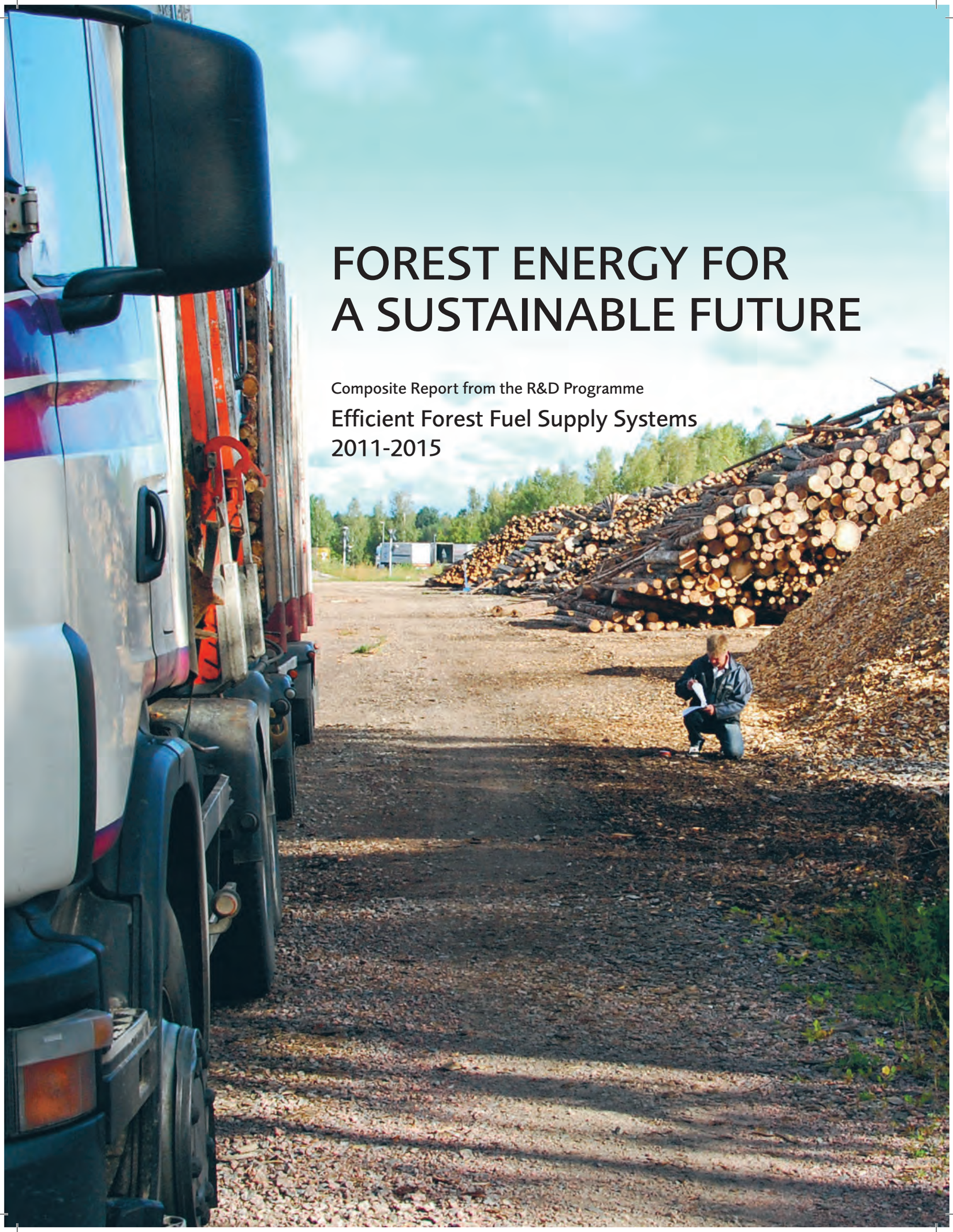

FOREST ENERGY FOR A SUSTAINABLE FUTURE

Composite Report from the R&D Programme

Efficient Forest Fuel Supply Systems 2011-2015

FUEL PRODUCTION

– RESOURCE-EFFICIENT COMMINUTION

Lars Eliasson, Skogforsk

The primary forest fuels cannot be incinerated in their original state. They must first be comminuted, i.e. chipped or ground, before they become a suitable fuel in the boilers of heating plants or combined heat and power plants. The type of chips preferred by customers varies (see Chapter 1), but since most suppliers sell chips to several different customers, they often try to deliver chips with characteristics that are acceptable to everyone. This increases flexibility, and means that chips can be delivered to several customers from one landing or from a pile of chips stored at a terminal.

The material is either comminuted on landings or transported to terminals before comminution, depending on which method gives the lowest total cost for comminution and transport. Comminution accounts for a large proportion of the total costs of handling forest fuel, so even a small cut in costs is significant in economic terms. One of the major cost items for comminution is the fuel on which the machines run.

In 2013, the average cost of chipping was SEK 48 per m³ of chips for logging residue, and SEK 42 per m³ of chips for small trees. Logging residue and small trees are usually comminuted on the landing, because it is difficult to attain acceptable payloads on residue and roundwood trucks while, in most cases, payload is fully utilised when chips are transported. Even if the recipient has efficient comminution facilities, it is difficult to justify transporting uncomminuted material further than 100 km.

On the landing, residue is usually comminuted using forwarder-mounted chippers or using chipper trucks. Chipping on the landing requires space, and requires careful planning and logistics if the potential of the chipper is to be fully utilised.

In 2013, comminution of energy wood cost approximately SEK 18 per m³ of chips. This is much cheaper than chipping logging residue and small trees because the energy wood is comminuted using larger and more efficient machines, either at a terminal or at the end customer. Comminution of energy wood does not increase payloads, so it is always more profitable to transport this assortment to the terminal or the end customer before chipping.

