

Efficient forest fuel supply systems

Composite report from a four year

R&D programme 2007-2010



SKOGFORSK





Preface

Forest-based biofuels are occupying an increasingly important role in Swedish energy supply. Over a number of years, forestry has increased harvest of forest products for bioenergy by 1-1.5 million m³ solid per year, and this trend is expected to continue. A worldwide focus on the issue of global warming has strengthened the argument for use of bioenergy. In a forested country like Sweden, bioenergy is almost synonymous with forest-based fuel. Such biofuel is almost neutral in terms of greenhouse gas emissions, and technology for converting the fuel to energy is well advanced.

The R&D program, Efficient forest fuel Supply Systems (ESS), is a broad collaborative project in which the Swedish Energy Agency, the forestry, energy and transport sectors and Skogforsk have together invested nearly SEK 60 million to develop forest fuel supply. The ESS program has run over four years, 2007 to 2010, administered by Skogforsk. The program is open for applications and ESS has thereby developed into a network. ESS provides coordination of development initiatives relating to forest fuels for a number of R&D organizations. Over the course of the program, a bank of expertise has been built up and organized. This provides a solid base for future development.

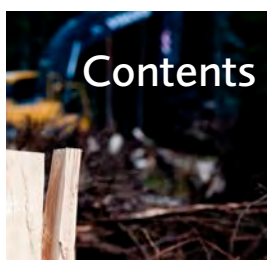
At the time of writing, December 2010, the program is close to termination. It has already been decided to prolong the work with a new four-year period, 2011-2014. This report summarizes many of the interesting findings from the first four years. Detailed information from any of the fields of study can be obtained from free pdf-documents at skogforsk.se/ess-rapport, unfortunately mainly in Swedish.

The report illustrates a field undergoing rapid development. It provides factual information that can be useful for decision-makers, it provides knowledge to an interested public, and – I hope – it provides ideas and stimuli for future development. I and my colleagues in the ESS program, both within and outside Skogforsk, are pleased to present our composite report. Although it has a strong national scope, we hope that it provides new insights into the problems and possibilities for forest fuel production, also for an international audience.

Hope you enjoy it!

A handwritten signature in black ink, appearing to read 'R. Björheden'. The signature is stylized with a large, flowing 'R' and a cursive 'Björheden'.

Rolf Björheden
Program Manager, ESS



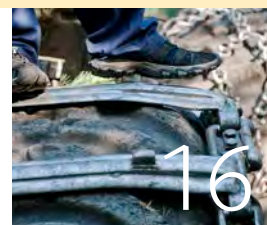
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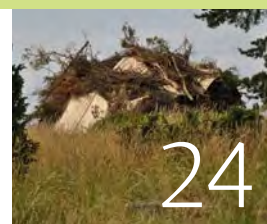
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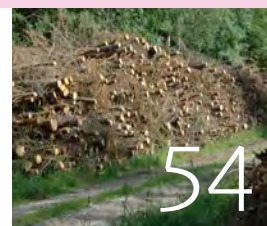
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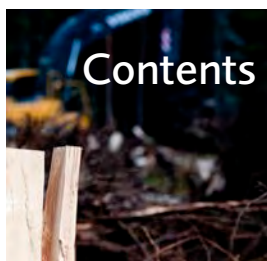


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GROWING ENERGY

- THE DEVELOPMENT OF FOREST ENERGY IN SWEDEN

Sweden's quest for a secure energy supply

The Swedish energy policy aims to ensure a reliable supply of energy at economically competitive prices, through sustainable energy sources and, thus, with minimized adverse effects on health, environment, climate and economic stability and development. In this section, the background to the current energy policy is briefly presented.

The Swedish economy is based on trade with other countries. By tradition, much of the exported goods are energy intensive, such as products from mining and metallurgy, heavy machinery, vehicles, pulp and paper. Further, Sweden is a country with a long and cold winter and, thus, with high demand for heating of homes and facilities. The Swedish per capita consumption of energy is high - over 40 MWh/person and year, excluding losses in energy conversion. Thus, the repeated 'oil crises' in the 1970's sent shockwaves through the Swedish society. At that time, Swedish primary energy was based to 77 % on fossil sources. Temporary shortage and rising fossil fuel prices made it clear that Sweden needed to develop economical, domestic energy sources.

Sweden started a comprehensive, 24-reactor-programme for nuclear power. Public opinion, influenced by and articulated through growing environmentalist movements, expressed great scepticism. In 1980, a year after the Harrisburg-accident, (a severe core meltdown at the Three Mile Island nuclear power plant in Pennsylvania, USA) a referendum was held in Sweden. The resulting political decisions were to delimit the Swedish nuclear programme to 12 reactors and to eventually phase out nuclear power by 2010 (this has not been achieved). Also, strong commitments to develop renewable energy sources were made.

Hydropower is important to Sweden. During the 1960's it was modernised and expanded. In the 1970's, the same environmentalism that opposed the nuclear power programme also opposed continued exploitation of renewable electricity from harnessed rivers.

