FOREST ENERGY FOR A SUSTAINABLE FUTURE

Composite Report from the R&D Programme

Efficient Forest Fuel Supply Systems 2011-2015

Preface

Forest fuel has become an established assortment on the market. Demand for primary forest fuel increased for several years but has declined somewhat recently. This is due to a succession of mild winters, reducing the need for energy, but also a number of market-related factors. More bark and sawdust have entered the biofuel market, as pulp and paper industries are now using less, and pellet production has declined. This has made a major impact on the market, forcing down the price of forest fuel. Use of other, cheaper fuel assortments, such as recycled wood and waste, has also increased. This is not a development we anticipated or wished for several years ago.

At the same time, a widespread discussion is taking place, at political level and in society in general, about renewable energy, climate-smart choices, and climate goals. There are great expectations about a biobased economy, where the forest is emphasised as an important energy and biomass resource for new fuels, chemical products, materials and other products. Intensive technological development is taking place in these areas. Continued and increased use of forest fuel supports the shift towards a sustainable biobased society, but clear political goals and incentives are needed to move development onward. Another big challenge is to reduce the total supply costs and ensure a supply of forest fuel with high, consistent and predictable quality.

This report summarises the research findings from the second period, 2011-2015, of the Efficient Forest Fuel Supply Systems R&D programme, aimed at improving efficiency in forest fuel handling. The report complements the report from the first programme period, Efficient Forest Fuel Supply Systems 2007-2010 (www.skogforsk.se/english/products-and-events/other/efficient-forest-fuel-supply-systems/).The current report contains around 40 articles, divided into five areas. Each section begins with an introductory synthesis of the state of knowledge and a review of the current situation. This is followed by articles describing in more detail the various projects, the results, and what we can learn from them. For anyone wishing to find out more, a list of references relating to each article is provided at the end of this report.

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EFFICIENT FOREST FUEL SUPPLY SYSTEMS

- THE SECOND PROGRAMME PERIOD

Rolf Björheden, 2011-2012
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The first phase of the ESS programme, 2007-2011, was a dynamic period of major developments for forest fuel. New biofuel-based combined heat and power plants were built and existing plants expanded, which increased demand for biofuel, 85% of which comes from the forest. Utilisation of primary forest fuel (logging residue, energy wood, small trees and stumps) increased during the first programme period by approximately 50% but, through robust technology and method improvements, costs could be kept at an unchanged level. The forestry sector and its contractors gradually strengthened the supply system through improved skills, better organisation, and advanced equipment. The expansion of forest fuel production was a major reason why Sweden, by the end of the first programme period, had already reached the EU goal for renewable energy by 2020, the first country to do so.

However, during the second programme period, 2011-2015, the positive development levelled off. Demand did not increase as expected, for several reasons. Mild winters reduced the need for fuel, and a general dampening of the economic climate reduced the need for energy generally. However, even more significant was that the continued expansion of combined heat and power plants started to involve other fuel types, particularly household waste, which is increasingly imported from other EU countries.

In Sweden, many environment-related taxes and charges are levied on fossil fuels, which makes biofuels competitive. Recently, the price of fossil fuels, including oil, has fallen dramatically, but there has been no corresponding increase in the environmental charges and taxes, so biofuels have become less competitive. This also reduced the demand for wood chips. Stagnating demand has resulted in increased stock levels and reduced profitability at all stages in the supply chain. Contractors have been hit hard, and optimism about the future has waned, and this will need to be built up again if bioenergy is to expand in Sweden.

Efficient Forest Fuel Supply Systems was run as a collaborative programme, financed by the forestry sector, the energy sector, and the Swedish Energy Agency. The objective of the programme was to enable a long-term, sustainable and greatly increased use of forest fuel, by supporting the development of a more efficient production system.

The objective of the second phase, ESS.2, was to further improve the efficiency of forest fuel harvest, by reducing costs, improving quality, and retaining profitability for all players involved. Reduced costs and greater added value are seen as the main ways of improving profitability.

We continued to develop existing and new technology for harvesting forest fuel.

- The work on logging residue primarily involved improving quality, efficiency in forwarding, and decision support to prevent ground damage during harvesting.
- The work on stump harvest involved optimising the handling chain, and reducing ground impact and the amount of contaminants in the material.
- The work on small trees examined extraction in new types of stand, efficient thinning methods, and the potential of multi-tree handling under various conditions.
- Various methods of comminution were studied, with the aim of improving efficiency and identifying the best technology in relation to the material comminuted and the chip quality required.
- The focus of the work on transport technology and logistics was on developing and demonstrating longer and heavier vehicles, but also on how to manage and optimise transports.
- Measurement issues were a natural focal point in view of the new Timber Measurement Act that came into effect on 1 March 2015. A prioritised project area was to improve and evaluate the technologies and methods that are currently available, as well as new methods.
- Pioneering work was initiated to define relevant assortments of forest fuel from a customer perspective.

A guiding principle in all projects and issues was to investigate what could be done to maximise quality in all stages of the handling chain.

Scope, funding and organisation

The financial framework of ESS.2 was SEK 73 million, divided into approximately SEK 18 million per year over a four-year period. Forestry stakeholders provided approximately half of the funding, and forest fuel users contributed just over ten percent. The Swedish Energy Agency matched the funding from industry by contributing 40 percent, and so was the major individual funding body. Seven percent of the funding was used for programme administration, 20 percent for common costs such as skills development, coordination, information and publishing, which meant no less than 73 percent could be used directly in the projects.

Calls for applications for funding were made three to four times a year. Skogforsk administered the programme and coordinated all activities. The Forest Fuel programme at Skogforsk continued to form the basis of the programme, and was responsible for coordination and disseminating information to the stakeholders. Many Skogforsk researchers and various other players – universities, institutes and consultants – were involved in projects. During the ESS.2 programme period, around a hundred projects were financially supported.

The Programme Board, which made formal decisions on which projects were to be supported in the programme, comprised strategic and executive representatives of the funding bodies and external scientific expertise. Over the years, the Programme Board comprised:

Antti Asikainen, LUKE (previously Metla), Finland, Peter Andersson, Skogsåkarna, Magnus Bergman, SCA skog, Håkan Bill, E.ON Värme Sverige AB, Rolf Björheden, Skogforsk, Staffan Dalbrink, Mellanskog, Åsa Forsum, Energimyndigheten, Jan Gustafsson, Stora Enso Skog AB (chairman), Per Kallner, Vattenfall AB, Björn Karlsson, Södra Skog, Johan Lindman, Stora Enso Skog AB (former chairman), Tommy Nilsson, Sveaskog, Sven Risberg, Energimyndigheten, Lennart Rådström, Skogforsk samt Jonas Torstensson, E.ON Värme Sverige AB.

A fuel technology collaboration group, comprising operative leadership personnel in participating companies, helped to identify R&D areas and helped develop project concepts through to completed applications.

We also linked a project pilot to each project, whose tasks were to ensure that the focus was on sector needs and interests, and to help the project manager with relevant study objects, networks and updated information. This organisation also made a significant contribution to rapid dissemination and implementation of the results.

In and around the programme, valuable expertise and networks were built up in each sector and in research organisations, both nationally and internationally. Great emphasis was placed on demonstration, implementation and communication, in order to disseminate knowledge about new technology and methods and to influence attitudes to the extraction of forest fuel.

The goals were largely attained, and practical aspects relating to forest fuel were implemented, incorporating many of the results.

Future challenges

There is great potential to increase extraction of primary forest fuel; today only one-third of the potential volume is utilised. However, the major fluctuations in demand make it difficult to encourage contractors and players to prioritise forest fuel activities; long-term and reasonably consistent demand is necessary. New market areas will be needed in the future.

Apart from reducing the total costs, the biggest challenge today is to improve quality aspects that will enable greater harvest and use of primary forest fuel. Here, we still see great potential. We must refine existing technology and develop new technology for felling, handling and transport. We must also improve consistency, predictability and measurability of the fuel qualities required.

Unloading of chips, Örnsköldsviks CHP-plant.


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FUEL CHARACTERISTICS AND MEASUREMENT

– FOR CONTROL, MANAGEMENT AND DEVELOPMENT

Lars Fridh, Skogforsk

Heating plants want forest fuel of consistent and, above all, predictable quality. This requires measurement and predictions of quality-related fuel characteristics throughout the production chain. Better knowledge about fuel characteristics is also an instrument in work to improve quality.

In Sweden, timber measurement has been regulated by law since 1935. The aim was to protect the weakest party in a timber transaction, i.e. the forest owner. In 2008, the Swedish Forest Agency started to revise the regulations and, in June 2014, the Swedish Parliament passed a new Timber Measurement Act, which came into effect on 1 March 2015. The major change is that the new Act includes not only roundwood but also forest fuel assortments, such as stumps, branches and tops. The legislation only concerns the first stage in the chain, when a forest owner sells the timber and the timber reaches the market. Purchase of standing forest timber and intercompany transactions are not covered by the Act.

The legislation does not stipulate who is to carry out the measurement, but the measuring company must be registered. The only measurement methods and equipment permitted are those proven to give satisfactory and documented results in research, trials at practical scale, or in practical application, and any systematic errors must be insignificant. Measuring companies must have systematic and appropriate quality control measures in place for equipment and methods used.

For forest fuel management, the new legislation means that considerably more delivery points are now subject to measurement requirements. A survey carried out by SDC/VMU showed that approximately 260 terminals and between 100 and 200 heating plants will be affected. The forest fuel sector has collaborated in trying to find solutions to ensure compliance with the new statutory requirements, and measurement issues have been given significant emphasis and priority in ESS.2.

Volume or weight?

Driver measurement. For many years, truck drivers have been measuring roundwood at small terminals and delivery sites. Quality control checks and follow-up have been lacking, but these are now required under the provisions of the new Act. One study compared stack measurement carried out by drivers with measurement carried out by wood measurement officials from VMF, the timber measurement associations. The results showed that, in many cases, the drivers were skilled at measuring stacks, but that the variation was greater between drivers than between VMF officials. Challenges when implementing driver measurement include driver training and organising the systematic checks of driver measurements to ensure compliance with the statutory requirements, while maintaining a realistic cost level.

Weighing. One alternative that has been investigated is weighing the roundwood, and then extracting sawdust samples with a chain saw to determine moisture content. The method is used in many countries, particularly at heating plants in Austria. One conclusion of the study was that the concept seems interesting, but must be improved and the sampling technology must be automated.

Another alternative currently applied by some players is to develop conversion functions for roundwood that allow conversion from weight to volume. The driver weighs the timber, and the volume is then calculated automatically in the timber systems. The quality checks would then be easier than when drivers measure stacks, because checks can be carried out for each individual weighing device and not on a collective of drivers. The challenge is to develop functions that include the parameters influencing density variations in energy wood.

Conversion from mass to volume has also been studied for partly delimbed energy wood assortments. Traditional stack measurement of these assortments is difficult at best, partly because the branches and the small diameters make estimates of the solid volume percentage uncertain. In addition, a stack of partly delimbed energy wood may contain a very large number of logs, sometimes as many as 800-900, which makes control measurement an expensive process. The volume models studied underestimated the volume by approximately 25 percent.

In Finland, tests have been carried out by taking sawdust samples with a saw and collector fitted on the grapple of the forwarder. Samples were taken for moisture content determination when logging residue and small trees were placed on the roadside. The moisture content of the collected sawdust was measured with a hand-held meter directly on the landing.

Comminuted fuel is measured by weighing, and the moisture content is used to calculate energy value, or the loose volume is measured. A study comparing different measurement methods for residue chips showed that the average solid volume proportion in 30 loads of chips was 42.6 percent, but varied from 38 to 50 percent. This may cause a variation in the loose volume estimate of up to 20 percent for a given mass of chips. The causes of this deviation were assumed to be the proportion of branches, fine fractions, and method of loading. Attempts are being made to automate the loose-volume measurement, for example by using laser scanning of the loads or image interpretation.

Weighing is an important component in many of the measurement methods. SDC/VMU have carried out several studies on both static and dynamic vehicle scales. In Finland, the use of crane scales has come a long way, both for energy wood and pulpwood, and ESS.2 has studied crane-mounted scales, mainly on forwarders, for the same purpose. The introduction of load cells on forwarders and trucks are other current applications of weighing.

Moisture content – an important quality parameter

Moisture content is one of the most important quality parameters for wood chips because it affects the effective energy content. The oven-drying method is currently the standard method for determining moisture content, but a disadvantage is that the method takes at least 24 hours, which is a problem for many heating plants. The consignment of chips may have been incinerated before the moisture content has been determined, thereby increasing the risk of inefficient incineration. The oven-drying method is also too slow and/or cumbersome for measurement at small terminals, or if knowing the moisture content is desirable during the production process. Faster methods are needed.

Several different meters that use various technical principles to determine the moisture content of comminuted material within a minute or so have been evaluated. The measurements were carried out on samples of 0.8 to 5 litres. Consequently, many samples must be measured to obtain a good estimate of the moisture content in a truck load, and the quality of the result also depends on how representative the samples are.

The more sophisticated the technology on which the meters are based, the higher the cost of the instrument. The simplest meter is a small, hand-held device that costs a few thousand Swedish kronor, and is accurate enough for measurement in the production chain. Meters that use electrical resistance to measure moisture content are more suitable for drier material than forest fuel, as measurement accuracy drops markedly when moisture content exceeds 30 percent.

In a pilot study, further development of X-ray technology has been tested. The results showed that a single measurement of a three-litre sample can show moisture content, ash content, and effective energy value with a high level of accuracy. However, further development is necessary before a finished product can reach the market.

Product descriptions improve information

Today, forest fuel can mean a whole array of materials. In order to improve the efficiency of ordering and delivery of the right forest fuel, at the right time, to the right customer, it is important to be able to describe the technical characteristics of the fuel in relation to incineration. The codes and descriptions of characteristics of forest fuel currently used in timber systems bear little relation to the fuel characteristics that are relevant to the heat and power industry.

In a joint project with SDC and suppliers and users of forest fuel, a proposal for standardised product descriptions has been formulated. The nature of the original material, such as sawdust or logging residue, is described, along with moisture content, ash content and fraction distribution.

In the proposal, the product characteristics are specified, so that they can be followed in the production chain from stump to industry gate. The characteristics are described using a combination of measurement data, historical data, and prediction calculations. The proposal covers both comminuted and non-comminuted forest fuel, such as energy wood, tree parts and logging residue.

Using carefully described product characteristics throughout the business chain can bring the sector a number of benefits compared with the current situation:

- The heating plant can place a more precise order, and a fuel can be delivered that is appropriate for their specific needs.
- The supplier knows in detail what the customer wants, and can plan activities accordingly.
- Both buyer and supplier can obtain a faster and more precise forecast, and feedback on deliveries, in terms of both volumes and characteristics.
- Allows bartering of forest fuel between suppliers with the aim of reducing transport costs and environmental impact.

Further work is needed on a broad front to implement the standardised description of product characteristics.

Moisture content is an important characteristic of forest fuel. It can be decreased by proper storage.

FOREST FUEL CHARACTERISTICS

Lars Fridh, Skogforsk & Linda Bäfver, Pöyry Sweden AB

Different incineration facilities have different requirements regarding forest fuel. A certain facility is designed for a fuel with a certain ash content, moisture content and fraction distribution. If the fuel varies too much from these values, the risk of operational problems and incomplete incineration increases.

The codes and descriptions of characteristics of forest fuel currently used in timber systems bear little relation to the fuel characteristics that apply in an incineration facility. Often, the characteristics say more about how the fuel has been produced and stored, and about other parameters associated with forestry activities.

In order to improve the efficiency of ordering and delivery of the right forest fuel, at the right time, to the right customer, it is important to develop defined product characteristics that are clearly linked to the fuel's incine-ration characteristics.

New proposal for descriptions of characteristics

A proposal has now been developed for definitions and descriptions of the product characteristics of forest fuel. In a joint project with representatives from the member companies in the Swedish District Heating Association and Svenska Trädbränsleföreningen (the Swedish Forest Fuel Association), Skogforsk and SDC, the ESS.2 programme arranged two workshops. The objective was to identify the most important characteristics for forest fuel. The focus was on characteristics that can define the fuel from an incineration perspective, i.e. fuel characteristics. These were:

Ash content, which is divided into three classes: ≤1 percent, ≤ 3 percent and ≤ 7 percent. Stemwood has the lowest ash content, with dry wood containing less than 1 percent ash. Bark normally has 2-4 percent ash content, but sometimes up to 6 percent. Logging residue comprises a relatively large proportion of bark, so has a higher ash content than stemwood. If an incineration facility is designed for stemwood, and fuel with a higher ash content is used, this can cause operational problems. Sometimes, facility requirements may be changed from those that applied in the original design; for example, the facility may be adapted to enable the use of fuel with a higher ash content.

Moisture content, which is divided into four classes: ≤ 25 percent, ≤35 percent, ≤45 percent and > 45 percent. If an incineration facility uses flue gas condensation technology, the fuel should have a high moisture content because the moisture supplements the energy generated – at 40 percent moisture content, the energy supplement can be, for example, 10 percent, and at 60 percent moisture content, the supplement can be 25 percent. The requirements regarding moisture content vary according to the season and whether the facility is to produce heat, steam, electricity or a combination.

Fraction distribution and fine fraction, the definitions in the proposal are those described in the *ISO standard 17225, Solid Biofuels – Fuel Specification and Classes*.

An earlier ESS project (Fraction distribution as a quality parameter of energy wood, from the perspective of power and heating plants) examined the requirements of various incineration facilities in terms of fraction distribution. The results showed that facilities that do not prepare the fuel themselves, generally small facilities with roster boilers, may encounter problems if oversized material is delivered, since there is a risk the material may block the screw conveyers. However, it is the fine fractions that cause most problems in the boiler, as they are swept along in the gas flow and burn in the wrong place. Moist or wet fine fractions can freeze into lumps that cause problems in the fuel handling system.

An interview study showed that heating plants rarely change their fuel specifications, and often retain the same specifications that applied when the facility was built. Generally, control and monitoring of the fraction distribution of the fuel is poor, particularly compared to the control and monitoring of moisture content.

However, many large facilities take random samples to estimate the fraction distribution. Campaigns are also run with more frequent sampling, often linked to operational problems, conversions or new installations. In view of the poor control of fraction distribution, this is probably an area with great development potential.

Other categories of characteristics

In the workshops, other properties that were important in describing the fuel at all stages through the production process, from felling to incineration, were discussed. In many cases, the information needs of the seller match those of the buyer. The supplier must know what they are producing in order to deliver material that matches the customer's requirements.

The supplier generally also needs information on, for example, ownership and other elements forming the basis of payments to land owners and contractors in the supply chain.

The remaining characteristics were grouped into five categories:

- **Administration**, e.g. specifying ownership, origin, stand data. Various administrative features may be added by users.
- **Harvesting**, e.g. cutting form, dates of felling and forwarding. This information will be important for forecasts and monitoring of fuel volumes and moisture contents.
- **Comminution**, e.g. method used, date and moisture content. These characteristics are important when predicting fraction distributions and as input to quality changes during storage.
- **Transport**, e.g. loading method, transport method, and date, all of which affect the fuel characteristics.
- **Storage**, which indicates how, where and for how long the material has been stored.

Product descriptions

A product description can be generated by combining descriptions of characteristics. However, the number of products that can be described in this way would be very large, since the number of possible combinations would run into thousands. Participants in the workshops agreed on a smaller number of base products, 23, of which 15 concerned comminuted forest fuel and 8 non-comminuted forest fuel, such as energy wood, tree parts and logging residue.

Some examples of the proposed base products:

TRB-2 is comminuted stemwood. The ash content is ≤ 1 percent. The moisture content may be up to 35 percent, and the fraction class P45 indicates medium-sized chips (60% of the mass in the range 3.15-45 mm, max 10% > 63 mm). Fine fraction is set to 15 (max 15% of the mass < 3.15 mm).

TRB-6 is sawdust from the wood industry. The ash content is ≤ 1 percent. The moisture content is > 45 percent.

Unloading forest fuel at a heating plant.

TRB-12 is comminuted branches, tops, or whole trees without roots. The ash content must be ≤ 3 percent, and the moisture content may be up to 45 percent. The fraction class P63 indicates larger chips (60% in in the range 3.15-63 mm, max 10% > 100 mm). Fine fraction is set to F10 (max 10% < 3.15 mm).

ENERGY WOOD-HT is non-comminuted stemwood. The ash content is ≤ 1 percent. The moisture content may be up to 45 percent.

RESIDUE-F is non-comminuted branches and tops. The ash content is ≤ 3 percent and moisture content over 45 percent.

Future work

Continued work on developing cross-sector definitions of forest fuel to enable implementation, based on the proposals developed in dialogue with market players.

If these detailed product descriptions are implemented throughout the business chain, the sector will benefit in a number of ways:

- The heating plant can place a more precise order, and a fuel is delivered that is appropriate for their specific boiler.
- The supplier knows in detail what the customer wants, and can plan activities accordingly.
- Both customer and supplier can obtain a faster and more precise forecast, and feedback on deliveries, via the ordinary timber management system.
- For many years, buyers of pulpwood have often sold and bought wood to minimise transport costs. So far, this bartering system has rarely been used for forest fuel, partly because forest fuel is a heterogeneous raw material that has been difficult to describe. In a working transport-saving bartering system, it is imperative that the parties know what they have and what they will get. The proposed product descriptions would make this possible.

PHOTO: MATS NYLINDER/ SLU

ROUNDWOOD MEASUREMENT

Mats Nylinder & Hans Fryk, SLU
Lars Fridh, Skogforsk

The economic value of forest fuel is strongly linked to the moisture content of the wood. Consequently, interest is growing in a measurement method for energy wood based on weighing the wood and determining moisture content. The trading unit can then be either dry weight or energy content (MWh), but conversion factors also allow calculation of biomass in m³ of chips.

The large variation in moisture content within a log and between logs suggests that the focus of development should not be on methods that are accurate and precise for an individual sample, but on finding a method that is robust for a stack or a delivery consignment. In a pilot project, such a method was tested. A sample-collection pocket was connected to a standard chain saw, and a number of cuts were sawn in a stack to produce sawdust whose moisture content could be determined.

In order to evaluate the accuracy of the method, a pilot study was carried out using wood from pine, spruce, birch and oak, and rot-damaged spruce, with various dimensions and degrees of freshness. Half-cuts were made in the logs, whole cuts, and cuts in intermediate discs. Only for fresh oak and stored small-dimension oak did the type of cut give different moisture contents, while no significant difference could be proved for any of the other materials tested.

The method was then tested in a larger study at ENA Energi AB in Enköping. The fieldwork was carried out in October and December 2011 and in February 2012. On each occasion, samples were taken from a total of nine stacks, of which three had a high proportion of coniferous trees, two were of mixed coniferous/deciduous trees, one stack comprised only deciduous trees, and three samples comprised stored wood from a terminal. The moisture content of the energy wood was determined using four different methods (Table 1).

The difference between the arithmetic means produced by the different methods was small. If it is assumed that Method C, based on ten samples of chips, is the reference result, then Method A (four sawdust samples per stack) and Method D (one chips sample per stack in accordance with VMF) gave approximately the same deviation from the reference result, while Method B (only one sawdust sample) was much more unreliable. For a homogeneous sample of, for example, chips, a standard deviation of 1-3 percentage points could be assumed, and for sawdust extracted with a chain saw, 3-5 percentage points.

The conclusion is that the concept of extracting samples with a chain saw could be improved and that sampling of one sample per stack would not be sufficient. For large scale applications the sampling process should be automated.

Method of measuring moisture content	Time of sampling	Moisture content (%)
A. Sawdust sample with motor saw, four cuts per stack	Before chipping	43.7
B. Sawdust sample with motor saw, only one cut at the top of each stack	Before chipping	44.0
C. Chips from ten sampling points immediately after chipping	After chipping	42.9
D. Chips from one sample taken from the upper part of each container according to VMF procedures	After chipping	41.9

Batch measurement of energy wood at terminals

The new Swedish Timber Measurement Act came into effect in 2015, and applies to all assortments in the first level of the trading chain. Significant volumes of energy wood are transported from felling sites to terminals, where the timber measurement association cannot always be present. Instead, one of the parties involved must measure the timber.

A study was carried out to examine whether stack measurement of energy wood on the truck carried out by drivers at a terminal can comply with statutory requirement. Eleven drivers and six VMF measurement officials each carried out 24 stack measurements, half from a measurement bridge and half from the ground.

As a group, the drivers on average measured the volumes well, with a deviation of only 1-2 percentage points from the log-by-log-measured volume. There was no significant difference between measurements taken from the bridge and the ground, but there was a large individual variation between the drivers, up to ±7 percentage points. On average, the results of the VMF measurement officials showed a greater systematic deviation: -5.1 percentage points compared with the drivers' -0.9 percentage points. However, systematic errors can be corrected with a collective conversion, using samples that are measured log-by-log.

If these results are representative, this means that a large buyer and a large supplier over time enjoy correct measurements when carried out by drivers. However, the delivery consignment of an individual supplier may be over- or underestimated depending on which driver measures the timber.

Driver measurements of volume showed a standard deviation of 8.0 percentage points when measuring from the ground, so within the control group approximately 70 stacks would be needed to obtain an average error of 1 percent. If a control group comprised a large area of operations involving large number of drivers, then 70 stacks would not be sufficient for individual drivers to calibrate their measurements. The measuring company responsible must then continually carry out checks of knowledge and skills, and conduct follow-ups to assure the quality of measurement of individual drivers and to enable them to calibrate their measurements.

For the factor 'solid volume percentage', the standard deviation was 3.5 percentage points, indicating that this factor is harder to measure than the other units. In this case, ten parameters would be given, where each parameter could assume four to seven values. A proposal to facilitate assessment of solid volume percentage was developed in the project, where the measuring official only needs to assess height, width, length and mean diameter, proportion of hardwood and stack properties. However, the proposal has not yet been tested.

Even height and average log length proved difficult to measure. What was clear was that better measuring tools are needed to improve the accuracy of stack measurement. A measuring stick is available on the market that has been developed to measure load heights on vehicles, and we have used this as a basis for a prototype of a new measuring stick, specially designed for measuring stacks.

Future work

Develop and validate measurement and control functions for batch measurements of energy wood (roundwood).

- Ensure systematic control by calculating and investigating measurement technology and economic consequences of how the control group must be designed to comply with the requirements in the Timber Measurement Act at the lowest possible cost.
- Develop and validate models for simplified assessment of solid volume percentage.

Sawdust samples, taken using a chain saw, for use in determining moisture content.

PHOTO: MATS NYLINDER/ SLU

PHOTO: MATS NYLINDER/ SLU

WEIGHING ENERGY WOOD

Mats Nylinder & Hans Fryk, SLU,
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Partly delimbed energy wood is difficult to measure in the same way as pulpwood, i.e. with stack measurement and assessment of solid volume percentage. The main reason is that it is difficult to assess the solid volume percentage because the logs are thinner and the number of branches vary.

Measurement of partly delimbed energy wood

In order to compare various measurement methods for this energy assortment, a study was carried out at the Stora Enso timber terminal in Stockaryd, in collaboration with Stora Enso Bioenergi, Sydved and VMF South.

The primary aim of the study was to evaluate the model used by Stora Enso to estimate volume by weighing in combination with historical data regarding variations in raw density throughout the year. In order to identify any seasonal variations, the study was divided into three periods: winter, spring/summer, and autumn. On each occasion, ten stacks were randomly selected, giving a total of 30 stacks.

The study examined five ways of measuring stack volume.

1. Stora Enso's model.
2. Top-butt measurement under bark, in accordance with VMF procedures.
3. Weighing of stacks combined with measurement of raw density of cut discs, to obtain volume over bark including tops and branches.
4. Stack measurement and assessment of solid volume percentage under bark (same procedure as for pulpwood).

As a reference volume, the chipped volume of each stack was measured, with an assumed solid volume percentage of 42 percent. From the volume figure, the energy content of each stack was calculated.

The basic density averaged 444 kg/m³ with the stack variation between 405 and 532 kg/m³. The raw density of the timber, including bark, averaged 799 kg/m³ with an average variation between stacks of 84 kg. Only marginal differences could be observed between the seasons. The model developed by Stora Enso is based on the raw density of pulpwood, i.e. the weight including bark in relation to volume under bark, and this varies from 978 to 1098 kg/m³.

The stemwood proportion under bark was 74.3 percent. The proportion of bark, branches and tops averaged 25.7 percent for all stacks, ranging from 10 to 40 percent, and the standard deviation between stacks was 7.0 percentage points.

Stora Enso's model (Method 1) gave largely the same total volume as VMF's calculation, which only applies to stemwood under bark (Method 2). Consequently, tops with diameters of less than 1 cm and branches were not captured by Stora Enso's model. This is probably because the model is based on wood with a higher moisture content than the wood used in this study. Moisture content of small-dimension pulpwood normally normally exceeds 50 percent, while in our study the moisture content was approximately 44 percent. Compared with the total volume per stack, Stora Enso's model underestimated by approximately 25 percent.

The standard deviation of the ratio between measured and reference values (ratio range) was approximately 10 percent for Stora Enso's model for estimating volume, which can be compared with current measurement of pulpwood, where the ratio range is 3 to 5 percent.