Even if some stumps are ground on the landing, most grinding takes place at a terminal. Despite this, the cost of grinding was as high as SEK 49 per m³ of chips produced in 2013. There are two reasons: in most cases, apart from the grinder itself, a separate loader is needed to feed the stumps into the grinder, and the fuel economy of grinders is worse than that of chippers used for logging residue and small trees.

Machine selection

The choice of machine for comminution is determined by the material, quality requirements relating to the chips, and where the comminution is to take place. Chippers can only be used to chip forest fuel that does not contain any contaminants, while grinders can comminute all types of forest fuel, regardless of whether they contain contaminants.

Disc chippers are the most specialised chippers, and are designed for use at terminals. Productivity is usually high and fuel economy good, and they produce high-quality chips from energy wood. However, chip quality is often unacceptable when tree parts or partly delimbed thinning wood are chipped, as the chips often contain too many splinters.

Drum chippers are available in many different sizes; medium-sized machines are designed for use on or beside a landing, and the largest are used at large terminals or at heating plants. Productivity depends on the size and engine power of the machine. Fuel economy is good, although more fuel is used than in disc chippers. Even if the chip quality is better for stemwood than for logging residue, the drum chippers produce an acceptable chip of all uncontaminated forest fuels.

Grinders are available in many sizes, but are generally larger than drum chippers. Grinders smash or crush the material, so they are not as sensitive to contaminants as chippers. However, more energy is used to crush or break up wood using blunt tools than to chip it using sharp knives, so grinders generally have higher fuel consumption. On the other hand, the hammers or teeth of a grinder do not need replacing as often as the knives in a chipper. The ground material is less uniform than chips produced by a chipper and, although it´s chip sice distribution may fullfill the requirements on the requested P-class, it may be unsuitable for some customers.

Chipping of logging residue.

On landings, drum chippers are mainly used. When a chipper needs to be moved in the forest terrain at the side of the road, it is usually mounted on a forwarder. Where the chipper can stay on the road, tractor-drawn chippers and chipper trucks (chip trucks with an integrated drum chipper, enabling both chipping and transport) are also used.

