

Figure 8. Wood chip storage and drying (Erwin Rotheneder, Waldverband Steiermark)

The production costs for different wood fuels in Austria are summarised in Table 1.

Table 1. Wood fuel production costs

Assortment	Felling	Forwarding	Transport (<25 km)	Chipping	Production costs (€/bulk m³ (at heating plant)
Thinning soft wood	11.6 €/m³	2.6 €/m³	0.75 €/m³ Truck	2.4 €/m³ Medium scale chipper	17.35 €/m³
Thinning hard wood	8.9 €/m³	2.6 €/m³	0.75 €/m³ Truck	2.4 €/m³ Medium scale chipper	14.56 €/m³
Final harvesting – Lowland forest	2.93 €/m³	2.94 €/m³	4.4 €/m³ Tractor with trailer	2.5 €/m³ Large scale chipper	12.77 €/m³
Final harvesting – Hard wood	2.8 €/m³	2.76 €/m³	3.6 €/m³ Truck container	2.5 + 1.18 €/m³ ad. Manipulation large scale chipper	12.84 €/m³

2.1.4. Wood Fuel Quality

The type of biofuel, its physical characteristics and its chemical composition, influences the whole process of biomass utilisation (fuel supply, combustion system, solid and gaseous emissions). An overview of the most important characteristics and their effects are shown in Table 2. The characteristics and quality of biomass as a fuel vary widely, depending mainly on the type of biomass and the pre-treatment technologies applied. For example, the moisture content of the fuel as fed into the furnace may vary from 25–55 wt% (w.b.) (bark, saw mill side-products) or drop below 10 wt% (w.b.) (pellets, dry wood processing residues). The ash sintering temperatures of biofuels used also exhibit a wide range (800–1,200°C) and there can be many particle shapes and sizes. Fuel quality can be influenced and improved by suitable pre-treatment technologies, but this increases costs.

On the other hand, different combustion technologies are available for different fuel qualities. In this context, it must be noted that less homogenous and lower quality fuels need more sophisticated combustion systems. Because of this, and for other "economy of scale" reasons, only medium-scale and large-scale systems are suitable for combustion of low-quality and cheap biofuels. The smaller combustion plants have higher demand concerning fuel quality and fuel homogeneity.

Table 2. Characteristics of solid biofuels and their most important effects–physical properties

Physical properties	Effects
Moisture content	storage durability and dry-matter losses, NCV, self-ignition, plant design
NCV, GCV	fuel utilisation, plant design
Volatiles	thermal decomposition behaviour, plant design?
Ash content	dust emissions, ash manipulation, ash utilisation/ disposal, combustion technology
Ash-melting behaviour	operational safety, combustion technology, process control system
Fungi	health risks
Bulk density	fuel logistics (storage, transport, handling)
Particle density	thermal conductance, thermal decomposition
Physical dimension, form, size distribution	hoisting and conveying, combustion technology, bridging, operational safety, drying, formation of dust
Fine parts (wood pressings)	storage volume, transport losses, dust formation
Abrasion resistance (wood pressings)	quality changes, segregation, fine parts

Notes: NCV: net calorific value, GCV: gross calorific value, according to Hartmann, 1998.

The moisture content influences the combustion behaviour, the adiabatic temperature of combustion and the volume of flue gas produced per energy unit. Wet biomass fuels need a longer residence time for drying before gasification and charcoal combustion take place, which means bigger combustion chambers are required. Consequently, knowledge of these parameters is necessary to adjust the temperature control system of the furnace properly (to avoid slagging) and to design the volume and the geometry of the furnace in a way that ensures a sufficient residence time of the flue gas in the hot combustion chambers for complete combustion. The efficiency of the combustion system (heat output of the boiler / energy input by the fuel (NCV)) also decreases as the moisture content of the fuel increases.

Moisture content u [wt.% d.b.]:	Moisture content of the fuel in weight per cent related to the mass of dry biomass (dry basis).
Moisture content w [wt.% w.b.]:	Moisture content of the fuel in weight per cent related to the mass of wet biomass (wet basis).

Conversion of moisture contents based on dry and wet basis:

$$w = \frac{100-u}{100+u}(w.b.) \quad u = \frac{100 \cdot w}{100-w}(d.b.)$$

2.2. Finland

2.2.1. Forestry and Wood Fuel Supply and Use

2.2.1.1. General

The forest cover in Finland is more extensive than in any other European country. Three quarters of the land area, some 23 million hectares (76%), is under forest. In Europe, Finland is a “forest giant”, there being over sixteen times more forest per capita than in European countries, on average. Because of Finland’s northern location, forest management is practiced under exceptional climate conditions. Geographically, Finland lies in an intermediate zone between maritime and continental climates.

Despite Finland’s northern position, its growing conditions are better than those in other areas at similar latitudes, such as Canada and Russia. This is basically because of the warming effect of the Gulf Stream. Growing conditions inside Finland vary a great deal, because Finland stretches more than 1,100 km from south to north. Most of Finland belongs to the boreal vegetation zone but the northernmost parts of Finland belong in the hemiboreal and tundra vegetation zones.

Towards the north, the climate gets increasingly colder and more humid, and precipitation exceeds evaporation. The growth period is about five months in the south and three months in the north. The average increment of growing stock in southern Finland, 6.1 m^3 per hectare per year, is twice as much as in Northern Finland.

There are only four coniferous tree species native to Finland, and fewer than 30 species of deciduous trees and arborescent shrubs. The majority of the forest in Finland is predominantly coniferous, with broadleaves often growing in mixed stands (Forest.fi, Metla).