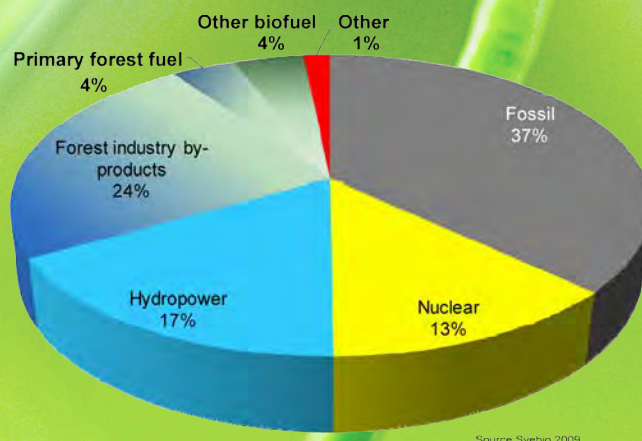
The blocking of both nuclear and hydropower put extra weight on the alternative to develop bio-energy. While Swedish deposits of fossil coal, oil and gas are insignificant, the forest resources are vast. Biomass, for Sweden almost synonymous to forest fuel, was identified as a potent energy source at an early stage. Since the 1970's, forests play an increasingly important role in the Swedish energy supply.

Energy from forest biomass

Today, renewable energy is an important part of the Swedish energy budget. With a renewable share of 47 per cent, closing in at the EU RES directive national goal of 49 per cent, Sweden has a unique position among the industrialized countries. Forests play an important role, but much of its potential remains untapped. Wood is the foremost traditional energy source in Sweden, but current, industrial-scale utilization has developed in the period after the 'oil crises'.

Today, one third of the energy use is based on biomass, most in the form of industrial residues from Sweden's comprehensive forest industry. But a growing share consists of primary forest fuels, i. e. material harvested for energy purposes. Currently, the contributions from the forest sector are equivalent to over 40 million m³ solid per year.

So far, the most important primary forest fuel source is branches and tops from harvesting operations. In this publication, the well-established term 'logging residues' will be used for this material, although 'residue' is misleading for a recognized product. Other sources of primary forest fuels are



Sources of energy in the Swedish energy budget 2009. Forest biomass accounts for almost a third of the energy used annually and is of the same order as hydropower and nuclear power combined.

stumps, small trees and other wood not in demand by the conventional industry. Thus, the supply depends on the intensity of conventional logging. Half the gross supply is exempt for ecological or techno-economic reasons. The remaining annual net supply is around 17 million cubic meters solid of stumps and logging residues from final felling and over 5 million cubic meters solid of small trees from young stands. Today, over 7 million cubic meters are utilized, mainly in the form of logging residues and sub-standard round-wood. Although the full primary fuel potential of Swedish forests cannot be economically harvested, it is possible to more than double the annual utilization.

The development of forest energy has been long-term and stable. From the late 1970's, the use of solid biofuel has increased by around 3 TWh, corresponding to 1,5 million m³ solid every year. This development is projected to continue.

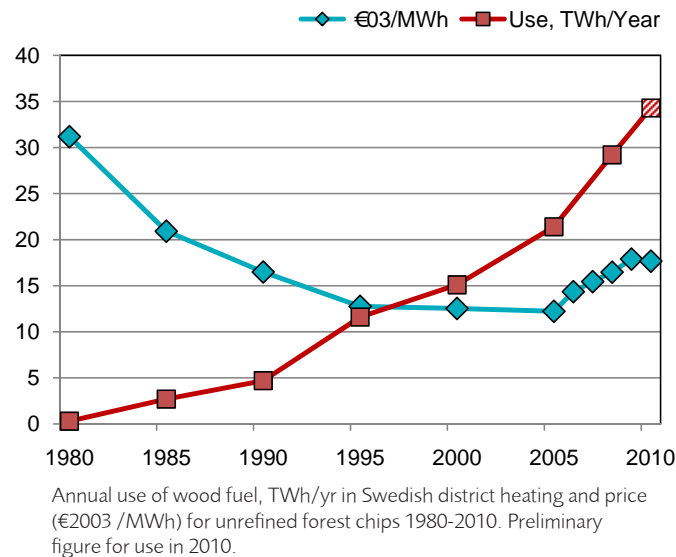
Until recently, the development took place in a situation of over-supply. The price development of primary forest fuels illustrates this. From 1980 to 2005, the nominal price remained stable at 13 €/MWh. In real terms, the price of forest fuel thus decreased markedly. In 2006, the price increased to 15 €/MWh and currently (2010) the price is 21 €/MWh. Most of this development is an effect of increased demand and local shortage of supply. The rising costs of forest fuel supply and the perceived shortage of feedstock motivate efforts to increase the efficiency of forest fuel supply systems and to increase the quality of the ready fuel.

Drivers behind the development

Sweden's significant forest resources, comprehensive forestry sector and long tradition of large scale forestry and forest biomass supply chains are important explanatory variables for the strong development of forest fuels in Sweden. The development of forest fuel operations started in a simple way. Resources from logging operations were becoming available as a result of continuous rationalization. A surplus of forwarders could be employed in residue extraction with limited modification, and chippers mounted on forwarder chassis provided in-terrain platforms capable of both extraction and production of an acceptable fuel. Initially, there was serious concern from the established forest industry that harmful competition for wood would occur. But since the chosen feedstock for wood fuels is industrial by-products and wood not in demand by the conventional forest industry such as logging residues, small trees and stumps, the development has been possible without destructive competition. Actually, the Swedish forest industries have played a key role in developing the use of forest biomass for energy and are themselves extensive users of forest fuels. The forest industries have developed from heavy dependence on fossil fuels into being a self-sustained net seller of 'green energy'.