In the past decade, chipper trucks have proved to be an interesting concept for chipping logging residue and tree parts forwarded to a road. Unlike the rest of Europe, few truck-mounted chippers are used on landings, i.e. machines where the truck merely serves as a base machine for a chipper and cannot be used to transport the chips. The truck-mounted chippers are dependent on efficient logistics and relatively large landings, to minimise waiting time in the system. The chipper truck system, on the other hand, is flexible and has no direct relocation cost between landings. Unfortunately, chipper trucks have been affected by fires in recent years.

Factors affecting productivity

Productivity and fuel economy of the comminution machines are affected by a number of factors. Some of these factors are the same as those that influence the choice of machine, i.e. type of material and desired chip quality, but other characteristics of the material are also important, such as target piece size of the chipped material, density, moisture content and whether the material is frozen or not. Machine parameters like engine power, sharpness of knives and sieve mesh size also affect productivity.

For chippers, productivity and profitability can be increased, and fuel consumption reduced, by 1) increasing the target length of the chips, 2) using the correct sieve for the desired chip quality, and 3) replacing the knives before they become too blunt.

New system solutions

In the past ten years, productivity in comminution has increased considerably, but there is still scope for improvement. Some examples of systems that, in pilot studies or in operation outside Sweden, have been shown to have potential, but need to be studied in more detail:

- In container systems, the proportion of time the chipper is in use can be considerably increased if the wood is chipped straight into the containers. The containers are then transported between the piles and the reloading point using a forwarder equipped with a hook loader. The chipper operator can then concentrate on filling the containers. If the proportion of chipping time for the chipper is increased by 20 percentage points, this system becomes more profitable than if the forwarder-mounted chipper performs all the work.
- If the chips are placed on a tarpaulin, there can be many benefits if the landing is planned in such a way that the chipper can blow the chips directly onto the tarpaulin instead of having to transport them there using the chip bin on the machine.
- In Finland and Central Europe, chips are generally blown directly into the trucks. We should be able to do the same on landings where there is room for the truck and the chipper beside each other. Filling a chip truck by chipper takes no longer than loading it with a crane, so direct loading saves time.
- If a chipper can run on both diesel and electricity, electricity can be used for chipping at terminals that have a power supply, and diesel on landings and terminals that lack a power supply. This reduces both operating costs and emissions.

In order to reduce comminution costs and retain acceptable levels of profitability for machine contractors, more research is needed into how to increase productivity and utilisation level of the comminution machines.

Another way to increase profitability is to increase the value of the end product. For ground stumps, we can reduce the ash content by sieving the comminuted material. In the same way, sieves can be used to produce a desired chip fraction to a customer if this sieved assortment has a sufficiently high value.


BRUKS

COMMINUTION ON THE LANDING

Lars Eliasson, Skogforsk

On landings, drum chippers are the most commonly used machines for chipping material that is not contaminated, such as logging residue or tree parts.

Chippers can be mounted on a forwarder, pulled by an agricultural tractor, or integrated in a chipper truck. The tractor-drawn chippers are primarily used where the terrain is flat or where the chipper can be placed on a road.

For stumps and contaminated material that cannot be chipped, grinders are used. Grinding forest fuel on a landing is often a complicated procedure because the landing, in addition to a relatively large grinder, must also accommodate a separate loader to feed the material into the grinder. In addition, a wheel loader is often needed to pile up or load the chips. During the past five years, a number of smaller grinders have been presented that can be used on smaller landings. A crane is mounted on the machine, so a separate loader to feed the material into the grinder is not needed.

Greater productivity... but shorter effective chipping time

In recent years, productivity of chippers used on landings has increased, while fuel consumption has remained unchanged or been slightly reduced per oven dry tonne of chips produced. A main reason for the increased productivity is that the power of the chipper engines has increased. Some manufacturers have also chosen to increase the target length of the chips to correspond better to the requirements of the larger heating plants. This also increases the productivity of the chipper.