One conclusion from the study is that Stora Enso's model gives a better estimate of energy content than raw weighing. A calculation of dry matter based on moisture content and weight of the chips gave by far the best estimate of the energy content of the stacks. However, in practice, it would be costly to extract the approximately ten samples of chips per load needed to obtain a sufficiently accurate moisture content figure. Stora Enso's model is cost-effective – precision and accuracy must be weighed against cost of measurement. If a cost-effective way of determining moisture content could be developed, this would be preferable to Stora Enso's model.

Evaluation of crane-mounted weighing systems

The possibility of weighing various timber assortments and measuring moisture content to determine the volume or energy content is becoming increasingly interesting, not least in view of the new Timber Measurement Act. One possible solution is to mount a scale on the forwarder crane. Today, there are two main technical solutions for crane-mounted scales, hydraulic weighing links and strain gauges. An experiment examined measurement accuracy and ease-of-use of five different weighing systems, three with hydraulic weighing links and two with strain gauges in the weighing link.

The control weighing procedures were divided into:

1) weighing during a load movement with a known weight, and
2) weighing during unloading and loading of pulpwood assortments.

Control weighing with known weights.

In terms of mean deviation, most of the systems gave very good measurement results, indicating that their calibration and calculation functions compensated for any major fluctuations in individual weight recordings.

The systems with hydraulic weighing links all showed greater ranges and standard deviations than the systems using strain gauges. They also tended to be affected more when the weighing link was subjected to rotational forces and unbalanced loading.

The systems with strain gauges showed a low standard deviation when there was a full load in the grapple. This indicates a smaller range of weight recordings per crane cycle, which in itself indicates a more stable weighing system.

In practical operation, a crane scale should be able to weigh dynamically and automatically, i.e. during movement and without the operator needing to record the measurement. In other cases, the performance is affected too much in forwarding. It must be remembered that weighing with a crane scale requires training, and necessitates a controlled and stable crane movement during the actual measurement process. The accuracy of the weighing links varied in sensitivity, depending on operator skills. The strain gauges were less sensitive to operator skills and how the weighing system was used.

Measurement accuracy at load level is the most interesting aspect in practical use. It is important to develop a control and calibration procedure that simulates the loading movement, rather than one that involves comparison with known weights in a static position. How the operator moves the crane during the work is of great significance to measurement accuracy.

Future work

Further work is needed to identify, evaluate and assure systematic control to enable implementation of weighing in the material flow from forest to industry gate with:

- Static and dynamic vehicle scales
- Scales connected to load carriers on trucks and forwarders
- Crane-mounted scales on trucks and forwarders

Fuel characteristics

MEASUREMENT OF COMMINUTED MATERIAL

Mats Nylinder & Hans Fryk, SLU

When trading chips from logging residue in final felling, buyer and seller must agree on the measurement unit is to be applied, and how the material is to be measured – volume, weight or energy content.

PHOTO: MATS NYLINDER/SLU

There are currently two main units used when trading residue chips:

- Volume: The chips are measured in m³ when the consignment arrives at the delivery point. Any conversion of volume to energy content is carried out using historical data, MWh per m³ of chips.
- Dry weight: The chips are weighed and the moisture content is determined on the basis of chip samples. This produces the dry weight and energy content.

A study was carried out by the Swedish University of Agricultural Sciences (SLU), Linnaeus University, VMF South, Växjö Energi AB and Södra to investigate the advantages and disadvantages of various measurement methods for residue chips.

The study involved 44 loads of residue chips, mainly from coniferous trees under winter and summer conditions. The chips were transported to the heating plant in a truck and trailer combination with a load of three chip containers. The volume and the weight of the chips in each container was recorded. In order to obtain a reference value for the moisture content, ten samples of chips per container were taken, so 30 samples per load.

Results of volume measurement. The degree of packing of the residue chips, and thereby the solid volume percentage, varied greatly, which affects the precision of a measurement method based on volume. The reason for this variation can be the proportion of branches, the relative proportions of coniferous and deciduous trees, freshness, whether residue is chipped dried (without needles or leaves) or fresh (includes needles and leaves), and the way the chips are loaded.

A study comparing different measurement methods for residue chips showed that the average solid volume proportion in 30 loads of chips was 42.6 percent, but varied from 38 to 50 percent. The large variation in solid volume percentage means that the chip volume per load expressed in m3 could vary by up to 20 percent, and so affect the price by the same amount. Changes to the load during transport also play a role; the greatest compaction occurs during the first few kilometres of transport, after which there is little further change.

Loose volume (m^3) of chips measured on the trucks at transport distances of 5 and 10 km, and on arrival at the industry gate. Most of the compaction occurs during the first 5 km of transport, after which little further compaction occurs.

Results of weighing and dry content determination. The average moisture content of residue chips in the entire study was 35.2 percent on the basis of ten samples per load (reference value), and 34.9 percent when only one sample was taken per load (an aggregate sample where one-third was taken from each container). The latter is the method applied by VMF South.

The effective heating value varied between 2.86 and 3.22 MWh per tonne and between 0.97 and 1.01 MWh per m^3 of chips.

Conclusion. Weighing with moisture content determination was the best measurement method. The standard deviation of the ratio between measured and reference values (ratio range) was 6.4 percent – the lower this figure the greater the precision. Other methods, based on m^3 of chips or tonne, performed consistently worse. However, extracting samples to measure moisture content is more expensive than simply measuring volume or weight.

MEASURING MOISTURE CONTENT

Lars Fridh, Skogforsk

Moisture content (M) is one of the most important quality parameters for wood chips because it affects the energy content. The oven-drying method is currently the standard method for determining moisture content. A sample of chips is dried in an oven until a constant weight is obtained. A disadvantage of this method is that the measurement takes at least 24 hours, which is a problem for many heating plants. The chips may have been incinerated long before the measurement results are known, thereby increasing the risk of inefficient incineration. At small terminals the oven-drying method is often either too slow and/or cumbersome to use, and the same applies if knowledge of the moisture content is desirable before delivery to the customer. Faster methods are needed.

Portable moisture content meters

Three portable moisture content meters have been evaluated. One is based on electrical resistance, and the other two are based on electrical capacitance. All three meters were able to measure moisture content of chips, on condition that the material was not frozen. However, none of the meters managed to measure correctly on all types of material and in all moisture content intervals.

The resistance meter, Humimeter BLL, showed good measurement accuracy up to a moisture content of approximately 30 percent. Above that figure, the deviations became large to very large. In theory, a resistance meter should show decreasing accuracy, as moisture content increases when the moisture content exceeds the fibre saturation point, which occurs at approximately 23 percent M. Our measurements showed good correspondence with these theoretical conditions. A resistance meter is therefore more suitable for drier material than for forest fuel, whose moisture content normally exceeds 30 percent.

Both the capacitance meters, Humimeter BM2 and WILE, measured the moisture content of chips from both logging residue and stemwood with average differences of 1 percentage point and a standard deviation of 2-4 percentage points. However, it was important that the instrument was calibrated for each individual material.

BM2 is heavier to handle, and the measurement procedure more complicated, as a 15-litre sample must first be weighed in the holder to obtain the bulk density. The calibration curve is then chosen depending on the type of material and the weight of the material. The instrument showed the smallest differences between the measured value and the reference method (oven drying). One reason for the higher precision seems to be that the meter compensates for the density of the material.

When measuring with the WILE meter, a probe is inserted into the chips, the meter is switched on, and calibration curve selected; after a few seconds, the moisture content is shown in the display. The instrument is used to carry out several measurements per load, and then the mean value is calculated. The small size, the simple handling procedure, and the relatively high level of precision (assuming correct calibration) makes the WILE meter a suitable instrument for monitoring production, where the aim is to quickly and simply obtain an estimate of the moisture content in a load.

Stationary moisture content meters

The *Metso MR Moisture Analyzer* uses magnetic resonance, and measures the moisture content of a sample in two minutes. The average difference compared to the reference


Preparation of chip samples for test measurements using a stationary moisture content meter.

method was 0.2 percentage points and the standard deviation 1.5 percentage points. This gave a 95% confidence interval within ±2.5 percentage points, which indicates that the machine is very accurate. The precision was so high that the variation in the reference method (oven drying) could affect the comparisons just as much as the variation between repeated measurements using the Metso device.

The device is calibrated using tap water as a reference, and can measure all types of material, such as bark, sawdust, pulp, and residue chips, without material-specific calibration. One limitation is that the technology does not allow measurement of frozen material, and another is that the meter uses standardised containers of 0.8 litres, which limits the length of chips that can be measured. The small sample size necessitates careful sampling and a sufficient number of samples to ensure that the results are representative.

The Prediktor Spektron Biomass uses near-infrared spectral analysis (NIR), and measures the moisture content of a 5-litre sample in 30 seconds. The instrument can measure both frozen and unfrozen material, but it must be calibrated for each individual material and state. In our experiments, the instrument showed good precision and accuracy for both frozen and unfrozen material. The average difference compared to the reference method for unfrozen material was 0.3-0.8 percentage points, with a standard deviation of 2.2-2.5 percentage points. For frozen material, the difference was 1-2 percentage points, with a standard deviation of 1.8-2.2 percentage points.

In every measurement, a NIR spectrum is created, and this is then compared with the spectra in a reference database. If a measured spectrum deviates too much from the spectra in the database, the moisture content must be determined using the oven-drying method, after which the spectrum can be added to the database. At delivery points where the chipped material, moisture content, and state (frozen or unfrozen) vary greatly, many reference measurements through oven drying are required initially.

New technical developments

Earlier studies of the Mantex Desktop Scanner have shown that the X-ray technology, DXA (Dual Energy X-ray Absorptimetry), can measure moisture content accurately on pure organic material with small variations in the material composition, such as stemwood chips. However, the measurements are not sufficiently accurate for heterogeneous material with great variations in ash content, such as chips from logging residue. Combining the DXA technology with another sensor that uses a different X-ray measurement technology, XRF (X-ray fluorescence), which determines the ash content, would considerably improve the accuracy of moisture content measurement.

The technique of combining DXA with XRF had not been used previously, so it was a pioneering development when Mantex modified a Desktop Scanner to work with both sensors in an ESS project. Our validation experiments showed that ash content could be measured accurately. The moisture content measurements showed deviations of approximately two percentage points, but with high standard deviations.

One unexpected finding was that estimation of the energy content of the chips, which is a product of the moisture and ash contents, was very good. If the results are correct, the energy content would be provided in two minutes. The technique looks promising, but a great deal of further development work is necessary before a finished product can reach the market.

GOOD PLANNING – THE KEY TO SUCCESS

Mia Iwarsson Wide, Skogforsk

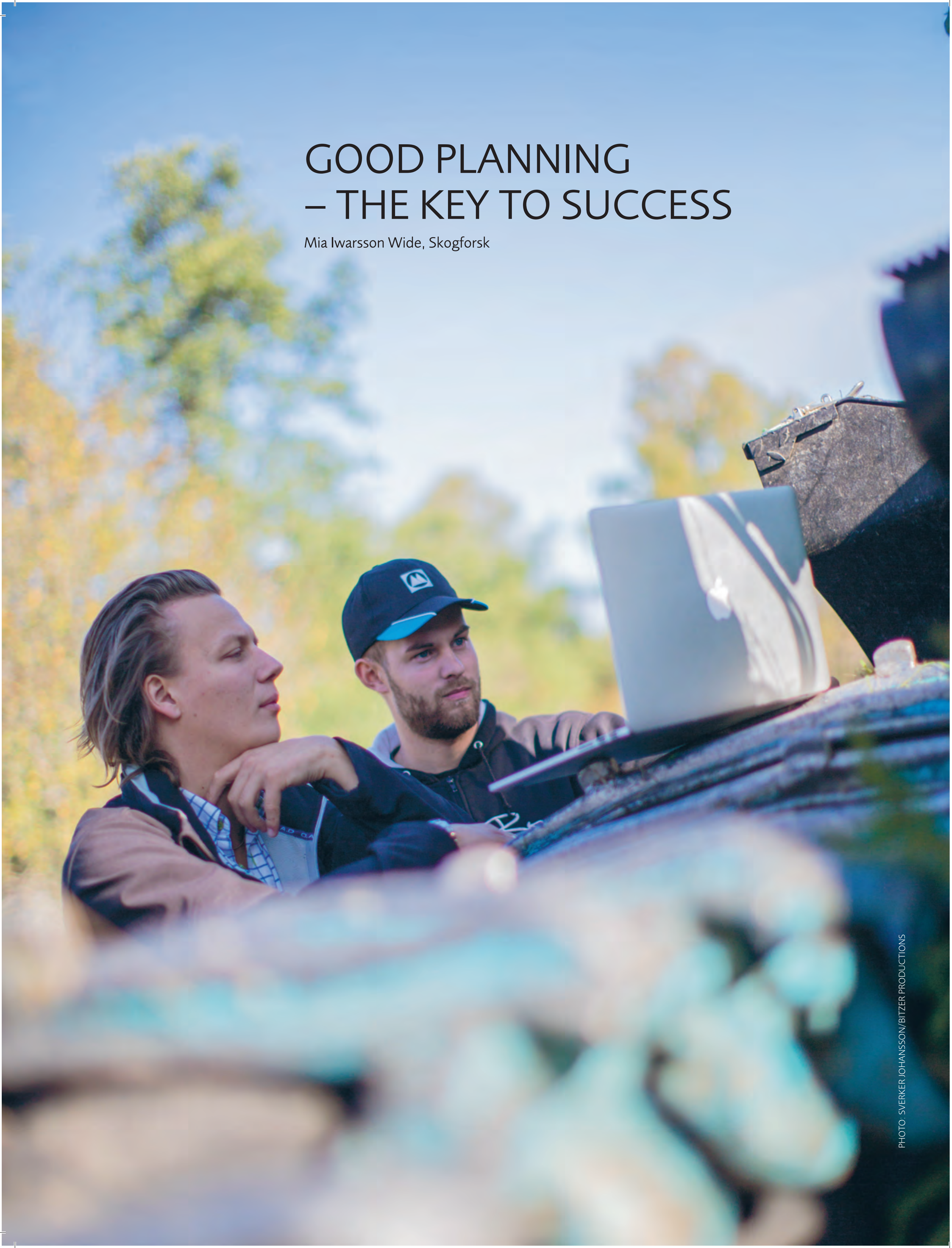


PHOTO: SVERKER JOHANSSON/BITZER PRODUCTIONS

For a successful outcome, in the form of high fuel quality and profitability, detailed and cohesive planning is needed. It is important that all players are aware of how their work affects both the next link in the chain and the end result, and who the customer is.

In order to learn, develop methods, and understand how everything is related, follow-up and feedback procedures must be improved. Simple and reliable systems are needed that relate to customer requirements and that are based on measurement data collected during harvest and handling, historical data, and forecasts.

Unlike roundwood, forest fuel can vary greatly in form and quality. In addition, the forest fuel market is characterised by an imbalance between supply and demand over the year, so biomass must be stored. Carefully planned storage can raise the quality of the fuel, and forest fuel can be stored and comminuted at a landing, a terminal or at the heating plant.

In order to deliver fuel of the right quality and quantity at a competitive price at the agreed time, storage points, comminution technology and transport systems must be carefully planned. All stages, from the planning of felling, harvest, storage, comminution to transport, must be carefully considered, to ensure that delivery specifications are fulfilled and that the entire process is cost-effective.

Planning is also made difficult by the long lead times in combination with uncertain market conditions at the time of the planned delivery. It is difficult for suppliers to adjust volumes retroactively in the event of reduced demand for wood chips, as much of the biomass is already in storage, and it is also difficult to increase delivery capacity without a relatively long period of forward planning.

Simulations – see the whole picture

To optimise management, the entire handling chain must be overviewed. Simulations allow analysis and comparison of different systems, both those in use today and ones that could be used in the future. Simulations can also show what happens if one factor changes, if a machine is replaced, or if the system is transferred to another situation with different conditions.

Simulations of stump supply systems showed that the cost of the best and worst logistical options may differ by a factor of two. Hot systems are sensitive to disturbances, and it can be hard to utilise the full machine capacity of both grinders and trucks in a system. The key to a cost-effective system is to minimise the cost of unutilised machine capacity through carefully considered resource planning in terms of transport distance for the trucks and production capacity of the grinder. Using a less hot system can often be positive, irrespective of transport distance and the number of stumps on the site. For short distances, transport of non-comminuted stumps/stump parts and grinding at the industry is a competitive alternative. The simulations also showed that one key to a cost-effective system is that the machines can work with high productivity and a high level of utilisation.

Simulations of logging residue supply systems are currently being carried out, with the aim of increasing understanding of how the individual processes in the delivery chain affect each other and the supply system as a whole, and how these processes interact with external factors. Important questions include examining how quality and value are affected by 1) whether the material is stored as logging residue or residue chips, 2) the weather during the period of storage, and 3) where the material is stored. The model will also show how these choices affect the costs of comminution and transport.

Another simulation showed that harvest of forest fuel in thinning of small trees could be made considerably more efficient by using new harvesting methods, such as boom-corridor thinning and bundle harvesters. The biggest effects were found in stands where the average volume of the whole tree (including branches and tops) was 0.025 m^3. A system where harvested tree parts were bundled and transported on designated vehicles showed a cost reduction of six percent compared with today's system of harvesting tree parts without bundling.

Reduced ground damage and more efficient forwarding

Harvest of forest fuel must not cause damage to the ground or water. In view of today's often wet autumns and mild winters, good planning and careful selection of forest stands for fuel harvest are needed. Studies of ground damage caused by forest machines have previously shown high frequencies of unacceptable damage. The aim of the STIG project was to develop better maps, combined with more detailed procedures to avoid carrying out forest operations on sensitive ground.

The groundwater model was a key focus in this work. This model calculates which areas have water close to the surface and where the bearing capacity can therefore be assumed to be poor. The calculations are based on data from airborne laser scanning concerning height above sea level, slope, and aspect. An evaluation showed that approximately 70 percent of ground damage occurred in areas classed as wet or waterlogged in the groundwater model.

The groundwater model gives the logging planner and the machine operators a good idea of the ground conditions in the area, and logging can be planned in such a way that machine activity is concentrated to the areas with the greatest bearing capacity.

The decision-support system, BesT Way, combines the above information with a laser scan that describes the forest. The planner decides the location of landings, and BesT Way then calculates the most efficient placement of base roads. No base roads are located in areas marked as wet, but the planning program can suggest suitable sites for crossings of these areas. It also facilitates testing of various base road alternatives with regard to transported volumes and time and costs for forwarding operations.

Harvester data provides valuable information

The harvester continually collects data about felled trees. This harvester data can be used to assess whether and, if so, where on the clear-cut stumps can be harvested, and the volume this can generate.

Since 2012, harvester data has been used to estimate and report the production of logging residue and stump quantities. The calculation module is part of the data standard StanForD 2010. The distribution of forest fuel on a clear-cut can also be visualised through a map layer that can be read in GIS programs in the forwarder that extracts the material.

Stump volumes – potential and actual harvests

With the aim of evaluating existing biomass functions for stumps, calculated and measured quantities were compared. Calculated figures were generated from harvester data, and material lost between the stump and the landing was also quantified. Earlier studies have indicated that the biomass functions produced by Marklund in the 1980s underestimate the actual stump biomass. In the pilot study, actual outcome on some plots was more than 50 percent greater than predicted. The study must be expanded to more locations throughout Sweden with different ground conditions before generally applicable conclusions can be drawn.

The study also examined the scale of wasted biomass in forwarding and grinding of stumps, and the proportion of stumps that were not harvested. The study shows that approximately 5 percent of the material is lost during handling, and that another 10 percent is left in the ground. The stumps are either smaller than the prevailing limit for removal, left for conservation reasons, or quite simply missed by the stump harvester.

Laser scanning to identify suitable stands

Forest-related variables were calculated using data from airborne laser scanning of a large number of experimental plots in unthinned young forest and on roadsides. The results were then compared with field measurements. Clear correlations were apparent for tree height and height distribution, but also for stand density. One conclusion was that laser data can be used to identify areas, or parts of areas, where it would be profitable to harvest forest fuel.

Predicting forest fuel value

In order to plan and manage the supply chains, and to ensure that the customer gets the assortment ordered, accurate inventories of the produced fuels and predictions of future production are needed.

The moisture content of forest fuel is important, because it is one of the most important factors affecting the net calorific energy content. The drying process is complex, and different heating plants have different requirements regarding moisture content. By studying the weight and moisture content of logging residue during storage, and comparing it with weather data for the storage site, functions have been developed to predict moisture content. The aim is to be able to predict the moisture content in a stack of logging residues on the basis of time of storage, storage site, and weather data during the storage. A prediction tool can then be integrated in systems for storage management and trading of forest fuel, which will enable suppliers to predict the moisture content in individual consignments. The work is being carried out in collaboration with the sector and SDC.

The study showed that the gross weight of covered residue stacks and smaller residue piles, resembling those stored on the clear-cut, changed considerably during storage and after rain. The fluctuations were greater in the small residue piles than in the covered stacks. The conclusion is that the degree of remoistening through precipitation is determined by the total volume of the residue stack in relation to its surface area exposed to rain.


Moisture content in the chips is considerably reduced if snow and ice can be removed from the material prior to chipping.

Forest fuel management – trends over five years

For benchmarking purposes, it is important to be aware of trends. Costs and methods in forest fuel supply in Sweden have been followed up over a period of four years. After a peak in 2011, remuneration to forest owners decreased somewhat, largely because the market prices for forest fuels on delivery to the heating plant fell. The proportion of logging residue increased at the expense of defect roundwood up until 2013, after which the assortments returned to the original distribution. The average cost as delivered to the end customer was SEK 175/m3 of chips. Chippers are the most common machines for comminution on the landing and at small terminals, and are increasing their share of the comminution work at the expense of grinders.

Training

Since 2007, Skogforsk has been arranging training courses for forestry professionals and machine operators who work with forest fuel production. Recent courses have also been aimed at buyers of forest fuel at the heating plants. Interview-based surveys have shown that good results are attained in the district or areas that have the most dedicated and interested players in the production chain. Commitment, smooth procedures for internal communication, and feedback are the most crucial factors for production and delivery of high quality fuels.

In view of the personnel turnover in the forestry sector, skills and commitment must always be kept at a high level. It is important to be able to evaluate results from the deliveries received over a period. MORRIS is a tool that shows diagrams of delivery data for certain time periods or specific recipients. If there are major variations in, for example, moisture content, an analysis is needed to examine the causes of the variations, because they have a negative effect on both fuel characteristics and value.

Correct location, careful stacking, and effective covering of the forest fuel stacks are vital for good quality. A decision-support tool has been produced in the form of a simple spreadsheet for comparing various stack locations in terms of forwarding distance, drying conditions, fuel value, and comminution. This decision-support tool has great potential for further development; for example, it could be combined with the prediction functions produced for estimating moisture content in the stack using weather data.


Cranab

SEE THE WHOLE PICTURE

– ANALYSIS OF SUPPLY SYSTEMS

Anders Eriksson & Dan Bergström, SLU

In forestry, machines and systems are constantly under development to increase cost-effectiveness. This work takes place in collaboration with innovators, manufacturers and academia. Theoretical analyses are a more time- and cost-effective way to evaluate new ideas and concepts than building prototypes for testing in the field or conducting time studies of entire machine systems in full scale. Simulations allow analysis and comparison of different systems, both conventional and hypothetical, under the same conditions. Simulations can also show the effects if one factor changes, such as replacement of a machine, or if the system is used in a new setting under different operational conditions.

Stumps

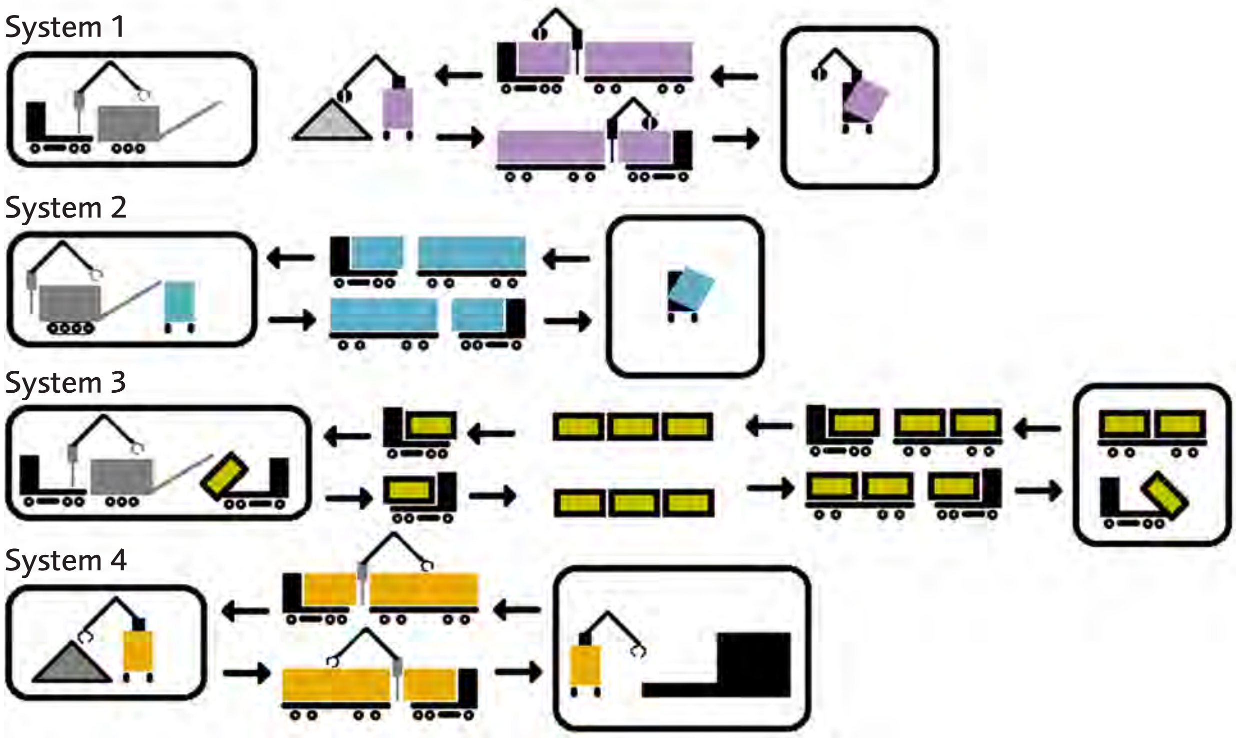
Four supply systems for stump wood were simulated from forest landing to heating plant.

1) Grinding at the landing and self-loading chip truck.
2) Grinding at the landing and direct loading into a waiting chip truck.
3) Grinding at the landing and direct loading into a waiting load-switching truck with containers.
4) Transport of whole stump wood and grinding at the customer's facility.

Systems 1 and 4 are cold, while 2 and 3 are hot, because grinding and trucks are dependent on each other.

The analysis showed that:

- The hot systems are sensitive to unforeseen events. In order to be competitive, the number of trucks must constantly be balanced against the capacity of the grinder and the transport distance in question. Costs of an unbalanced system may be double those of a system in balance. If there are too few trucks, the grinder, which is the most expensive component in the system, must stand idle. If there are too many trucks, they must wait instead.
- Comminution at the landing and transport with self-loading trucks (system 1) is cost-effective, regardless of transport distance and the amount of stump biomass on the landing.
- For short distances, transport of whole stump wood and grinding at the customer's facility is a competitive alternative.



Schematic sketch showing the simulated systems for transport and comminution of stumps from landing to end customer.

The project also examined how 15 different factors affect the cost per delivered MWh for the entire chain, from stump removal to fuel delivery. These factors included fuel quality, biomass losses, machine productivity, machine specification, transport distance, and stump quantity per site. For each factor, a base value was defined, based on earlier studies and previous data, and a 'reasonable' low and high value. Two systems were studied, one with comminution before transport and one after.

Some results from the simulation:

- The base value gave a cost of approximately SEK 156/MWh. When all factors were changed to their lowest values, the cost fell to SEK 97/MWh, and when all factors were set to their highest values, the cost increased to SEK 278/MWh, regardless of system.
- Loss of biomass through, for example, waste, had a greater negative effect the later in the delivery chain it occurred. Missing processed stumpwood at a landing proved, in economic terms, to be nine times worse for the economy in the system than simply leaving the stumps in the ground, assuming the same quantity was lost.
- The cost per delivered MWh could be reduced by 12.5 percent through good storage, which reduced moisture, ash content, and loss of substance.
- Transport distance and stump quantity per site were the two most important factors affecting the system.
- Machine productivity was also important, particularly for the stump harvester and the forwarder. Avoiding sites with poor conditions proved to be important in preventing low productivity of machines.
- In general, sites should be chosen where more than 150 tonnes dry matter of stumps can be harvested, and that are located close to the customer.
- Comminution at the landing is preferable to comminution at the customer's facility if the transport distance is between 30 and 70 km, depending on stump quantity per site.

One conclusion is that stumps can be harvested with a positive net result, assuming appropriate site and delivery system are chosen.

Systems for tree parts from thinning of small trees

National estimates show there is great potential to harvest biomass from unthinned young forests. These forests often have a great diameter distribution, they give relatively low volumes of pulpwood, but they can generate a lot of biomass if small trees, branches and tops are harvested as forest fuel.

Tree parts placed in a stack for drying.

In a project, 14 systems for harvesting and transporting tree parts from thinnings of stands with small trees were analysed. Nine of these were conventional systems and five were innovative systems that potentially could be used in the future.

