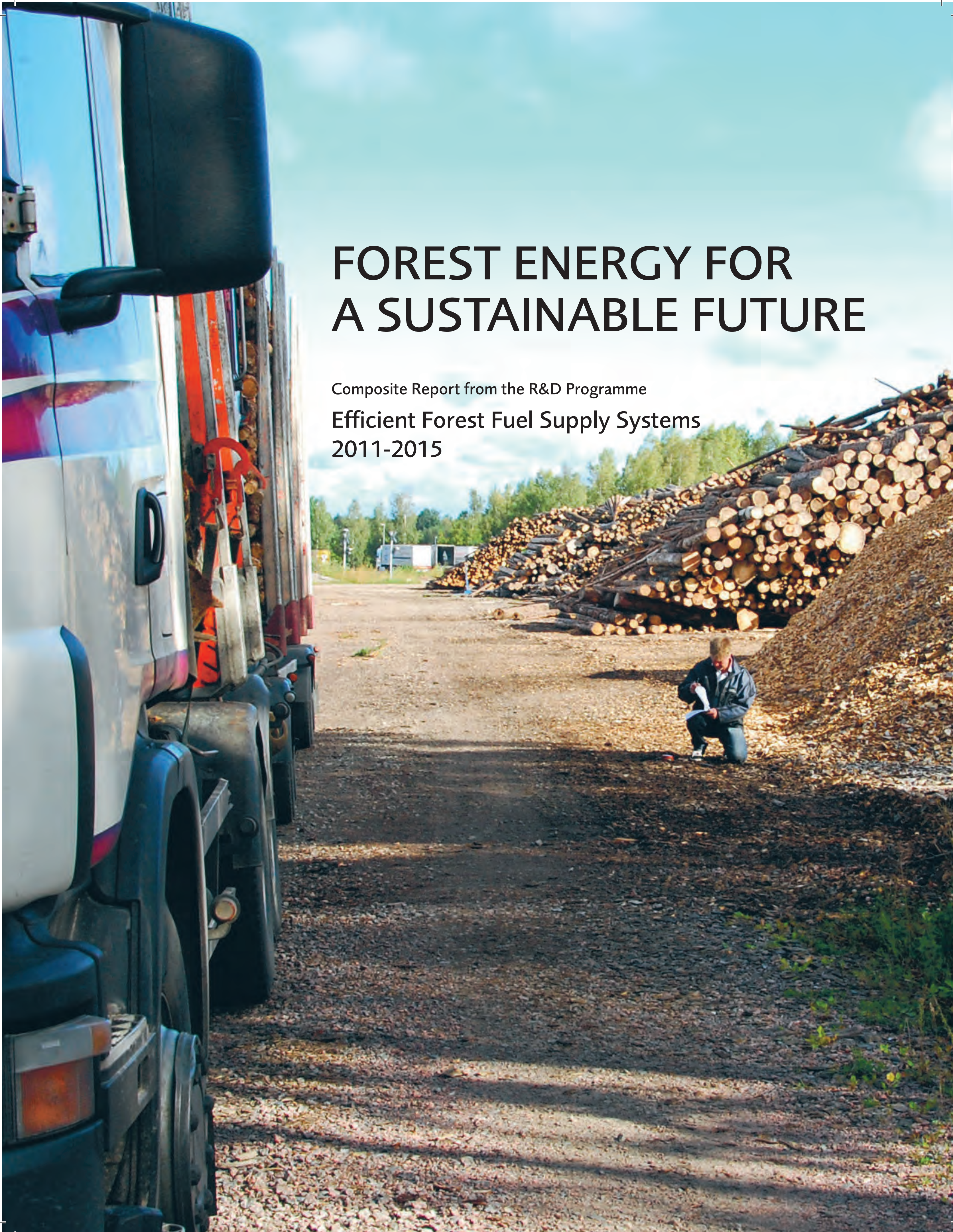


FOREST ENERGY FOR A SUSTAINABLE FUTURE

Composite Report from the R&D Programme

Efficient Forest Fuel Supply Systems 2011-2015

EFFICIENT FOREST FUEL SUPPLY SYSTEMS

- THE SECOND PROGRAMME PERIOD

Rolf Björheden, 2011-2012
Mia Iwarsson Wide, 2012-2015

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.