According to the first national forest inventory (1921–1924), the total growing stock volume was 1,588 million m^3. The latest estimate, based on the tenth inventory, is 2,206 million m^3. The annual average of total removal has been 69 million m^3 for the years 2005–2010 (Figure 9).

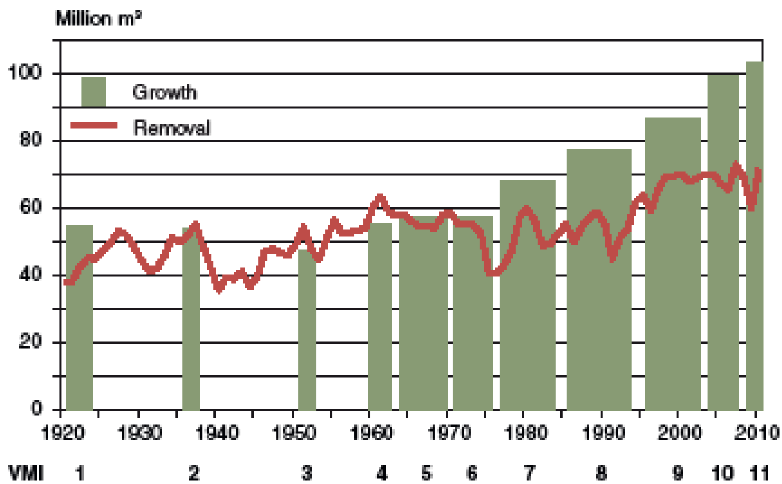


Figure 9. Growing stock and annual removals of Finnish forests (Metla, www.findikaattori.fi)

Removal figures are presented as floating averages over five year periods. They also include natural loss. Estimates of growth refer to the inventory years, respectively VMI denotes National Forest Inventory. The results of VMI 3–5 have been corrected to allow comparisons with later inventories (Statistical Yearbook of Forestry 2011, Finnish Forest Research Institute).

Scots pine's share of the growing stock is 50% and that of Norway spruce 30%, leaving 20% for the broadleaved species, mostly birch. This distribution has been a stable one. However, Scots pine is the dominant species, on 65% of the forest land area (Metla & Forest.fi).

Forest ownership

As in other countries in Western Europe, forests in Finland are mainly owned by private individuals and families. In the principal growth area, southern and central Finland, about 3/4 of all forest is in private ownership (Figure 10), and in some areas in southern Finland the percentage can exceed 90%. State forests are for the most part situated in northern and eastern Finland. Private forestry is in fact the linchpin of the Finnish forest economy, as the growing stock volume, annual increment and fellings in private forests each account for between 64% and 83% of the total. Private forests produce over 80% of the roundwood purchased annually by the forest industry in Finland.

Typically, Finnish forest holdings are small. The number of holdings above two hectares is around 440,000 and there are approximately 266,000 under 20 hectares. The average area of a private forest holding (>5 ha) is 44 hectares (Forest.fi, Metla, Stat.fi).

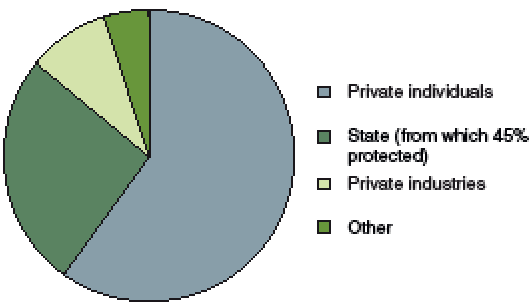


Figure 10. Forest ownership in Finland (Forest.fi)

2.2.1.2. Forest Energy in Finland

The total consumption of energy in Finland (Figure 11) has slowed down due to the recent recession (2008–2009). At the same time, the amount of wood-based energy sources used has increased in the 21st century. In the spring of 2012, the amount of wood fuel exceeded the amount of oil as the most significant source of energy in Finland. Finland aims to increase its percentage of renewable energy sources in energy consumption from 28% at present to

38% by 2020, as per the renewable energy requirements of the EU. This will mean a substantial increase in the use of wood-based fuels; the use of forest chips will also have to be more than doubled from the present annual level of 6 million m^3 to 13.5 million m^3.

Of the total consumption of energy by the forest industries, 75% comes from wood-based fuels. The majority of forest industry plants produce their own energy using bark, sawdust and chippings, as well as logging residue from thinning and regeneration fellings and waste liquors from industrial processes, which makes them energy self-sufficient (Figure 12). On the whole, however, the forest industry is a highly energy-intensive industrial sector: it consumes about one third of Finland's total electricity production.