However, for a forwarder-mounted chipper, the increased productivity when chipping is not matched by any corresponding reduction in the time needed for transport, tipping of chips, and maintenance. The result is that the proportion of time devoted to chipping has fallen – currently, a forwarder-mounted chipper spends only about half its operational time actually chipping.

Effective chipping time for chippers or grinders that process the chips directly into containers can be increased if a successful solution is found for shunting of containers. A prerequisite for this is sufficient room on the landing and a sufficient number of container trucks available. Unfortunately, this is not always the case, and there is often a lot of waiting time.

In order to utilise chippers efficiently, it is important to plan the forwarding of the material and choose a suitable landing to optimise conditions for chipping. A chipping contractor cannot be expected to utilise the equipment efficiently if conditions are less than optimal.

When planning the forwarding of logging residue, it is important to choose a site for the landing that is beside or close to a road, where the stack can be kept dry and preferably exposed to sun and wind. If a stack can be placed on a roadside, it should be placed if possible on the right-hand side of the road in relation to the direction of transport. The residue can then be chipped either with a forwarder-mounted chipper or with a chipper truck. The stack must be placed in such a way that it is close to a place on the roadside where there is sufficient room to place containers or pile the chips if they are to be transported in a self-loading chip truck. Preferably, there should be enough room at this reloading position to allow both chipper and trucks to operate without disturbing or blocking each other.

If the chips are placed in a pile, it is not necessary for transport to take place in conjunction with chipping – on condition there is room for the chips. If the chips can be stored until the chipper has left the landing, there is no risk that the trucks and the chipper disturb each other, which eases the work, particularly if the landing is small.

When working along heavily-trafficked roads, the ideal situation is that the working vehicles can be passed by other traffic, to minimise disruptions to the work and to ensure that the working vehicles do not block the road for emergency vehicles.

Chipper trucks are a competitive alternative to forwarder-mounted and tractor-drawn chippers on small sites and where the distance to the customer is short. Rational work requires that the pile be placed on the right-hand side of the road in relation to the direction in which the transport will take place, as turning a fully-loaded rig can be problematical. Furthermore, the material must lie no further than 8-9 metres from the roadside to be within reach of the crane on the chipper truck.

Future work

- How can we plan landings to minimise the time that the comminution contractors spend on tasks other than actual chipping??
- Are technical solutions available that would allow the chipper to spend more time chipping and, if so, are these competitive compared with current machines?
- Evaluation and development of new, more energy-efficient chipping solutions.

COMMINUTION AT THE TERMINAL

Lars Eliasson & Henrik von Hofsten, Skogforsk

Comminuting forest fuel at a terminal or at the end customer has many advantages. The large volumes mean that the costs of comminution can be kept down, as larger and more efficient machines can be used compared with comminution at a landing. The chipped material can be stored at the terminal, so the chipping machine is not dependent on unloading and transport; instead, it can work independently of incoming deliveries. Comminution at terminals and end users is carried out using either mobile comminution machines or fixed equipment.

Permanently fitted comminution equipment is found at all pulp mills and at some of the larger heating plants. The pulp mills use chippers because they only handle pulpwood, which is a material with little contamination. The heating plants have instead chosen to use grinders, to allow processing of different types of material, such as recycled wood, stumps and logging residue.

Fixed equipment has the advantages that it can be built in, which reduces dust and noise in the vicinity, and can use electrical power, which reduces operating costs. The disadvantages are that all material must be transported to the grinder, high investment costs, and often a high fixed charge for the electricity connection.

Future work

Studies of comminution at terminals have generally involved mobile machines. Large, fixed facilities and associated terminal logistics need to be studied in more detail.