The cost and energy efficiency of the systems were analysed using variables like mean stem volume, type of assortment, forwarding distance and road transport distance. The effect of introducing load compression of unprocessed tree parts on forest and road transport was also analysed.

The analyses showed that a possible supply system based on boom-corridor thinning and direct bundling in the field can reduce costs by 12 percent and energy use by 32 percent compared with systems currently in use. The effects were greater when mean stem volume was smaller and transport distance greater. This system was suitable for stands with a mean stem volume of less than 0.030 m³.
Another system, involving a bundling harvester, boom-corridor thinning and optimised bundling, reduced costs by 15 percent and fuel consumption by 22 percent. This system, which was suitable for stands with a mean stem volume exceeding 0.030 m³, has largely been implemented today by the Finnish company, Fixteri.

Future work

- More system analyses to show possible measures and potentials for reducing the total cost in the supply chains for the various forest fuel assortments.
- Models for stump and logging residue supply, which are still under development, would enable simulation of all activities from forest to heating plant. Simulations based on historical weather data that show how weather affects the customer's fuel needs and the quality of the fuel during storage would enable evaluation of various delivery strategies.
- Future R&D should be aimed at new technologies for felling small trees and examining how these technologies can be integrated with direct bundling. The models developed in the project can be used to carry out further analyses, such as by comparing them with delivery systems

STUMP PREDICTIONS FROM HARVESTER DATA

Maria Nordström, Björn Hannrup, Tomas Johannesson
& Henrik von Hofsten, Skogforsk, Erik Anerud, SLU

Appropriate planning of stump harvest requires prediction tools to assess available and harvested quantities. Biomass functions for estimating stump and root biomass have already been developed in Sweden and Finland. The functions calculate the quantity of biomass for stump cores and, to varying degrees, also for roots, in kg dry weight. For the simpler functions, breast height diameter is sufficient as input variable, so the tree data generated by the harvester can be used.

Previous studies have shown that harvester data can be very useful in generating detailed and precise information about available quantities of logging residue from felling. On the basis of these results, an automated system has been developed that calculates the available quantity of logging residue from felling sites, based on harvester data and existing biomass functions. The calculation system is implemented in SDC's wood management systems and has now been introduced in production reporting of the major forestry companies.

The system is also prepared for handling stump and root biomass in the same way. For this to be meaningful, studies are needed to investigate how well biomass functions for stumps and roots can be used to predict available and harvested quantities, and what adjustments may be needed. In Sweden, smaller follow-up studies have indicated that estimates based on Marklund's biomass functions underestimate the actual quantity of stumps and roots.

The aim of this study was to evaluate existing biomass functions for stumps and roots by comparing calculated and measured quantities of stump harvest. Calculated figures were generated from harvester data. The study also tried to quantify the waste occurring from stump harvesting until the material had been ground on the landing. This was a pilot study with the aim of establishing a work method for a larger-scale study involving nationwide material.

The study was carried out approximately 50 km north of Strömsund, Jämtland, in central Sweden. The experimental area comprised two felling sites on opposite sides of a small road. Both sites were dominated by spruce, with some pine.

The trees on the plots were felled in May 2011 and harvester data (pri-files) about each individual tree was saved for every plot. Timber and logging residues were forwarded immediately after felling. The stumps were lifted in September 2011 using a tracked excavator (Hyundai, 210LC) with a Biorex 30 stump harvest head. The stumps were forwarded to a landing, and then kept separate in marked piles. After a couple of weeks, the stumps were coarsely ground with a slow-speed grinder, Doppstadt Büffel DW-3060. The ground material was fed directly into marked containers without sieving. The chips were weighed in the container, after which the moisture content and ash content of the material were determined, and the raw weight converted to a dry weight.

From this initial pilot study, we can draw three conclusions:

- The existing functions for calculating quantities of biomass in stumps and roots greatly underestimate the quantities actually harvested, on average by 33 percent.
- At least 5 percent of the material was lost as waste during forwarding and grinding.
- Another approximately 10 percent of the material was left unharvested, i.e. in the ground, because the stumps were too small for harvest or because they were missed during extraction.

The experiments must be expanded to equate to nationwide material to establish whether the results from the pilot study can be regarded as being generally applicable to other sites.

Future work

Issues that could not be tackled within the scope of this study, but which could be investigated, are:

- How is the harvest affected by the time since felling? The pilot study was carried out on fresh stumps, so further studies of how the harvest level is affected by degradation of the stump are needed. A reasonable range would be 0 to 1.5 years.
- How is the harvest affected by the soil?

Stack of stumps at the roadside.

FOREST FUEL

– TRENDS OVER 5 YEARS

Torbjörn Brunberg, Skogforsk

For benchmarking purposes, it is important to be aware of current trends. In 2010, the ESS programme initiated a project in which annual surveys are used to map assortment distribution, costs and methods used in production of primary forest fuel in Sweden. Respondents in the latest survey are mainly the same high-volume suppliers as in previous surveys. Costs to the roadside and to the end customer delivery point are therefore thought to be comparable between the years, but the different cost items to the roadside vary somewhat, along with other activities between roadside and end customer.

Since 2009, the cost of forest fuel has fluctuated (Figure 1). After a peak in 2011, the cost has fallen somewhat, largely because of lower payments to the forest owner.

The proportion of logging residue increased at the expense of energy wood from 2009 until 2013, after which the relative proportions returned to the former level (Table 1).

Table 2 shows the distribution of costs in 2013 across various cost items. The weighted average supply cost to the end customer was SEK 175/m3 of chips.

Generally, wood chip deliveries have increased at the expense of bundles and loose logging residue (Table 3). However, due to investments in centralised large-scale comminution equipment, the proportion of loose logging residue has risen in certain locations, such as around Örebro. If comminution on the landing and at small terminals is considered, the proportion of grinding has fallen in recent years, but grinding still takes place on the wood yards of combined heat and power (CHP) plants and at larger terminals.

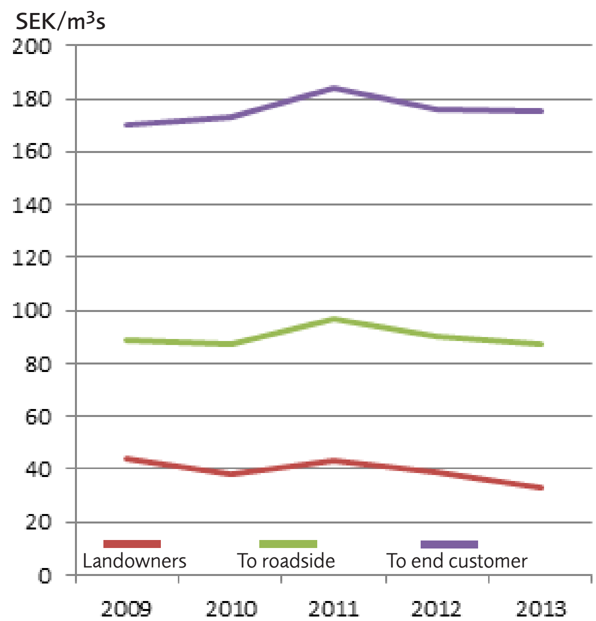


Figure 1. Forest fuel costs, 2009-2013.

Table 1. Reported costs (SEK/m3) of chips for different assortments in 2013, divided into cost items. Note that payment to the landowner is shown as a cost.

	Logging residue from final felling	Small trees from thinning	Energy wood	Stumps from final felling
Payment to landowner	31	8	48	1
Felling/Extraction	0	43	0	52
Forest transport	37	29	18	32
Overheads	8	9	7	6
Cost to roadside 2013	76	89	103	91
Cost to roadside 2012	76	92	117	87
Comminution	48	41	18	49
Terminal costs	3	2	10	6
Road transport	41	41	27	42
Administration	10	9	8	9
Total cost to end customer 2013	178	182	166	197
Total cost to end customer 2012	172	180	181	193

Table 2. Distribution by method (%) per year.

Logging residue

	Bundles	Whole tree residue	Wood chips
2009	4	13	83
2010	1	11	88
2011	0	10	90
2012	0	10	90
2013	0	9	91

Comminution method

	Chipping	Grinding	Other
2009	89	11	0
2010	91	9	0
2011	91	9	0
2012	93	7	0
2013	96	4	0

Small trees

	Harv.head	Shear	Other
2009	46	46	8
2010	59	35	6
2011	74	19	7
2012	73	27	0
2013	82	10	8

Base machine used for the chipper

	Truck	Forwarder	Other
2009	14	83	3
2010	33	65	2
2011	40	58	2
2012	40	60	0
2013	37	59	4

Road transport

	Truck	Railway	Other
2009	84	5	11
2010	88	8	4
2011	95	3	2
2012	96	4	0
2013	96	4	0

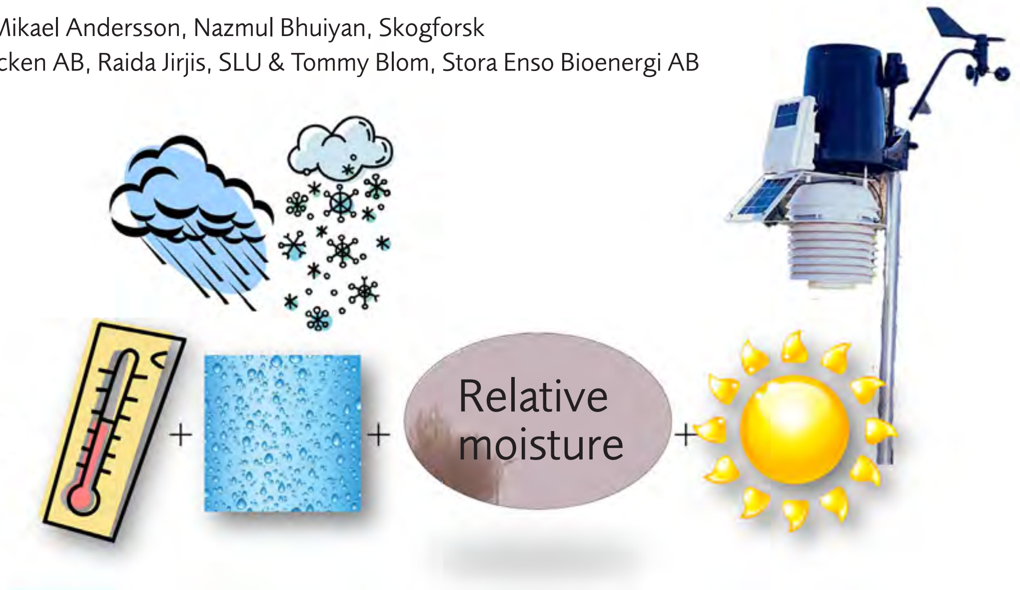
Chipper trucks, i.e. trucks with a chipping unit and a chip bin, have become more common. They are often a cost-effective alternative, particularly on smaller sites and where transport distances are short.

When utilisation of energy from small trees began, shear-type felling heads were commonly used. However, because of the flexibility and higher productivity of harvester heads, particularly in taller forest, this technology rapidly became the most commonly used. Today, felling heads are only used locally and mainly on smaller sites, e.g. in felling of unwanted undergrowth in pastures or trees growing on roadsides.

The amount of long-distance transport of forest chips has decreased, due to the declining demand and price levels for forest fuel in central Sweden. This is mainly because of an increasing proportion of imported fuels, such as waste and chips from recycled wood, but also because of milder winters in recent years.

USING WEATHER DATA TO PREDICT MOISTURE CONTENT

Lars Wilhelmsson, Mikael Andersson, Nazmul Bhuiyan, Skogforsk
Erik Persson, Askbacken AB, Raida Jirjis, SLU & Tommy Blom, Stora Enso Bioenergi AB



Heating plants want control over the moisture content of forest fuel in order to optimise incineration. Moisture content varies greatly and there are currently no methods that are fast and able to determine moisture content with sufficient accuracy. Heating plants have to rely on the oven method, which is slow and often the result is not obtained until after incineration. One alternative that can facilitate delivery and production planning is to estimate moisture content, using weather data for the time the logging residue is stored in piles on the clear-cut and in stacks at the landing. A prediction tool is therefore needed for estimating moisture content of stored logging residue, to help improve delivery quality to different fuel customers.

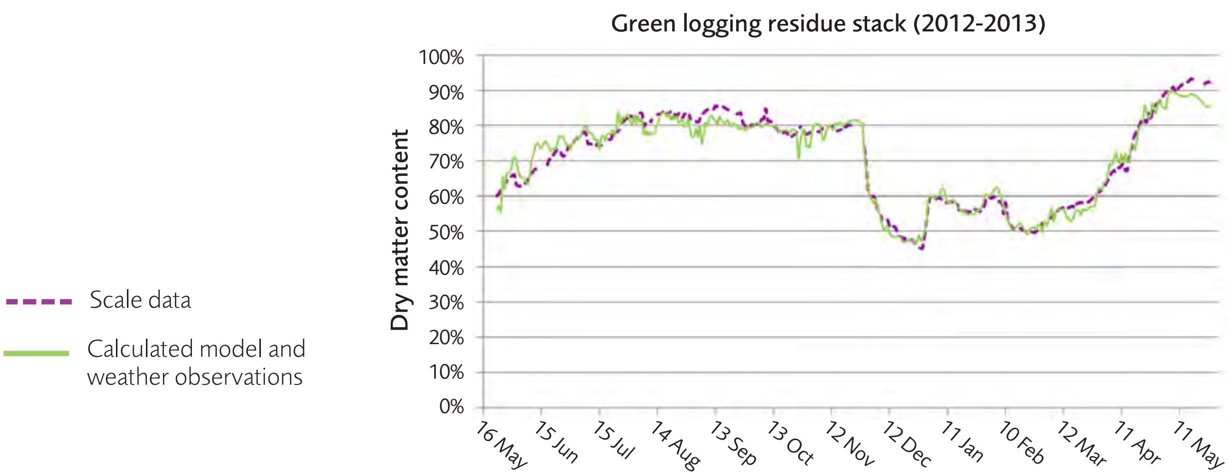
In collaboration with Stora Enso Bioenergi and SLU, Skogforsk carried out an experiment involving continual weighing of stored logging residue in combination with collection of weather data. In May 2012, we placed logging residue from a spruce-dominated final felling stand close to Tierp, in Uppland, on platforms that were placed on electronic scales. The composition of the residue was described using data from the harvester's production files.

Fresh ('green') residues were placed on two small platforms, simulating piles of residue on a clear-cut, and on a large platform, simulating a stack at a landing. At the end of August, the experiment was supplemented with another large platform simulating a stack of summer-stored, dried ('brown') residues that had been forwarded from other residue piles on the clear-cut. The residue was covered immediately after stacking.

The total weight of the residues on each platform was recorded twice per hour. Using the sampled moisture content at the start, and the total weight, the drying and remoistening process could be calculated, along with the quantity of snow accumulated on top of the stacks during the winter period.

In order to link the continual weight changes to the weather, a weather station was set up close to the platforms to record temperature, precipitation (rain and snow), relative humidity, insolation and wind.

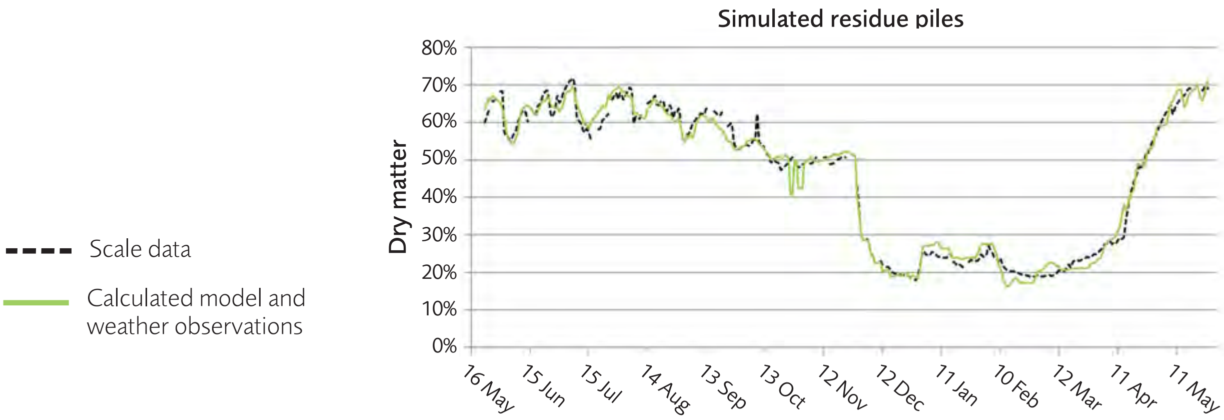
Continual weighing of the residue stacks and piles showed great changes in gross weights, and the changes could largely be explained by weather variables. In periods of rain, the residue piles absorbed considerably more water than the covered stacks. The moisture content in the piles increased by up to 20 percentage points, compared with 5 percentage points for the covered stacks. The difference can



be explained by the covering paper, and also by the residue piles having a considerably greater surface area exposed to the rain in relation to volume, compared with the stacks. Snow gave a maximum weight increase of 75 percent for the stacks and 180 percent for the residue piles.

The weight changes in the two residue stacks were similar but, in particular, the green stack had lost so much weight by the end of the summer that we suspected that some of the weight loss could be due to substance loss. We conducted visual and scent checks of the green residue stack on several occasions in summer 2012, and when the stack was chipped in May 2013, but found no visible signs of microbial growth. Our continual measurement of temperature and air humidity in the stacks did not show any signs of heat development compared with the surrounding air.

When the residue from the stacks was chipped at the end of May 2013, a large number of samples were taken to determine moisture content. Both the green and the brown residue stacks had an average moisture content of 16.5 percent, with a standard deviation within the stacks of only 1.2 percentage points for the green stack and 1.4 for the brown stack. The conclusion is that substance losses were not abnormal, and were at the same level for both green and brown logging residue. Moisture content in the small residue



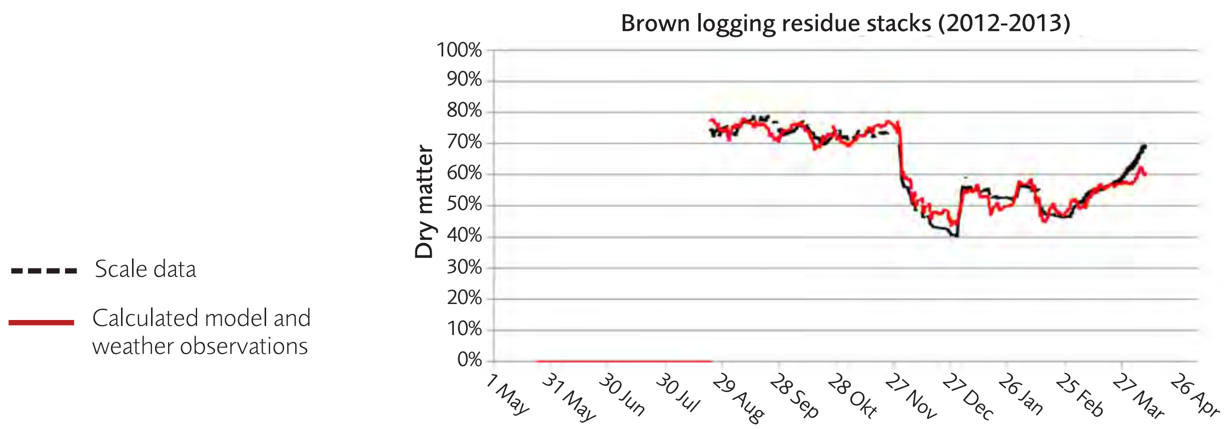
piles was much higher, nearly 40 percent, and with a standard deviation between samples within piles of 5 percentage points.

Using collected data, functions were developed that describe the moisture content of logging residue on the basis of storage time and weather data. After validation, the functions can be incorporated into a planning tool where the user, on the basis of continual weather data from e.g. the Swedish Meteorological and Hydrological Institute (SMHI), can predict the day-by-day moisture content in residues stored in piles on the clear-cut and in stacks at roadside. It will also be possible to forecast future moisture content using weather forecasts or weather scenarios. Such information can be used to plan the supply so that customers get material with the desired moisture content, and to describe the expected moisture content in future deliveries.

Snow is a problem. If a method can be developed to avoid including snow in comminution, the moisture content in the logging residue will be considerably lower. The Finnish research institute, VTT, has successfully tested using rotating brushes fitted on the crane to remove snow.

Storage trials using similar experimental setups, with different forms of stored materials and storage periods, have been carried out within the scope of the INFRES project, in both Finland and Austria

PHOTO: TOMMY BLOM/SEBAB



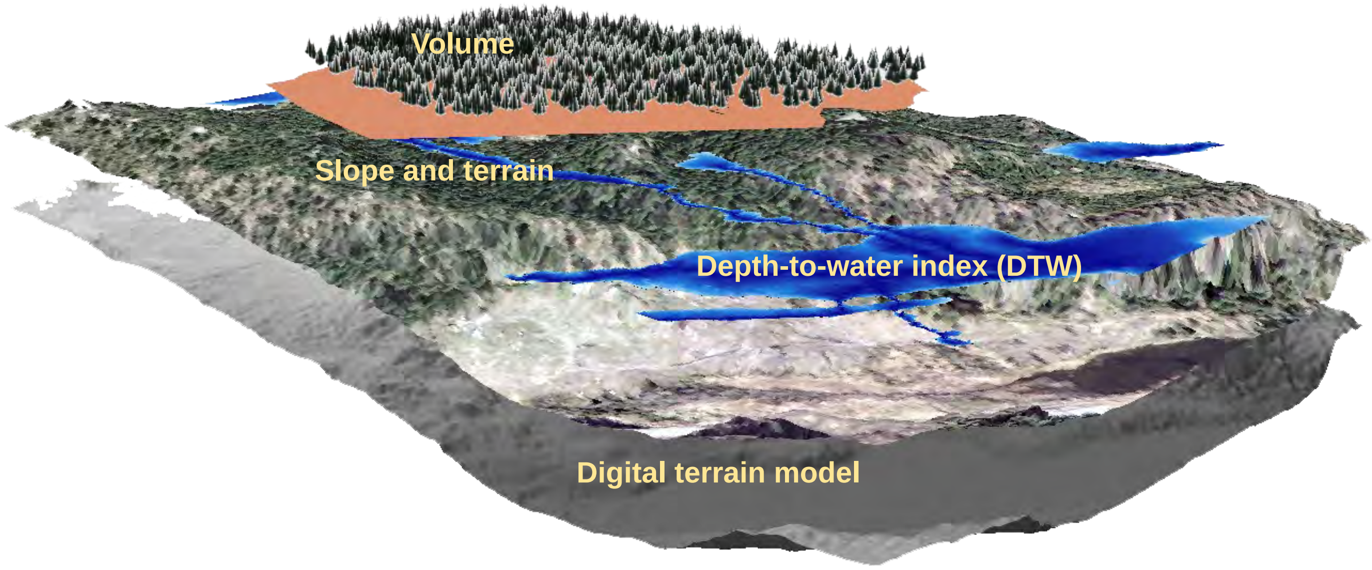
Future work

In order to improve control, management and feedback, prediction instruments and models for moisture content must be developed and validated. Data can be retrieved from measurements or historical data in the supply chain and/or meteorological and geographical data from practical experiments or documented experienc.

"There is a move towards commodification of biofuels, where moisture content is the single most important variable. The customers want to know what will be delivered, rather than see what they get. The prediction tool will therefore be interesting for the supplier, who can use it to direct the right material to the right customer, so that they can supply a cost-effective and competitive biofuel.".

Tommy Blom, Stora Enso Bioenergi.

Forestry activities always involve a risk of damage to ground and water. The problems can be reduced by planning operations carefully, by building crossings over streams and wet areas, and by using tops and branches to strengthen and protect the ground in areas with low bearing capacity.



BETTER PLANNING REDUCES GROUND DAMAGE

Gustav Friberg, Karin Westlund, Sima Mohtashami, Isabelle Bergkvist & Gert Andersson, Skogforsk

The STIG project

In the STIG project, Skogforsk, has worked with the forestry sector to develop the use of depth-to-water (DTW) maps, generated from airborne laser scanning data, in forestry operations. The laser point cloud generated in scanning enables models of the terrain to be produced in the form of height above sea level, slope and aspect. This in turn makes it possible to identify areas that are wet and waterlogged, and insert them on a map. This material also gives the logging planner a good idea of conditions on the site already in the office.

The depth-to-water index map method used was developed in Canada by the University of New Brunswick. To investigate whether DTW maps could work in Sweden, such maps were made for an area in eastern Uppland. Ten test quadrats with sides of 1 km were laid out, and sampling points were placed at 50-metre intervals along each side. Each point was surveyed in the field, and ground moisture was recorded in one of four classes, depending on the estimated depth to the water table.

Waterlogged 0 m

Wet < 1 meter

Moist 1 – 2 meter

Dry > 2 meter

The surveyor's assessment corresponded to the DTW map in 68 percent of the points. For 25 percent of the points, the map had indicated too wet conditions, while in the remaining 7 percent the map indicated too dry conditions.

Ground damage, defined as ruts penetrating the humus layer where mineral soil was exposed for a distance exceeding one metre, was evaluated after harvesting on 36 sites. All damage was recorded and mapped, and the result compared with a DTW map and the recorded operational paths of

The DTW map can serve as a useful tool, both in the office and in the field.

Better planning of crossings reduces damage caused by forestry activities.

the harvester and forwarder. Damage was found on approximately 50 percent of the length of strip and base roads situated on wet ground; for roads on waterlogged ground the figure was almost 20 percent, and on dry ground less than 10 percent. The lower damage rate on waterlogged ground compared to wet ground is correlated to a higher rate of road reinforcement with slash and fewer passages on these sections.

Skogforsk has also evaluated Stora Enso's harvesting instruction 'The Right Method'. In brief, this method means that logging is to be planned so that timber is transported efficiently, high-intensity base roads and strip roads with poor soil bearing capacity are covered with branches and tops, and extra care is taken in wet and waterlogged areas. Most forestry companies have developed similar instructions to reduce ground damage. The study examined 36 sites, where 18 had been harvested using 'The Right Method' and 18 had been harvested with no special directives.

After harvesting, the sites were surveyed in detail using the same definition of ground damage as above. For each occurrence of damage, coordinates, length, width and depth of damage, proximity to water or conservation area, and whether any ground protection measures had been made (e.g. reinforcement of base and strip road with tops and branches, logs or log mats) were recorded. The damage was also classified in accordance with the common ground damage policy applied by the forestry sector.

The study involved a total of 433 hectares. On this area, 3400 occurrences of ground damage were recorded, giving an average of 7.8 occurrences of damage per hectare. The number of damaged tracks per hectare was less than half on the sites where 'The Best Method' had been used. The occurrence of serious (unacceptable) damage was only a quarter of that on the sites that had been harvested with no special directives.

The results indicate that ground damage can be reduced considerably if clear directives are given about logging procedures on sensitive ground. There were also indications that quality and volume of tops and branches available for extraction as logging residues could be increased with better planning of operational routes and effective reinforcement of base and strip roads.

BesT Way

The STIG project has been the starting point for the development of a decision-support tool for operational planning of harvesting site that combines the information in the digital terrain model, the DTW map, with route optimisation for forwarding. The tool is called **BesT Way** (Decision Support for Site Planning).

Approximately ten years ago, Skogforsk started to develop a route optimisation program for forwarding of roundwood, logging residue and stumps. This forerunner of BesT Way was able to present alternative forwarding route options on the basis of the harvester's production files, which gave information about how much had been felled and where the timber was located on the clear-cut. The program then calculated the best route for the forwarder to minimise the transport distance.

BesT Way is based on the same idea but, instead of harvester data, data from the laser scanning is used to describe the forest. This technology gives a good estimate of the timber supply at pixel level, small areas of just over 100 square metres. Accessibility in the terrain is described by factors such as slope, ground wetness, soil, and height above sea level.

In the basic version, BesT Way calculates the most efficient placement of the base roads in relation to the position of the landing. BesT Way places no base roads in areas marked as wet or waterlogged on the DTW map. However, it can indicate one or more suitable sites for reinforced crossings of wet areas, and calculate a new optimal road placement based on these new conditions. The program can then test various sites for landings and crossings, and see how these affect, for example, forwarding distance and time consumption for forwarding, total cost, extractable volumes of roundwood and logging residues, number of passages at a certain point in the road network.

Field planning is expected to be more efficient with BesT Way, as a preliminary plan proposal can be drawn up in the office and the subsequent field visit can focus on confirming and modifying this proposal.

A graduate student compared the actual forwarding distance on two sites to the forwarding distance using the optimal route placement suggested by BesT Way. In both cases, BesT Way shortened forwarding distance by more than 20 percent.