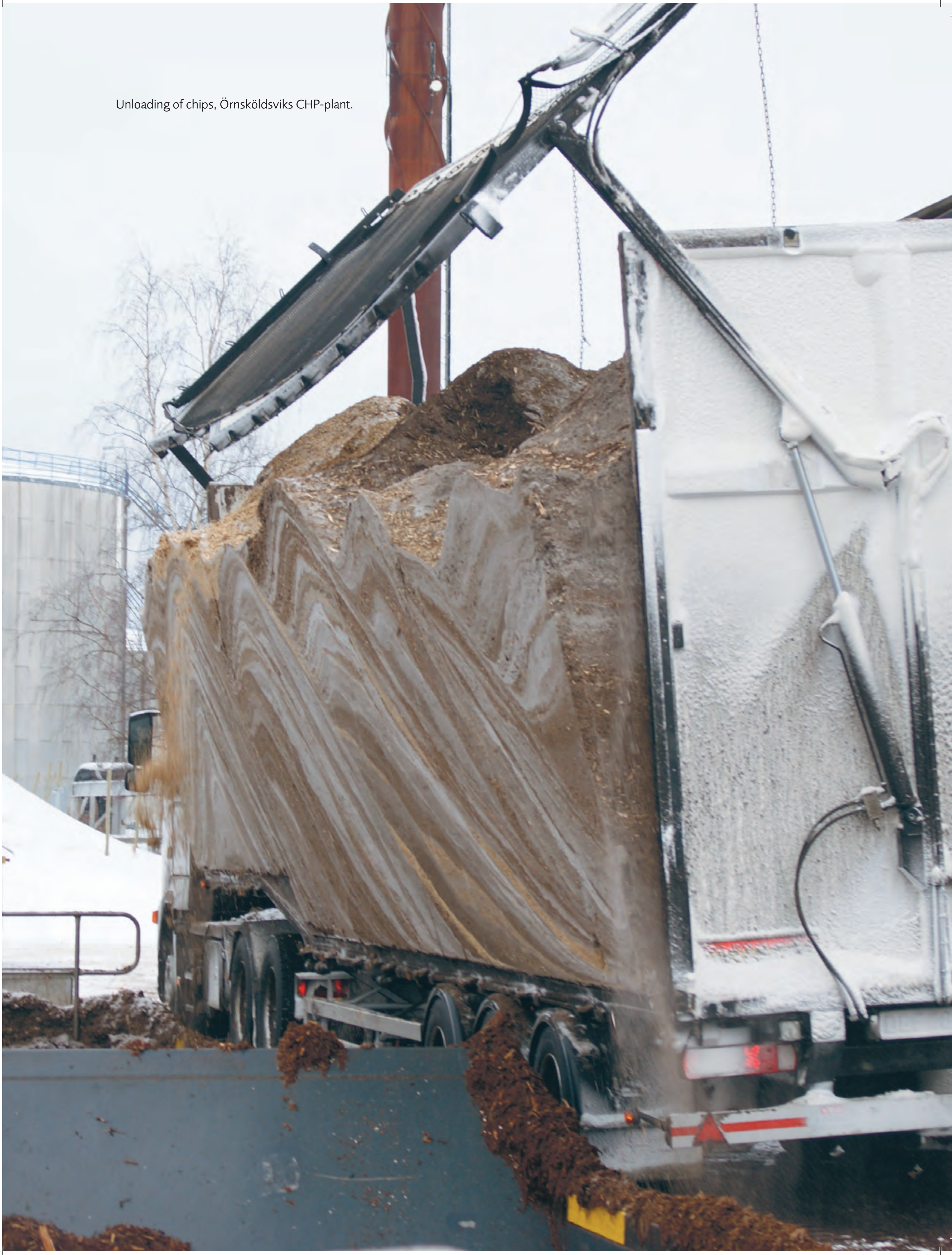
In and around the programme, valuable expertise and networks were built up in each sector and in research organisations, both nationally and internationally. Great emphasis was placed on demonstration, implementation and communication, in order to disseminate knowledge about new technology and methods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


AKE 523
KING ROAD

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.