Three types of comminution machines are used at terminals:

1. **Grinders** can handle all types of biofuel, and are not so sensitive to contaminants. They are therefore the only option for comminuting stumps, which normally contain a large amount of soil and stones. The grinder breaks up the wood to chips and finer material with hammers or shredders. The chips are therefore uneven in quality and the proportion of fine fraction is often high. Breaking up the wood requires a great deal of energy, and the fuel economy of grinders is therefore worse than that of chippers.
2. **Drum chippers** can comminute all contamination-free forest materials, i.e. logging residue, energy wood and tree parts. A chipper cuts the wood into pieces using sharp knives, so the chips have a consistent quality that is mainly determined by the type of material that is chipped.
3. **Disc chippers** give the most consistent chip quality, and have the best fuel economy of the three machine types when energy wood is chipped. They are designed to chip logs and do not work satisfactorily with other material, which reduces productivity, and there are also problems of splinters in the chips.

Chippers are preferred by many small fuel customers, as they produce chips of a high and consistent quality. For large combined heat and power plants, the influence of machine type on chip quality is less relevant. Choice of technology does not have much effect on productivity, but a grinder needs to be larger, heavier and more powerful than a chipper with the same capacity, as it has to be able to handle the l arger forces necessary to crush the wood. Maintenance of the terminal machines is important, and knife maintenance on a chipper probably costs more per dry tonne of chips produced than maintenance of the hammers in a grinder.

One advantage of mobile comminution equipment is that a contractor can work for several terminals, thereby allowing a high level of utilisation for the machines. The machines can move along the stacks at the terminal, and there is no need to move material to the machine, so the contractor is less dependent on other activities at the terminal. A disadvantage is that the machines run on diesel, so fuel costs are higher than for machines powered by electricity. How emissions are affected is difficult to determine, because there is no need to transport the material to the machine, which is necessary for a fixed installation. One clear disadvantage is that the mobile machines are very noisy.

SYSTEMS FOR GRINDING AND CLEANING STUMPS

Henrik von Hofsten & Lars Eliasson, Skogforsk

Transporting stumps from the landing to the customer is expensive, mainly because stump parts are difficult to load and compact. With einforced metal sides on trucks and a powerful crane, the material can be compacted somewhat, but the overall result is usually that the kerb weight of the truck increases… but not the payload.

One problem of transporting whole stumps is that they contain large quantities of contaminants in the form of soil, sand, gravel and even large stones. A natural solution to these problems is to comminute the stumps to chips before transport and, by doing so, remove as much of the contamination as possible.

Stump parts require powerful grinders, partly because of the hardness of the stump wood and also because of all the contaminants. The in-feed opening of the machine must be large, as the stump parts are hard, irregular in shape, and cannot be compacted in the feed system. A number of different grinders fulfil these requirements, both with and without sieving equipment. The equipment that should be chosen depends on a number of factors.

Fraction sizes and fraction distribution of the chips are important, not just in terms of customer requirements but also because of how contaminants can be removed from the material. If stump parts are chipped to an incineration fraction, e.g. P45 or P63, grinding takes longer, and more diesel is used compared to when the material is chipped to a larger fraction.

One way to reduce the problem of contaminants is to place whole stump parts on a vibration table for 30-60 seconds before grinding. The method has been tested, and works well for contaminants on the outside of the wood, but cannot remove stones, etc. that are embedded in the wood or trapped in the roots. Currently, no vibration tables are commercially available but, in theory, one could be integrated into the in-feed system of a grinder.

However, commercial equipment is available for sieving the chips after grinding. This also removes contaminants embedded in the wood. The disadvantage is that all contaminants must first pass through the grinder, which increases wear.

Studies carried out by Skogforsk and SLU indicate that, for several reasons, the material should be ground to a relatively large fraction, 100 mm or more. Grinding and sieving at the landing are expensive, as several large machines must be transported there. Consequently, it is important that the machines can maintain high productivity; grinder production increases with increasing fraction size, while the proportion of fine fraction decreases. If the target chip length is as short as 45 or 63 mm, many chips become smaller than the target length. This increases the risk of large wood losses during sieving, as chips smaller than the mesh size in the sieve will be lost together with the unwanted soil and sand.