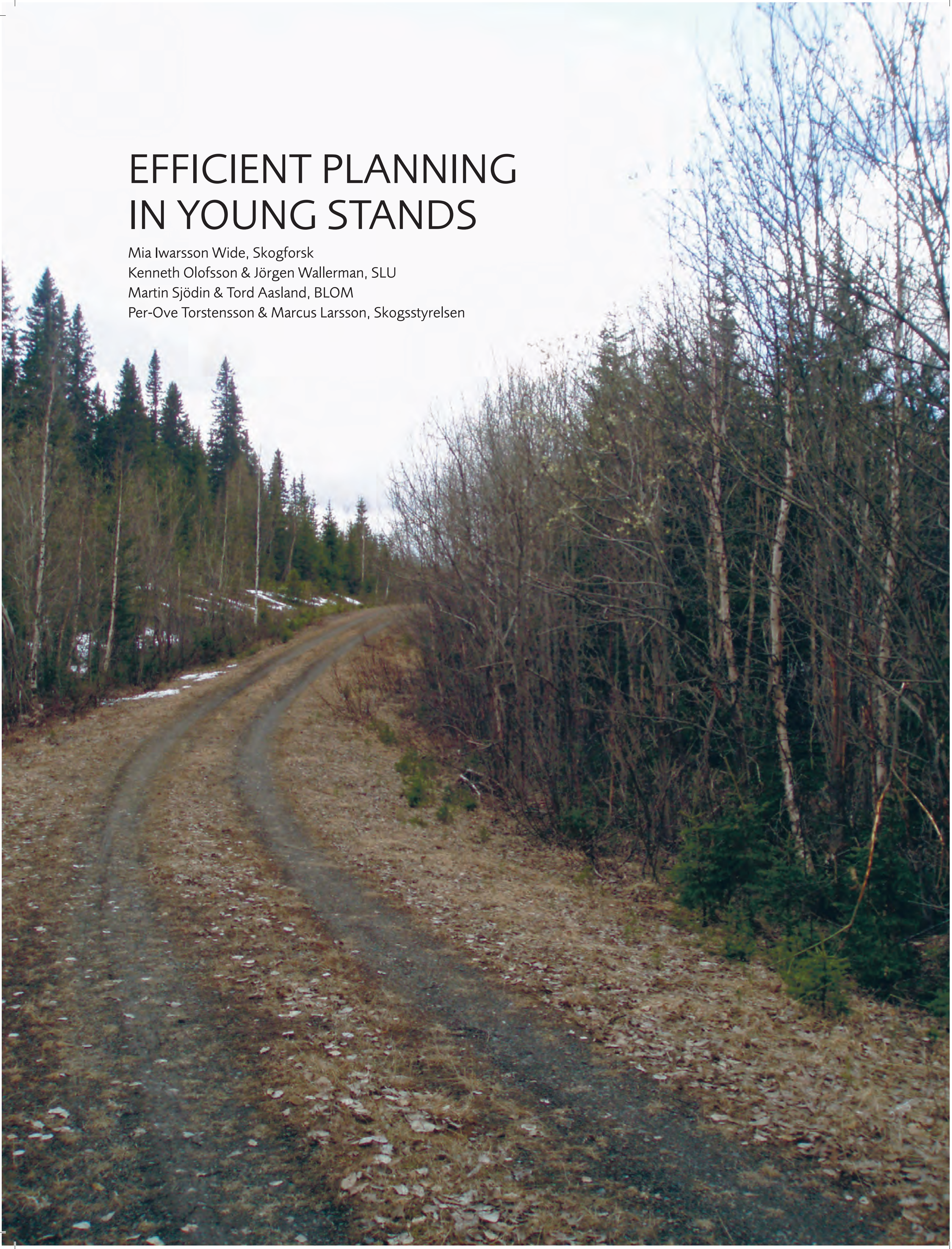
In a first step, we believe that general calculations of base road patterns, forwarding distance and volumes of logging residue can be very interesting. In the longer term, more advanced applications can be discussed, such as time and cost calculations, navigation support for forwarder operators, and flow calculations at stand level.

Future work

- Decision support to find the best placement of base roads to minimise risk of ground damage needs to be developed further, and implemented in forest operations.

EFFICIENT PLANNING IN YOUNG STANDS

Mia Iwarsson Wide, Skogforsk
Kenneth Olofsson & Jörgen Wallerman, SLU
Martin Sjödin & Tord Aasland, BLOM
Per-Ove Torstensson & Marcus Larsson, Skogsstyrelsen



Identifying young forests that fulfil requirements for profitable forest fuel harvest using traditional field surveys is expensive and difficult. A study shows that laser scanning may be an effective tool.

Stands of small trees are a large potential source of forest fuel. Sweden has large areas of dense or very dense young forests with small trees in need of thinning, where only some of the harvested trees are of pulpwood dimensions. Calculations show that the potential harvest of forest fuel in thinnings of small trees lies between 5 and 7 TWh per year, taking into account technical and economic limitations.

Vegetation along roadsides is also a relatively unutilised forest fuel resource. In Sweden today, there are approxi-mately 213,000 km of roads without state funding, and the energy potential along these roads is estimated to be approximately 1.5-2 TWh per year.

Calculation tools

Previously, Skogforsk has developed a calculation tool for estimating volumes and economy relating to harvest of forest fuel in stands of small trees based on the age of the forest, site index, number of stems per hectare, and mean diameter or mean height. The assortments to be extracted are also specified, and how many stems are to be left in the stand after thinning. The tool calculates extractable volume and the cost of felling and forwarding. The results are first presented as a net cost to the roadside, but the tool can also calculate costs for various types of comminution, storage and transport, and thereby calculate a net cost for the fuel delivered to the heating plant.

A problem for users of the calculation tool is that the accuracy of the input data is usually poor, because field surveys of young forests and roadsides are expensive. The effect is that the results are very unreliable.

Laser scanning – an alternative?

Data from airborne laser scanning allows accurate estimation of forest height and density in middle-aged and older forests. A large study was carried out to investigate whether laser scanning could be used to assess the potential for forest fuel harvest in younger forests and along roadsides.

Stand data for 250 reference plots representing forests with small trees was recorded in a field study. A further 96 reference plots were placed along roadsides. Measurement data from the plots was then compared with national laser scanning (NNH) data from Lantmäteriet (The Swedish Mapping, Cadastral and Land Registration Authority) for the same plots. The analyses were carried out using the area method, which is based on multiple linear regression. Vegetation indices were calculated by comparing the relationship between the laser hits that reach vegetation compared with all hits, including those that reach the ground. A high vegetation index indicates dense vegetation, while a low vegetation index indicates sparser vegetation, because many laser hits reach bare ground.

Regression models were used to calculate five basic forest-related variables: basal area weighted mean height, basal area weighted mean diameter, arithmetic mean diameter, total biomass and total number of stems. The direct estimates of forest variables and vegetation density showed relatively high accuracy, particularly for the range of heights, but also for density of the vegetation.

On the basis of the laser scan information about mean diameter and total number of stems, the profitability of harvesting tree parts was calculated. The results were compared with the same calculation based on field-measured data from the reference plots. In 76 percent of the cases, the model using laser scanning provided a correct answer to the question: Is harvesting of forest fuel viable on this plot?

Calculating stem density and profitability of harvest along roadsides proved more difficult. There was a large variability, with a standard deviation of 27 percentage points for estimates of biomass. For roadsides, the calculation of whether harvest of forest fuels would be viable or not was correct in 64 percent of the cases.

Conclusion

Laser scanning allows identification of stands or parts of stands where it would be viable to harvest biofuel in young forest, but roadsides are rather more difficult. The method can probably be improved by combining NNH data with other data sources, such as aerial photos or satellite images that give information about the mix of tree species (the proportion of deciduous trees has a considerable influence on the profitability of biofuel harvest).

It would also be interesting to investigate whether a higher point density in the laser data would improve the accuracy.

Lantmäteriet's laser scanning means that there is now a comprehensive ground model for Sweden. In the future, tree height can be calculated using an automatic stereo matching of aerial photos, which gives the height of the forest canopy. In other studies, this has been shown to give almost as good an estimate of forest variables as laser scanning.

PROCESS MAPPING OF SUPPLY CHAINS

Birger Eriksson, Lars Eliasson & Jenny Widinghoff, Skogforsk

Production and deliveries of forest fuel, and in particular logging residue, are characterised by long lead times and many different players involved in handling the material. This entails a risk of sub-optimal activities, duplication of work, and/or information disappearing in the supply chains.

In Germany and Finland, process mappings of forest fuel handling have indicated large potentials for streamlining business processes by systematically describing the work carried out to avoid duplication. It should be possible to adapt the method used in these process mappings to Swedish conditions, while also harmonising it with other methods for describing supply chains, e.g. skogs-SCOR.

Process mapping can increase players' awareness of the whole process, their respective roles in the process, and the possibility to influence both the end result and other parties' work situation. It can also identify which tasks need to be done, who should do them, and how information should be handled to make it available to parties that need it. Process mapping can also clarify the potential for rationalisation of the work, both for the company responsible for the forest fuel chain and for the contractors who perform the physical work.

In autumn 2013, a project was started with the aim of using the Finnish study method to develop and apply a method for mapping all processes in a supply chain for forest fuel, from planning of the harvesting operation to delivery of fuel to the end customer. The method was developed during a pilot study producing a process map of the biomass supply chain of a forest owner association. It was then used for a detailed process mapping of the biomass supply chain at a major forest company. While the forest owner association bought all the forest they felled, a significant proportion of the timber catchment of the forest company was from their own forest lands.

The work began with an introductory interview to create an outline process map of the business, and to map which players were active in the supply chain. Interviews were then held with the various players in the chain. After the interviews, the process map was drawn up in detail, and the interview responses compiled, compared and analysed. During the analysis, notes were made regarding each activity or element in the process chain:

- that, according to one or more respondents, cause irritation, generate unnecessary costs, or that could be performed better or more efficiently
- where the respondents had different views on how the activity is carried out, and/or who should carry out the activity
- where the analysis shows that there are, or that there is a clear risk of, sub-optimal activities, duplication of work and/or information losses.

Results show that, in the first mapping, many different problems and causes of irritation were noted in the supply chain studied, such as shortcomings in procedures, poorly and/or wrongly placed landings, and insufficient information transfer between the different players. In the second mapping, the respondents recognised some of these problems, but felt that most of the problems had been resolved. However, there were still work processes, procedures, etc. that could be improved upon.

There are many reasons for the differences between the surveys. The process is more complicated in the first mapping, because the forest owner association harvests and produces the forest fuel on behalf of many small private forest owners; in the second mapping, the company mainly works on its own land and only a small proportion of the volumes handled are purchased from other owners. The people and companies involved in the second mapping also have more extensive experience of handling logging residue than those who took part in the first mapping. One contractor company in the second mapping provides several services in the supply chain, i.e. harvesting, forwarding of both roundwood and residues, chipping and transport of chips. This contractor has worked actively to improve internal communications and has a comprehensive view of the services provided, so disruptions and problems occurring within its part of the chain have already been identified and minimised or eliminated.

Future work

The process mapping project shows that information can disappear in Swedish supply chains and that work descriptions are not always adequate, causing irritation and extra work. What remains is to examine the scale of the savings potential if the chain is streamlined, and how this can be done in the best way.

FOREST FUEL

– TECHNOLOGY AND METHODS FOR HARVEST AND ASH RECYCLING

Örjan Grönlund & Henrik von Hofsten, Skogforsk

Today, primary forest fuel is extracted in the form of whole or partly delimbed trees in thinnings, as energy wood (usually defective roundwood), as logging residue after final felling, or as stumps. The various assortments differ in terms of harvesting method, but subsequent handling – forwarding, comminution and onward transport – is very similar.

In the period 2009 to 2013, the cost of harvest and terrain transport increased somewhat for all forest fuel assortments. In 2013 average costs per m³ of chips were SEK 52 for energy wood, SEK 43 for logging residue, i.e. branches and tops from final fellings, SEK 80 for small trees, and SEK 81 for stumps. The greatest potential for an increased harvest of primary forest fuels lies in stumps and small trees. Biomass prices have fallen in recent years, and costs must be reduced in all parts of the supply chain to retain profitability in the forest fuel business and to generate income for the forest owner.

Logging residue

Today, logging residue is harvested in most final fellings in southern and central Sweden. The work methods and technology used for residue-adapted harvesting and forwarding of residues can be regarded as mature and well proven, so fine-tuning of techniques and methods is becoming an increasingly important part of the work to improve efficiency. Planning tools like STIG and Grotsporre improve the planning and simplify the forwarding work, while considerably reducing the risk of ground damage.

The first productivity standard for residue forwarding was presented in 2013, based on long-term productivity statistics and detailed time studies. The main factor affecting productivity is the amount of harvested material per hectare, but load quantity, transport distance and terrain difficulties are also significant. However, whether the logging residue is forwarded fresh or dried first on the clear-cut does not affect the productivity of residue forwarding.

Even if the technology is mature, technological development continues, including improvements to load carriers and grapples. Compacting load carriers and other special constructions give higher payloads than simple home-made constructions, but are not suitable for roundwood forwarding. Removable load carriers, such as the Hultdins load carrier, enable greater payloads of logging residue than the home-made modifications, and are suitable for contractors who often switch between forwarding roundwood and logging residue. Such contractors also need a

grapple that works well for both assortments, such as the asymmetric grapple, or a grapple that can quickly be adapted to the task at hand, such as the HSP combi-grapple.

The move towards more flexible technology means that roundwood and residue can be forwarded using the same machine. This reduces relocation costs and improves profitability of logging residue harvest, especially from small felling sites, and also gives the contractor flexibility.

The residue bundler was a machine that improved the efficiency of residue forwarding. The bundler compacted residues into 3-m long 'residue logs', which can be transported using an ordinary roundwood forwarder. However, high relocation costs along with a high cost per hour for the bundler means that that the technology requires meticulous planning and rather large cuts in order to be profitable. In Sweden, bundling of forest fuel has almost completely stopped, but the use of bundlers and technical development continues in Spain.

Residue is still largely forwarded in the period of snow-free ground and, in order to maximise machine utilisation, contractors must be able to forward roundwood during the rest of the year. One alternative is to forward the residue immediately after felling, and allow it to dry in stacks on the roadside. An in-depth literature study has shown that this method has advantages in terms of logging technology and silviculture but, as fresh residue contains more needles, more plant nutrients are removed from the stand compared to when the residue is dried on the clear-cut. However, it is unclear whether this affects the forest's future biomass production.

The placement and covering of the residue stacks at the landing affects the quality of the logging residue. When uncomminuted material is stored, a number of factors must be considered, such the logistics on the landing, regulations regarding road safety and, in certain cases, how tree-living insects are affected by the appearance of the stack.

Forest fuel from thinning operations

There is great potential to increase the harvest of forest biomass for fuel in early thinnings, where small trees are removed, but the assortment has become less attractive due to high logging costs in combination with falling demand and prices for forest fuel. Over 1.4 million hectares of forest in Sweden has not been pre-commercially thinned, so there is a great need to find less costly technologies and methods for harvesting small trees in early thinnings, and this is a driver for further development work.

The key to viability in harvesting small trees in thinning is the capacity to handle more than one tree at a time. When using multi-tree handling harvester heads, the potential is greatest in stands with a low mean stem size (0.02-0.05 m^3) and where many stems are extracted per hectare. Studies show that multi-tree handling can increase productivity by 15-50 percent. A follow-up of multi-tree handling in forestry companies shows that harvester productivity increased by 17 percent where the mean stem size was 0.02 m^3 and by 11 percent where the mean stem size was 0.05 m^3. The opportunity for realising this potential is greatest when only one assortment is harvested.

The Flowcut harvester head has been developed for logging in stands of small trees. It works with continual cutting and accumulation, which allows geometric crane corridor thinning. This is a principle that, according to simulations, can triple productivity in very early thinnings. A first in-field test of the functionality and performance of the Flowcut felling head shows a potential to increase harvester performance in early dense thinning. The principle for cutting and accumulation was operational, but improvement is needed.

The machine manufacturer Bracke has a prototype head for felling, accumulating and compacting small trees, the Bracke MAMA. This is equipped with a circular saw and feed rollers, while Flowcut uses a saw blade that is fixed at both ends and lacks the ability to buck.

In order to realise the potential for multi-tree handling, Skogforsk, in collaboration with an instructor and several companies, has compiled examples of good practice into a working method called thinning in sections. An evaluation of this type of thinning in a simulator environment has shown that the method can increase productivity by up to 18 percent.

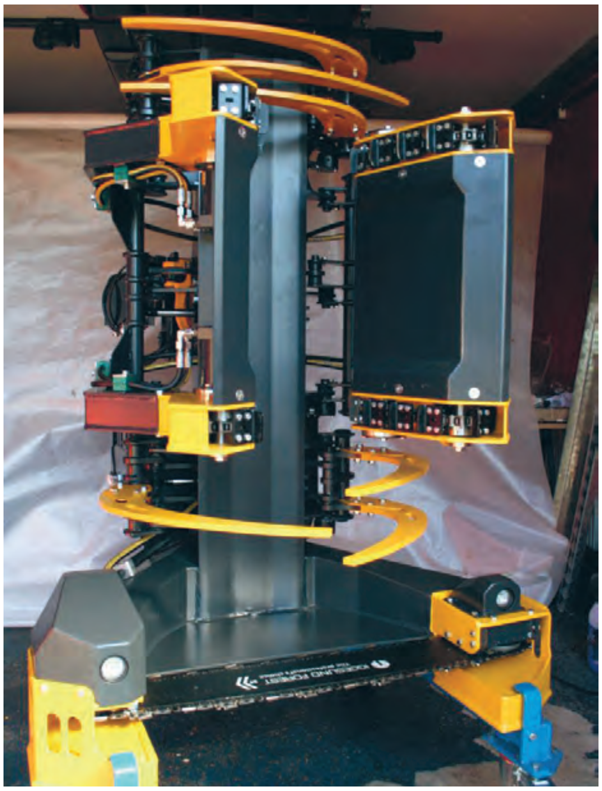


PHOTO: LENNART JANSSON/MEKFAB AB

Flowcut. A felling head prototype for continuous felling of small trees.

In order to streamline forwarding and onward transport in thinning of small trees, a bundling unit developed by the Finnish company Fixteri has been tested. The unit is mounted on a harvester, and the benefit is greater compaction compared with whole-tree harvest, while utilising most of the biomass. Evaluations indicate good performance in bundling – the greatest potential for improving the concept lies in equipping the unit with a more efficient harvesting head.

Much of the harvester's time in stands of small trees is spent on crane operation. The Cintoc harwarder for forest fuel has two partly automated cranes, one for separation and one for processing. The hope is that this can improve productivity in thinning of small trees.

There are several methods for estimating volumes in a stand where there is potential for harvesting small trees; this report, for example, presents methods for analysing felling in dense stands and on roadsides. Apart from analyses at stand level, there are also methods for analysing the individual tree, where different methods of handling the material in harvest of small trees affect the quantity of biomass harvested. In order to quantify how much of the biomass is extracted when small trees are harvested, bundles were weighed after whole-tree extraction, after partial delimbing, and after pulpwood bucking.

There is concern about an increased risk of damage caused by, primarily, snow and wind when dense stands of small trees have been thinned. However, in inventories of 14 stands, two to four years after first thinning, on average only 3.6 percent of the stems were affected by such damage.

Earlier studies of harvest of small trees have often involved pine-dominated stands. In order to broaden the perspective, the removal of birch shelterwood and forest fuel harvest in stands of Lodgepole pine have also been studied. When birch shelterwoods were removed, the proportion of damaged spruce after felling was found to be low, but the small mean stem volume made profitability of the extraction low.

There are no provisions regarding lowest final felling age for Lodgepole pine in the Swedish Forestry Act, so the stands can be felled at any age. In final felling of a 33-year-old Lodgepole pine stand, it was observed that productivity in whole-tree harvest can be high, but the extraction method may remove a large amount of nutrients, despite the concentrations of nutrients in Lodgepole pine being lower than in Scot's pine and spruce.

Stump harvest

The environmental impact of stump harvest is a controversial issue, which is why the Forest Stewardship Council, FSC, has set strict limits on which areas may be harvested on certified land until the environmental

Very little ash recycling takes place today, but technical developments are ongoing, and there is a growing need to find another use for ash as landfill capping is completed.

consequences have been investigated in more detail. This has created an uncertainty that has slowed technical development. Stump chips are a forest fuel with high production costs, approximately SEK 180/MWh at the industry gate and, as demand and prices for forest fuel declined during the 2013-14 and 2014-15 incineration seasons, stump harvest has stagnated.

However, development has not stopped completely. The contractor company, TL-GROT AB, has focused on the environmental issues, and has developed a stump harvester with an improved extraction method that cuts the roots approximately 30 cm outside the stump. This means that considerably fewer thin roots (< 5 mm) are pulled out with the stump compared with conventionally extracted stumps, and this significantly reduces ground impact. The method also reduces the amount of contaminants attached to the stump, which simplifies later handling and improves fuel quality.

One factor that has caused particular concern in conjunction with stump harvest is the reduction in quantity of thick dead wood. Recent research has shown that a large number of organisms colonise stumps, but it is unclear how dependent these organisms are on logging stumps, or whether logging stumps simply comprise an emergency substrate when there are no better alternatives.

In order to obtain an indication of how many stumps are actually left in the ground, an inventory was carried out of stump-harvested clear-cuts at Sveaskog and Holmen Skog AB. In normal stump harvest, a large number of stumps were left, up to 25 percent of the total number. Most of these had been left deliberately. They were relatively evenly spread over the clear-cut, and represented all diameter classes from the original stand. Of the stumps left in the ground, at least one-third were in principle undamaged, and could therefore still comprise a good substrate for various organisms.

A decision-support model for stump harvest has been developed, making it possible to select suitable areas for stump harvest and estimate the economic outcome. The model calculates the distance from every stump to the nearest landing, and then estimates the cost of harvesting and forwarding the stumps. The stumps are classified according to how profitable they would be to harvest. Input data for the model is production data and GPS-logged harvester routes, together with data about the felled stand

Technology for ash recycling

The increasing use of forest fuel in Sweden has triggered a debate on ash recycling. The debate is motivated and ash recycling is not without controversy, as there is a great deal of uncertainty about its actual benefits. On the one hand, ash recycling raises the pH in the soil and reduces the risk of long-term negative impact on the nutrient balance after forest fuel harvest. On the other, there is a risk of damage to the remaining stand, while the short-term effect on growth does not cover the cost of the activity. For these reasons and others, ash recycling is performed on a relatively small scale, and much of the ash that could be returned to the forest is used for other purposes, such as in roadbuilding or as capping material in landfills.

Returning ash to the forest is costly, as it involves the use of yet another machine in the stand. Usually, relatively small forwarders with specially designed disc spreaders are used. With the aim of reducing spreading costs, Skogforsk has examined whether ash recycling could be combined with other activities in the stand. One example is to temporarily fit a disc spreader on the forwarder that is already on the site.

The various stages in traditional ash recycling were studied to provide data for system comparisons. Preliminary results show that a forwarder spreading ash has a lot of down time waiting for ash deliveries, so a solution whereby logging residues are forwarded and ash applied using the same machine seems promising. Another advantage is that the investment cost can be divided between several players if they collaborate by using the same equipment. Interest in ash recycling is growing, as many landfills will soon be finally capped, and large volumes of ash will be available for recycling in the next few years.

Work environment in forest fuel handling

In view of the long-term growing demand, more people have started to work in the production of forest fuels. A good work environment is necessary in order to attract and retain machine operators. The work environment relating to forest fuel handling involves challenges that do not arise in other areas of forestry. The Swedish Work Environment Authority carried out a survey in 2009-2011 of the shortcomings and success factors in the sector.

The biggest challenges are the whole-body vibrations that occur in all machine work, the risks of mould and dust when handling mainly stored material, and the noise generated by comminution machines and how this affects operators and the environment. In order to disseminate knowledge of how to promote a good work environment in forest fuel production, information material based on current research has been produced by Dalarna University (www.du.se/arbetsliv_skog). The aim is to support everyday work concerning the work environment in forest fuel handling, and the compilation comprises six modules; Purchase of Equipment, Planning, Forwarding, Stump Harvest, Comminution, and Machine Development/Manufacture.

Forwarder-mounted chipper equipped with a high-tipping chip bin.

DAMAGE AFTER EARLY THINNING

Örjan Grönlund & Mia Iwarsson Wide, Skogforsk

'Dense young stands' is a management system where a denser stand, around 4000 stems per hectare, is retained after pre-commercial thinning than in conventionally managed stands. In the subsequent first thinning, more stems are extracted so that the stand density after thinning is comparable to that in a conventionally managed stand.

In dense young stands, and stands in which no pre-commercial thinning has been carried out, the trees in the remaining stand are thin and have high crowns due to the high stand density prior to thinning. Furthermore, extraction rate in the first thinning is relatively high. Earlier research has indicated that both these factors contribute to an increased risk of, particularly, snow and wind damage after thinning in such stands.

The aim of this project was to identify stand and tree characteristics that can explain the occurrence of damage in dense stands after first thinning.

The study involved 14 dense, pine-dominated stands in central Sweden. Inventories were carried out on a total of 160 sample plots of 100 m² two to four years after thinning. On the sample plots, breast height diameter and tree species for all standing trees, stump diameter and species of felled trees, and the proportion of the sample plot lying within strip roads were recorded. The heights of three sample trees per plot were also recorded. Damaged trees were divided into three classes:

1. Broken, leaning, fallen trees (i.e. trees damaged by snow and wind).
2. Trees damaged in felling or forwarding.
3. Other damage.

The sample plots contained between 500 and 4400 stems per hectare before thinning, and the basal area weighted mean diameter was 13.3 cm. Mean extraction was 1080 stems per hectare. The inventory of damage showed that 3.6 percent of the stems showed snow and wind damage, 0.9 percent felling damage, and 0.7 percent damage of unknown cause.

The statistical analysis showed few correlations between the frequency of tree damage and stand and tree characteristics. The characteristic that best explained the occurrence of damage was damage previously recorded in the stand. Sample plots with smaller basal area weighted diameters before thinning tended to have a higher frequency of damage. Consequently, in the 14 surveyed thinnings, only a relatively small part of the damage could be explained by tree and stand characteristics affected by the stand management. The damage that was observed is assumed to be more dependent on weather conditions and location than on factors affected by the thinning operation.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BIOMASS RECOVERY RATES FOR SMALL TREES

Örjan Grönlund & Mia Iwarsson Wide, Skogforsk

The growing use of forest fuel in the years 2007-2012 encouraged greater harvests of biomass from Swedish forests. In thinning, this can be done by harvesting whole trees, but whole trees are difficult to compact, causing low payloads in forwarding and onward transport.

By reducing the pressure exerted by the harvester feed wheels on the tree, and using blunt delimbing knives, the branches can instead be snapped, and only some are completely removed from the stem. This creates an assortment called partly delimbed energy wood.

In order to find out how much of the biomass is removed using different delimbing methods, delimbing of spruce, pine and birch trees was studied. Trees were sorted in three diameter classes, breast height diameters of 6-8, 8-12 and 12-18 cm. Ten bundles of each diameter class and tree species combination were weighed first as whole trees, and then partly delimbed by the harvester. In the next stage, the bundles were separated into individual trees that were delimbed and topped. Finally, the stems were bucked to pulpwood logs. After every step, the trees/stem parts were weighed. The aim of the treatments was to simulate harvesting of four different types of wood:

1. Whole-trees
2. Multi-tree handled, partly delimbed energy wood
3. Fully delimbed whole stems
4. Conventional pulpwood.

As tree properties affecting the delimbing process vary over the year, the study was carried out on three occasions, two under summer conditions and one under winter conditions.

The results from the studies gave a conversion table per species and diameter class. The conclusion was that the thicker the trees, the smaller proportion of material removed during delimbing. The studies also showed that a greater proportion of the biomass fell off during the winter, when the branches can be expected to be more brittle and break easily.

The measured weights of whole trees, stemwood, and branches used in the study were compared with existing biomass functions for small trees. There was a large variation between actual weights and estimated weights according to the biomass functions, but no systematic deviations were observed for any of the biomass functions. However, the biomass functions generally predicted a lower weight than that measured for small trees, and the opposite applied for larger trees. The biomass functions for spruce showed greatest correspondence with the measured trees.

Future work

- Dissemination and implementation of conversion factors and conversion tables as support for calculations and comparisons regarding harvest of fuel assortments or pulpwood.

Table 1. Recovered amount (%) of total biomass for partly delimbed energy wood and pulpwood according to tree species and breast height diameter.

DBH	6-8 cm	8-12 cm	12-18 cm
Partly delimbed energy wood			
Scots pine *(Pinus sylvestris)*	91	86	79
Norway spruce *(Picea abies)*	81	80	75
Downy birch *(Betula pubescens)*	89	86	88
Pulpwood			
Scots pine *(Pinus sylvestris)*	70	69	71
Norway spruce *(Picea abies)*	52	56	61
Downy birch *(Betula pubescens)*	60	63	88

Multi-tree handling has been carried out since the 1980s, and was developed with the aim of increasing harvester productivity in first thinnings. However, more recently, the method has become widely used when small trees are harvested as forest fuel in early thinning.

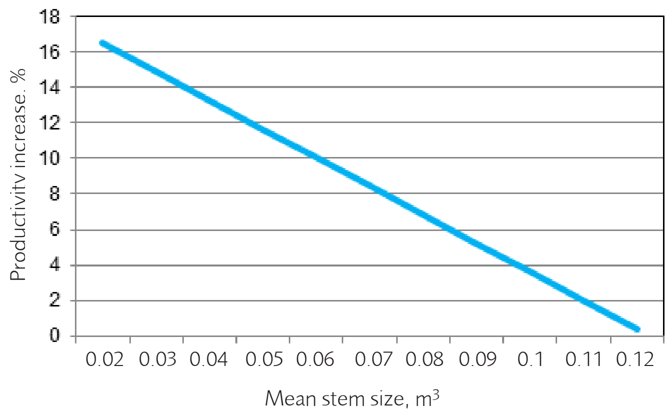
MULTI-TREE HANDLING INCREASES PRODUCTIVITY

Torbjörn Brunberg & Mia Iwarsson Wide, Skogforsk

Studies of harvester productivity when using multi-tree handling have shown varied results. In order to obtain a reliable estimate of the potential of multi-tree handling in practical logging, data from existing studies has been combined with follow-up data provided by a number of forest companies.