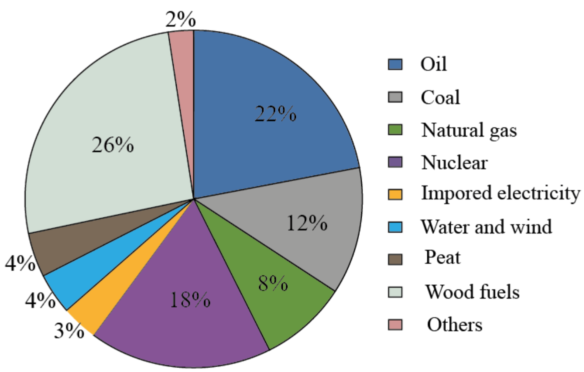


Figure 11. Energy consumption by energy sources in Finland (Forest.fi)

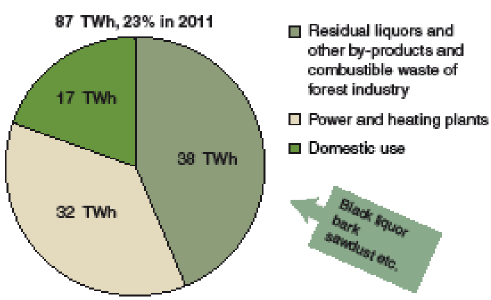


Figure 12. Total amount of forest derived wood fuels in Finland, 2011 (Metla, 2012)

Wood is also used increasingly domestically, in both rural areas and population centres, especially for heating, either in individual heating systems for single homes or at district heating plants that supply heat to both homes and other sites. Finland is a world leader in combined heat and power (CHP), with high levels of development in district heating (DH), industrial CHP and the use of biofuels. For example, in North Karelia Province 70% of all energy consumed is wood-based.

This high national level of CHP utilisation has been achieved with little direct government support. In a country with a cold climate and limited energy resources, CHP has been the natural economic choice for many applications (Figure 13). The main drivers of CHP have been the need to reduce energy imports, the need to maximise economy of energy supplies, and in some cases, governmental energy taxes that increase the economic attractiveness of CHP over heat-only generation. A highly economic and mainly centralised CHP has offered favourable energy prices – low prices even at the European level – to Finnish customers. Regardless of low sale prices, CHP has been a successful business for its owners, usually municipalities (Source: IEA).

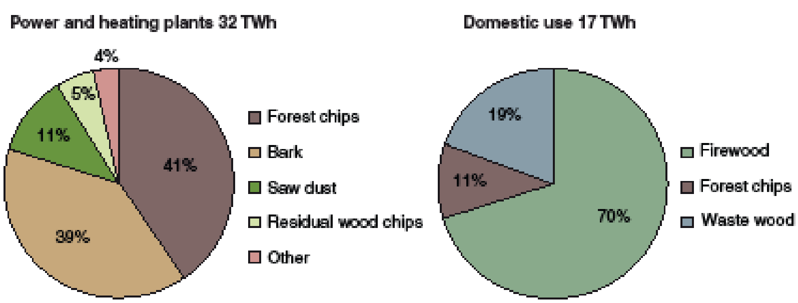


Figure 13. Use of wood fuels in power and heating plants in households in Finland, 2011 (Metla, 2012)

2.2.2. Supply Systems for Forest Chips

Comminution is the primary process of the forest chip supply chain affecting the whole system (Asikainen 1995, Routa et al. 2013), because the location where comminution is performed determines the form of the material to be transported. When the comminution takes place at the end-use facility or at the terminal, it is conducted in a centralised area, and offroad transportation is followed by long-distance transportation. In a system where comminution takes place at the roadside landing, it is linked to long-distance transportation. In the terrain comminution system, forwarding and comminution work phases are conducted by a single machine in one pass (Ranta 2002).

Centralised comminution at the end-use facility or at the terminal enables the efficient use of comminution machines that are either stationary or mobile. If raw material is transported in an unprocessed form, it results in low bulk density and therefore higher transportation costs compared to pre-processed, comminuted, delimbed or bundled material (Laitila 2012). Comminution and long-distance transportation are independent of each other, which results in a high degree of capacity utilisation and thus relatively low comminution costs. However, extensive investment in the centralised comminution system presupposes full employment and large annual comminution volumes (Asikainen et al. 2001). In Finland terminals operate as buffer storage facilities, enabling a more secure supply of fuel chips and also serving as a process management tool for the whole supply chain. The use of a terminal is also a compromise between comminution at the landing and at the plant (Vartiamäki et al. 2006).

Comminution at the landing is a suitable and cost competitive procurement system for power and heating plants of all size categories. When the comminution is done at the landing, the chipper and truck are dependent on each other and some of the working time of the chippers or chip trucks may be wasted in stoppages or waiting (Asikainen 1995). Idling time reduces the operational efficiency of the supply chain and increases costs. Comminution in the terrain is a seldom-used harvesting method in Finland. A terrain chipper is heavier and more expensive than a forwarder; furthermore, the payload is quite small and hence the forwarding distance must be short and the ground has to be flat and firm (Ranta 2002). A terrain chipper is also more likely to experience technical failures and this also increases harvesting costs (Ranta 2002). High snow or water content in the wintertime might also spoil the heating value of fuel chips.

Roadside comminution is the predominant form of forest chip production

(Kärhä 2011b). In Finland, approximately 70% of the logging residues are comminuted at a roadside landing close to the logging site. Approximately 83% of small sized wood and some 10% of large-sized roundwood for energy was comminuted at roadside in Finland, in 2010 (Kärhä 2011b). Comminution is performed at the landing using farm tractor-driven chippers (Figure 14) in smaller operations, and heavy truck-mounted chippers (Figure 15) or crushers in Finnish large-scale operations (Laitila 2012).