Apart from the existence of available machinery and skilled labour, several other drivers have played important roles. The emergence of a functioning market and bio-energy infrastructure is a key element. Two segments are worth mentioning especially. The district heating systems started using wood fuels in a small scale around 1980. In 2010 they used equivalent to 17 million solid cubic meters of wood fuels every year. As mentioned, the forest industry is itself an important player, using a similar volume.

The need for heating will not grow in Sweden, rather the opposite, as houses become more energy efficient. Today, heat is seen not as a main product, but as a by-product of conversion into high end products such as electricity. Also refined fuels usable outside the large CHP plants such as pellets and feedstock for zymotic processes, for torrefaction or for gasification and production of gaseous and liquid fuels are currently receiving interest and development resources.



Equally important, is the relative stability of the Swedish policy, and the way that it has been supported through legislation, taxation, certificate systems, fees and subsidies. The political will to escape from dependence of imported fuels and, instead, secure a domestic supply of energy has been persistent. From the 1970's, energy taxation has been seen as a mean to direct developments in the energy sector. Taxes are used both for fiscal purposes and for achieving various objectives of energy and environmental policies. In 1991 grants to re-furnishing heating plants to Bio CHP as well as a Fossil Carbon Tax were introduced. Today, market based policy measures have been introduced, where taxes were previously the main means. The electricity certificate system, introduced in May 2003, stipulates mandatory quotas for the proportion of renewable energy that the market must deliver, based on the proportion of renewable electricity in the grid. The system makes it advantageous to generate electricity from renewable sources. The emission trading system, launched in January 2005 sets a ceiling on carbon dioxide emissions. The system with market based drivers ensure that development is directed towards a defined goal but allows for the market to decide on the most appropriate way to reach that goal, which in turn leads to cost efficiency. The Swedish government does not imperatively demand from market players to take any particular action, but has through taxation, tariff and certificate systems made it 'good business' to gradually develop efficient renewable alternatives. The competition from fossil and other energy sources is always present, providing incentive for continuous improvement. Another important role of the public sector has been to initiate, fund and co-ordinate the necessary research and demonstration projects during the course of development. Recently, large contributions to research have also been privately funded.

There are several other policy measures which affect the use of energy in buildings, transport and industry in various ways, or which tend to reduce emissions. Despite the differences in the many policy measures, they all work in the direction towards a sustainable energy system.

A recent driver for increased use of forest biomass in energy conversion is the concern for risks of global climate change. The Swedish standpoint is that sustainable, well managed forests play an important role in a switch-over to renewable energy systems with low impact on climate and environment. The risk of climate change has emphasized the need for development of sustainable energy solutions with low GHG-emissions.

Political statements and decisions addressing these needs provide additional drivers for continued development of bioenergy and other GHG-neutral solutions. During 2008, EU adopted new directives on several areas coupling energy supply with environmental concern and climate issues. The second Energy and Climate Package, released in January, was discussed and negotiated and in December the new legislation was adopted by the Council and the European Parliament. At the EU level, the Renewable Energy Share (RES) has been set to 20 per cent by 2020. Further, at least 10 percent of the energy used by the transport sector must be renewable and, through the mechanisms of the EU Emission Trading System, the emissions from large scale producers will be reduced by 21 per cent in 2020 compared to 2005. As a result of consideration to national differences, the RES goals vary between countries.

The Swedish RES target for 2020 set by EU is 49 %. (Sweden has unilaterally declared that it will aim at 50.2 %). The Swedish RES is unique for a heavily industrialized, boreal country. Excellent opportunities for hydropower and wind energy and a well invested infrastructure for district heating and efficient use of organic municipal waste for energy conversion are part of the explanation for the ambitious Swedish RES, but the main source of renewable energy is the large scale use of forest biomass. In 2009, biomass provided 32 per cent of the used primary energy in Sweden (116 TWh), more than the combined contributions from nuclear and hydro power.

In practice, the economy of operations remains the basic driver. The nature of forest energy operations is challenging. The available primary forest fuel feedstock combines difficult operational properties such as bulkiness, small piece size and scattered occurrence with low relative value. The operations must be performed under the constraints of a sensitive environment with no or low impact on soil, water and any growing forest stand.

To meet these challenges, in 2007, a four-year national R&D programme, Efficient forest fuel Supply Systems was launched by the Swedish forest and energy sectors, strongly supported by the Swedish Energy Agency. The principal aim is to increase the use of forest biomass for energy and the means are increased efficiency, lower costs and higher quality of the fuels. Results include new technology, efficient supply chain design and in-depth knowledge of the operational milieu of forest fuel operations. Some identified paths to cost reduction and increased availability of forest biomass for energy are:

- Purpose-built technology for key forest fuel operations
- Deepened integration of fuel operations with logging operations
- Operator training improving performance and quality of work
- Information chains for improved control, planning and management of production
- Increased co-operation between the supply chain tiers
- Re-engineering of supply chains to enable efficient use of expensive machinery
- Improved intermodal transport systems making distant fuel sources accessible

The programme has demonstrated measures that would lead to substantially lower costs. Alternatively, it is possible to double the production of primary forest fuels, within current cost levels. Recently, the funders decided to continue development by financing a new four-year period, 2011-2014, with the scope of further developing the efficiency and purposefulness of forest fuel operations. In this publication, we present some of the more than 50 different projects of the ESS programme. We hope that the overview will be both inspirational and lead to fruitful contacts between the ESS network and an international community working with similar development.