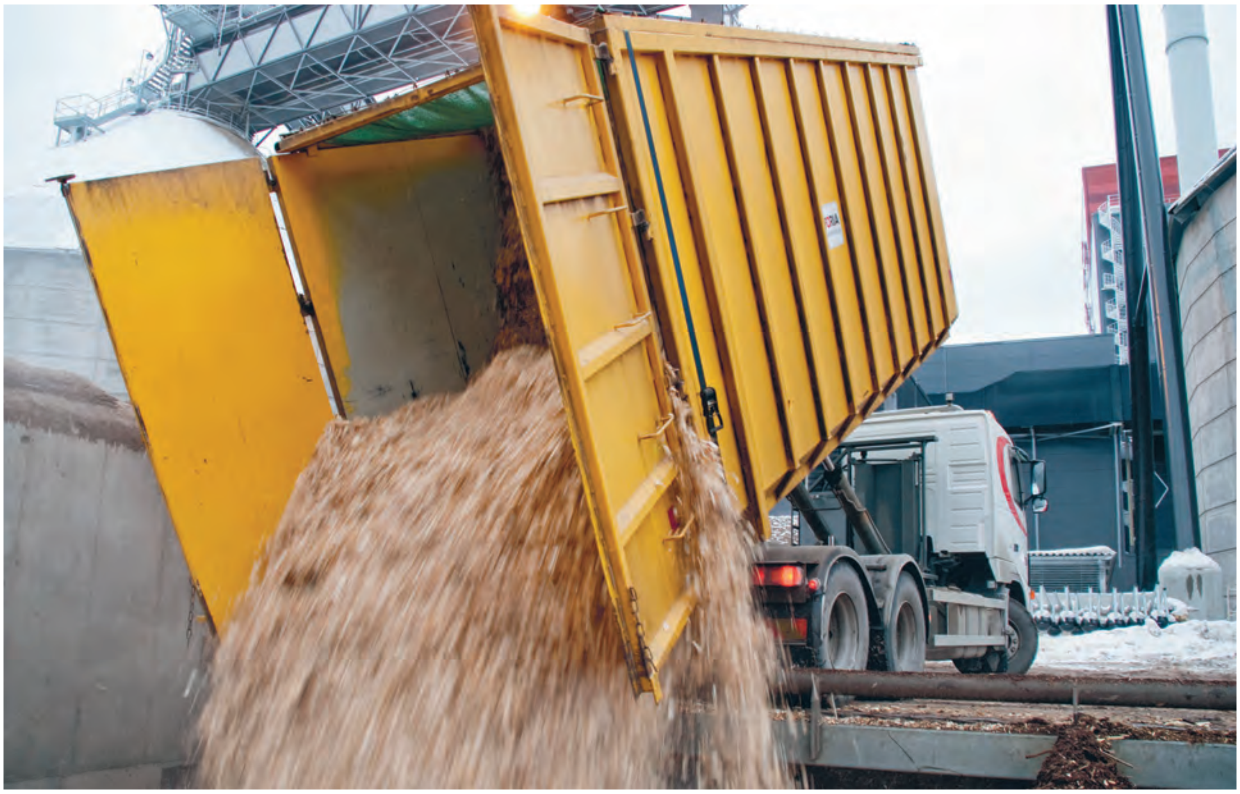
Comminuted fuel is measured by weighing, and the moisture content is used to calculate energy value, or the loose volume is measured. A study comparing different measurement methods for residue chips showed that the average solid volume proportion in 30 loads of chips was 42.6 percent, but varied from 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.