Figure 14. Farm tractor-driven chipper operating at the roadside landing (Kesla)

Figure 15. Heavy truck-mounted chipper comminut- ing large-sized roundwood at the terminal (Kesla)

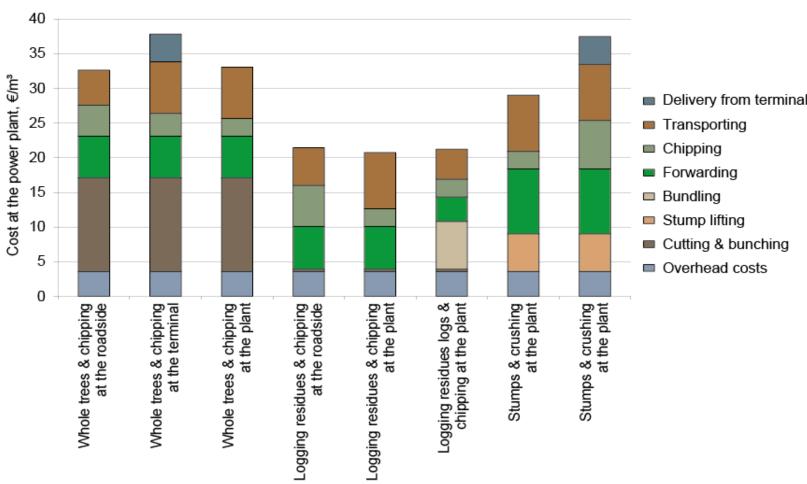


Figure 16. Procurement costs (€/m³) of forest chips with different harvesting systems from different raw materials. The forwarding distance was 250 m and transport distance was 45 km (Laitila et al. 2010)

In Finland, the majority of stumps are crushed either at the plant or terminals with heavy, often stationary, crushers (Kärhä 2011b). Approximately 7% of logging residues, 10% of all the chips from small-sized wood, 23% of large-sized roundwood (Figure 16) and 41% of stump and root wood were comminuted at terminals in Finland in 2010 (Kärhä 2011b). Correspondingly, about 23% of the logging residues, some 7% of all the chips from small-sized wood and 51% of stump and root wood, were comminuted at power plants in Finland in 2010 (Kärhä 2011b). In addition, in 2009, 70% of the large-sized roundwood for energy was comminuted at power plants (Kärhä 2010).

The recovery of logging residues and stumps from final fellings is more cost competitive than harvesting small trees from early thinnings (Figure 16, Laitila et al. 2010). The difference in the production cost is caused by the high cost of cutting small trees, whereas in off- and on-road transportation, as well as in comminution, the cost differences between logging residues, stumps and energy wood from thinnings are relatively small (Laitila et al. 2010). In the harvesting of logging residues the piling of tops and branches is integrated into the cutting of round wood by changing the working method in order to allow logging residues to pile up along the strip road (Figure 17), whereas in the normal method the branches and tops are collected on the strip road in order to protect the soil and to improve the bearing capacity of the ground (Nurmi 1994).

Figure 17. Integrated cutting of industrial roundwood and logging residues with a single-grip harvester (Juha Laitila)

Figure 18. Harvesting of stumps at clearcut area with a single-grip stump harvester (Juha Laitila)

According to several studies, the piling of logging residues has only a nominal effect on the cutting and forwarding productivity of industrial roundwood, whereas an integrated working method significantly improves both the yield and recovery of logging residues, thereby reducing harvesting costs (e.g. Nurmi 2007). In stump harvesting, the volume of harvested stumps is considerably higher compared to trees from early thinning, which improves productivity and reduces costs (Laitila et al. 2010). Furthermore, in clearcut areas, the protection of standing trees does not limit the productivity of the stump harvester (Figure 18) and the operating hour costs of an excavator based stump harvester are also somewhat lower compared to those of a medium-sized thinning harvester (Laitila et al. 2010).

Figure 19. Traditional two-machine system for mechanised logging of small diameter thinning wood (Juha Laitila)

Figure 20. Forwarder based harwarder for mechanised logging of small diameter thinning wood (Moisioforest)

In Finland logging systems for small diameter wood thinning can be classified into those which are based on the motor-manual or mechanised cutting of trees (Laitila 2012). Less than ten years ago, this work was still mainly done motor-manually, but nowadays it is done almost entirely using mechanised solutions (Laitila 2012). Manual cutting is carried out using a chainsaw, which is equipped with a felling frame. This working technique is called "lift-felling". Two alternative systems are used in mechanised logging: (1) the traditional two-machine system (harvester and forwarder) (Figure 19) and (2) the harwarder system (i.e., the same machine performs both cutting and forest haulage to the roadside) (Figure 20). Forwarding energy wood from young stands to the roadside after motor-manual or mechanised cutting is carried out using forwarders designed for thinning operations (Laitila et al. 2007) (Figure 19).

Both the harvester and the harwarder utilise the multi-tree processing technique. When using harvesters as a base machine, the cutting of whole trees can be done with purpose built accumulating felling heads or with normal harvester heads equipped with multi-tree handling accessories. The advantage of accumulating felling heads is that they are cheaper than standard harvester heads (Laitila 2008, Laitila 2012). This is explained mainly by their simpler structure and technology. The use of standard harvester heads is supported by the fact that the investment required to modify an existing head to suit another kind of work amounts to just a few k€. One option is to use forestry-equipped excavators (Figure 21) and tractors (Figure 22) as base machines for harvesters in logging operations (Laitila & Väätäinen 2013ab). The advantages of excavators and tractors produced in high volumes include a lower purchase price compared to forest machines and, outside the harvesting season, the possibility of removing the forestry equipment and using the base machine in the work for which it was originally designed (Laitila & Väätäinen 2013ab).