The risk of negative impact on the environment due to logging and extraction transport is particularly great near streams and rivers.

FOREST FUEL, ENVIRONMENT AND FOREST YIELD

Rolf Björheden, Skogforsk



Forest fuel is an energy source that is almost carbon dioxide neutral and, from a climate perspective, is considerably more environment-friendly than fossil fuels. Swedish use of forest biofuel is extensive, but can be increased considerably. However, increased harvest of biomass from forests involves the risks of negative impact on biodiversity, soil, water and on the long-term yield of forest land. Risks can be reduced to acceptable levels through selection of suitable logging sites, careful planning, adapted methods, conservation and appropriate compensation measures.

Forest biomass for fuel is almost completely carbon dioxide neutral, when linked to sustainable forestry. Lifecycle analyses show that the energy in the fuel used in harvesting, processing and transport of forest-based biofuels corresponds to 3-5 percent of the energy value of the extracted biofuel. If logging residues, stumps and small-dimension trees had not been harvested, they would nevertheless have decomposed and given off carbon dioxide. Consequently, utilization of Swedish forest-based biofuel has great climatic benefits. However, increased harvest of raw materials from our forests also brings risks. What are these risks? And are the negative consequences of more intensive harvesting acceptable or can they be prevented?

Environmental impacts associated with increased biomass harvest from forests fall under the categories:

- Biodiversity on forest land and near streams and rivers
- Environmental impact (mainly through impact on water)
- Yield and buffer capacity of forest land
- Aesthetic qualities and recreational value in the forest landscape

On the basis of comprehensive research and environmental impact surveys, the Swedish Forest Agency has issued recommendations about harvest of logging residues and stumps after roundwood harvest. The general recommendations include preserving 'eternity trees', bushes, high stumps and fallen logs on the logging site. In the forest landscape, there is a general shortage of dead wood, and this is particularly pronounced in the case of coarse woody debris (and charred wood, which was formerly more common due to more frequent forest fires). The occurrence of coarse dead wood and charred wood is hardly threatened by greater harvest of logging residues, stumps and small-dimensioned trees, but greater utilization of forest biofuel reduces the amount of minor dead wood and puts wood-living organisms under greater stress. The situation is particularly serious when harvest of forest-based biofuel, through negligence or ignorance, includes or damages dead and down trees or high stumps, which had been left for general conservation. This sometimes occurs, and it is important that rules about general and specific conservation are disseminated and implemented more stringently as extraction of forest biofuel increases.



PHOTO: BJÖRN SVEINSSON / AKOGENBILD

Supply of coarse dead wood and especially wood affected by forest fire is a limiting factor for many species in need of conservation.

In recent years, the spotlight has been particularly drawn to the link between silviculture and aqueous environments. Ground damage also impacts on aqueous environments further down the drainage basin. Rutting caused by work with heavy machines is a general problem area in forest engineering. A combination of technical and methodological adaptations is needed in order to reduce the problem. The risks of negative impact are especially pronounced in areas with fine soil particles and moist soil. The water quality can be impacted negatively by sludge, humus substances and increased leaching of nutrients, methylated mercury and other heavy metals. The link to forest fuel extraction is that harvest of logging residues may reduce the possibility of using branches and tops to strengthen routes used by forest machines in sensitive areas. Stump harvest reduces ground bearing capacity and thereby increases the risk of ground damage and compaction.

Removal of logging residues

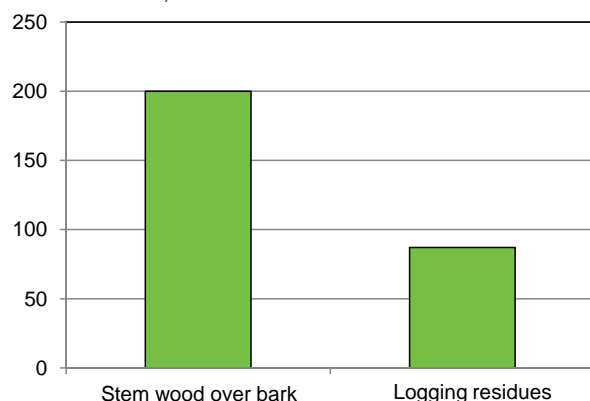
Harvest of logging residues after final felling is not thought to be a significant risk for reduced biodiversity compared with traditional harvest of stem wood. However, logging residues from hardwoods (particularly aspen, oak and other broadleaved species) left on top of the sunlit stack can provide a breeding substrate for many beetle species that require conservation measures. This wood should therefore be excluded from collection and left on the cutover during the time when eggs and larvae can be found in the material. Even when logging residues from softwoods is harvested, the Swedish Forest Agency recommends that harvest should be limited to 80 percent of the gross quantity of logging residues. In areas with particular pools of threatened species (e.g. pastoral landscapes with old oaks), it may be necessary to develop locally adapted methods and rules.

A pronounced environmental effect of logging residue harvest is the risk of reduced ANC (Acid Neutralizing Capacity), which is a measure of the buffering capacity of water in the soil. During logging, organic material containing base cations is removed, and the smaller limbs and foliage have a high content of base cations. This is reflected in the high ash content of the material.