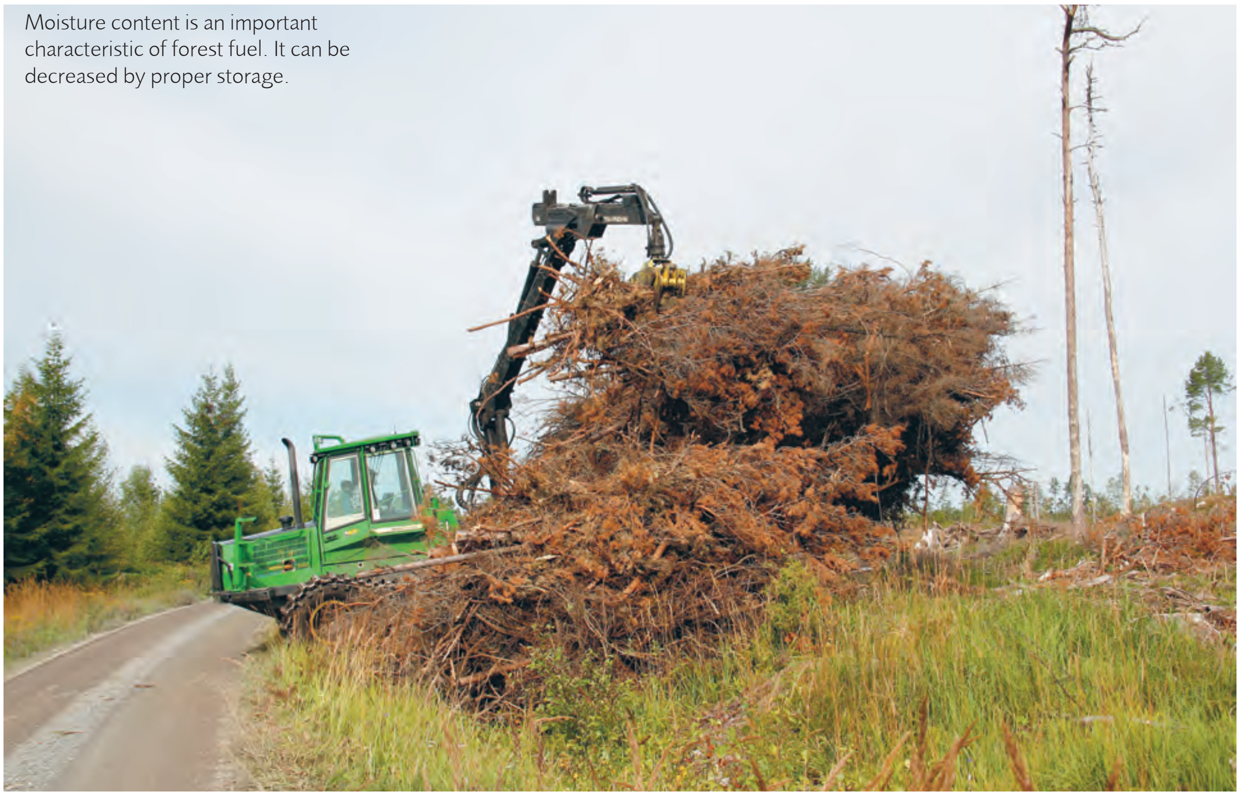
In a joint project with SDC and suppliers and users of forest fuel, a proposal for standardised product descriptions has been formulated. The nature of the original material, such as sawdust or logging residue, is described, along with moisture content, ash content and fraction distribution.

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.