Figure 21. An excavator equipped with extension boom and accumulating harvester head (Juha Laitila)

Figure 22. A forestry-equipped farm tractor (Juha Laitila)

The harwarder method provides more diverse work for the operator, since the cutting and forwarding tasks are integrated. A dual purpose machine diminishes organisational costs and need for management, where two tasks can be accomplished with a machine and a single pass at the site. It also enables better employment of machinery and a higher degree of capacity utilisation, when two tasks are done with a single machine (Laitila & Asikainen 2006, Rottensteiner et al. 2008). However, the harwarder is a compromise machine; it is designed both for harvesting and loading, and it is thus somewhat clumsy compared to specialised machines (Laitila 2008, Laitila 2012).

Thinning wood delivered to heating plants and power plants is comprised mainly of non-delimbed whole trees, but the harvesting of delimbed energy wood is a harvesting alternative alongside whole-tree harvesting. Delimbed material produces uniform fuel stock devoid of needles and branches, which may be a benefit, especially at some power plants with a restricted capability for handling the high levels of chlorine and alkali metals contained in the branch material (Nurmi & Hillebrand 2007). The cutting of whole trees is cheaper, but the cost difference diminishes as a function of tree size (Laitila & Väätäinen 2012). The productivity of forwarding, transportation and chipping of multistem delimbed energy wood is significantly higher compared to that of whole trees (Laitila & Väätäinen 2012).

Figure 23. Forwarding of logging residues in a clear-cut operating area (Juha Laitila)

Figure 24. Forwarder-mounted logging residue bundler in a clear-cut area (Juha Laitila)

The most productive forest sites in Finland are dominated by Norway spruce (Picea abies) and recovery of logging residues is mainly carried out after the final felling of such areas (Ranta 2002, Hakkila 2004). After drying, the logging residues are forwarded to the roadside, normally by a forwarder with an enlarged load space and a residue grapple (Ranta 2002) (Figure 23). The importance of bundling (Figure 24) has decreased in recent years and approximately 10 bundling units are currently operational in Finland. Bundling aims to improve efficiency and flexibility in supply chains, especially when transportation distances are long (e.g. Laitila et al. 2013). This system is cost efficient only if the logistics and cost savings in the other work phases of the supply chain covers the costs of bundling, or if the fuel customers are willing to pay extra for the improved storage and handling properties of the bundled material (Routa et al. 2012).

Figure 25. Forwarding of stump and root wood in a clear-cut area (Juha Laitila)

Figure 26. Biomass truck equipped with solid side panels and bottom (Juha Laitila)

Stumps are harvested mainly from Norway spruce (Picea abies) regeneration areas since spruce stumps have a high wood content as well as being superficially and, thus more loosely, anchored in the ground (Hakkila 2004, Laitila et al. 2008). The stumps are uprooted using an excavator that is equipped with a stump lifting-splitting device (Laitila et al. 2008). Processed stump and root wood is piled into small piles in the stand. Piles are located so that the rain and weathering can rinse soil and dry the material. On smaller sites, soil preparation for forest regeneration can be combined with stump extraction using a mounding blade, which is a part of the extraction device (Laitila et al. 2008). After initial storage in the stand, the piled stump wood is forwarded to the roadside for further storage (Laitila et al. 2008). Forwarders are similarly equipped as logging residue forwarders (Figure 25). After seasoning at the roadside, the stumps are transported to the terminal or end-use facility for comminution by a truck specifically developed for transporting uncomminuted biomass (Hakkila 2004, Ranta & Rinne 2006) (Figure 26).

2.2.3. Transport Logistics

The users of forest chips are mainly local district heating or combined heat and power (CHP) plants and the average transportation distances are shorter than for industrial timber assortments. Trucks therefore dominate energy wood transportation (Kärhä 2011a) and at the present time there are only a few large CHP installations that can even use a railway or waterway transportation (Karttunen et al. 2008, Tahvanainen and Anttila 2011). The demand for fuels is largest in southern, western and central Finland, while the production potential is greater in eastern and northern Finland (Laitila et al. 2010b, Kärhä et al. 2010). Disturbances in local fuel supply and the need to balance regional supply and demand during periods of peak consumption require efficient systems for long-distance transportation of biofuels. Planned largescale production of liquid biofuels and the development of the so-called biorefinery concept may also increase the need for long-distance transportation of energy wood (Tahvanainen and Anttila 2011).

Current legislation on the physical dimensions of the truck-trailer combination limits total length to 25.25m, width to 2.55m and height to 4.2m (Ranta and Rinne 2006). Weight restrictions limit gross vehicle weight to 60 tonnes (Ranta and Rinne 2006) but currently there are plans to raise the gross vehicle weight limit to 78 tonnes. A truck can usually carry a payload of 43–44 m^3 of chips (Figure 27), 25–30 m^3 of loose whole trees, 47–48 m^3 of pulpwood or multistem delimbed shortwood, and 42–48 m^3 of whole-tree bundles (e.g. Laitila 2008, Laitila et al. 2009, Laitila et al. 2010b, Jylhä et al. 2010, Kärhä et al. 2011, Jylhä 2011, Laitila and Väätäinen 2012). Loose material trucks are typically purpose-built with a solid bottom and sideboards around the load space to prevent material from falling out during transport (Figure 28). The bundling system (Laitila et al. 2009, Jylhä et al. 2010, Kärhä et al. 2011, Jylhä 2011) and multistem delimbed shortwood (Laitila et al. 2010, Laitila and Väätäinen 2012) enable the use of standard timber trucks for transportation.