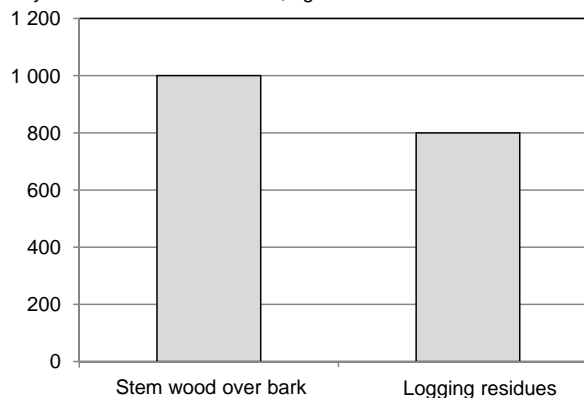
Reduction of ANC can be counteracted by returning the ash to the soil in a form that dissolves slowly, e.g. hardened and crushed wood ash. Dosages equivalent to 1.5-3 tonnes of dry ash/ha are common. In Message 2-2008, the Swedish Forest Agency details recommendations about ash recycling after harvest of logging residues. Today, ash is recycled on just over 10,000 ha/year, mostly in southern Sweden. Ash should be recycled over a considerably greater area in order to reach a level corresponding to the recommendations, but there is little interest and supply of suitable ash is limited. It is important to develop technology and to reduce costs systems for ash recycling and other compensatory measures. Compensation initiatives should also be made more attractive for the forest owner. If ash recycling could be simply combined with, for example, nitrogen fertilization, interest would surely increase.

Moderate increment losses seem to occur after harvest of logging residues, probably the equivalent of 1-2 years' extension to the rotation. Peat land forests and higher yield classes normally react well to ash treatment, but in many cases ash recycling has moderate effect on compensating for increment losses, which seem to be the result of reduced supply of accessible nitrogen. It can therefore be simply corrected by applying a nitrogen-based fertilizer.

Biomass harvest, tonnes DM/ha



Dry ash content in the harvest, kg/ha



Left: Example of total biomass harvest in DM/ha during one rotation. Logging residue harvest after final felling does not considerably increase the harvest. Right: Ash content of the harvested biomass as kg dry ash/ha. The right diagram shows that logging residue harvest nearly doubles the ash content in the harvest. The ash contains large quantities of mineral nutrients.

Stump harvest

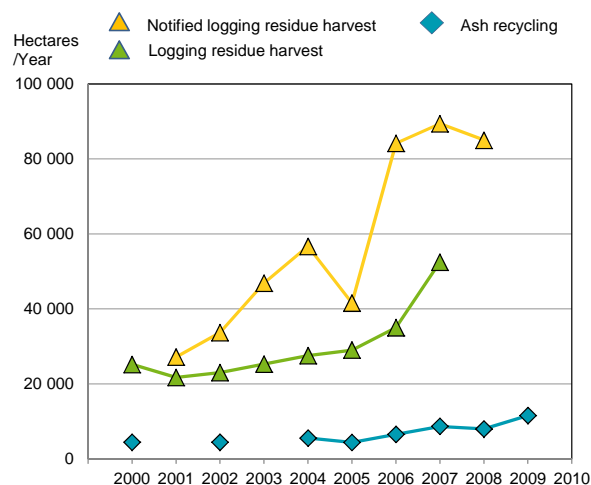
The environmental consequences of stump harvest have been investigated in a major research program, at the Swedish Agricultural University, SLU. Stump harvest only moderately increases removal of mineral nutrients and base cations. Current knowledge suggests that stumps are a substrate of limited significance for wood-living species that require conservation measures. At the present scale of stump harvest (< 1 percent of the annual regeneration cutting area), the effects at landscape level should be negligible. This is particularly so since only larger softwood stumps (predominant spruce) are harvested, that stumps are retained near streams, rivers and wetlands and also close to stand boundaries, and where down and dead logs, high stumps and 'eternity trees' are retained. However, an extensive stump harvest would reduce the amount of coarse dead wood in the forest landscape. Compensation for stump harvest by leaving valuable high stumps may probably increase the supply of suitable substrate for species needing conservation measures. Practical rules for such practices have yet to be developed.

Stump harvest can have a negative impact on ground stability and soil chemistry. Extra caution should be taken on moist cutover sections that are rich in organic material and adjacent to water environments, where it has been shown that rutting and soil disturbance can lead to methylation of mercury. Further research is needed before clear guidelines can be formulated. In April 2009, the Swedish Forest Agency issued preliminary recommendations about stump harvest, which can be expected to apply until a revision in 2013.

Harvest of small-dimension trees

Extensive whole-tree harvest in young stands shows larger negative effects in the form of increment loss compared with logging residue harvest. The explanation is that the harvest takes place in a closed forest, with intense competition for nutrients. Consequently, the effects are seen more clearly than on a cutover, where plant establishment and growth is not initially limited by nutrient supply.

Partial delimbing, where trees or tree sections are compressed and roughly delimbed by forcing them through the harvesting head, means that most, according to preliminary studies 50-85 per cent, of the nutrient-rich small limbs are left in the stand. This reduces the problem. Ash cannot be recycled while pulp wood is being harvested because ash contamination of the pulp wood is devastating for the industrial processes. But ash recycling in thinnings where only forest biofuel is harvested can be a method of recycling base cations. However, as mentioned earlier, nitrogen must probably also be added to eliminate loss of production.