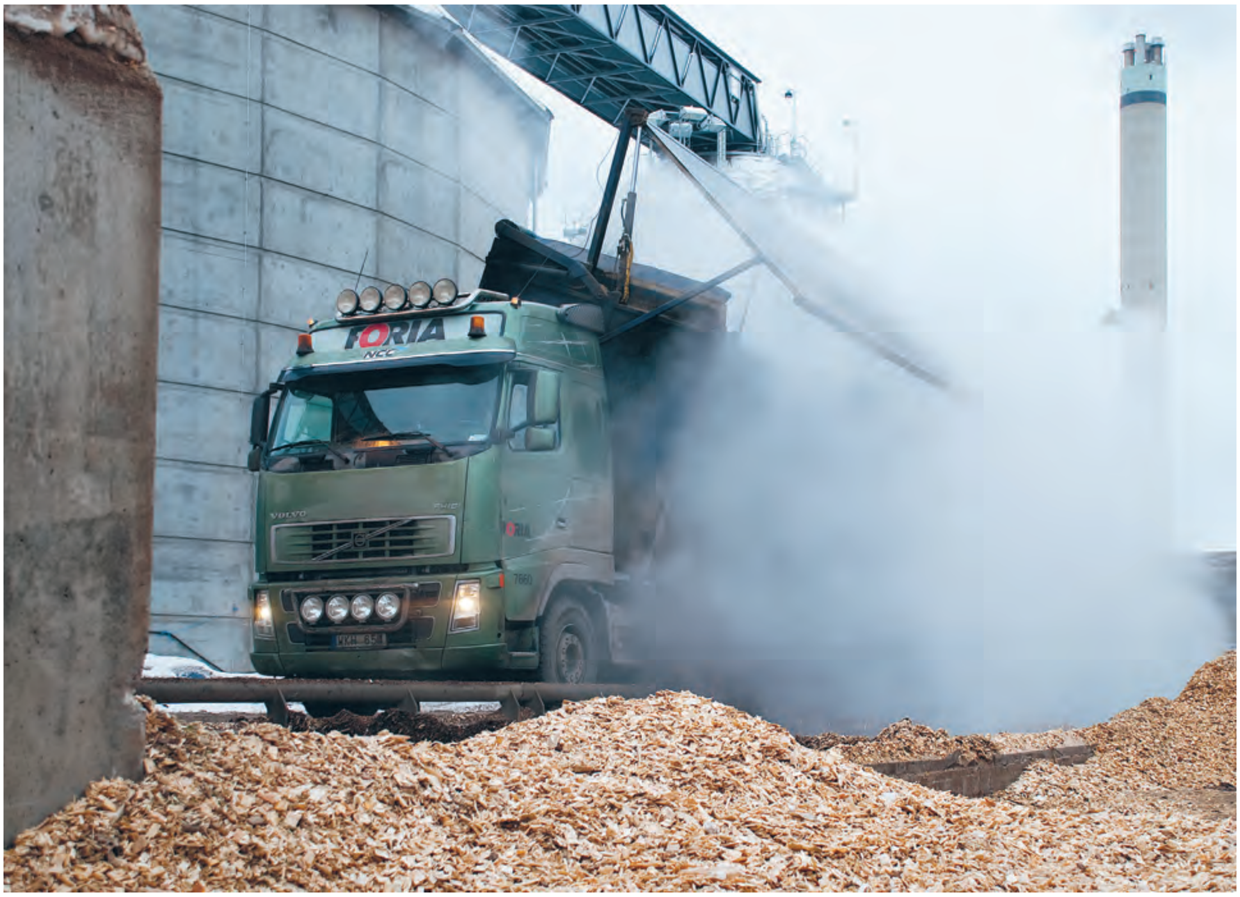
Product descriptions

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.