Figure 27. Standard chip truck (Juha Laitila)

Figure 28. Storage of harvested whole trees at a roadside landing (Juha Laitila)

In a study by Tahvanainen and Anttila (2011) railway transportation was compared to the most commonly used truck transportation options for long-distance transport. The potential for the development of supply chains was analysed using a sensitivity analysis of 11 modified supply chain scenarios. For distances shorter than 60 km, truck transportation of loose residues and end-facility comminution comprised the most cost-competitive chain. Over longer distances, roadside chipping with chip truck transportation was the most cost-efficient option. When the transportation distance increased from 135 to 165 km, depending on the fuel source, train-based transportation offered the lowest costs. The most cost-competitive alternative for long-distance transport included a combination of roadside chipping, truck transportation to the terminal and train transportation to the plant (Tahvanainen and Anttila 2011).

The amount of information needed for the procurement of energy wood is comprehensive and operations must remain on schedule (Seppänen et al. 2008, Windisch et al. 2010). The stores of energy wood (Figure 28) need to be chipped at the right time to ensure the quality of the chips, and the chips must be delivered at the right time to the appropriate end-use facilities. Furthermore, the roadside storage points must be accessible throughout the delivery period. When appointing the chip supplier, the reliability of deliveries is an important criterion from the viewpoint of the end user of the chips. Capital is tied up in the stored raw material due to be chipped, and this, along with quality, imposes its own demands on the turnover rate of the material in storage (Seppänen et al. 2008). It is essential from the point of view of planning the procurement operations that the parties involved in the procurement chain are provided with details of the harvesting targets well in advance. A challenge of its own in chipping lies in the uneven distribution of the work. During the cold season of the year, the chipping machinery and transportation equipment are in intensive use, while during the summer months the problem is lack of work.

The controlling of operations in the procurement of forest chips is also hindered by problems associated with the measurement of the amount and energy content of the material and the measurement practices. The accuracy of measurement is often poor and the causes of its variation and magnitude are not known. When applying two-stage measuring, obtaining the final result can be unduly delayed (Hakkila 2006). Moreover, the costs of measuring may rise excessively when considering the value of the material being measured, especially if several measurements are made at different stages of the delivery chain or if the ownership of the material changes between harvesting and end use (Lindblad et al. 2008, Laurila and Lauhanen 2012).

2.2.4. Wood Fuel Quality

2.2.4.1. Quality Management

Increased demand for wood fuels has presented producers with the challenge of being able to provide high quality fuel materials (Loibnegger 2011). From a bioenergy producer's point of view, the quality of the wood-based bioenergy can be divided into quality of fuel and quality of fuel deliveries. Quality of the fuel must also meet the boiler requirements and therefore consistency of the fuel is often more important than achieving the highest possible quality. Large variations within the fuel may disturb the balance of the production process. The smaller the boiler, the more critical the quality and heating value of the fuel. Moisture content and particle size distribution are the most important physical parameters determining heating value and quality of the fuel.

Supplying high quality fuels requires relevant know-how of customer quality demands and state-of-the-art technology to ensure reliable, timely wood fuel deliveries. In the bioenergy feedstock supply chain, costs and quality of the wood fuel produced can vary a great deal depending on supply chain efficiency, harvesting method and local conditions. By introducing a comprehensive quality management system, quality can be assured throughout the forest bioenergy feedstock supply chain. Quality management makes quality criteria and requirements transparent and understandable for every party involved and profitability can be achieved with modifications to existing supply chains (Loibnegger 2011). By optimising harvesting method, storage point and storage time, the whole feedstock supply chain can be competitive and flexible and the quality of the fuel can be improved. In many instances, it is a question of doing the right things properly at the right time, which makes a difference (Röser 2012).

Work phases at the forest-end of the bioenergy feedstock supply chain have most effect on the quality of the fuel. The selection of the right harvesting technology and working methods are the basis for high quality and cost efficient feedstock supply. For instance, a wrong decision about machinery or careless logging may cause serious tree and soil damage with an economic effect that might overcome the revenues from energy wood sales. It may also affect the forest owner's willingness to sell energy wood in the future.

One of the most important phases of the feedstock supply is the storage period of raw material before comminution and transportation. The storage place should be carefully selected in order to ensure easy accessibility of machinery and the best possible drying conditions (point of the compass, wind, sun). Storage piling also has to be made carefully in order to ensure efficient operations. Pile properties also have an effect on drying conditions.

2.2.4.2. Quality Standards

When producing quality wood chips, standards are used to improve the operating environment of the supply chain. Use of standardised, evenquality biomass reduces costs and emissions during the production process. Standards make it possible to describe a fuel more accurately and are therefore useful for both producers and consumers of wood fuels. The development of international standardisation for wood-based biomass advances international fuel markets and overall quality assurance.

Standardisation of solid wood fuels, e.g. wood chips, has been an on-going process for several years. In addition to this international standard, national standards and manuals are used (Alakangas 2012). The European standard for solid biofuels was prepared by the Technical Committee CEN/TC 335 for the multipart European standard and it is applicable to all solid biofuels originating from agriculture, forestry or industry (including waste) (EN 14588). Standardisation of solid biofuels is subdivided into parts including standards on fuel specification and classification of solid biofuels based on origin and source (EN 14588) and standards determining fuel quality (EN 14961). Standard EN 14961-1 defines general quality specifications for solid biofuels and EN 14961-2 – 6 are product-specific standards defining product standards and product quality specifications for the domestic consumer (Loibnegger 2011). EN 14961-4 is a standard defining wood chip quality.