Time per boom cycle is shortest when the trees are processed one-by-one, but time per handled tree can be shortened if multi-tree handling is applied effectively. However, the time gain per tree is reduced as the number of trees accumulated increases, so there is an optimal number of trees per boom cycle. This optimum depends on the volume of the handled trees, the tree species, and the number of extracted stems per hectare. Analyses of the operational follow-up shows that the average degree of accumulation falls with increasing mean volume of stems in the harvest. Multi-tree handling is used in 60 percent of the boom cycles where the mean stem volume is 0.03 m^3, and only in 20 percent of the cycles where the stem volume is 0.10 m^3.

The conclusion is that the main factor affecting harvest productivity in first thinnings is the number of felled stems per hectare. This has a greater effect than the mean stem volume of the felled trees, but these two factors are strongly correlated. As the mean stem volume is the main factor in the cost models currently used, a model was constructed where the increase in productivity for multi-tree handling was only dependent on mean stem volume. The model, which involves a correction for the study material generally overestimating productivity, shows that multi-tree handling is expected to increase productivity by 0 to 17 percent when the mean stem volume harvested is in the interval 0.12 down to 0.02 m^3. The potential is greatest in stands with a low mean stem volume (0.02-0.05 m^3) and where a large number of stems are extracted per hectare.



Estimated productivity increase resulting from multi-tree handling in relation to single-tree handling vs mean stem volume of the harvested trees.

When thinning dense stands of small trees, the harvester operator is faced with the problem of many stems and a low economic value for each stem. The operator is forced to make many decisions in a short time, and must use a rational method to maintain a high level of productivity and reduce the mental work load.

THINNING IN SECTIONS

Örjan Grönlund, Martin Englund & Mia Iwarsson Wide, Skogforsk

Crane operation accounts for much of the time och used in thinning work and significantly influences fuel consumption for the harvester, while the risk of damage to the remaining stand increases with the number of crane operations. Together with Peter Larsson, Progalli Skog AB, Skogforsk has collected and compiled examples of good working practice in early thinnings and integrated them in a work method called 'thinning in sections'. The aim is to minimise crane operations by harvesting trees in sections perpendicular to the harvester, by efficiently applying multi-tree handling, and by positioning the machine so that most work involving the crane is done close to the machine.

In 2014, a systematic evaluation was carried out of the productivity and work load involved in thinning in sections. Five experienced harvester operators were studied in Skogforsk's simulator. The simulator study was divided into three parts. Firstly, the operators spent a day getting to know the simulator environment, and the following day they were studied while thinning using their 'usual' work method. The operators then underwent training in thinning in sections, and were encouraged to use the method in their ordinary work. Three months after the training course, they returned to the harvester simulator, where they thinned the same stand again using the thinning in sections method.

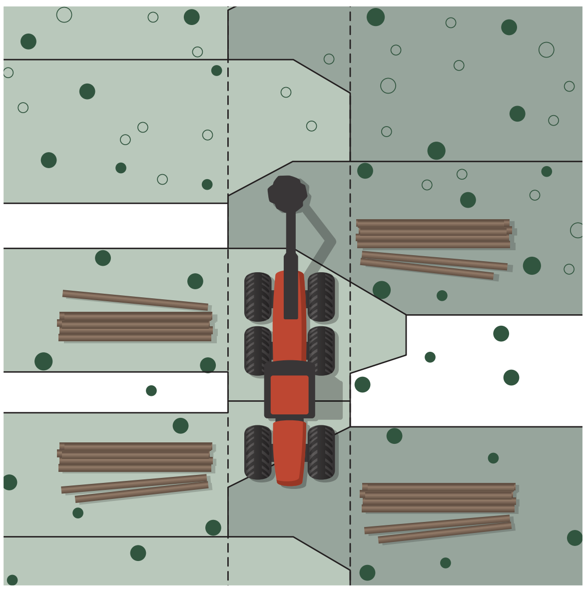


ILLUSTRATION: PER TORNEUS

Diagram showing thinning in sections.

In order to measure operator performance, continual time studies were carried out with pre-determined work processes. The software in the harvester simulator recorded the distance moved by the boom tip during thinning and, from this, the average number of crane movements per felled stem was calculated. The work load was studied using six cameras that recorded the number of head movements per felled stem, and also by the operators completing a self-assessment questionnaire. On the final day in the simulator, the extent to which the operators applied the method of thinning in sections was assessed.

The five operators performed a total of 60 thinning operations that lasted, on average, 16.5 minutes each, and in which the operators felled an average of 56 trees. The operators moved the boom tip an average of 11.26 metres per felled stem, and turned their heads an average of 33 degrees per felled stem.

Three of the operators improved their productivity by between 6 and 18 percent with the new working method. Two of these were considered to apply the thinning in section method more or less completely, but the third to a much lower degree. The productivity of the other two operators remained unchanged. One of these applied the thinning in section method completely, while the other had only changed the working method to a very small degree. The number of boom operations was reduced by an average of 4.3 percent when thinning in sections was applied.

Both the recorded and the experienced work load were largely unchanged after the change in work method. The exceptions were one operator whose number of head

The simulator can be developed into an efficient study environment for comparing different technologies and methods.

movements increased while productivity was also increased, and another whose number of head movements was reduced per felled stem but whose productivity was unchanged.

Earlier studies have shown that operators attain roughly the same level of productivity in the simulator as in reality, but there have been relatively few studies of how a harvester simulator can be used to study changes in work load.
In conclusion, the study shows that thinning in sections can help to increase the productivity of harvester operators considerably, but no effect was shown regarding work load. The conclusions are supported in follow-up studies by companies that have changed the work method, which show an increase in productivity of 10 to 25 percent when thinning in sections is introduced. These follow-ups have also shown positive consequences in the forwarding work, with reduced fuel consumption and a reduced work load for the operator.

Thinning in sections – instructions

For each machine position along the strip road, find an area where the main extraction will take place – it is this area that is called a section. The depth of the section is determined by the reach of the crane, and the width of the section is determined by the stem density. Sections in dense parts of the stand should be quite narrow, while they can be wider in less dense parts.

The sections should be established perpendicular to the strip road, and the harvested wood should be piled where the extraction in the section is greatest. Process the stems into piles on the same side of the strip road as they are standing. Fell the trees within approximately three metres from the tyre side inwards over the strip road, and feed them out into the section, but fell those trees outside the three-metre limit outwards, and feed them towards the machine. Make sure that the entire section is thinned before moving on to the next. Complete the section by reinforcing the strip road with branches, if conditions require this.

By being consistent and working within the section limits, boom movements are shortened, damage is minimised, and the stand is well thinned. The work can be carried out calmly and methodically, and the timber ends up perpendicular to the strip road, in a good position for the forwarder.

Future work

In order for forest fuel extraction in shelterwoods of birch to be viable, logging costs must be reduced through development of harvesting technology and work methods. Promising current development themes are felling heads for continual felling and part-automation of work processes.

FOREST FUEL FROM BIRCH SHELTERWOODS

Örjan Grönlund, Skogforsk

Birch shelterwoods are used as a nurse crop to reduce the risk of frost damage to young spruce trees on fine-grained soils and low-lying ground. A birch shelterwood should be managed in such a way that it can be harvested at low cost, while the understorey spruce trees can benefit from the protection without their growth being too inhibited by the overstorey. One of the major challenges is to ensure profitability as the birch shelterwood is gradually removed. Increasing demand for forest fuel is generating opportunities for revenue from this activity.

We studied productivity, costs, and frequency of damage to the spruce plants in the understorey during harvesting and forwarding of the birch trees that form the shelterwood. Shelterwoods were felled in two districts, Toftaholm and Odensjö (Table 1), and three 100-m long experimental plots were established in each district. During harvesting both energy wood and pulpwood were produced on all plots.

The felled material was weighed with a crane scale during forwarding, and samples were taken to determine moisture content. Based on the dry weight and time study data, productivity in tonnes of dry matter (tonne DM) per effective work hour (G0h) was calculated for both harvesting and forwarding (Table 2).

After the shelterwood removal, almost no birch trees were left in any of the stands, leaving approximately 1400 spruce trees per hectare in Toftaholm and 2600 in Odensjö. Of these, 5.9 percent were damaged in Toftaholm and 10 percent in Odensjö, which was lower than the expected proportion of damage.

The shelterwood removals did not provide the landowners with a net income. Based on the observed productivities, average hourly machine costs, and local timber pricelists, the net cost of shelterwood removal was estimated at approximately SEK 6000 per hectare, irrespective of district.

Today, shelterwoods of birch are mainly used to ensure successful regeneration, and thereby avoid other costs involved in establishing a new stand. However, this study shows that shelterwood removal is costly even if forest fuel is harvested, but the risk of damage to the remaining stand seems to be low.

Table 1. Description of stand before removal of shelterwood.

	Odensjö		Toftaholm	
	Spruce	Birch	Spruce	Birch
Stems/ha	3658	2225	1750	2390
Mean height (m)	7.5	11.2	4.3	9.2
Mean diameter (cm)	7.0	8.9	4.3	7.1
Volume (m^3/ha)		104.7		50.7

Table 2. Productivity in tonnes of dry matter (tonne DM) per effective work hour (G0h), in felling and forwarding.

	Odensjö	Toftaholm
Felling	2.99	2.38
Forwarding - energy wood	5.00	4.46
Forwarding - pulpwood	6.24	4.64

As a complement to Scot's pine and Norway spruce, Lodgepole pine began to be introduced to Sweden on a large scale in the 1970s. The species was seen as a good alternative that displayed strong growth, less damage from moose browsing, and wood characteristics similar to Scots pine.

FINAL FELLING OF LODGEPOLE PINE

Örjan Grönlund & Tomas Johannesson, Skogforsk

The stronger growth was regarded as a possible solution to counteract a feared timber shortage and as a way of increasing the level of felling. Establishment of Lodgepole stands was intensive in the 1970s and 1980s, and there are now approximately 600,000 ha of Lodgepole pine in northern Sweden.

Lack of knowledge about suitable provenances to use in Sweden and which site indexes were suitable for plantation with Lodgepole pine resulted in some of the current stands being of very poor quality, with thick branches and crooked stems. As Lodgepole pine is not covered by the provisions in the Forestry Act about lowest permitted age for final felling, there is greater freedom about how the species can be managed. In areas where quality development has been poor, one option may be to carry out final felling and extract the timber as forest fuel.

Skogforsk has studied harvesting, forwarding and chipping productivity, as well as drying effects and nutrient removal, in final felling of a 33-year-old Lodgepole stand in Alanäs, northwest Jämtland. In the stands, 2056 stems grew per hectare, with a mean diameter of 13.1 cm and mean height of 13.1 m. The harvested volume was 225 m^3 of biomass, total quantity of biomass over the stump cut, per hectare, and harvested mean stem volume was 0.07 m^3. Two harvesting methods were studied: whole-tree extraction and residue-adapted pulpwood harvest.

Productivity in felling, forwarding and chipping was studied through continuous time studies. As the harvesting methods involve different machines performing different tasks, system costs had to be compared, as comparisons for each individual machine were not possible. After correcting for the variation in extracted volume per hectare between the harvesting methods, the time taken for felling, forwarding and chipping was 36 percent higher for residue-adapted pulpwood extraction than for whole-tree extraction (Table 3). A contributing factor to this was that the operators were more experienced at whole-tree extraction, and because the handling of the logging residue took time. Residues comprised a quarter of the extracted material, but accounted for nearly half of the forwarding time.

The harvested biomass was left to dry on the clear-cut between felling in May and forwarding in September 2014, and samples for moisture content determination were taken continually during the period. As Lodgepole pine has a large quantity of needles, the hope was the whole trees would dry more effectively than the delimbed and cut stemwood sections. However, this was not the case, and at the end of the experiment, pulpwood and logging residues had dried better than the whole trees.

Nutrient removal was analysed through samples from different fractions of representative trees in the stand. The nutrient concentration in Lodgepole pine is low, as it is a resource-efficient tree species. Despite this, the analyses showed that the large quantity of green mass on Lodgepole pine means that extraction of all available biomass can considerably affect access to nutrients on the felling site.

The conclusion is that harvesting, forwarding and chipping is made most effective through whole-tree extraction. However, cut and completely or partly delimbed trees dry better on the clear-cut during the summer season than whole trees. In order to reduce the risks of excessive nutrient removal, parts of the green mass should also be left on the clear-cut.

Table 3. Productivity in felling, forwarding and chipping, expressed in tonnes of dry matter per effective work hour (tonne DM/G_0h).

	Whole-tree extraction	Stemwood	Logging residue
Harvester	EcoLog 860C, LogMax 4000B head		
Harvester productivity	4.51	3.26	-
Forwarder	Valmet 860.3, residue grapple with grapple saw		
Forwarder productivity	6.02	6.29	2.29
Chipper	Eschlböck 92, Claas Xerion 5000		
Chipper productivity	30.29	28.48	21.96

Chipping of whole-tree-harvested Lodgepole pine stems stored in stacks.

STORAGE OF LOGGING RESIDUE

Lars Eliasson, Skogforsk & Bengt Nilsson, Linnéuniversitetet

Increased utilisation of logging residues for energy production can replace fossil fuels with a domestic raw material. However, it is important that the residues are extracted in a sustainable way, so that it does not affect the future growth of the forest or is detrimental to the environment. The Swedish Forest Agency recommends that residue should not be extracted in forests with high natural values, or in a way that affects conservation measures taken during the harvesting operation, such as deadwood retention. Furthermore, at least one-fifth of the residues should be left on the clear-cut.

Since the 1980s, the recommendation has been that logging residues should be stored on the clear-cut over the summer, partly so that the material can dry to increase the effective energy value, and also because the needles should drop off. Heating plants do not want to incinerate needles, as this causes problems in the boiler and increases NOx emissions. It is also thought to be important that the nutrients in the needles are left on the clear-cut. Residue extraction in conjunction with final felling increases the removal of nutrients, which can have a negative effect on forest production. In field experiments with whole-tree extraction, spruce growth was impaired, but not pine. In those cases where the needles had been left on the clear-cut, height increment for spruce was at the same level as if only stemwood had been extracted.

Storing residue on the clear-cut means that the residue must be forwarded using a different machine to the one that forwarded the roundwood, so another machine must be moved to the site. Residue forwarding is also concentrated to periods of snow-free ground, which seems illogical if a stand with low bearing capacity has been felled during the winter to avoid ground damage. In addition, a clear-cut with

residue piles cannot be scarified and planted in the first summer after felling. All in all, this has led to increasing interest in forwarding the residue directly after felling, and drying it in stacks on the roadside.

In order to describe the state of knowledge about the advantages and disadvantages of storing residue on clear-cuts, the ESS programme carried out a literature review.

Results

Even if the ambition is to remove 'all' logging residue from a clear-cut, some is always left; in normal cases this is normally 20 to 40 percent, regardless of whether the residue is forwarded fresh or stored on the clear-cut. Most of the residue, 10 to 30 percent, is left between the piles on the clear-cut, because it is neither technically possible nor financially worthwhile to process all trees to ensure that the branches and the tops end up in a residue pile. Approximately 10 percent is left under the residue piles, because it is not worthwhile gathering all residue from the bottom of the piles. Doing so would also increase the risk of contamination in the residue. On weak ground, where branches and tops must be used to reinforce base and strip roads, even more residue is left on the clear-cut.

The quantity of needles that drop off during clear-cut storage has been studied using two methods. Some studies have measured the quantity of needles under the residue piles and compared this with the total quantity of needles, while other studies have involved chipping the piles and measuring the quantity of needles in the chips, which is then compared with the quantity of needles in chips from piles that were chipped directly after felling.

Studies of needle litter under residue piles stored for a summer on the clear-cut show that between 20 and 70 percent of the needles drop off and, in most locations, the residue piles had lost between 20 and 30 percent of the needles. In experiments where the quantity of needles was measured after chipping, between 60 and 95 percent of the needles had disappeared after a summer of storage on the clear-cut. One difference between the studies can be that the needles loosened from the branches in the residue piles get stuck in the pile, and drop off during forwarding and chipping instead.

The studies show that there is a great variability between sites in the quantity of needles that drop off the residue during clear-cut storage. This can depend on the weather during the storage period and the microclimate in the piles. Needles loosen more readily from dry branches, and more needles seem to drop off during loading if the piles are drier. If it assumed that 20 percent of the residue is left on the clear-cut between the piles, and 30 percent of the needles in the piles drop off during clear-cut storage, then 44 percent of the total quantity of needles is left in clear-cut storage compared with 20 percent when fresh residue is forwarded.

Moisture content is also of interest from a commercial perspective. In a study of six sites in Götaland, logging residue from half the sites was forwarded directly after felling, and the other half after the residue had dried over the summer. The mean moisture content was then measured to 36 percent for the stacks of directly forwarded residue, and 31 percent in stacks where the wood had been dried on the clear-cut before forwarding. The time of forwarding seems to have had a small effect on the moisture content of the residue at the time of delivery.

However, in a Finnish comparative study, the moisture content was 28 percent when residue was stored for nine months on the clear-cut and three months in a stack at the roadside, and 42 percent for residue that had been forwarded 'fresh' and stored in roadside stacks for a year.

Probably, the choice of where and how the residue pile is placed has at least as big an effect on the drying process as if the residue had been dried on the clear-cut before it was forwarded. It must also be remembered that residue in small piles on the clear-cut are quickly remoistened by rain and damp weather conditions, while the covered residue stacks are not affected as much.

Conclusions

The difference in fuel characteristics between clear-cut stored residue and residue stored in stacks at the roadside is often marginal, so the difference between the two systems can be difficult to define. The moisture contents are similar and, in both cases, needles are left in the material. Differences between clear-cuts seem to affect the material more than when the material is forwarded to larger stacks.

The argument for storing and drying residue in small piles on the clear-cut so that the needles can drop off can be questioned. Not 'all' residue and 'all' needles are removed in forwarding of newly-felled residue, and not 'all' needles are left in forwarding of clear-cut stored residue; It is not possible to say whether this difference is big enough to affect the long-term growth of the new forest to any noticeable extent.

When forest production is compared, consideration should also be taken to the fact that the clear-cut can be replanted one year earlier when residue is forwarded directly after felling, compared with when the residue is stored on the clear-cut. In areas felled in the winter, the risk of ground damage is reduced if the residue is forwarded directly after felling while the ground is frozen, compared with when forwarding is postponed until the following autumn.

Forest fuel harvest

MORE EFFICIENT TECHNOLOGY FOR STUMP HARVEST

Henrik von Hofsten, Skogforsk

Stump harvest or stump extraction has been practiced in Scandinavian forests since the Middle Ages. Up until the 1970s, it was mainly pine stumps that were harvested with metal rods, spades and winches, in order to extract pine tar.


The Stelpa stump head

In the early 1970s, concern arose that the pulp industry would have problems with supplies of raw materials, and attention turned to the possibilities of using, primarily, spruce stumps for pulp chips. The lifting devices that were developed then are still in use today, although some improvements have been made. Broadly speaking, the conventional lifting devices are based on powerful grapple pliers that are used to split and pull up the stump. The method works relatively well, but requires great power and often causes major disturbance to the ground. However, in the past decade, there have been some new technical developments in the field, with the focus now on producing fuel chips from the stumps.

The first completely new approach to stump harvesting in Nordic conditions was the **Rotary stump cutter**. It loosens the stump before lifting by sawing/grinding off the thick roots with a rotating drum that is placed over the stump.

In studies, the principle has been shown to work quite well, but the machine is sensitive to rocks and stones and works best on sedimentary soils or other soils with few large stones and rocks (stones smaller than a tennis ball present no problems). Similar machines have been used since the 1960s in southern Europe in conjunction with clearing poplar and eucalyptus plantations, and are mainly fitted behind agricultural tractors.

The productivity of the rotary stump cutter, calculated in number of stumps/hour, is comparable with many conventional machines. However, because most of the thick roots are not extracted, productivity in terms of stump biomass per hour is only 50-60 percent of a conventional stump harvester. On the plus side, the roots that are left largely undisturbed in the soil mean that the bearing capacity of the ground is not reduced to any great extent, which is a great advantage when it comes to forwarding.

The amount of disturbed ground is less than one-fifth of the amount disturbed when extracting stumps with a conventional lifting device.

The TL-GROT stump head
– prototype under development.

The Xteho stump head.

Xteho is a Finnish lifting device with four grapple claws that are placed over the stump, after which the claws are forced into the wood and press up the stump. The four claws are also equipped with a 'splitting iron' on the inside, so that the stump is split into four parts during the removal. Another feature is that the grapple claws can vibrate, so that contaminants are loosened from the stump and roots. There is no need to shake the entire lifting device, which considerably improves the work environment for the operators.

Xteho performs well compared to conventional lifting devices, and gives clean and high quality stump material. The disadvantage is that the head hangs freely from the boom tip, so the operator cannot use the crane for support when moving the machine, which is common with caterpillar excavators. Xteho is also rather too heavy (2.5 tonnes) for most wheeled forest machines.

The effect of Xteho on the ground must be regarded as moderate, but fitted on an excavator the caterpillar tracks can certainly be a disadvantage on certain types of ground. Because the operator cannot use the crane to help in movements, there is a lot of slipping and rotating, particularly in sharp turns.

One recently developed lifting device designed specifically to minimise both ground impact and the quantity of contaminants is the **TL-GROT** stump head. With two 'claws' and one 'thumb' that shoot out, it is relatively easy to cut off a buttress a short distance out from the stump, while the stump is twisted upwards towards the claws and thereby lifted slightly.

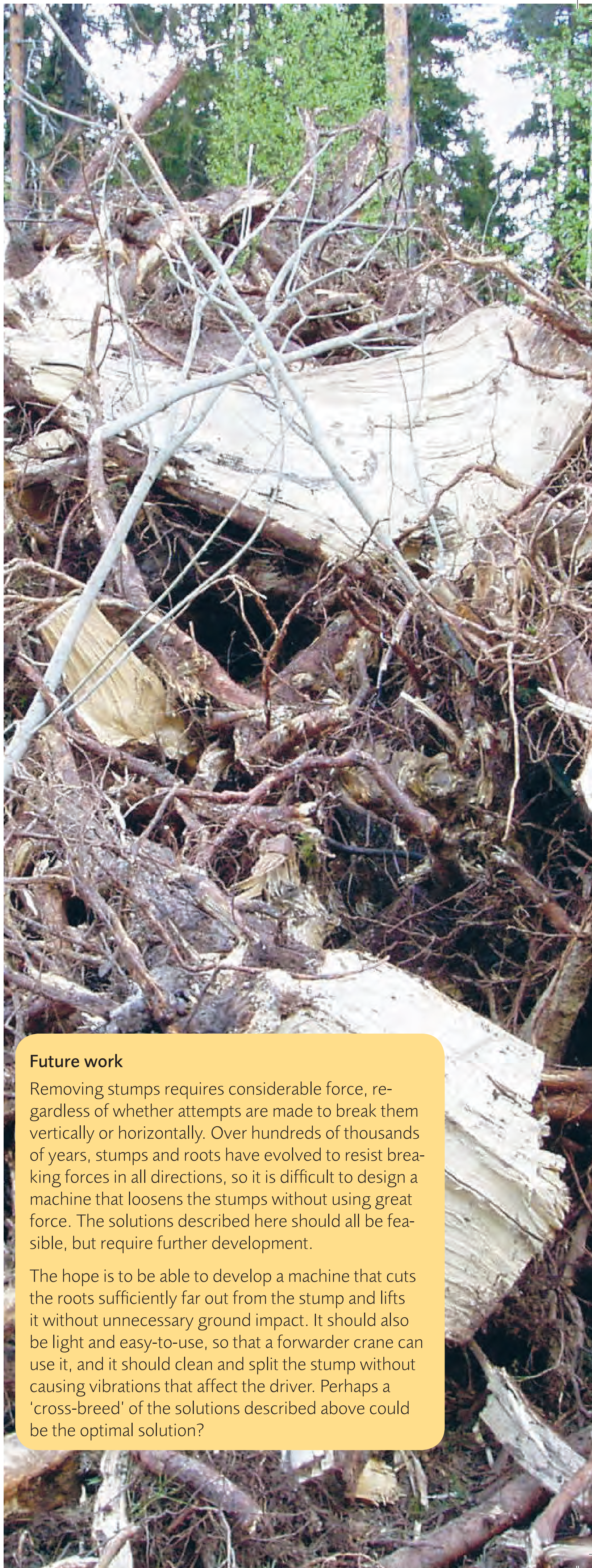
The head sits in a rotator, so can be turned in several directions to cut more roots before the final lift. Because the lifting device is still under development, no comprehensive studies have been carried out. However, a smaller study showed that ground impact was considerably reduced, particularly the size of the cavity after the stump, whose area was only a third of that created by a conventional device. The number of remaining roots was almost halved, while the mean diameter at the rupture surface of the remaining roots increased from just under 5 mm to 15 mm, which also indicates that the quantity of remaining fine roots is drastically reduced.

Drills. One interesting solution for stump harvest, which to the best of our knowledge has yet to make any impact, is a drill that is used to first crack the stump in the ground and then the stump parts are lifted with a claw. The biggest advantage should be that the method does not require a lot of power in the crane, because the buttress is partly broken by the screw. Ground impact would probably be less than for conventional devices. A disadvantage can be that it is difficult to further split a loose stump part with widespread roots. The loose stump part would simply roll away before the screw could grip it.

CBI/Lasco Stump Screw is a variation of the same concept, but with a slightly different design. The productivity has been tested by METLA in a thinning stand. The drill was used to crack the stump in the ground before it was lifted by the forwarder. The productivity was only 30 percent compared with conventional technology in final felling stands, but at the same time the ground impact was only 50-60 percent of that caused by conventional technology.

The **Järvinen** lifting device places a ring on the ground around the stump, after which the stump is gripped and pulled upwards through the ring, which serves as a counterweight. The ring can break off roots of up to approximately 10 cm. However, certain improvements are needed, because the machine cannot harvest stumps whose roots are too thick, nor can it split or clean stumps, which are important aspects for a viable stump harvester head.

In an experiment carried out by SLU in Umeå, an attempt was made to twist stumps loose from the ground. The hypothesis was that the roots would be less resistant to a lateral force than a vertical one. The aim was to develop a technology that would not need great breaking force and heavy base machines. However, the experiment showed that the torque required to twist the stumps loose would be too high – far higher than the torque that can be generated today by a rotator. Somewhat lower torque was needed to cut off the roots laterally around the stump, but even this was more than current machines can generate. Ground impact was not improved noticeably, because many roots did not break off before the entire stump started to rotate.



Future work

Removing stumps requires considerable force, regardless of whether attempts are made to break them vertically or horizontally. Over hundreds of thousands of years, stumps and roots have evolved to resist breaking forces in all directions, so it is difficult to design a machine that loosens the stumps without using great force. The solutions described here should all be feasible, but require further development.

The hope is to be able to develop a machine that cuts the roots sufficiently far out from the stump and lifts it without unnecessary ground impact. It should also be light and easy-to-use, so that a forwarder crane can use it, and it should clean and split the stump without causing vibrations that affect the driver. Perhaps a 'cross-breed' of the solutions described above could be the optimal solution?

Spruce stump with emergence holes of the pine longhorn beetle, a common species that regenerates in many forms of dead wood.

Spruce stump that has grown over an old stump should not be harvested.

ENVIRONMENTAL EFFECTS OF STUMP HARVEST

Henrik von Hofsten, Skogforsk

The environmental effects of stump harvest have been a source of constant debate since stump harvesting took off at the start of the 2000s. Many concerns have been put forward, such as that stump harvest would be a serious threat to the biological diversity because of removal of vital substrate, and that the ground impact would be unacceptably high. The effect on the carbon balance has also been debated. In order to investigate these issues, a theme programme has been carried out in two four-year periods (Theme Stumps) at SLU in Uppsala. Like ESS, the theme programmes have largely been financed by the Swedish Energy Agency, but also by SLU and forestry companies. Read more at www.slu.se/stubbar

One question that quickly arose was how many stumps are left on a clear-cut after stump harvest. This was examined by conducting an inventory of ten stump-harvested clear-cuts in Bergslagen and on a larger clear-cut (approximately 10 ha) in Västerbotten. On the Bergslagen clear-cuts, data was also collected from the harvester that had done the felling, in order to compare the number of cut trees in each stand with the number of remaining stumps.

The inventory showed that up to 25-30 percent of the stumps were left on the clear-cuts. The distribution over the diameter classes was good, and stumps of all sizes remained in the stands. One important and natural reason for leaving a stump was that it was at the edge of the clear-cut or a ditch. Another reason was that the stump was near a conservation site, such as an anthill, high stump, eternity tree or similar. In total, 60 percent of the stumps left in the ground were left for these reasons. The other 40 percent had, quite simply, been missed by the machine operator, the equivalent of approximately 66 stumps per hectare.