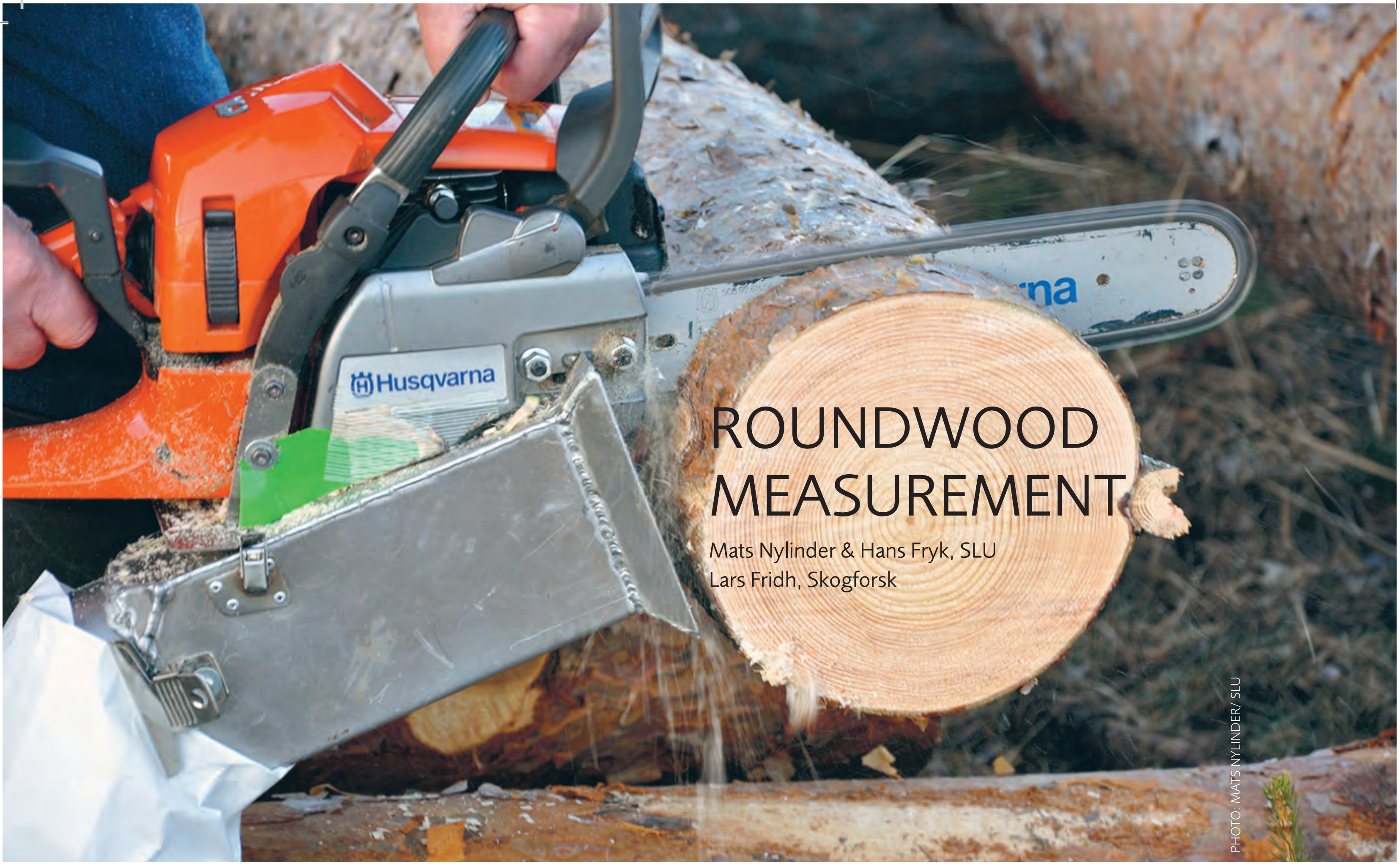


PHOTO: MATS NYLINDER/ SLU

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

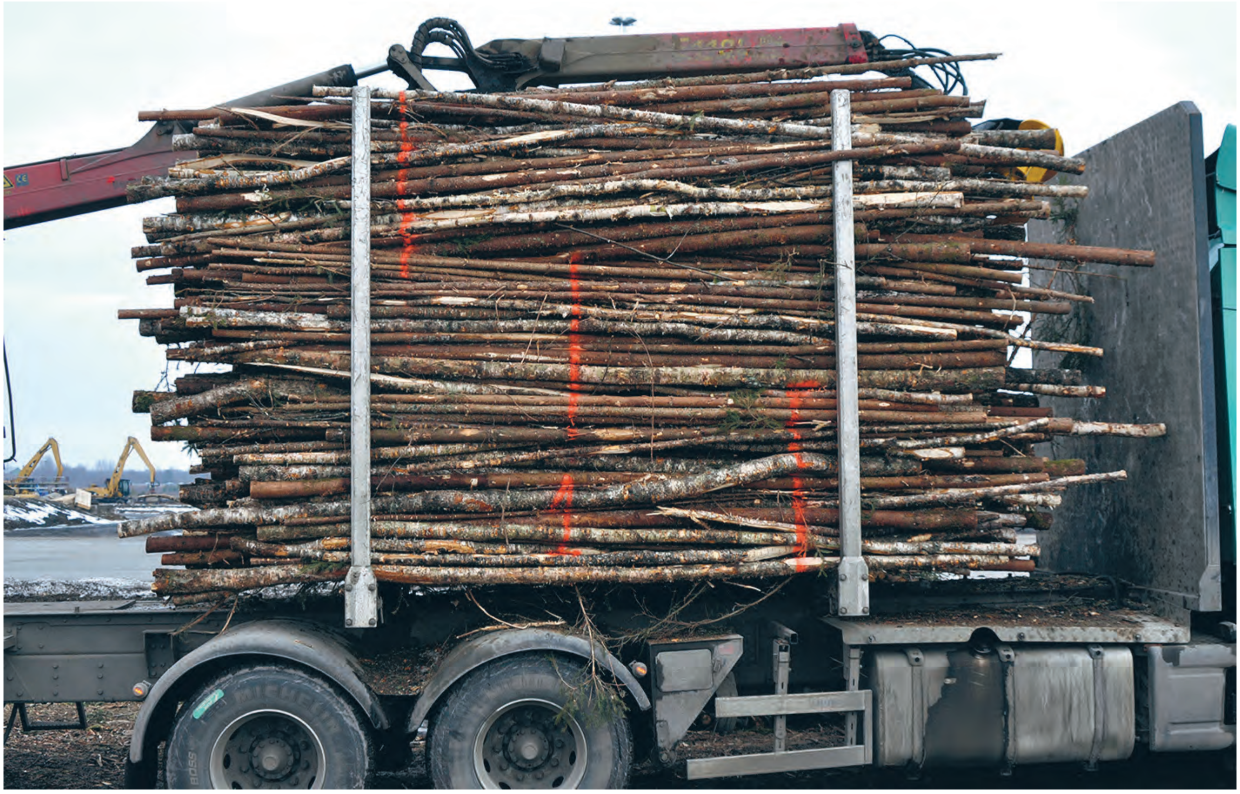


PHOTO: MATS NYLINDER/ SLU

WEIGHING ENERGY WOOD

Mats Nylinder & Hans Fryk, SLU,
Mia Iwarsson Wide, Petrus Jönsson & Örjan Grönlund, Skogforsk

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.

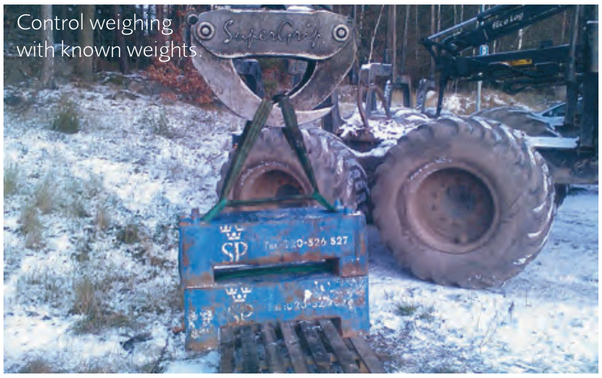
One conclusion from the study is that Stora Enso's model gives a better estimate of energy content than raw weighing. A calculation of dry matter based on moisture content and weight of the chips gave by far the best estimate of the energy content of the stacks. However, in practice, it would be costly 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

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.

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.