EN 14961 is being supported by other EN standards, which are mainly concerned with quality control and sample testing of solid biofuels (Alakangas 2012):

- Fuel quality assurance – multipart standard (EN 15234)
- Sampling and sample preparation (EN 14778, 14780)
- Physical and mechanical properties (EN 14918)

Standard 15234-2 defines the quality assurance process concerning wood chips throughout the whole supply chain and defines the procedures to guarantee wood chip quality (quality control). Standard EN 14778 describes methods for preparation for taking samples, e.g. as a part of quality control measures. Standard EN 14780 describes methods of sample preparation in combined and laboratory samples, for calorific value, moisture content, ash content, bulk density, durability, and particle size distribution, ash melting behaviour, chemical composition and impurities (Loibnegger 2011).

2.2.4.3. Moisture

Moisture is one of the most significant factors affecting the quality of energy wood. Moisture content affects the net calorific value, energy density and the fuel efficiency of wood combustion (Figure 29). In addition, the combustion of wet wood material increases carbon monoxide, carbon dioxide and fine particle emissions (Hakonen & Laurila 2011). The moisture requirements of woody biomass depend strongly on the size and the type of the plant and combustion equipment, and combustion. Basically, small scale heat and power plants require more homogenous and drier fuel and bigger plants can utilise even fresh energy wood.

In the combustion process, the water is first evaporated from the fuel, which requires energy. Using moist fuel for energy production is therefore not efficient; the wetter the fuel, the more energy is needed to evaporate the water and the less energy it produces. The net calorific value of wood decreases linearly as moisture content increases and there is a faster decrease of energy density with high moisture content (Figure 29). To achieve the same amount of heat or power, much more wet than dry fuel is required. In addition, higher the moisture content, more water is carried with forest chips, which also has a strong influence on transportation costs. High moisture content also makes handling and mixing of the fuel more difficult, especially in winter; wet fuel may form ice bridges and lumps in storage bins or in conveyors.

Freshly harvested wood is usually too wet for energy use, thus it must be seasoned before use. The fresh moisture varies on the basis of, for example, tree species, tree compartment and harvesting period. For instance, the fresh moisture of stump wood is influenced by the tree species, the period between final felling and stump harvesting and the water conditions of the soil.

In addition to the fresh moisture, the drying of different tree species and tree compartments varies. Energy wood is stored for periods from a few months to a couple of years before comminution and transportation. After harvesting, the wood is usually first seasoned in small piles at the site and afterwards in bigger storage piles on the road side. During storage (in field conditions) the moisture of energy wood can be reduced to only 20–30% (e.g. Jirjis 1995, Nurmi 1999, Nurmi & Lehtimäki 2011), but in Finnish climate conditions, the maintenance of a low moisture content through autumn and winter is challenging, and in practice, energy wood remoistens during that period (Jahkonen et al. 2012 a). The amount of intercepting rain and snow can be reduced by covering the pile.

Covering reduces the moisture of logging residues more than the moisture of stem wood because the amount of surface per volume in logging residue is much higher. It has been reported that covering lowers the moisture of stem wood 3–6% (Nurmi & Hillebrand 2007) and in logging residues as much as 10–15% (Hillebrand & Nurmi 2001) during the storage period.

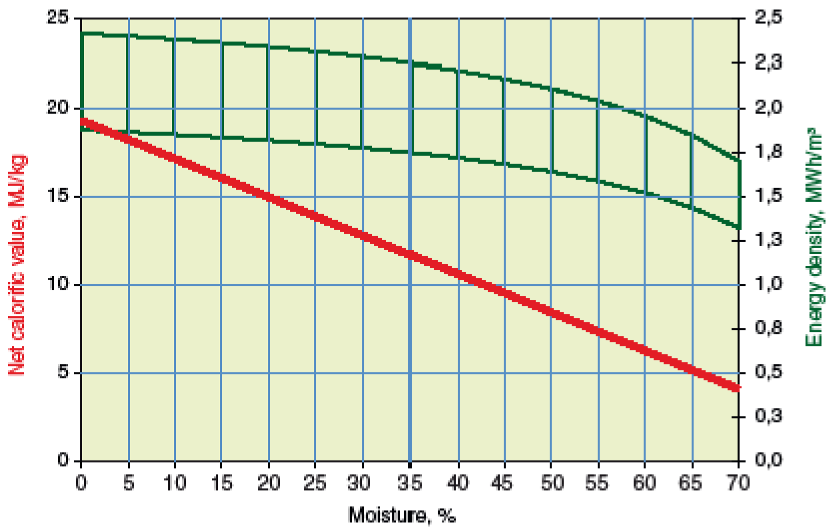


Figure 29. Net calorific value (MJ/kg) and energy density (MWh/m³) of energy wood with an energy wood moisture content from 0 to 70%. The range used in energy density calculations was 350–450 kg/m⁻³ (Jahkonen et al. 2012 b)

During the storage period moisture can cause mouldering and decay, which lowers the quality and dry mass content of wood. Long storage periods for chipped wood in storage piles may decrease the quality of wood chips, decrease the dry matter content, and increase the risk of selfignition, especially in high logging residue piles if the temperature inside the pile rises.

2.2.4.4. Impurities

Impurities, such as soil, stones, ice and snow, or plastic and metal pieces in chipped energy wood significantly affect both quality and cost factors of forest energy production. Soil can be introduced to the storage pile, for example when energy wood frozen into the soil is loaded and moved to road side storage. Road side storage is susceptible to snow, soil and other debris from snow ploughing.