Sieving after grinding can be carried out using two types of machine:

- A top-feed low-speed grinder, which feeds the material onward to a drum sieve. This combination works well, but synchronising the two machines can be difficult. The big disadvantage is that both the grinder and the sieve are long and, with a separate loader in front of them, and the feed-out belt opened out, the entire combination can be up to 40 metres long. In addition, a wheel loader is needed to load the chips and remove the sieved rejects from the landing. The advantage is that the different units can be used separately in other applications when not used for stump grinding
- A grinder with a built-in sieve. Usually, this also comprises a top-feed grinder, where a disc or star sieve is fitted under the grinder. The star sieve comprises a large number of axles placed about 20 cm apart. Particles that are too small drop down between the stars and are fed out at the side of the grinder, while the chips are fed out at the back. This machine is more compact than the two-machine system. A disadvantage is that the grinder cannot be operated without sieving, and that the sieve cannot be set to retain pieces smaller than approximately 20 mm, because the stars would then be too close together and risk disrupting operations.

The advantages of grinding and sieving on the landing, apart from increased payloads, are that a purer wood material can be delivered without fine fractions. This should increase the customer's willingness to pay for the fuel, particularly if the chips can be incinerated immediately without further processing. The contaminants removed by sieving can easily be spread out over the ground adjacent to the landing or used to fill in surface irregularities such as wheel tracks. One common problem with all sieving is that stones that are larger than the sieve size are left in the material. Removing them requires special density separators, so yet another machine on the landing.

In some cases, it can be a good idea to grind the material on the landing to increase payloads and reduce transport costs, but to delay sieving until a later stage when there is a clearer idea about whether the material really does need to be sieved. The material can be sieved at a terminal where there is room for both a star or drum sieve and a density separator, but a disadvantage is that the rejected material must then be transported away. On the other hand, the cost of comminution can generally be reduced, as smaller, lighter and often truck-mounted units can be used in the forest.

THREE WAYS TO IMPROVE CHIPPING EFFICIENCY

Lars Eliasson, Skogforsk

Comminution accounts for a third of the costs of handling logging residue before it reaches the heating plant. Consequently, even a small reduction in costs is significant for the economy throughout the chain. By adapting target length of the chips to customer requirements, using the right sieve for the desired chip quality, and by replacing knives in good time, productivity can be improved, while also reducing fuel consumption.

Adjust target length of the chips

Changing the settings for the knives changes the target length of the chips. This affects both the quality of the chips and the productivity of the machine. Changing the knife settings can be difficult, as many machines are designed for a more or less fixed knife setting that is adapted to the market for which the chipper is built. In Central Europe, small boilers that need a fine chip size dominate, while in Scandinavia, there are large boilers that can often use larger chip fractions. Consequently, it is important to check the type of chips a machine produces before purchasing.

Studies of machines where the knife setting can be changed show clearly that a larger target length improves the efficiency of chipping, assuming the machine is powerful enough to drive the in-feed rollers at the appropriate speed and evacuate the chips produced. In a study of a large disc chipper, productivity increased by 6 percent when knife blade length was increased from 30 to 33 mm. A further increase to 36 mm reduced productivity by 4 percent compared with the standard setting, which was because the flow of hydraulic oil to the in-feed table was then too low to attain a correct feeding speed. Corresponding studies of a drum chipper gave a similar result (Figure 1).

Use an appropriate bottom sieve

Equipping the chipper with a bottom sieve is regarded as an effective way to adapt chip size to customer requirements. However, this is only partly true, as the sieve only reduces the proportion of chip sizes that are larger than the mesh size. In order to increase or reduce the target length of the produced chips, the knife settings must be changed. The effect of the sieve depends on the design of the chipper.