The crab-of-the-woods fungi (Laetiporus sulphureus) is a typical deciduous tree fungi; its presence signals that the stump should not be lifted.

Measurement of the affected ground around a stump cavity left by the TL-GROT stump head. Each square is 15 x 15 cm.

Theme Stumps has identified a sizeable number of organisms such as mosses, lichens and insects that colonise felling stumps. For some of the insects, successful regeneration requires that the stump is intact and has no bark abrasion. In the inventory above, approximately 80 percent of the stumps were undamaged or only very slightly damaged.

Ground impact after stump removal is an important issue. A field study carried out by SLU, Umeå, showed that on average 6.1 m² of the ground surface was impacted per lifted stump, and the area of impact increased with stump size. In total, 60 percent of the ground was affected, half from stump removal, and half by the tracks left by the machines that had driven on the clear-cut in conjunction with felling, stump removal and scarification.

The root rupture diameter is also interesting, since it reflects how much of the ground is damaged in the stand. The finer the roots that accompany the stump, the higher too is the ash content and nutrient loss. The quantity of remaining roots also affects the ash content of the stump material and the bearing capacity of the ground in forwarding. In the SLU study, the root rupture diameter averaged only 5 mm. Neither the ground impact nor the root rupture diameter were affected by the time span between felling and stump extraction.

In an experiment to reduce ground disruption and associated contaminants, Skogforsk tested a new lifting device, developed by TL-GROT AB. The device is designed to cut off the roots approximately 30 centimetres outside the stump, in order to leave more of the smaller roots in the ground. The results of the first test operations showed that the theory seemed to be correct. Compared with the SLU study above, the number of remaining roots on the lifted stumps decreased by more than a half, and the diameter at the rupture surface was tripled. Because more thin roots were left in the ground, the impacted area decreased to approximately 40 percent of that found in the SLU study.

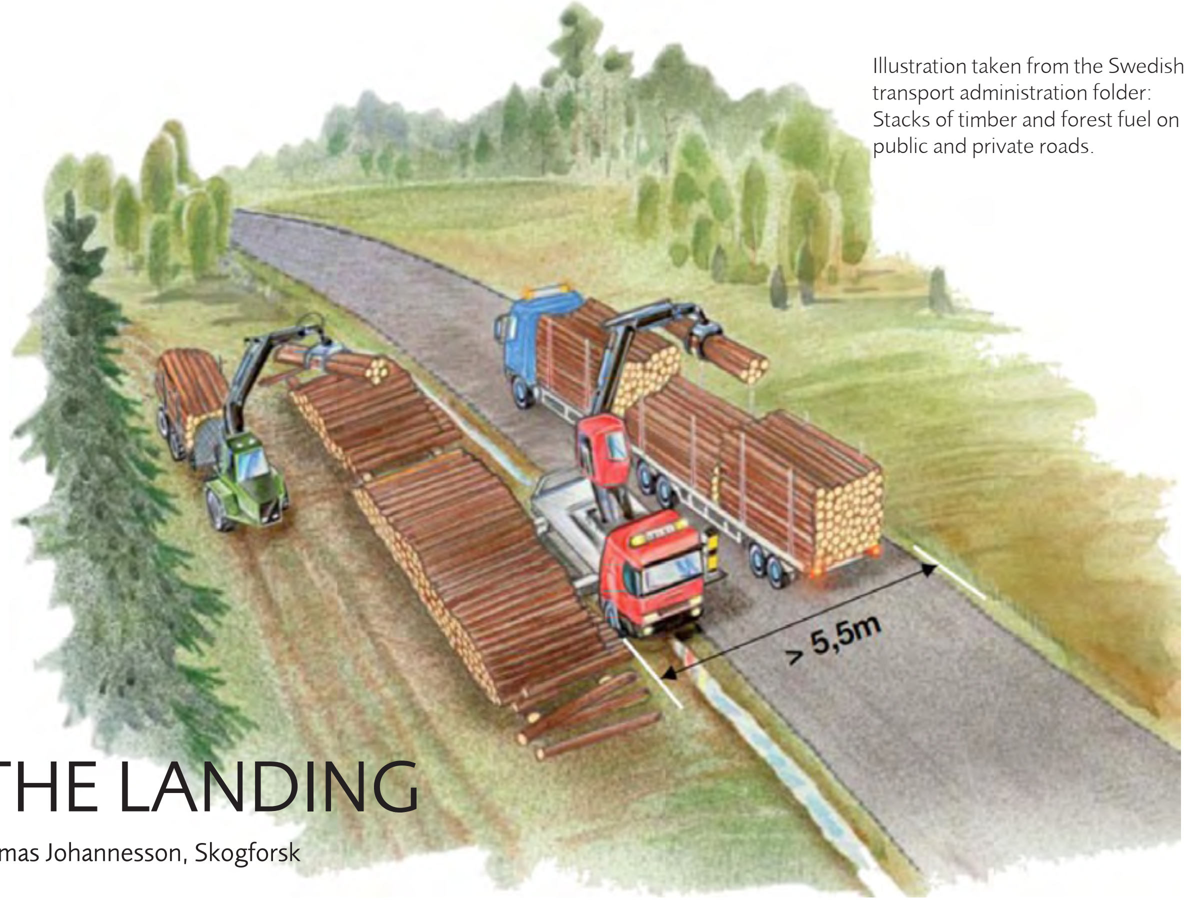


Illustration taken from the Swedish transport administration folder: Stacks of timber and forest fuel on public and private roads.

THE LANDING

Tomas Johannesson, Skogforsk

Stacking timber on the roadside requires a permit from the body responsible for maintaining the road; for public roads this is the Swedish Transport Administration. Applications can be submitted for a general permit that applies for certain roads in a county, via the Swedish Transport Administration website.

The permit must be supplemented en with an application at the start of felling for each individual project. For roads or situations to which a general permit does not apply, an application can be submitted for a specific permit in the same way. Stacks of stumps are not covered by the general permits, because they are regarded as being far too irregular in shape and may cause serious damage in the event of a collision.

Together with the ESS programme and representatives from the forestry sector, the Swedish Transport Administration has developed a regulatory framework and guidelines for stacks of timber and forest fuel. The aim is to reduce risks to traffic and for the personnel who handle and transport the material. The safety distance from roadside to a stack of wood depends on the permitted speed on the road – two metres at 50 km/hour, three metres at 60 to 80 km/hour, seven metres at 90 km/hour, and nine metres at 110 km/hour.

In the preparatory work on the new regulations, our request for consideration for the special requirements relating to forest fuel was respected, for example that the piles must be accessible to the machines that are to comminute the forest fuel.

The Swedish Transport Administration accepts six weeks of roadside storage for roundwood stacks and no less than 18 months for stacks of forest fuel. It is positive that forest fuel piles can be stored for such a long period, as these assortments are not in demand all year round. The landing is used as interim storage, where the forest fuel stacks are normally allowed to dry over a summer season. The extended storage time for forest fuel stacks does increase the risk of exposure for other road users, so it is extra important that activities and planning regarding the landing are handled correctly.

The stack must be placed in such a way that it does not hinder road maintenance, such as snow clearance, nor may it block roadside ditches. The ideal height of a stack is 3-3.5 metres, and it must not be higher than 4.5 metres above the road surface when it is to be loaded onto trucks for onward transport or chipped with a chipper truck.

The side of the stack facing the road must have an even surface, with no protruding logs or other tree parts that could penetrate a vehicle in the event of a collision. It may be necessary to trim parts of forest fuel stacks to make the surface on the side facing the road even. No part of the pile may lie within the safety distance.

It is important to avoid overhead electricity cables. For low-voltage cables, the minimum permitted distance is two metres between the stack and the crane. For high-voltage cables of max 40 kV, the safety distance is four metres, and for cables of higher voltage six metres. In practice, a safety distance of 15-25 metres is recommended, depending on the length of the timber or forest fuel, the working area of the crane, and the voltage in the cables.

Loading and transport

According to the traffic regulations, anyone placing a vehicle along a road to load or unload must ensure that other road-users can detect the vehicle in time. The driver may use a warning triangle, warning lamps, hazard warning lights or flashing lights built into the ramp of rear lights or timber stakes. There is also a special warning sign (sign X6 according to the Road Signs Ordinance) showing that accessibility on a road is reduced because of a temporary obstacle. The sign can be reinforced with a yellow flashing light to signal the need for special caution. Side marking shields can be used to direct traffic past the truck if necessary (sign X3).

Fuel quality

In addition to successful use of the landing from safety and logistical aspects, the time of storage is significant for reducing the moisture content of the fuel. Generally, it can be argued that ambitious planning of the landing improves profitability. If the moisture content decreases, the increased revenues usually cover the costs of the extra work involved, as shown in the example below.

Example: If an alternative site for the landing can be found that offers better drying conditions, so that the moisture content decreases from 50 to 45 percent, the value of a forwarder load increases by approximately SEK 130. This corresponds to extra forwarding time of no less than ten minutes (equivalent to an extra total forwarding distance of approximately 250 metres). Shorter extra distance and/or greater reduction in moisture content is pure profit.

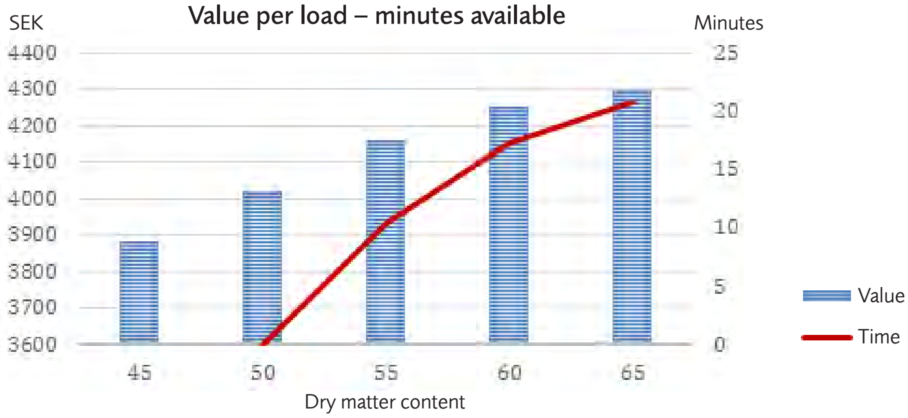


Figure 1. The blue columns show the value of a forwarder load with different moisture contents on delivery. The red line shows how many extra minutes the forwarder can invest in order to reduce moisture content while retaining the net value of the biomass.

Conditions for the calculation:

- The calculation is based on fresh logging residue forwarded to the landing.
- The fresh residue has a moisture content of 50 percent, which corresponds to an energy content of 0.87 MWh per m³ of chips.
- A forwarder load contains the equivalent of 25 m³ of chips. The load volume is not affected by the moisture content.
- The hourly cost of the forwarder is SEK 800.

How to create good conditions for drying:

- The ground surface should be dry and well-drained, and free from stones and undergrowth that may contaminate the residues during handling and cause delays during comminution.
- The landing should be exposed to sun and wind.
- The cover should be applied carefully so that the covering paper remains intact and is not damaged by the wind.

Large variations can often be observed in moisture content of fuel deliveries from the same district, where the conditions for the logging residue should in theory be equal, but where the stacks have been placed in different locations. In certain cases, a more careful choice of landing site would probably have improved overall profitability for the fuel deliveries from a cutting site.

GROUND DAMAGE

Lars Högbom, Skogforsk

Ground damage caused by machine traffic during harvesting operations is a major problem that is attracting increasing attention, both in and outside forestry. In order to minimise the problem, training and information are required, and greater knowledge about the factors that influence ground damage.

Greater extraction of logging residues risks increasing ground damage for two reasons: the total number of transports in the forest terrain increases, and tops and branches are removed that could otherwise be used to protect the ground.

We have followed up a number of logging sites in central Sweden. The aim was to develop guidelines for how, when and where fuel assortments can be harvested in conjunction with regeneration felling.

Ground damage in conjunction with logging has increased in recent years. The Swedish Forest Agency's Polytax shows that the proportion of severe cases of ground damage in connection with stream crossings increased from 4 to 18 percent between 1999 and 2007. The figures are an average figure for the felled area where streams are present.

There are currently no indications that ground damage will decrease in the future. On the contrary, in fact; extraction of both roundwood and forest fuel assortments is expected to increase in the next 20 years, and forestry will be moving into areas with increasingly difficult conditions. In combination with an expected climate change, this will lead to increased extraction on more difficult areas.

Examples of the effects of using, and not using, branches and tops to reinforce tracks. The picture above, and the one to the right, were taken 15 m apart on the same type of ground and on the same day.

About the study

In order to obtain a representative selection of samples, we based our study on all reported fellings in 2010 from four counties around Lake Mälaren (Stockholm, Uppsala, Södermanland, and Västmanland). This gave a total of 4728 fellings. Of these, 60 were selected at random from each county. In the years 2011-2013, these 240 sites were visited; three were excluded for various reasons, so the final total was 237.

In the study, we focused on ground damage close to various types of watercourses and, to avoid delimitation problems, we treated all occurrences of water in a standard way. The limit for 'close to water' was set to 30 metres.

Every wheel track was assessed separately, i.e. every vehicle movement gave two wheel tracks. Within each site, the general distribution of ground damage was placed in four classes – none, sporadic occurrence, occurrence and general. The rut depth was also assessed in four classes: 0-5 cm, 5-25 cm, 25-50 cm and >50 cm. Rut depths were only measured on the sites where we had recorded damage close to water.

Some results

- Of the 237 sites visited, 211 were felled and 26 unfelled.
- 142 of the felled sites were adjacent to water in some form.
- Of these 142 sites, 99 had incidences of damage to varying extents. In total, 1088 individual cases of ground damage were recorded.
- 484 of the cases of damage were in direct contact with water, and the rest lay within the 30-metre zone, but outside the actual water area.
- Of the direct damage, 447 cases occurred on crossings, and 37 where machines had been operated along watercourses.
- 236 cases of damage caused visible sludge transport, 223 caused damming, 125 caused removal of humus, and 108 lacked visible negative effects.
- The 12 most damaged sites accounted for over half of the damage.
- Two sites had more than 10 cases of damage per hectare.

The general pattern was that areas of peat and fine-grained soil showed most damage. However, there were areas of fine-grained soil with no damage, which indicates that the time of felling is very important.

The data also showed that ground reinforcement measures, such as bridges, log mats, tops and branches, had been used to a significant extent to prevent damage from machines.

One of the aims of the study was to see whether extraction of logging residue caused more ground damage. Since residue had been extracted on virtually all sites, it was difficult to analyse this aspect. Other factors than residue extraction have had greater impact.

The conclusion was that a small number of sites accounted for most of the damage and that the soil type – hardly surprisingly – was very significant. The finer the grain of soil, the greater the proportion of damage. The time of felling was also important, since there were sites with fine-grained soil that showed no damage.

Future work

- The results of this study can be used to improve procedures and planning tools, such as digital maps.

PHOTO: ANN HEDLUND/HÖGSKOLAN DALARNA

OPERATOR WORK ENVIRONMENT

Ann Hedlund & Ing-Marie Andersson, Högskolan Dalarna

Since 2009, the work science group at Dalarna University has been studying work environment issues relating to the handling of forest fuel. In the earlier ESS programme, the focus was on knowledge exchange between contractors, the attractiveness of the forest energy sector, client responsibility, mould, and systematic improvements to the work environment. In the 2011-2014 programme period, further studies have been carried out on noise, dust and mould, whole-body vibrations, and repair work. Operator views on working conditions and work environment risks have been collected via a questionnaire survey.

Noise

Chipping and grinding of forest fuel generates noise levels that are so high that the operator must take measures to prevent harm. The levels vary between different types of machine combinations, and operators in crane cabs are especially vulnerable. A well-insulated operator environment and closed windows and doors reduce exposure to noise. Noise levels around the machines are high, so anyone working in the vicinity must use ear protectors.

At a distance of 200 metres from the comminution site, noise levels usually exceed recommended levels for residences, work premises and recreational areas. In such conditions, the machines can be placed, for example, behind natural barriers, so that the noise is buffered, and operation can be avoided in early mornings, evenings and at weekends.

Dust and mould

Earlier studies have indicated high levels of dust and mould in conjunction with the handling of logging residue. In case studies carried out in 2012/2013, in a period of high precipitation, no high levels of dust and mould were recorded. The studies showed that the highest peaks of exposure occurred when the operator got in and out of the cab, and when changing blades in the comminution machine. Elevated dust levels were also observed when the operator carried out service and maintenance work outside the cab. Operators are recommended to keep windows and door closed, to change air filters regularly, and to place the machine appropriately in relation to wind direction, to reduce the risk of exposure to dust and mould.

Whole-body vibrations

In a smaller study of comminution of logging residue, the level of whole-body vibrations was so high that measures to prevent harm were needed in approximately half of the cases. It was mainly crane movements while feeding residue into the chipper that affected vibration levels.

Harmful vibration levels have been recorded in connection with stump harvest. In these cases, the vibration levels were affected by ground conditions in the form of surface structure and bearing capacity, and how firmly the stumps were fixed in the ground. Exposure peaks also occur when stumps are shaken, when the cab rotates, and when the harvester head is used to push stumps along the ground or to even out the ground. The operator can reduce vibration levels by adapting operation to the terrain conditions and by synchronising crane handling.

Service an repair

Service and repair work is often heavy, dirty and risky. Good work environment solutions can be created already at the development and manufacture stage of machinery. Important areas to consider are access paths, placement of service points, access for daily inspection, elimination of power sources, and manuals. Operators and service personnel can minimise their risks by reading the service manual carefully, and by using protective equipment, ladders and appropriate tools. It is also important to handle chemicals carefully.

What machine operators think

A questionnaire completed by machine operators showed a high level of use of protective equipment.

Operators who worked with comminution reported more problems than those working with stump harvest and forwarding. The operators experience less discomfort inside the cab than outside in terms of noise, cold and draughts, and dust. More than half of the operators working with comminuted material reported problems caused by various degrees of mould odour.

Overall, the mental workload was experienced as greater than the physical.

Most of the operators reported a risk of accidents in their work, the most common being cuts and slipping, followed by falling.

Information material for better work environment

In order to disseminate knowledge about work environment issues, a module-based implementation material in the form of PowerPoint slides with associated instructions has been developed. The modules are Purchasing, Planning, Forwarding, Stump Harvest, Comminution, and Development/Manufacture. The material is available at www.du.se/arbetsliv_skog

ILLUSTRATION: ANN HEDLUND/DALARNA UNIVERSITY

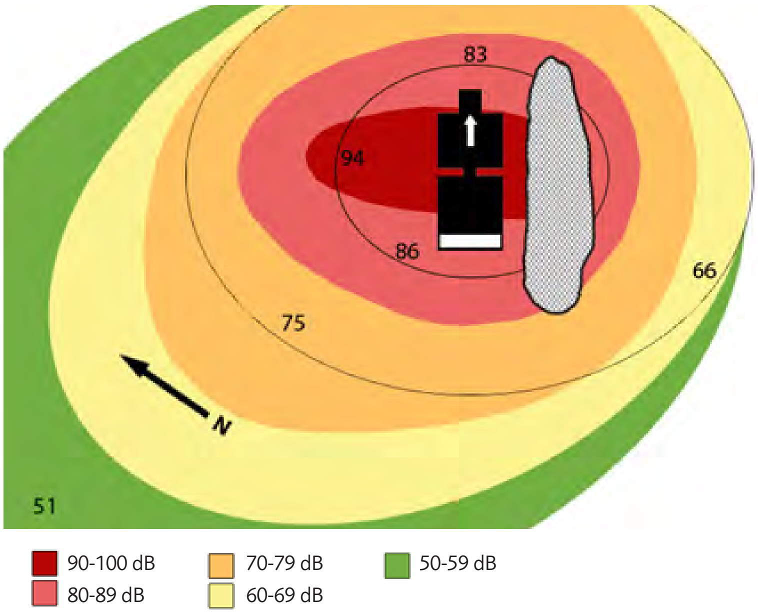


Figure 1. Noise-level contours around a forwarder-mounted chipper. The inner ring is 5 metres from the machine, the outer ring is 25 metres away, and the measurement figure in the bottom left is 200 metres away.

Future work

Further research and development is needed to

1. Reduce
   - noise during comminution
   - vibrations during comminution and stump harvest
   - the number of accidents and severe injuries, particularly during service and repair.
2. Identift the causes of high mental workload, and use organisational and other measures to enable improvements to the work situation.
3. Generate more knowledge about work environment conditions in stump harvest.

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.

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.

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.

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

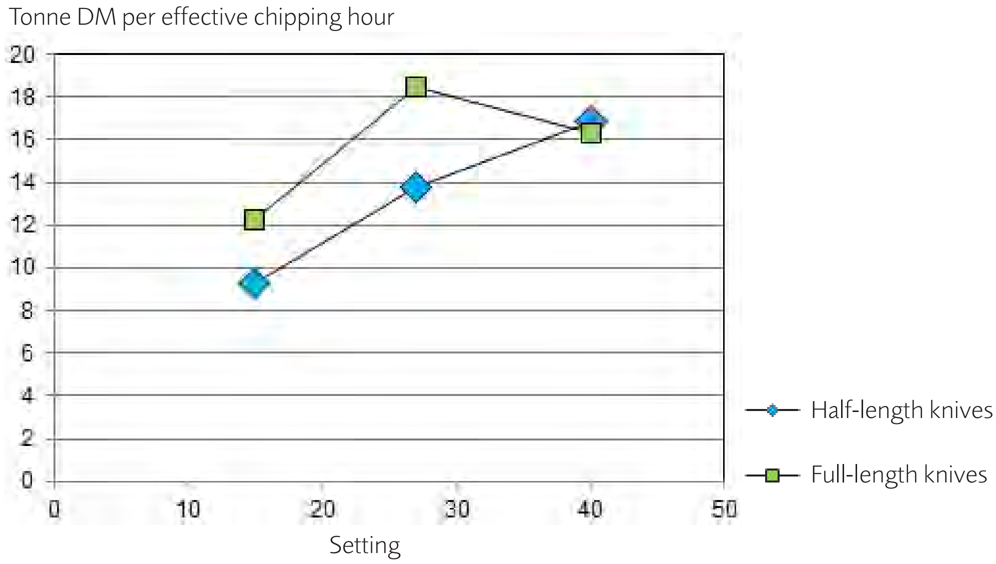


Figure 1. Effects of setting and choice of knives on performance of a small drum chipper, tonne DM per effective chipping hour.

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.

Transport accounts for nearly 30 percent of the costs of handling forest fuel up to the point of delivery to the end customer. Since a landowner's net income from forest fuels is, at best, low, reducing transport costs can increase the viability of harvesting forest fuel in much of Sweden, and also increase the use of renewable energy. However, if this is to be attained, the entire logistics chain must be efficient.

FOREST FUEL LOGISTICS
– EFFICIENT TRANSPORTS

Johanna Enström, Skogforsk

Forest fuel logistics covers everything from technical issues like side shields when transporting partly delimbed energy wood to complex issues like location bartering and transport management. Terminals and storage also affect both costs and product quality. All parties involved in logistics and storage must collaborate in the work to improve technology, methods and logistical tools.

Higher payloads

Three 74-tonne chip trucks have been studied in the ESS programme. The vehicles are also part of the ETT (One More Stack) project, and all three vehicles were commissioned in 2014. They are 25.25-metre side-tipping truck and trailer combinations that hold approximately 150 m3 and have a legal payload of almost 50 tonnes. The potential fuel saving for 74-tonne trucks is 10-13 percent compared with conventional 60-tonne vehicles. To realise this potential, a high load utilisation is needed, which has been attained so far. The next stage is to lengthen one of the chip trucks to 33.7 m (gross weight 98 tonnes) by connecting a link between the truck and trailer. A new research project to test and evaluate this is under way.

In addition to these three chip trucks, a chipper truck system is being tested in which a 32-tonne chipper truck with a 42-tonne trailer works in collaboration with a 74-tonne chip truck configured as above. Trailers are exchanged at the landing, so the chipper truck is mainly used for chipping, with only occasional trips to heating plants, while the chip truck does most of the transport. Compared to a conventional chipper truck, the increased gross weight enables the use of a powerful chipper on the truck, without sacrificing any transport capacity because of the larger trailer.


MVB
MVB

Chipping with a 74-tonne rig.

Up to now, permits have only been issued for heavier trucks in research projects, but the Swedish Government is monitoring developments and, as a first step, a 64-tonne gross weight has been permitted since 1 June 2015.

The issue of gross vehicle weights is under discussion in many parts of the world. In southern Europe, there is opposition to large trucks, but even there the issue is being discussed. Examples of countries that have recently increased gross vehicle weights are Norway (60 tonnes) and Finland (76 tonnes), and 60-tonne vehicles are also being tested in the Netherlands, Germany and Denmark.

Side shields for safe transport of partly delimbed energy wood

Tree sections and partly delimbed energy wood present a challenge for transport. These assortments make it difficult to attain a high payload, and material can fall off if an ordinary timber truck with stakes is used. As a possible solution, light metal side shields were tested; these could be easily fitted to and removed from the stakes on a timber truck.

The shields did not increase payloads, but road safety was improved. As loading and load securing proved to be faster with the side shields, the conclusion was that their use was worthwhile over short transport distances.

Bartering of forest fuel

Today, forestry companies commonly barter pulpwood and timber, to match supplies with customer requirements and reduce transport distance. As yet, the practice has not been so common for forest fuel, but a simulation of the supply in Mälardalen has shown great potential. Average transport distance could be reduced by 3-15 percent if companies could freely barter forest fuel with one another. One obstacle is that it is difficult to objectively describe the value and quality of the stored forest fuel assortments – the parties know what they have but not what they will receive.

System optimisation

In order to simplify the choice of system for comminution and transport, a web-based analysis tool, Opium, has been developed by Creative Optimization Sweden AB. In the tool, the user selects point of delivery, terminals available for load transfer and onward transport, and sees which assortments and comminution and transport systems are available. The optimal system selection and destination of the forest fuel is presented simply and clearly on a map. The tool is free to use, and is available from http://opium.creativeoptimization.se/

Intermodal transports

A major project run at the University of Gothenburg has examined the possibilities for intermodal transports of biofuel, i.e. transport using the same container on both truck and train; this can also apply to ship transport. No economic gains were found when handling biofuel in the same container from forest to industry gate using trucks and trains. However, the study did show the importance of choosing the right terminal to create a successful transport chain and minimising the number of handling stages in a supply chain that includes both road and rail transport.

Karttunen et al. (2013) are more positive about the possibility of transporting forest fuel in a single load carrier. However, the study is based on an innovation, a composite container with associated unloading rig, which is not yet on the market. The composite container has been shown to effectively prevent the chips from freezing to the floor and walls of the container, which is otherwise a problem when the material is stored in a container for some time.

The problem of chips freezing to container walls during transports on trucks has also been examined in the ESS programme, but no clear answer could be found about how to treat the containers to prevent the problem. Today, most chip trucks and chip trailers have composite floors and walls, as this reduces the kerb weight of the vehicle. As a side effect there is no problem with chips freezing on to either the floor or the walls. As the same materials are used in composite containers, introducing this type of container could improve transports if they can be made durable enough.

Terminals

Correct location is the most critical factor for a successful forest fuel terminal, according to an interview study. Terminals, particularly railway terminals, must be sited in areas where large volumes of fuel are produced, and a location near the forest also allows the terminal to be placed away from built-up areas. High material turnover is also important, and good measurement facilities. Service, flexibility, skills, orderly layout, and smooth-running terminal logistics were also emphasised as strengths.

A company owning its own terminal can have a competitive advantage, but a commercial terminal may be more cost effective because of coordination gains, such as increased use of measurement facilities and the possibility of return loads.

A geographical analysis showed that 95 percent of Sweden's logging residue and stump volumes is located within the catchment areas of existing terminals, and 65 percent is within the catchment area of existing railway terminals. Many catchment areas overlap, suggesting there are too many terminals in some parts of the country, while other parts of the country lack terminals.

Approximately 30 percent of forest fuel in Sweden passes through some kind of terminal. Many terminals are small, and over half the volume passes through terminals that are smaller than two hectares. Standardised measurement takes place at only half of these small terminals, and at even fewer of the medium-sized terminals. This is a challenge for the sector now that the new Swedish Timber Measurement Act has come into effect.

Storage

Storing chips at a terminal entails a risk that the chipped material can become remoistened and biomass may also be lost. Another risk is fire because of heat generation. The risks increase as the proportion of fine fractions increases, so it is important not to comminute the chips into finer fractions than necessary.

The irregular demand for forest fuels results in an uneven utilisation of comminution equipment, which increases costs. Efficient storage of chips could be a way to even out machine utilisation, thereby reducing comminution costs. A study examined whether covering piles of chips with a semi-permeable cloth can protect against remoistening. Half of a 6.5-metre pile of chips was covered with this cloth, which prevented the chips becoming remoistened by precipitation but allowed water vapour to escape. After seven months of storage, the chips in the covered part were drier and had a higher heating value than the chips in the uncovered part. Substance losses were also lower in the covered half.

Ship transport and port logistics

Is it economically viable to transport forest fuel by ship from northern Sweden to Mälardalen in central Sweden? A cost estimate transporting chips by ship between Umeå and Stockholm showed a cost for transport, handling and storage in the ports of SEK 83 per MWh. The ship transport accounted for 71 percent of this cost. This is a high cost in relation to the energy price of forest chips at the user, which was approximately SEK 190 per MWh in 2014. Despite the cost, some large users must still receive forest fuel by train or ship, but it is highly probable that railway solutions can be found that are cheaper than ship transport.