Soil attachment is a major problem with stumps. The amount of soil attached depends on the form and shape of the stump, soil type, stump harvesting method and storage (Jahkonen et al. 2012 b). The ash content of stumps after a long storage period according to Laurila and Lauhanen (2010) is on average 1.7%, but ash content can increase if plenty of soil particles are attached to stumps, even up to 14% (Alakangas 2000). Impurities cause extra costs during transportation to the plant and also when the extra soil is transported from the plant to landfill site.

Impurities such as stones, pieces of iron or large pieces of ice may break fuel conveyors or the structures of the boiler (Figure 30). In fluidised bed boilers soil reduces the quality of the sand bed and increases the need for maintenance. Impurities usually end up as ash and when the number of impurities increase, ash content also increases. An increase in ash content usually also reflects lower calorific value (Jahkonen et al. 2012 b).

Figure 30. Large ice pieces may break conveyors and boilers (Miina Jahkonen, 2013)

2.2.4.5. Chemical Composition

Chemical composition and nutrient content of wood chips have an effect on the quality of the fuel and energy production process (Alakangas 2000). During storage, the properties of energy wood change due to physical, chemical and microbiological processes. Decomposition by micro-organisms and chemical oxidation processes produce heat, carbon dioxide and water, and under certain conditions piles of chipped wood accumulate so much heat, that there is a risk of self-ignition (Thörnqvist 1985).

The main organic components of woody biomass are cellulose, hemicellulose and lignin, which mainly consist of carbon, oxygen and hydrogen. Wood also contains smaller amounts of inorganic compounds, e.g. chlorine, nitrogen, sulphur and potassium. Slagging and fouling reduce the heat transfer of combustor heat exchanger surfaces and cause corrosion and erosion problems, which reduce the lifetime of equipment. The main contributors come from inorganic fraction (Khan et al. 2009).

Especially high percentages of chlorine and alkali have proved to be a major concern in energy production. Needles and leaves are rich in chlorine because of its role in photosynthesis. At high temperatures chlorine may cause corrosion of superheater tubes (Alakangas 2000, Khan et al. 2009). The amount of chlorine can be reduced by seasoning logging residues until the needles/leaves have lost their green colour (Alakangas 2000). Alkali together with silicon forms silicates, which melt or soften in lower temperatures in a boiler, and alkali together with sulphur forms alkali sulphates on heat transfer surfaces. In fluidised bed boilers chlorine, potassium and silicon also cause agglomeration problems (Khan et al. 2009). Alkali metals reacting with silica from the ash can block the airways of boilers. Biomass usually contains only a little silicon, but soil contaminants increase the amount and the risk of operational difficulties caused by silica (McKendry 2002).

2.2.4.6. Particle Size

The particle size of wood chips depends on the raw material, tree species, moisture content, operator experience and the type and maintenance of wood chipping machine. Chipping is comminution using sharp tools, usually at high speed. Chipping is commonly used for roundwood, whole trees and logging residues. Chipping machines are susceptible to impurities and metal pieces and stones can break the blades; smaller impurities such as sand wear the blades. Hogging is comminution using blunt tools (crushing or grinding) and it can be either high or low speed (Kofman 2013 b). Stumps always contain some soil and stones and so they are always crushed using blunt tools.

Solid volume factor depends on chipping/crushing techniques and transport. It indicates how many solid m^3 one bulk cubic metre contains (Alakangas 2005). Solid volume factor depends on the shape and size of chips, wood species, and on the tree compartment and loading method. The optimal length of a wood chip is usually 30–40 mm. For endusers, a uniform particle size would be optimal. However, chip size in one consignment is not uniform and smaller chips tend to fill the spaces between bigger chips during loading and transport. At the plant, long particles and branches cause bridging and may block the conveyors, and fine particles may block the air intake of a boiler so that in fluidised bed boilers the combustion of fine particles takes place in the air, not in the sand bed as intended (Kofman 2013a). Pieces that are too big burn at too high a temperature, which may cause sintering of sand in the boiler. Fine particles also block air movements inside the storage pile and thus slow the drying process.

2.2.4.7. Origin of Wood

The origin of wood can be seen as one of the quality factors of wood chips. The production of energy from forest based biomass is going to face more detailed control through the European Community (EC). EC Directive 2009/28/EC on the promotion of the use of energy from renewable sources (referred to later as the RES directive) defines the sustainability criteria and verification of compliance with the sustainability criteria for biofuels and bioliquids. It is very likely that solid biofuels follow the same control in the future.

The RES directive states that irrespective of whether the raw materials of biofuels or bioliquids are cultivated inside or outside the European Community, raw materials have to fulfill the sustainability criteria in order to take energy production from biofuels and bioliquids into account for purposes such as national renewable energy production targets, measuring compliance with renewable energy obligations and eligibility for financial support for the consumption of biofuels and bioliquids. Concerning the utilisation of forest biomass, the sustainability criteria of the RES directive deals with greenhouse gas savings, biological diversity, land use changes and drainage of peatlands.

In Finland, the sustainability requirements of the RES directive and national legislation are not problematic from a raw material applicability perspective. The majority of wood chips are produced in connection with silvicultural operations such as pre-commercial thinnings and timber harvesting. Nature protection areas and other valuable nature habitats are either protected or harvesting operations are restricted by law. However, the RES directive requires that the origin of raw material and compliance with the sustainability criteria has to be verified by the producers of biofuels and bioliquids. This requirement creates extra costs for producers as the origin of every raw material delivery has to be verified.