A bottom sieve causes resistance to the flow of chips, which has a negative effect on both productivity and fuel consumption. For two different drum chippers, a reduction of mesh size in the bottom sieve from 100 to 50 mm reduced productivity by over 10 percent, and also increased fuel consumption by 13 to 33 percent (Table 1). The 50-mm sieve on the Biber chipper studied can be

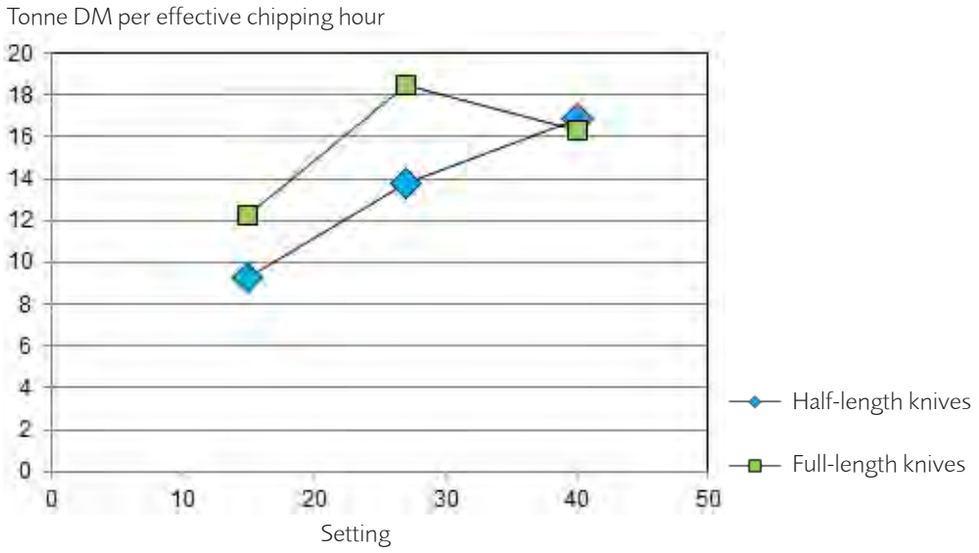

Figure 1. Effects of setting and choice of knives on performance of a small drum chipper, tonne DM per effective chipping hour.

motivated if the customer is sensitive to excessively large chip pieces. However, there is no reason to use the 35-mm sieve, as this reduced productivity and increased fuel consumption without improving chip quality.

Table 1. Productivity and fuel consumption with different sieves.

Machine	Sieve mesh, mm	Productivity, tonnes DM/effective chipping hour	Diesel consumption, litres/tonne DM
Biber 92	100	30.0	2.1
Biber 92	50	25.8	2.8
Biber 92	35	23.0	3.2
Kesla 645	100	14.5	3.0
Kesla 645	50	13.1	3.4
Kesla 645	25	6.7	7.0

Sharp knives important

The knives in a chipper become worn with use. The speed of wear depends on the material chipped and degree of contamination. The life length of the knives can range from less than 57 tonnes DM (~350 m3 of chips) for contaminated material to more than 245 tonnes DM (~1400 m3 of chips) for uncontaminated material. As the knives become worn, the productivity of the chipper falls and fuel consumption rises. These effects are, in principle, linear to the produced quantity of chips. As the knives become blunter, their action changes from cutting the material into pieces to breaking it up; this reduces the quality of the produced chips, as the proportion of chips in the target fraction decreases.

Constantly maintaining sufficiently sharp knives to avoid the negative effects of knife wear is a good way to improve the efficiency of chipping. The challenge lies in adapting the replacement interval for the knives to minimise the total chipping cost. The gains produced by sharp knives must be weighed against the cost of replacing the knives. The effect of knife wear on operational economy can be divided into three components:

- Increased production cost per tonne DM because of lower productivity.
- Increased fuel consumption per tonne DM because wear increases fuel consumption.
- The cost of replacing the knives, which includes the labour cost and the cost of sharpening or purchasing new knives

Of these costs, the first two increase as production volume increases. However, the cost of knife replacement is a cost that is spread over the produced quantity of chips, so it declines as production volume increases. If the total chipping cost per tonne DM is minimised, the finding is that the knives should be replaced before they are completely worn out. However, the curve for the mean cost is flat around the minimum, so there is great latitude for choosing a suitable time for replacing the knives if a small deviation from the minimum costs is acceptable.