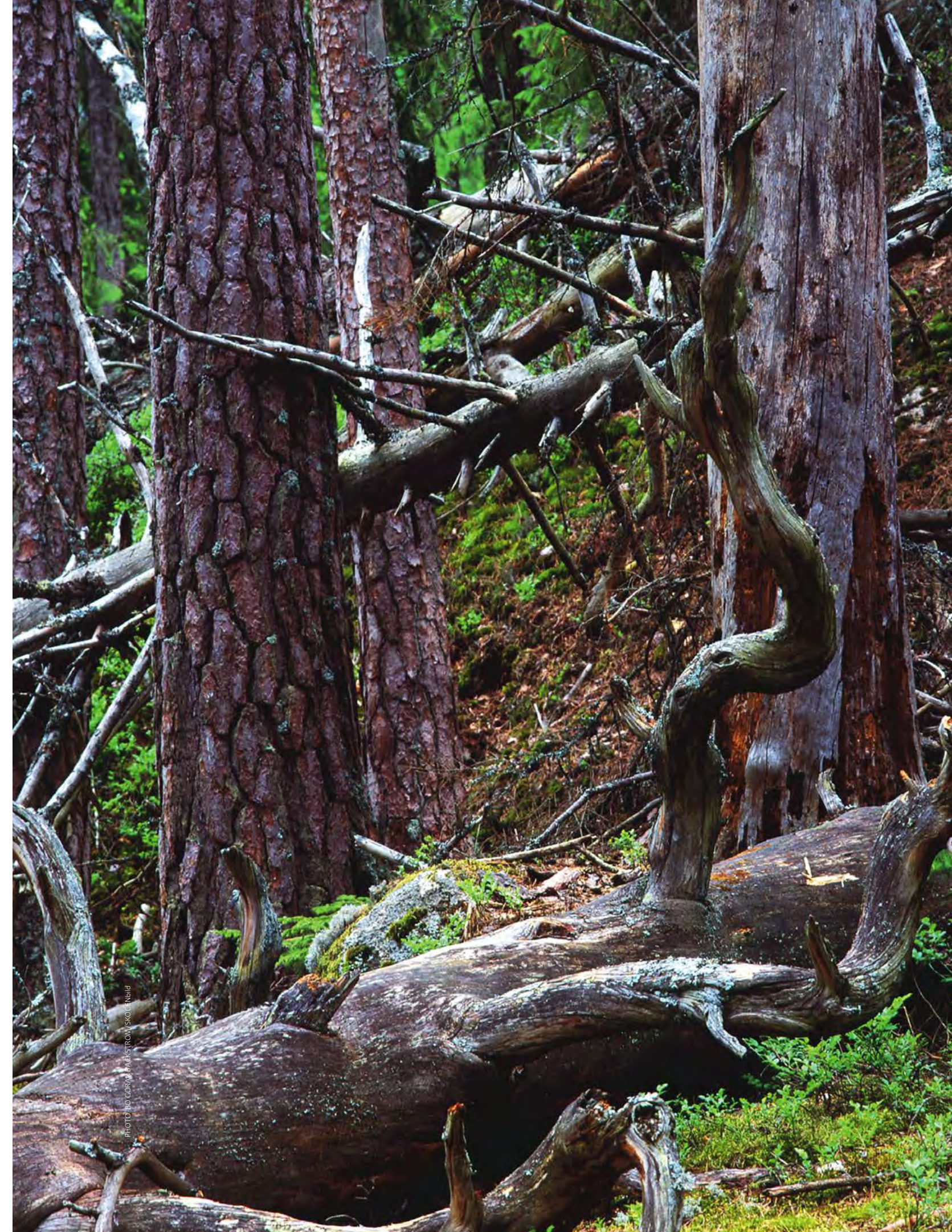


Annually notified area of logging residue harvest, actual area harvested (preliminary figure for 2007), and the area on which ash was recycled. Notified logging residue harvest denotes the area for which the Swedish Forest Agency has got the mandatory notification that removal of residues may occur. The harvest of logging residues is growing rapidly, while ash recycling is increasing at a slower rate. As the intensity of harvesting is increased, compensation measures may be needed to ensure sustainability of forest production.

Overall assessment

When forest utilization is intensified through increased harvest of biomass, future production can be affected negatively because the supply of accessible plant nutrients is decreased. In principle, this also reduces the ability of forest soil to withstand acidification because base cations are removed. If carried out incorrectly, harvest of forest biofuel can entail greater ground damage, resulting in, for example, a negative impact on water quality. An extensive harvest of logging residues, small-dimension trees and, above all, stumps can also reduce the supply of substrate for certain species requiring conservation, particularly wood-living beetles.

However, if current knowledge is applied, it is possible to greatly increase the harvest of forest biofuel without unacceptable consequences for the environment and biodiversity. Compensation and cautionary measures can be applied and developed further to ensure that greater utilization of forest biofuel can take place without serious environmental effects.