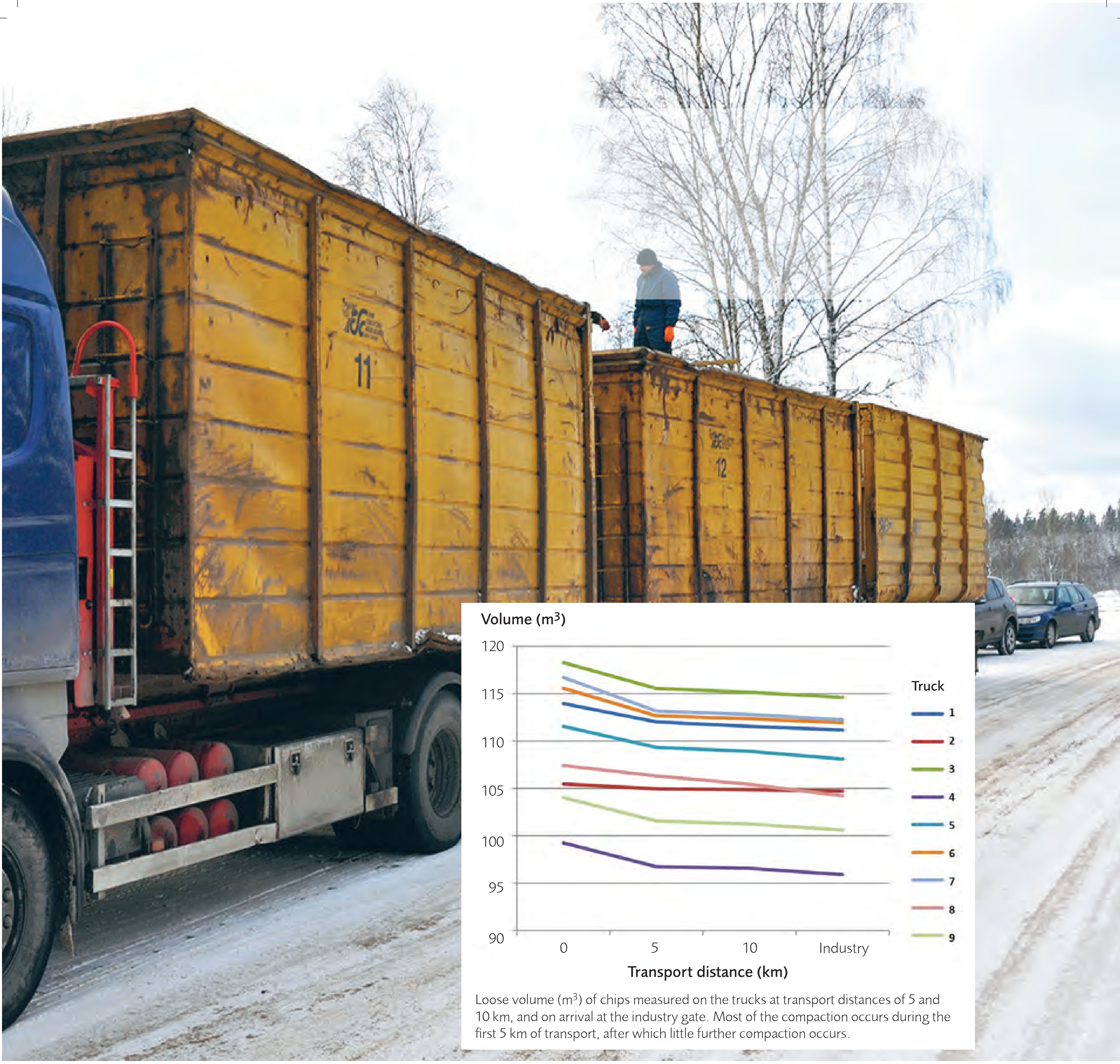
A study was carried out by the Swedish University of Agricultural Sciences (SLU), Linnaeus University, VMF South, Växjö Energi AB and Södra to investigate the advantages and disadvantages of various measurement methods for residue chips.

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.

PHOTO: MATS NYLINDER/SLU

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.