Future work

How can the settings in a chipper be adjusted to produce chips that meet customer requirements?

How does the material to be comminuted affect the fraction distribution in the chips?

Chipper trucks have proved to be a competitive concept for chipping logging residues and tree parts at roadside landings.

PREVENTING CHIPPER TRUCK BREAKDOWN

Lars Eliasson & Henrik von Hofsten, Skogforsk
Fredrik Johansson, consultant

Although the weight of the chipper makes the payload smaller than that of a chip truck, chipper trucks are often the most profitable option on small sites and where transport distance is moderate. This is because the chipper truck is an easily moved unit that can chip material from several different landings on one day. This simplifies planning, and makes it easier to deliver fuel of the right quality to the customers; if the fuel on one landing does not match the requirements, the machine can easily be moved to the next. On the other hand, chipper trucks have specific requirements regarding the landing. The truck should be able to turn before starting chipping, and the stack must be located on the right-hand side of the road.

The material for chipping must be free from contaminants. Stones and metal in the material damage the chipper – at best, the knives have to be resharpened, but in the worst case scenario, the entire chipping unit must be renovated.

In addition to the problems caused by contaminants, a number of chipper trucks, many of them relatively new, have been damaged by fire since 2010. In order to investigate the scale of the problems caused by contaminants and fires, a questionnaire was sent out to all chipper truck contractors in Sweden.

Owners of 28 trucks responded and, of these, six trucks had suffered serious damage to the chipper on account of contaminants in the chipped material in the period 2008-2012. Five of these had been caused by metal objects and one by stones. Metal objects may derive from the forwarding, but also from forgotten equipment. It cannot be excluded that contaminants may have been thrown into the stacks during the period of storage after forwarding.

In the same period, nine chipper trucks had been affected by fires, and three of these had been totally destroyed. Five of eight fires occurred during chipping, which is not surprising as chipping is the process that generates most heat. The fires not detected until transport probably also originated from the chipping stage – air turbulence during transport supplies oxygen that can cause glowing chips to ignite.

The fires usually started behind the cab, on the right-hand side, i.e. in the area where the silencer and exhaust pipe are situated. The silencer contains the catalytic exhaust cleaner, which must be very hot to function efficiently.

Hauliers, clients and bodybuilders are responsible for reducing the number of breakdowns. Main responsibility for contaminants lies with the client and the forwarder operators, as they can influence the amount of contaminants in the forwarded material or choose to use either a chipper or grinder on the basis of perceived risk of contaminants in the stacked material.

Main responsibility for reducing fires lies with the haulier and the driver. In particular, this involves cleaning the truck after a load has been chipped. Manufacturers also have a responsibility; hot areas should be shielded, and cleaning the machine must be an easy operation. The client can also contribute, for example in warm weather, by assigning the haulier tasks involving material that is not too dry.

Measures to reduce damage to chippers

- The forwarder must be equipped with a residue grapple.
- The forwarder operator must realise the importance of the forwarded material being uncontaminated.
- If a pile is suspected of containing contaminants, the material should not be chipped but ground.

Measures to prevent fires

- Thorough cleaning of the machine after chipping.
- Good access to the hot areas when cleaning the truck, and appropriate equipment for cleaning.
- Limiting chip waste in the area behind the cab.
- Shielding and protecting hot areas, assuming this does not make cleaning difficult or affect warranties and CE marking.
- Avoiding chipping extremely dry material, with moisture content less than 25-30 percent, during the driest and warmest part of the summer.
- Using sharp knives in the chipper to minimise the quantity of dust and fine fractions.