The study included interviews with personnel from ports, shippers and dock companies, where the representatives were asked about which factors are important for ship transport. For the customer, the most important are opening hours, unloading capacity, and that ships can be accommodated at short notice.

Normally, some type of material handler with a knuckle boom loader is used in the ports, often with a clamshell bucket or orange peel bucket specially designed for chips. This is a technology that could also be interesting for rail transports.

MORE EFFICIENT CHIP TRUCKS
– IMPORTANT FOR FOREST FUEL

Johanna Enström & Henrik von Hofsten, Skogforsk

Currently, three chip trucks with a gross vehicle weight of 74 tonnes instead of the usual 60 are being evaluated in commercial operations. Skogforsk is monitoring fuel consumption and load utilisation, and practical experiences relating to the vehicles are being compiled. Operations were monitored over two winter months, and here we present the results.

Heavier and longer trucks have been studied for approximately seven years in Sweden. Much of the research has taken place within the ETT (One More Stack) project. Studies have shown that fuel consumption per tonne km for a 74-tonne roundwood truck without crane is nearly 13 percent less compared with a corresponding 60-tonne truck. Cost savings are around 10 percent, but this potential can only be realised if full payloads can be utilised. However, volume capacity is also important for dry forest fuel assortments. In Sweden, trials are currently under way involving 17 roundwood trucks and 8 chip trucks that exceed current weight or length restrictions.

The 74-tonne vehicles are no longer than today's maximum length of 25.25 m, and have a maximum payload of 49 to 50 tonnes. Their road-handling properties are as good as those for new 60-tonne vehicles, for example in terms of braking distance. Consequently, there are no road safety issues, and road wear is not increased because the weight is distributed over nine axles instead of seven. Problems can arise with bridges, where the gross vehicle weight is the limiting factor. The Swedish Transport Administration has identified a road network, mainly comprising European motorways, in which all bridges can support 74-tonne vehicles. At present, this road network does not include all the roads on which the test vehicles are operating, but the Swedish Transport Administration is working to extend the network.

The introduction of heavier (and longer) vehicles is very much a political issue. It is therefore important that research results are disseminated to decision-makers, so that they can be implemented. The Swedish government has permitted 64-tonne vehicles with seven axles since 1 June 2015, while tests involving 74-tonne, 90-tonne, and even longer and heavier vehicles will continue.

PHOTO: ANDREAS LINDHOLM/SÖDRA

Three vehicles – three different conditions

The three 74-tonne vehicles in the study were all commissioned in 2014. They are side-tipping trucks that hold approximately 150 m³ and are 25.25 metres long. They are in principle identical, but have been driven under different conditions, so the results are not directly comparable. All three vehicles run completely or partially on RME (rapeseed methyl ester), depending on local access to filling facilities. Unfortunately, there have been a number of problems relating to clogged fuel filters; as a result, the Södra vehicle has reverted to normal diesel fuel until new filter types have been developed. This problem is not specific to 74-tonne vehicles.

Ove Lindkvist Transport (Foria) transports forest chips for Söderenergi between the railway terminal in Nykvarn and the Igelsta combined heat and power plant in Södertälje. This is a distance of 20 km, of which half is on motorway and the other half includes three roundabouts and just as many junctions. The proportion of time for loading is relatively high, due to the short distance. Weighing takes place at the terminal, and the vehicle can generally be filled with sufficiently heavy material to attain a full payload. The truck transport comprises the final part of a railway system, where forest chips are brought to the terminal by train from various parts of Sweden. Because the truck runs as a shuttle between the terminal and the heating plant, the loaded distance, i.e. the proportion of total driving distance in which the vehicle is loaded, is around 50 percent.

Södra Eget Åkeri operates a 74-tonne vehicle in its ordinary transport operations in south-east Sweden, which involves various types of transports between Södra's industrial plants. The truck is mainly used to transport bark, chips, pulp bales and sawn timber. Like the haulier's other vehicles, the 74-tonne truck is driven on a specific route. Loaded distance is 68 percent, which can be regarded as very high.

Kent Åkerströms transport, a member company in Dalafrakt, operates a 74-tonne vehicle for transporting various assortments between Stora Enso's industrial plants in northern Svealand and Bergslagen, where the geography is different to that in southern Sweden. The haulier actively tries to find return transports, which has increased loaded distance to 67 percent.

Table 1. Fuel consumption of each vehicle per transported tonne and kilometre. Load utilisation, loaded distance, and mean transport distance all affect fuel consumption.

	Fuel consumption, (ml/tonne km)	Load utilisation, %	Loaded distance, %	Mean transport distance with load, km
Lindkvist Transport	31.6	97	50	22
Södra Eget åkeri	18.5	95	68	148
Åkerströms åkeri	17.3	98	67	176

Fuel consumption data is retrieved directly from the computer in each vehicle through the Scania Fleet management system. In order to calculate fuel consumption per transported tonne, the driver records the weight for each trip. Skogforsk then compiles all the data.

Fuel consumption for the Södra and Åkerströms vehicles is very low compared to other vehicles in the ETT project. The hauliers are careful not to overload, as overload fines are high, so we regard average load utilisation figures of 95-98 percent as very good. The large difference in fuel consumption between Lindkvist and the others is not at all surprising in view of the different conditions in terms of transport distance and loaded distance. Instead, it illustrates the importance of not comparing apples with pears. Other differences that may have affected the result are the varying length of follow-up period between vehicles, as well as the proportion of RME and diesel fuel used.

In practical operation, the 74-tonne vehicles have performed very well. Because of a rather different axle configuration, brought about by the extra axles, these rigs are actually more flexible and provide better road handling in cramped situations than the corresponding 60-tonne vehicles. The regulations regarding axle distance in the EU module system contribute to the good road handling, but this also means that the rear overhang of the trailer is rather large, so there is some risk of overload on the rear axles.

The vehicles are built according to the European module system (EMS) with truck, dolly and trailer. This makes it possible to insert a link between the dolly and the trailer and extend the vehicle to 34 metres. Already from the start of the project, there were plans to do so with the Lindkvist chip truck. The vehicle would then weigh 98 tonnes, distributed over 12 axles, and the load volume would be over 200 m³. A project involving such a trial, financed by Vinnova, is currently in the starting blocks.

In a transport chain, it is important to work with every part in order to ensure efficiency in the chain as a whole. At Söderenergi, for example, trains have been lengthened by adding more wagons, and the efficiency of truck transport from the railway terminal to the Igelsta CHP plant has been improved by using the 74-tonne vehicle.

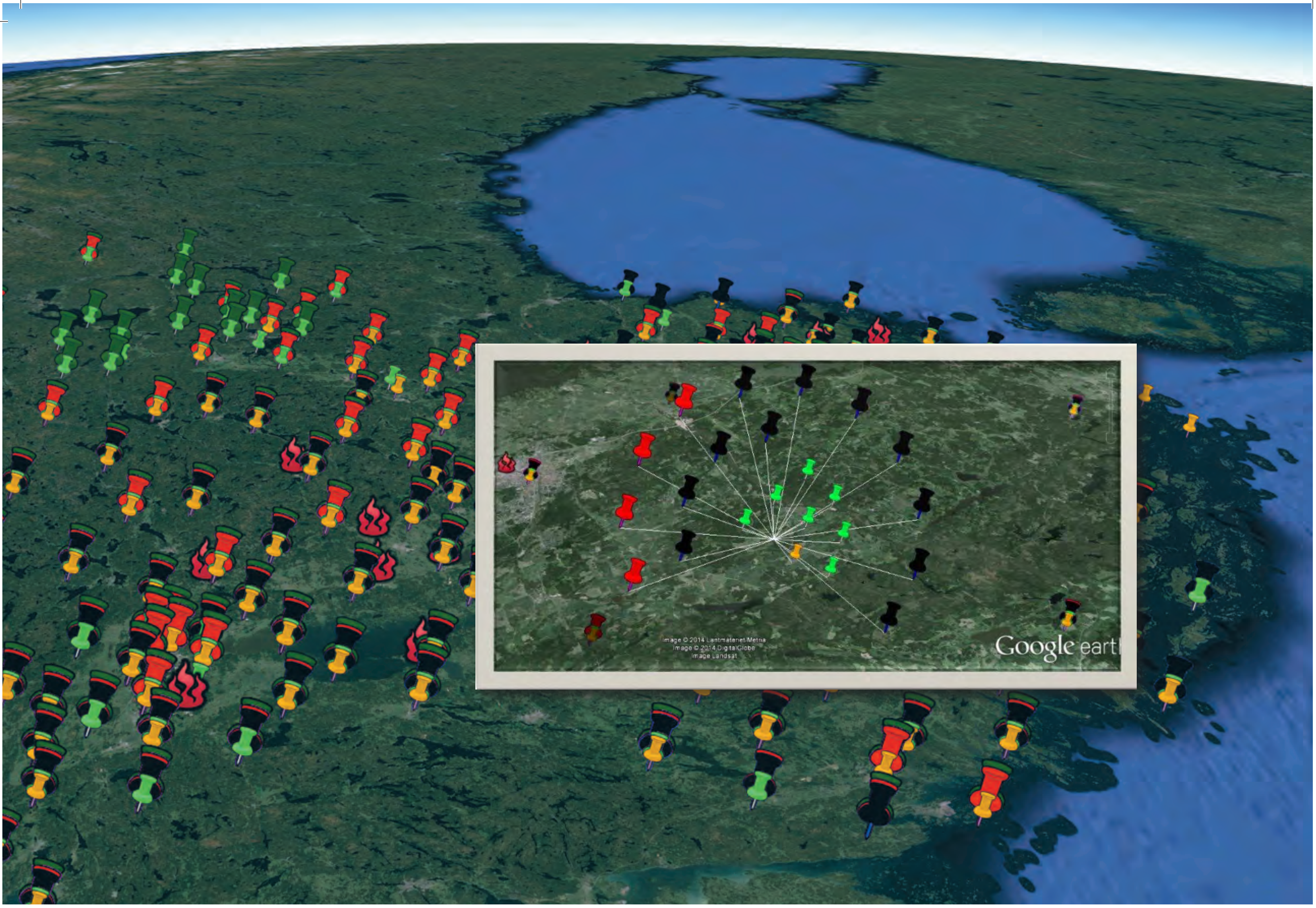
In many cases, truck transport is the only alternative. Working to improve efficiency through active planning of return transports is very beneficial, as can be seen clearly in fuel consumption per tonne km for the 74-tonne rigs operated by Södra Eget åkeri and Åkerströms åkeri. Greater load capacity is then one of several important contributions to efficient and sustainable transports.

Future work

- Improving the efficiency of transport now includes a project investigating a 98-tonne vehicle for Söderenergi.
- Skogforsk is helping the Swedish Transport Administration to identify important routes on which the forestry sector could introduce 74-tonne vehicles. This will give guidance about where to start upgrading sub-standard bridgesr.
- Wear and total economy regarding 74-tonne vehicles should be followed up until the vehicles are replaced.
- The Swedish Transport Administration HCT programme is also conducting important research involving longer and heavier trucks. The research ranges from effect on road wear to system effects of longer and heavier trucks. Skogforsk's ETT project will continue until 2016.

"Ship and train are always our primary transport modes, but we must always use trucks for the final stage from the railway terminal. Consequently, more efficient trucks benefit society as a whole – the natural environment, the traffic environment and the competitiveness of industry all benefit."

Olle Ankarling, fuel manager at Söderenergi.



LOCATION BARTER CAN IMPROVE EFFICIENCY OF CHIP TRANSPORTS

Petrus Jönsson, Johanna Enström, Lars Eliasson & Rolf Björheden, Skogforsk

In Mälardalen, efficiency of chip transport could be improved by approximately 12-15 percent if hauliers bartered biofuel volumes with each other. This is shown by simulating biomass supply in an area characterised by a large number of heating plants and many fuel producers with overlapping areas of activity.

Chips are mainly delivered by truck, and transport accounts for approximately 20 to 30 percent of the total forest fuel supply cost. For timber and pulpwood, a relatively common procedure is location barter, where forestry companies barter volumes of the same assortment with each other to reduce transport costs. One of the benefits is that the number of return transports can be increased.

Up to now, location barter has not been applied to any great extent for forest fuels. In order to investigate the potential, an analysis was carried out using data from SDC. The study involved 42 heating plants, five hauliers, and 4500 landings with GPS coordinates. The total demand of the heating plants was approximately 1.75 million tonnes DM/year.

The first step in the analysis involved calculating the mean transport distance for the actual transports from landings to the heating plants during the study period. This was followed by two different simulations. The first involved both internal and external destination, which means that the exchanges could take place both within a company and between companies. This was followed by a simulation where only external destination was allowed. In this, no location barter within a company were permitted – all bartering must involve two different companies.

Table 1. Number of transports and mean transport distance for the five companies. The table also shows potentials for reducing mean transport distances with internal and external destination.

Company	Number of transports per year	Mean transport distance, km	Reduction in transport distance with internal destination, %	Reduction in transport distance with external destination, %
A	6157	54.5	12	6
B	2759	54.7	11	12
C	6500	56.6	15	5
D	7276	48.4	12	9
E	545	82.8	2	3

In the model 'pure' exchanges on a one-for-one volume basis were assumed, as the aim of the analysis was only to investigate the potential for location barter. In reality, moisture content and quality of wood chips affect the value of the chips, and must be taken into account in bartering.

The analysis shows great potential for location barter, as shown in Table 1. Seen over the whole year, between 9 and 24 percent of transports could be bartered, with the level depending on the company. Total transport distance could be reduced by 10-15 percent if the hauliers could freely barter biofuel volumes with each other.

Interviews

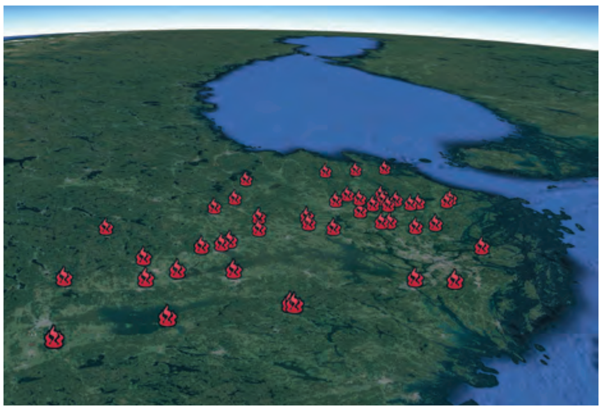
We also asked four forestry companies operating in central Sweden for their views on forest fuel barter. The interviews showed that three of these had already tested some sort of location barter. This did not involve bartering as such – instead it involved purchasing material from one another. However, because many of the deals are made with the aim of reducing transports, we can still regard this as location barter.

There are two possible ways in which location barter can take place. When companies barter forest fuel, ownership is eiter transferred at the landing, and the company acquiring the forest fuel becomes responsible for chipping and/or transport; or ownership is transferred at the point of measurement, i.e. the selling companies haulier delivers material to the customer on the basis of the companies acquiring agreement with the customer.

In the first case, there may be problems if the landowner does not approve the arrangement while, in the second, the customer's approval is normally required. Most forestry companies expressing their views on bartering forest fuel said that they preferred delivering on the basis of each other's agreements, but both approaches are used.he company´s Uncertainty about what is being traded was taken up as a major problem by all the companies in the survey. The product and its quality are poorly defined and, unlike pulpwood, there are no fixed pricelists for forest fuel, which increases sensitivity in the transaction. Within ESS, work has been carried out to define standardised fuel assortments (see page 14), and standardised product descriptions are needed to provide good conditions for location barter

Future work

- A theoretical potential of 10-15 percent reduction in transport costs raises the issue of whether the sector can afford not to continue investigating the concept of location barter.
- Location barter of forest fuel can reduce transport costs, and a pilot project to investigate this could involve interested companies. Here, Skogforsk could act as coordinator, and provide an analysis that indicates flows where the companies could benefit from bartering.
- A clear description of products would reduce the risks for companies that barter forest fuel volumes. The work must be carried out in parallel.



The small fire symbols represent the heating plants in the analysis. The pins in the larger diagram on page 106 show the landings of the different forestry companies.

OPTIMISED COMMINUTION AND TRANSPORT

Mikael Frisk, Mikael Rönnqvist, Patrik Flisberg & David Bredström, Creative Optimization

A correct choice of method for comminution and transport of forest fuels is important for profitability in the supply chain. The choice is not always self-evident, because it depends on various factors, including distance between forest and heating plant. The best method also varies between assortments, and can depend on where comminution takes place and the mode of transport.

Determining which comminution/transport system is most cost-effective at a certain distance is a relatively simple calculation, providing sufficient data is available about the costs. However, determining which system is best for many different distances simultaneously requires detailed knowledge about the road network, a correct calculation of the best route option, and calculation of distances between forest, terminal and industry. If the results are to be shown in map form, in order to quickly gain an impression of which combination of comminution equipment and transport vehicles is most cost-effective in different locations, a tool is required to visualise the results.

The web-based analysis tool, Opium, developed by Creative Optimization Sweden AB with support from ESS, is a decision-support tool that helps the user to quickly gain an overview of which system alternatives are most cost-effective for a selected delivery point.

Opium is designed so that the user can steer the calculations by making six simple choices:

1. State the delivery point to which the calculation applies, either choosing from a drop-down list or by clicking on the map.
2. Select whether the calculation is to consider terminal handling, either for comminution and reloading to another vehicle, or just for reloading to another truck or train.
3. Select the unit and moisture content to be used when presenting the result. The default unit is m³ loose and normal moisture content.
4. State the assortment, logging residue or energy wood, and system alternatives available (combination of comminution equipment and transport vehicle). There are five possible system alternatives per assortment, and one of them includes transport by rail where possible.
5. Set a cost profile. Here, the user can either choose default values or enter their own values so that the calculation corresponds to the user's actual costs for different system alternatives.
6. State whether the calculation is to limit transport distance and/or total cost. For example, the user can specify that areas from which it is more expensive to deliver forest fuel than a given maximum total cost are not shown on the map. The same applies for maximum transport distance.

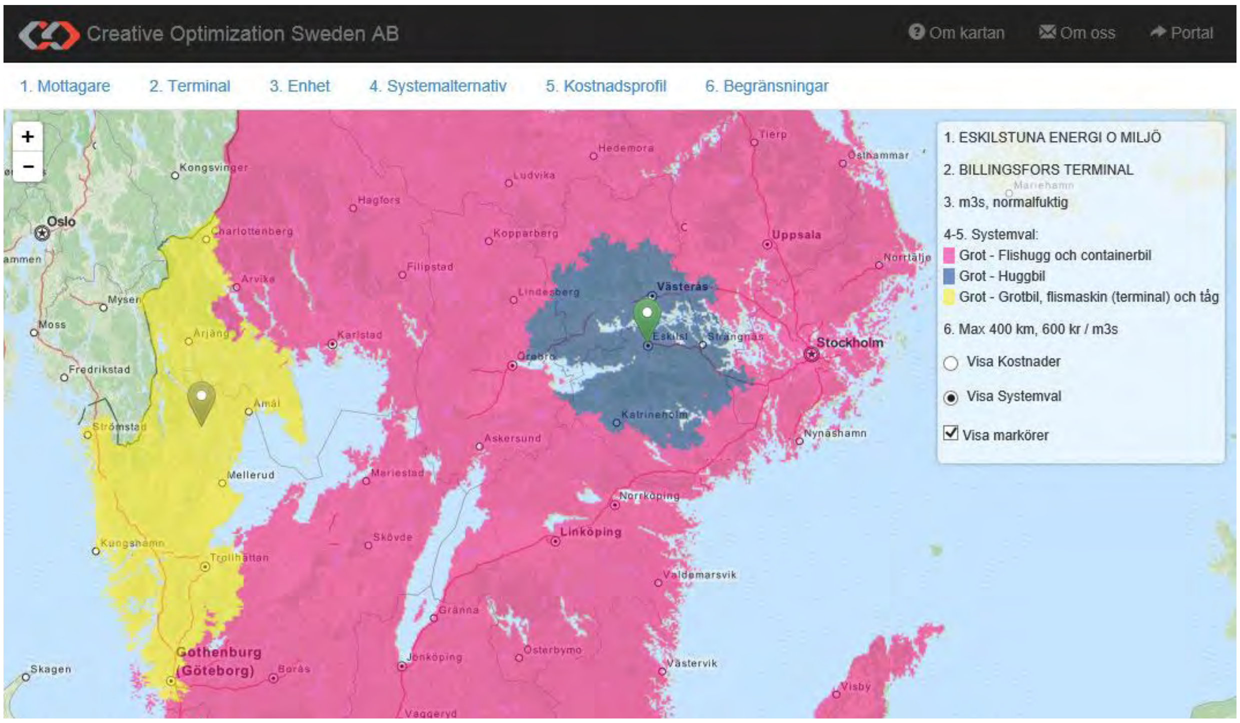
The result is presented in two ways: 1) the relationship between the lowest cost in a certain location and the user-defined maximum total cost, shown in the form of a colour scale (green corresponds to 0-25 percent of the maximum cost, blue 25-50 percent, purple 50-75 percent, and red 75-100 percent); 2) colours showing which system alternative is the most cost-effective.

An information box on the map shows the choices the user has made. To obtain the exact costs for a certain location, the user can click on the map, which brings up an information box with transport distance and cost to a selected delivery point and terminal.

Opium includes 189 delivery points and 174 terminals. At 19 of the terminals, material can be transferred from truck to train. Rail transport is possible to 19 different delivery points.

In order to calculate correct transport distance, a grid of 5-km squares was placed over Sweden. From the centre point of each square, the distance to all delivery points and terminals is calculated using the SNVDB and the route selection function Krönt Vägval 2.0. Rail transport is calculated as the shortest route by rail from the terminal to the delivery point.

The tool is free to use, and is available at: http://opium.creativeoptimization.se/



SHIP TRANSPORT OF FOREST FUEL

Johanna Enström, Skogforsk

The market for forest fuel has decreased in recent years, but new biofuel-powered combined heat and power plants and new bio-based products are expected to generate greater demand in the future. This could greatly increase the need for long-distance transport. Up to now, long-distance transport has mainly involved rail transport, while imported material (largely recycled wood) has been transported by ship. Between 2016 and 2018, two large combined heat and power plants are expected to become operational in Mälardalen with a total demand of 4-5 TWh of biomass.

A pilot study was carried out to examine the possibilities for using coastal maritime vessels for transports of wood chips from northern Sweden to Lake Mälardalen in central Sweden. The aim was to describe current cost levels for ship transport and storage, loading and unloading of wood chips. We have also compiled examples of 'best practice' for ship transport and cargo handling in ports under Swedish conditions.

Interviews were held with representatives of four Swedish ports with experience of handing wood-based fuels, as well as purchasers of maritime transports, shipping agents and dock companies.

Handling

Today, chips are not shipped from Swedish ports. This project examined the situation in Estonia, where sawmill chips are loaded with a material handler. A bottleneck in

Loading of sawmill chips in Kunda, Estonia.

the loading operation was transport of the material by truck from the storage site to the quay. This delayed the work of the material handler, as it had to wait for material.

Material handlers are generally used for loading and unloading chips. Some contractors prefer an orange peel bucket for unloading on the quayside, as this type can more easily dig down into the tightly-packed chips. For loading or unloading directly from or to a vehicle, a clamshell bucket may be more suitable, as it reduces waste and can more easily pick up the final material in the pile. As far as possible, chips are unloaded directly from the ship to a truck but, when no truck is available, the chips are stacked on the ground instead. A wheel loader can then move the material. Handling systems vary greatly between ports.

Harbour cranes generally have a high level of utilisation, and various accessories are used for different types of cargo. Effective productivity of approximately 180 tonnes per hour for loading, and 140 tonnes per hour for unloading, was assumed in the analysis (calculated over one shift, including downtime). These figures are relatively high, but not unrealistic for a large crane or a large material handler.

The ports included in the study all have limited loading space on the quay, but offer customers storage a short distance away. Truck transport is usually required between the storage area and the quay. In Swedish ports, there is generally access to measuring facilities, and VMF wood measurement officials are commissioned either directly by the customer or are available on request. Large combined heat and power plants with their own harbours may have various types of permanent solutions, and new measurement technologies for large facilities are under development.

Customer requirements of a port

The unloading capacity in the harbours is crucial, and is affected by the port's opening hours, as unloading and loading generally take longer than one shift. If the port is not open 24 hours a day, and the ship cannot be completely loaded or unloaded during opening hours, costs can quickly escalate, as the ship stands idle until next day. Most ports promise a certain unloading capacity, but the figures they state are not necessarily binding. Specific requirements apply for ports in the Stockholm area, where, in particular, limits on noise levels are a challenge. For other ports, the following factors were mentioned as being important:

- Working hours.
- Unloading capacity (linked to working hours).
- Flexibility, the ability to adapt operations and accommodate ships quickly to prevent waiting time.
- Safe storage of the chips on an asphalt surface.
- Correct and proper compaction in the port of loading. Certain equipment is needed, such as a sufficiently powerful crane to lift a smaller machine onto the ship.
- Surveillance of the chips, visually and using temperature measurements.
- Separation from other players.
- Possibility for sampling the loads. When wood products are imported, Swedish Board of Agriculture requirements must be met (for example, to prevent entry of insects).
- Good infrastructure for road transports.
- The ice situation in the port. It is cheaper to transport material in the summer.

Material handler with orange peel bucket unloading chips in Hargshamn.

Cost

A rough estimate of the cost of transporting chips by ship between Umeå and Stockholm (no entry to Lake Mälaren) is presented in Table 1. All costs in the example are conservative estimates. For example, no extra costs are included for overtime work. In the calculations of ship transport costs – by far the biggest cost – it is assumed that a return load is available. Larger vessels offer normally more efficient and cheaper transport, but the large loads require extensive storage areas close to the port. Loading also involves several shifts, which can entail added costs for overtime and/or compensation for night work or downtime for the vessel. In the Baltic Sea, bulk vessels where capacity exceeds approximately 12,000 m³. are uncommon.

Table 1. Cost example for a chips transport from Umeå to Stockholm

Storage 1 month on asphalt	2,92	SEK/m^3	3.59	SEK/MWh
Dock handling, loading	15	SEK/tonne	6	SEK/MWh
Dock handling, unloading	9	SEK/tonne	3.6	SEK/MWh
Loading with crane	12.2	SEK/tonne	4.9	SEK/MWh
Unloading with crane	15.7	SEK/tonne	6.3	SEK/MWh
Ship transport*	56.7	SEK/m^3	59	SEK/MWh
Total			**83.39**	SEK/MWh

*) Cost estimated by an experienced shipping agent.

The port of Stora Vika has invested in an electrical harbour crane, and harbour manager Milan Tomich is very satisfied. "Because it's run on electricity, the crane is much quieter, which is important for us, as people living nearby have previously complained about noise. The cable can be a problem, but since we were able to specify the machine to 690 V (instead of the standard 450 V), the cable is relatively thin, which makes things easier."

Average cost for purchase and production of logging residue chips in Sweden in 2013 was approximately SEK 209/MWh (page 37). However, we assume that transport from the forest to the port of loading is SEK 24/MWh, i.e. half of the average total transport cost from forest to industry gate due to a shorter transport distance on road. The total cost for chips transported from Umeå to Stockholm including ship transport will then be SEK 268/MWh. As the energy price of forest chips at the user in 2013 was approximately SEK 199/MWh (Swedish Energy Agency), it is clearly not viable to transport the chips from Umeå by ship.

However, the example does not provide a full picture. Using only locally sourced forest fuels is often not an option for large combined heat and power plants in the Mälardalen region because supply does not meet demand. The use of trucks and trains may be limited, and if a proportion must be transported by ship, the Swedish forestry sector must instead be able to match other imported biomass-based raw materials on price. Here, it can be pointed out that maritime transport of wood chips from Riga to the UK is in a similar price class to that of transport between Umeå and Stockholm. A heating plant that can accept rail deliveries of forest fuel can probably find a transport option from northern Sweden that is considerably cheaper than sending the material by ship.

The costs were estimated before the new sulphur regulations came into effect in January 2015. However, the new regulations coincided with a historically low oil price, so low-sulphur fuel is cheaper today than the price of fuel with a higher sulphur content was in 2013. There is still a certain competitive disadvantage in relation to maritime transport using cheaper fuel, but the significance of the fuel for the total cost has nevertheless fallen. This means that the transition to low-sulphur fuel for Swedish maritime shipping has been less dramatic than expected.

INVEST IN THE RIGHT FUEL TERMINALS

Johanna Enström & Örjan Grönlund, Skogforsk
Dimitris Athanassiadis & Mikael Öhman, SLU

No less than 95 percent of Sweden's logging residue volumes and stumps is located within the catchment areas of forest fuel terminals. There is little need for new terminals, but the new regulations regarding measurement of forest fuel assortments make it important to choose which terminals to invest in.

Many forestry companies are reviewing their terminal structure, for example by conducting flow analyses with the Skogforsk software, FlowOpt. In collaboration with SLU, Skogforsk has carried out a study that will supplement the companies' own analyses.