BUSINESS MODELS IN FOREST FUEL OPERATIONS

Klas Norin, Skogforsk & Anders Tosterud, Tosterud Forest Consult

The business models used for buying and selling of forest fuel also influence the development in the sector. Current models have been surveyed, using in-depth interviews. Of the six models identified, the 'Negotiation Model' and the 'Partnership Model' are judged to have the greatest potential to form a strong platform for developing the forest fuel business in Sweden.

Forest fuel has been traded for a long time, but only in small volumes. It is only very recently that forest fuel operations have grown so much that it can now be regarded as the forestry industry's third assortment, after timber and pulp wood. The rapid expansion has increased the need for greater efficiency, and there is clearly great scope for improvement. Earlier experiences of business development in forestry, including use of contractors for logging, show that close and successful cooperation between the parties is the key to improvement. The development environment is closely related to the nature of the business process, which can either slow down or stimulate development. Models for forest fuel business activity have therefore been surveyed through in-depth interviews with 15 major sellers and 23 major buyers of forest fuel.

After analyses, six different business models have been identified:

Competition model. Many heating plants rely on competition between the fuel producers stimulating development. Procurement is made through an open tendering procedure or tendering by invitation.

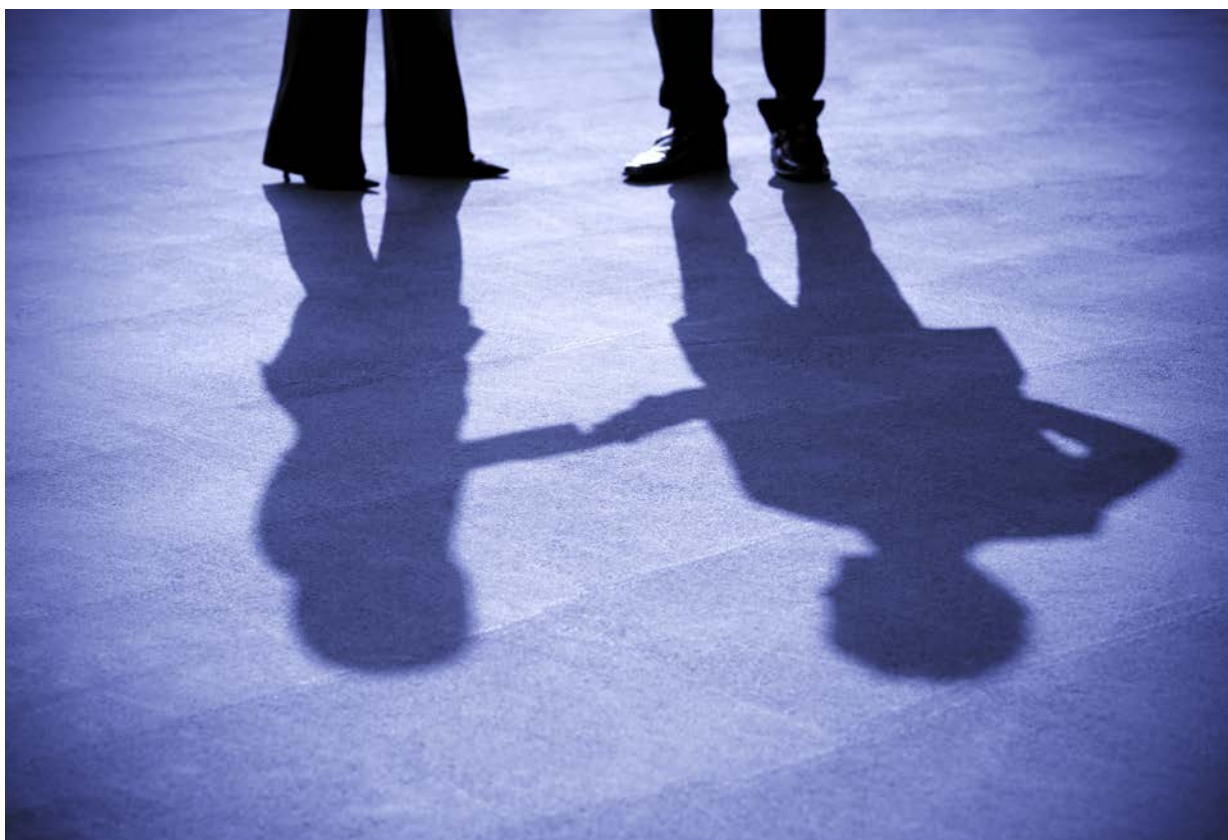
Negotiation model. A traditional purchasing model where buyers and seller, who usually know each other, negotiate a business agreement with which they are both satisfied.

Pricelist model. This is a model in which one, often a major, supplier of forest fuel sells the fuel according to a unilaterally-decided pricelist. The model is most suitable when a major player conducts business with many small players. This is a model that does not stimulate joint development work.

Direct purchasing model. There are also a couple of heating plants that contact private-forest owners directly, sometimes with a fixed pricelist for various fuel products.

Energy market model. A conceptual model that would be similar to the way in which, for example, electricity is bought and sold. It is hard to believe that it would work for forest fuel, where the quality and energy content vary greatly and are also difficult to determine in advance in the field.

Partnership model. This is not strictly a business model, but rather an approach that can be applied to the other models. Some of the interviewees mentioned this as a possible way of improving the efficiency of development work. One example of a possible partnership project could be a jointly-owned terminal where the forest fuel is stored and processed. Partnership in various development projects can be combined with the negotiation model.