The project focused on three issues:

1. What factors lie behind successful establishment of terminals??
2. How do forestry companies look upon their ownership of terminals? When is it advantageous to own a terminal, and when is it better to use a commercially operated terminal?
3. Are more terminals needed and, if so, where?

Criteria for successful investment in terminals

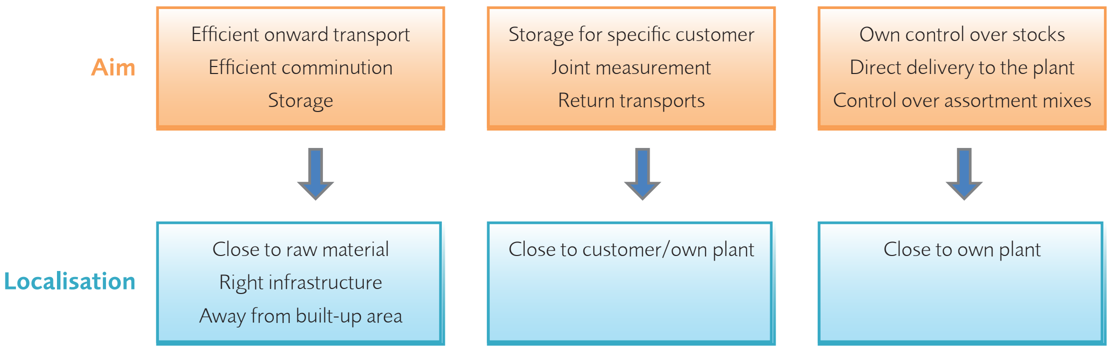
Literature studies enabled us to map important factors for terminal establishments. These factors were investigated in more detail through qualitative interviews with five representatives from forestry companies, four from energy companies, and four from logistics companies that run independent terminals. We were also looking for examples of 'best practice', so each company gave examples of successful terminal establishment.

According to all interviewees, the most important success factor was location. However, strategies for deciding on the location of a terminal varied according to its purpose. Figure 1 shows the different strategies.

Other important factors were:

- **Volume**. A large terminal for forest fuel stores 50,000-100,000 m³ of chips over the course of the year. For a railway terminal, with costly investments in tracks, it is not enough to store such volumes seasonally; turnover must be several times per year.
- **Measurement facilities**. The planned flow should tolerate an investment in, for example, scales, possibly in collaboration with other players.

Figure 1.



- **An asphalt surface for handling chips** is positive, on condition that the customer is prepared to contribute to the investment or that such an investment is required to win the contract.
- **Skilled personnel with focus on the customer**. Service-minded and flexible personnel, capable of carrying out various types of work at the terminal, are required. Flexibility towards the customers was an issue mainly raised by the logistics companies.
- **An orderly site and terminal logistics**. When the drivers can find their way around easily, internal handling is reduced. Some of the terminals have clear signs, so drivers could easily find their way to the correct area on the site. It is also important to plan the area so that the material is accessible for loading.
- **Commitment**. A committed project leader is needed in order to maintain momentum in the often lengthy process of establishing a new terminal.

Own terminal or collaborate with other companies?

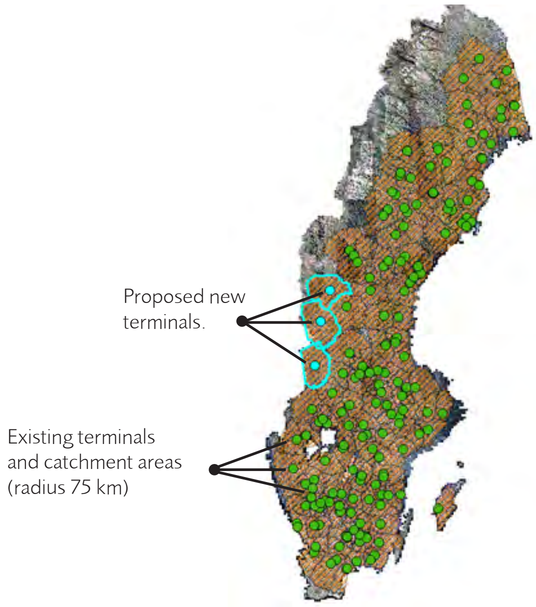
Many terminals are situated close together, and have overlapping catchment areas. There should be great opportunities for collaboration, such as by shared ownership of measuring equipment. Combining terminals to generate coordination benefits may also be justified, or using a commercially operated terminal to avoid committing to a major investment. However, company views vary on the issue of joint use. Several forestry companies feel that logistics is a core activity and a competitive tool they want to control, which may be an obstacle for joint terminals. However, a joint measurement station may be a less controversial solution.

Are more terminals needed?

Because the supply of raw materials is a crucial factor, a geographical analysis was carried out of all terminals used for forest fuel handling, as well as all supplies of logging residue and stumps in Sweden. The aim was to find out whether there were areas that are not covered by the catchment areas of existing terminals. A separate analysis was carried out for terminals located within a kilometre of a railway.

Data on forest resources was retrieved from SKA-VB 08 and data on terminals was taken from SDC's inventory of terminals in 2012. Each terminal was assumed to have a catchment area with a radius of 75 kilometres.


PHOTO: STOCKARYDSTERMINALEN AB



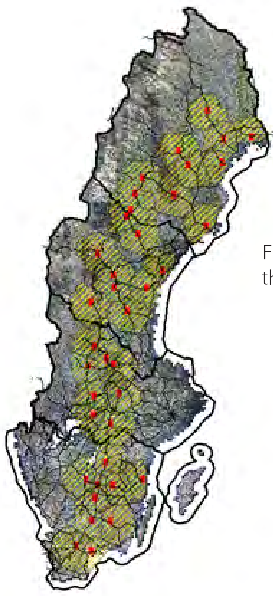


Figure 2. Railway terminals and their catchment areas.

The largest volumes outside catchment areas of existing terminals were found in western Dalarna (Figure 2). However, when other aspects are taken into account, it is not certain that this would be the best location for new terminals. The interviews showed more support for upgrading existing terminals at strategically important locations with appropriate infrastructure. Existing railway terminals capture approximately 65 percent of the available forest fuel, a figure that seems high in view of the small proportion of forest fuel that is transported by rail today. Several of the companies in the study were positive to the idea of using railway terminals.

Future work

- Internal logistics at terminals, and support for these, should be studied further. It is also important to investigate how improving communication in the supply chain can help to improve the efficiency of internal logistics.
- The move towards new bio-based products will probably influence how the forest raw materials will be used and how they should be handled. Terminals may come to play an important role in a diversified flow, and this should be examined in collaboration with the producers of these products.

EFFECT OF COVERING ON LARGE-SCALE STORAGE OF CHIPS

Erik Anerud & Raida Jirjis, SLU
Lars Eliasson & Henrik von Hofsten, Skogforsk

Comminution of forest fuel to chips is an expensive process, partly because of the low machine utilisation caused by the seasonal nature of the activity. One way to reduce costs is to utilise the machines for a longer period and store the chips. This also makes it possible to meet sudden increases in demand. Costs of winter road maintenance can also be reduced, because some of the forest fuel has already been delivered to the terminal.

Storage of chipped forest fuel generates heat, and can lead to spontaneous combustion. A number of studies show that storing chips can lead to high substance and energy losses, higher that when non-comminuted material is stored. However, a moderate heating of the pile is positive, because the material then dries and the effective heating value increases.

One way to minimise the negative effects of storage is to cover the chips with material that prevents precipitation from remoistening the chips, while also allowing water vapour to escape. A number of pilot studies involving the Toptex fibre cloth have shown that fuel quality is preserved and, in certain cases, even improved. Fuel quality and substance losses were studied in large-scale storage of wood chips covered with the Toptex cloth at terminals.

Logging residue chips were placed in a pile approximately 6.5 m high, with an estimated volume of 1450 m³. Half the pile was covered with the Toptex fibre cloth, and the other half was left uncovered. Moisture content, ash content and

temperature were measured at the start of the trial and twice in the period June 2013 to January 2014. Substance losses were also measured.

In the first three months of storage, the moisture content decreased from 51 percent to 48 percent. The reduction was the same in both halves of the pile. After approximately seven months of storage, the moisture content in the covered part of the pile had fallen to 45 percent, while the figure remained unchanged at 48 percent in the uncovered part. The difference in moisture content between the two halves was noticeable from a height of approximately two metres and upwards. After seven months, the moisture content at a height of 4.5 metres was 39.7 percent in the covered half, compared with 54.7 percent in the uncovered part.

Temperature increased at approximately the same rate in the covered and uncovered parts of the pile. In the first month of storage, the temperature increased from 20°C to 64.2°C, and then to 75.1°C in the subsequent three weeks. Substance losses, expressed as the percentage loss of dry matter, were measured after three months of storage to 4.4 percent in the covered part, and 4.2 percent in the uncovered part. After seven months, substance loss was 5.3 percent in the covered part and 7.3 percent in the uncovered part.

If both moisture content and substance losses are considered, the energy content after four months of storage was unchanged, in both halves of the pile. After seven months, energy content remained at the same level in the covered part, but had fallen by seven percent in the uncovered part. This can be an effect of a combination of higher substance losses and unchanged moisture content.

The conclusion is that fuel quality can be improved and energy content preserved if the pile of chips is covered with a ventilating cloth that protects the biomass from precipitation but allows water vapour to escape. The economic calculation depends on three factors: the price of the chips, the total cost of covering, and changes in energy content. As the cloth can be reused several times, covering of piles of chips is probably viable.

PHOTO: ERIK ANERUD/SLU

Future work

- Covering of chips should be tested at a larger scale – one important issue is how many times a cloth can be reused.
- Experience shows that length of storage can be difficult to know in advance, so it can be unclear whether a pile of chips is worth covering. The use of specific planning support for forest fuel storage may increase the possibility of benefiting from covering. Cooperation and communication in the supply chain can also increase predictability. These aspects should be examined in more detail.

FUEL CHARACTERISTICS

Fuel characteristics

Bäfver, L. & Renström, C. 2013. Fraction distribution as a quality parameter of energy wood, from the perspective of combined heat and power plants and heating plants. Skogforsk, Arbetsrapport No. 805.

Fridh, L., Vestlund Ekerby, K., Engberg, M. & Bäfver, L. 2015 Forest fuel product characteristics – Proposal for categories, structure and definitions. Skogforsk, Arbetsrapport No. 873.

ISO. 2014. Solid Biofuels – Fuel specification and classes – part 1: General requirements. SS-EN ISO 17225-1:2014.

Roundwood measurement

Fridh, L. 2013. Quality-assured measurement of energy wood at terminals. Skogforsk, Arbetsrapport No. 794.

Weighing energy wood

Grönlund, Ö. & Iwarsson Wide, M. 2014. Load indicators and weighing devices on load carriers. Skogforsk, Arbetsrapport No. 824.

Iwarsson Wide, M. & Jönsson, P. 2012. Evaluation of crane-mounted weighing systems. Skogforsk, Arbetsrapport No. 770.

Measurement of comminuted material

Nilsson, D., Nylinder, M., Fryk, H. & Nilson, J. 2012. Measuring of fuel chips. The Swedish University of Agricultural Sciences, Department of Forest Products, Report No 21.

Measuring moisture content

Fridh, L. 2012. Evaluation of portable moisture meters. Skogforsk, Arbetsrapport No. 781.

Fridh, L. 2014. Evaluation of the METSO MR Moisture Analyser. Skogforsk, Arbetsrapport No. 832.

Fridh, L. Volpé, S. & Eliasson, L. 2014. An accurate and fast method for moisture content determination, International Journal of Forest Engineering, 25:3, 222-228.

Fridh, L. 2015. Evaluation of the Prediktor Spektron Biomass moisture content analyser. Skogforsk, Arbetsrapport No. 866.

Saw dust collection for estimation at moisture content.

PLANNING AND MANAGEMENT

Good planning – The key to success

Andersson G., Flisberg P., Rönnqvist M. & Åkre, A. 2014. Swedish forestry heading towards increased precision and new value chains, Precision Forestry Symposium, 3-5/3, Stellenbosch, Sydafrika.

Bhuiyan, N., Arlinger, J. & Möller, J.J. 2012. Map support for forwarding of logging residues through export of shape files. Skogforsk, Arbetsrapport No. 764.

Bhuiyan, N. Arlinger J. & Möller, J.J. 2013. Quality assurance of calculation results from hprCM and conversion of prifi les to hpr files. 24. Skogforsk, Arbetsrapport No. 788.

Björheden, R., Grönlund, Ö. & Lundström, H. 2013. Does it pay to cover forest residue piles? Effect of tarpaulin width on the quality of forest chips. Skogforsk, Arbetsrapport No. 799.

See the whole picture – Analysis of supply systems

Bergström, D. & Di Fulvio, F. 2014. Comparison of the cost and energy efficiencies of present and future biomass supply systems for young dense forests. Scandinavian Journal of Forest Research.

Bergström, D. 2009. Techniques and systems for boom-corridor thinning in young dense forests. Doctoral thesis, Acta Universitatis Agriculturae Sueciae 2009: 87.

Bergström, D., Nordfjell, T. & Bergsten, U. 2010. Compression processing and load compression o f young Scots pine and birch trees in thinnings for bioenergy. International Journal of Forest Engineering 21(1): 31-39.

Eriksson, A., Eliasson, L. & Jirjis, R. 2014. Simulation and modeling of wood chip container logistics at forest landings. Book of Proceeding Bioenergy from Forest 2014, Benet OY Helsingfors 2014.

Eriksson, A. 2014. A discrete-event simulation approach to improve efficiency in stump fuel supply chains. The Swedish University of Agricultural Sciences, Department of Energy and Technology, Report 69. Licenciate thesis.

Jundén, L., Bergström, D., Servin, M. & Bergsten, U. 2013. Simulation of boom-corridor thinning using a double-crane system and different levels of automation. International Journal of Forest Engineering, 24(1): 16-23.

Stump predictions from harvester data

Marklund, L.G. 1988. Biomass functions for pine, spruce and birch in Sweden. The Swedish University of Agricultural Sciences, Department of Forest Survey, Report No. 45.

Nordström, M., Hannrup, B., Anerud, E., Johannesson, T., von Hofsten, H. & Eliasson, L. 2012. Validation of functions for calculating the quantity of forest fuel in stump harvest – a pilot study. Skogforsk, Arbetsrapport No. 780.

Using weather data to predict moisture content

Erber, G. Routa, J. Wilhelmsson, L. Raitila, J. Toiviainen, M. Riekkinen, J. & Sikanen, L. 2014. A prediction model prototype for estimating optimal storage duration and sorting. Working Papers of the Finnish Forest Research Institute 297. 776 pp.

Better planning reduces ground damage

Bergkvist, I. Friberg, G. Mohtashami & S. Sonesson, J. 2014. The STIG Project, 2010-2014. Skogforsk. Arbetsrapport No. 818.

Flisberg P., Rönnqvist M., Jönsson P & Andersson G. 2014. Soil damage avoidance while maintaining efficient logistic operations. Precision Forestry Symposium, 3-5/3 Stellenbosch, Sydafrika. Book of proceeding.

PLANNING AND MANAGEMENT

Friberg, G. 2014. A method to optimize forwarding towards minimized driving distance and minimized effect on soil and water. The Swedish University of Agricultural Sciences, Department of Forest Products, Examensarbeten No. 138.

Jönsson, P., Westlund, K., Flisberg, P. & Rönnqvist, M. 2011. Forwarding routing planning of round wood, stumps, tops and branches Projects SPORRE och GROTSPORRE. Skogforsk, Arbetsrapport No. 753.

Mohtashami, S. 2010. Planning forest routes for silvicultural activities using GIS based techniques. KTH Land and water resources egineering. Masters theises KTH.

Sonesson, J., Mohtashami, S., Bergkvist, I., Söderman, U., Barth, A., Jönsson, P., Mörk, A., Jonmeister, T. & Thor, M. 2012. Decision support and methods to minimise ground impact in logging – Final report of project ID 0910/143-10. Skogforsk, Arbetsrapport No. 772.

Efficient planning in young stands

Bohlin, J., Wallerman, J. & Fransson, J. E. S. 2012. Forest variable estimation using photogrammetric matching of digital aerial images in combination with a highresolution DEM. Scandinavian Journal of Forest Research, 27 (7): 692-699.

Iwarsson Wide, M., Olofsson, K., Wallerman, J., Sjödin, M., Torstensson, P-O., Aasland, T., Barth, A. & Larsson, M. 2013. Effective estimate of biomass volume on roadsides and in young forests using laser data. Skogforsk, Arbetsrapport No. 804.

Naesset, E. 2002. Predicting forest stand characteristics with airborne scanning laser using a practical two-stage procedure and field data. Remote Sensing of Environment, 80(1), 88–99.

Process mapping of supply chains

Windisch, J. 2015. Process redesign in development of forest biomass supply for energy. Dissertationes forestales 189, Finnish Society of Forest Science.

Eriksson, B., Widinghoff, J., Norin, K. & Eliasson, L. 2015. Process mapping – A tool for improving supply chains. Skogforsk, Arbetsrapport No. 879.

FOREST FUEL HARVEST

Forest fuel – Technology and methods for harvest and ash recycling

Anerud, E. 2012. Stumps as fuel – the influence of handling method on fuel quality. SLU, Acta Universitatis Agriculturae Sueciae 2012:85.

Björheden, R. & Nuutinen, Y. 2014. Study of Fixteri FX15a small-tree bundling unit. Skogforsk, Arbetsrapport No. 819.

Eliasson, L. & Lundström, H. 2013. Forwarding of dried logging residue: study of Hultdins Biokassett. Skogforsk, Arbetsrapport No. 790.

von Hofsten, H. & Brantholm, M-Å. 2013. Productivity and costs in stump harvest systems – A case study. Skogforsk, Arbetsrapport No. 795.

Biomass recovery rates for small trees

Holmberg, S. 2014. Removal of biomass in delimbed assortment from thinning. The Swedish University of Agricultural Sciences, Master thesis skogsmästarprogrammet No. 2014:02.

Multi-tree handling increases productivity

Brunberg, T. & Iwarsson Wide, M. 2013. Productivity increase after multi-tree handling during thinning. Skogforsk, Arbetsrapport No. 796.

Thinning in sections

Iwarsson Wide, M., Larsson, P. & Mörk, A. 2012. Thinning in sections smoothes operation and increases productivity. Skogforsk, Resultat Nr. 4.

Forest fuel from birch shelterwoods

Grönlund, Ö & Iwarsson Wide, M 2015. Harvest of forest fuel in birch shelterwood removal. Skogforsk, Arbetsrapport No. 875.

More efficient technology for stump harvest

Berg, S., Bergström, D., Athanassiadis, D. & Nordfjell, T. 2012. Torque required to twist and cut loose Scots pine stumps. Scandinavian Journal of Forest Research 27(8): 724-733.

Kärhä, K. 2012. Comparison of Two Stump-Lifting Heads in Final Felling Norway Spruce Stand. Silva Fennica, 46(4): 625-640.

Läspä, O. & Nurmi, J. Stump extraction with a stump drill from an intermediate thinning of a spruce stand. In: Belbo, H. (ed. Proceedings of Forest operations research in the Nordic Baltic Region, Honne, Norway, 20-22 Oct 2010, pp. 17-18.

von Hofsten, H., Johanneson, T. & Anerud, E. 2012. Impact of stump splitting on harvest productivity. Skogforsk, Arbetsrapport No. 759.

von Hofsten, H., Johanneson, T. & Anerud, E. 2012 Comparative study of two stump lifting heads, Biorex 50 and the Rotary stump cutter – Effects on stump procurement system from lifting to grinding on landing. Skogforsk, Arbetsrapport No. 783.

Environmental effects of stump harvest

Berg, S. 2014. Technology and systems for stump harvesting with low ground disturbance. SLU, Acta Universitatis agriculturae Sueciae, 2014:95

Berg, S. & Läspä, O. 2013. Comparison of the ground disturbance between two stump lifting concepts. Forest refine info sheet 2.9.

Persson, T. (Ed.) 2015. Tree stump harvesting and its environmental consequences. Tema–Stubbar, SLU, www.slu.se/stubbar

von Hofsten, H. 2014. Evaluation of the TL-GROT AB stump harvester. Skogforsk, Arbetsrapport Nr. 853.

von Hofsten, H., Nordström, M. & Hannrup, B. 2014. Stumps left in the ground after stump harvest. Skogforsk, Arbetsrapport No. 844.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FUEL PRODUCTION

Fuel productions – Resource efficient comminution

Eriksson, G., Bergström, D. & Nordfjell, T. 2013. The state of the art in woody biomass comminution and sorting in Northern Europe. International Journal of Forest Engineering 24(3): 194-215.

Eliasson, L. & Lombardini, C. 2014. Efficient chip supply systems improve chipper utilisation. In: Eds. Vuillermoz, M. and Cacot, E., 5th Forest Engineering Conference, Gerardmer, France, 23-26 september 2014. FCBA.

Picchi, G. and Eliasson, L. 2015. Chip truck utilization for a container handling chipper truck when chipping logging residues and the effect of two grapple types on chipping efficiency. International Journal of Forest Engineering 26(3): 203-211.

Comminution on the landing

Eliasson, L., Granlund, P., von Hofsten, H. & Björheden, R. 2012. Study of a truck-mounted CBI 5800 grinder. Skogforsk, Arbetsrapport No. 775.

Eliasson, L., Lombardini, C., Lundström, H. & Granlund, P. 2013. Performance and fuel consumption of a forwarder-mounted Eschlböck 84 chipper and performance of a John Deere 1410D forwarder when shunting chip containers. Skogforsk, Arbetsrapport No. 810.

Eliasson, L., Granlund, P. & Lundström, H. 2014. A performance and fuel consumption when chipping logging residues of beech. Skogforsk, Arbetsrapport No. 833.

Eliasson, L., Lombardini, C., Granlund, P., Magagnotti, N. & Spinelli, R. 2014. Performance and fuel consumption of a truck-mounted Pezzolato PTH 00/820 chipper. Skogforsk, Arbetsrapport No. 823.

Lombardini, C., Eliasson, L. & Spinelli, R. 2013. Cantiere di cippatura, strategie per ottimizzare la logistica. L'Informatore Agrario(28): 27-29.

Lombardini, C., Granlund, P. & Eliasson, L. 2013. Performance and fuel consumption of the Bruks 806 STC chipper. Skogforsk, Arbetsrapport No. 793.

Nati, C., Eliasson, L. and Spinelli, R. 2014. Effect of chipper type, biomass type and blade wear on productivity, fuel consumption and product quality. Croatian J For Eng 35(1): 1-7.

Comminution at the terminal

Eliasson, L., Granlund, P., Johanneson, T., von Hofsten, H. & Lundström, H. 2012. Effects of target chip size on performance, fuel consumption and chip quality for a large disc chipper. Skogforsk, Arbetsrapport No. 776.

Eliasson, L., Granlund, P. & Lundström, H. 2012. Effects of raw material on performance, fuel consumption and chip quality for a large disc chipper. Skogforsk, Arbetsrapport No. 777.

Systems for grinding and cleaning stumps

Anerud, E., Jirjis, R. & Gebresenbet, G. 2013. Cleaning of harvested Norway spruce stumps using a vibrationbased method. International Journal of Forest Engineering, 24, 121-128.

Fogdestam, N., Granlund, P. & Eliasson, L. 2012.Coarse grinding of stumps and sieving of the produced hog fuel. Skogforsk, Arbetsrapport No. 768.

von Hofsten, H. & Brantholm, M-Å. 2013. Productivity and costs in stump harvest systems – A case study. Skogforsk, Arbetsrapport No. 795.

Three ways to improve chipping efficiency

Di Fulvio, F., Eriksson, G. & Bergström, D. 2015. Effects of wood properties and chipping length on the operational efficiency of a electrical 30 kW powered disc chipper. Croatian Journal of Forest Engineering 36(1): 85-100.

FUEL PRODUCTION

Eliasson, L., von Hofsten, H., Johanneson, T., Spinelli, R. & Thierfelder, T. 2015. Effects of Sieve Size on Chipper Productivity, Fuel Consumption and Chip Size Distribution for Open Drum Chippers. Croatian J For Eng 36(1): 11-17.

Eliasson, L., von Hofsten, H., Spinelli, R. & Johannesson, T. 2014. Effects of sieve size on chipper productivity, fuel consumption and chip size distribution for open drum chippers. In: Eds. Vuillermoz, M. and Cacot, E., 5th Forest Engineering Conference, Gerardmer, France, 23-26 september 20014. FCBA.

Grönlund, Ö. & Eliasson, L. 2013. Effects of knife wear on performance and fuel consumption for a small drum chipper. Skogforsk, Arbetsrapport No. 786.

Nati, C., Eliasson, L. & Spinelli, R. 2014. Effect of chipper type, biomass type and blade wear on productivity, fuel consumption and product quality. Croatian Journal of Forest Engineering 35(1): 1-7.

Spinelli, R., Cavallo, E., Eliasson, L. & Facello, A. 2013. Comparing the efficiency of drum and disc chippers. Silva Fennica 47(2 article id 930): 11.

Spinelli, R., Cavallo, E., Eliasson, L., Facello, A. & Magagnotti, N. 2015. The effect of drum design on chipper performance. Renewable Energy 81: 57-61.

von Hofsten, H., Johanneson, T. & Anerud, E. 2012. Impact of stump splitting on harvest productivity. Skogforsk, Arbetsrapport No. 759.

Preventing chipper truck breakdown

Johansson, F., Grönlund, Ö., von Hofsten, H. & Eliasson, L. 2014. Chipper truck breakdowns and their causes. Skogforsk, Arbetsrapport No. 836.

FOREST FUEL LOGISTICS

Forest fuel logistics – Efficient transports

Floden J., Awais F., Woxenius J., Williamsson J., Bärthel F., Berglund M., Billing Clason H., Hersle D., Falkenberg A., Sökjer Petersen S., Kordnejad B. & Enström J., 2015. Sustainable Intermodal Biofuel Transport – Intermodal Road-Rail Transport of wood biofuel for heating plants. Handelshögskolan, Göteborgs universitet.

Föhr J., Karttunen K., Enström J., Johannesson T. & Ranta T. 2015. Metal and Composite Intermodal Containers in Comparative Cold Tests with Wood Chips. Journal of Sustainable Bioenergy Systems. 5: 32-39.

Kons, K. Bergström D., Eriksson U., Athanassiadis D. & Nordfjell T. 2014. Characteristics of Swedish forest biomass terminals for energy. International Journal of Forest Engineering. 25, (3): 238-246.

Widinghoff, J. 2015. Logistics solution for partly delimbed energy wood – Lightweight side-shields on timber trucks transporting partly delimbed energy wood. Skogforsk, Arbetsrapport No. 856.

More efficient chip trucks – Important for forest fuel

Edlund J., Asmoarp V. & Jonsson R. 2013. Monitoring fuel consumption of two rigs in the ETTdemo project, ST-crane and ST-group. Skogforsk, Arbetsrapport No. 803.

High Capacity Transport web page. http://www.skogforsk.se/EnergiEffektivaTransporter/

Location barter can improve efficiency of chip transports

Flisberg, P., Frisk, M., Rönnqvist, M. & Guajard, M. Potential savings and cost allocations for forest fuel transportation in Sweden: A country-wide study. Accepted, ENERGY The International Journal.

Jönsson P., Eliasson L. & Björheden R. 2014. Location barter may reduce forest fuel transportation cost. Skogforsk, Arbetsrapport No. 849.

Ship transport of forest fuel

Enström, J. 2015. Possibilities for coastal maritime transport of forest fuel in Sweden. Skogforsk, Arbetsrapport No. 874.

Karttunen, K., Ranta, T., Jäppinen, E., Korpinen, O. J. & Hämäläinen, E. 2008. Biomass production through satellite terminals and waterway transportation of wood chips. Proceedings of the World Bioenergy Conference, Jönköping, Sweden. Sid. 331-335.

Invest in the right fuel terminals

Enström J., Athanassiadis D., Öhman M. & Grönlund Ö., 2013. Success factors for larger energy wood terminals. Skogforsk, Arbetsrapport No. 813.

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Forest energy for a sustainable future

Skogforsk is developing effective systems for producing forest-based bioenergy fuel. The focus is on technology, methods and systems for logging residues, stumps, smaller-dimension trees, chipping, measurements, transports and logistics along the whole supply chain. (Programme manager, Mia Iwarsson Wide)

FOCUS AREAS

Efficient supply systems for biomass from final fellings. Improved planning and efficient handling to increase supplier profitability and customer value. (Lars Eliasson, Tomas Johannesson)

Increased fuel value when harvesting stumps. Increased efficiency in stump harvestings, higher fuel quality and reduced environmental impact can be achieved with better technology and methodology. (Henrik von Hofsten)

Great potential in small-dimension trees. New technology and multi-tree handling improve supplier profitability and make large volumes financially viable as forest fuel. (Örjan Grönlund)

Resource effective comminution to produce high quality fuels. Comminution has a large impact on fuel quality and logistic costs. It must therefore be made in the right location using proper equipment. (Lars Eliasson)

More efficient logistics and transports. Development of new transport options, logistical solutions, terminals and long-distance rail transports reduce transport costs and increase the security of delivery. (Johanna Enström)

Improved measurement and specifications for forest fuel. Development and evaluation of new measurement methods for a well specified forest fuel, provides greater benefits in the forest fuel supply chain. (Lars Fridh)

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