The interviews showed that the two most common business models are the Competition Model and the Negotiation Model. In addition, there are sellers of forest fuel who apply the Pricelist Model and buyers who apply the Direct Purchase Model. Two other possible business models were also discussed in the interviews, the Energy Market Model and the Partnership Model. Of the six, the Negotiation Model and Partnership Model are judged to have the greatest potential for creating a good base for developing forest fuel activities in Sweden.

Another important business process that can be developed is the services that are purchased from forestry contractors and haulage companies. The forestry sector's normal way of purchasing contractor services is through performance-related pricing, where the work is paid for according to other criteria than a time rate for the hours worked. This pricing method has so far been little used in the forest fuel sector, because production is difficult to measure and there is a lack of objective measurement tools and methods. A third important business process concerns the raw material purchased from private-forest owners. Today's forest owners are mostly positive to extraction of forest fuel from their properties. However, this situation can change rapidly if there is a sense that the transaction is not taking place in a way that benefits both parties.

Future R&D needs

The interviews raised some important development areas relating to the business models:

- Develop and disseminate business models that promote development. The models will concern purchase of forest fuel, contractor services and raw materials from private-forest owners.
- Description and review of the fuel assortment.
- The heating plants' ability to pay for various assortments.
- Joint partnership projects, such as jointly-owned terminals.
- Training of personnel, both from the forestry sector and the users, so that there are people throughout the forest fuel sector with in-depth understanding of the entire process from stump to energy.
- A more comprehensive study and in-depth analysis of drivers of development in the forest fuel sector than has been possible in this study.
- Examine what parties experience as good business.
- Create different forums for exchange of experiences and development between users and suppliers of forest fuel.



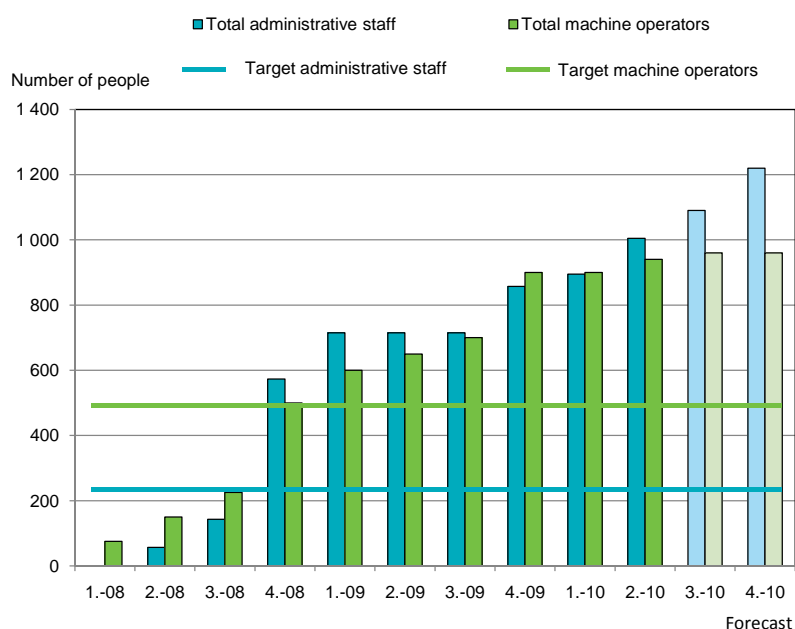
TRAINING FOR MORE EFFICIENT HANDLING OF LOGGING RESIDUES

Tomas Johannesson & Rolf Björheden, Skogforsk

In April 2008, Skogforsk started a campaign to improve efficiency and quality in practical aspects of logging residue management. After two years, more than 2,000 machine operators, contractors and administrative staff have been trained in areas that concern choice of correct method and technology, planning of the work, and how results influence subsequent tiers of the production chain. It is estimated that the training initiatives have generally improved efficiency in logging residue management by 5-10 percent.

Conditions for forest fuel production vary considerably between different regions and areas in Sweden. The differences influence utilization potential and the methods and management models that are best suited to local conditions. Field personnel sometimes had limited knowledge about available methods, and could not comfortably choose between the alternatives.

In April 2008, Skogforsk started a massive training campaign about logging residues. The focus was on issues and procedures relating to handling and on improving participants' insight into their own work and how it affects other stages in the production chain. These training programmes have been company-oriented to ensure accordance with local conditions. Forestry companies operate largely under the same circumstances, so the course content has often



Accumulative number of machine operators and administrative staff that have completed logging residue training programme by quarter, and the target numbers of participants set at the start of the campaign.

been similar. More comprehensive adaptation of the course content was needed for forest owner associations and owners of smaller forests.

Two primary target groups were identified for the training courses: administrative staff in forestry companies and machine operators. In addition, around 15 instructors were trained at the start. Of these, 6-8 are currently active in various training programmes that are primarily aimed at machine operators in forestry companies.

The training in practical management of logging residues comprises:

- Choice of correct method and technology,
- Appropriate planning,
- Greater and simplified cooperation between the various players in the logging residue supply chain.

The training programme provides a greater overview and better understanding of logging residue production, but also more in-depth knowledge about methods. This improves the ability to choose the correct method under different conditions, thereby improving efficiency and quality in the work. Particular importance has been placed on awareness of the preceding and subsequent stages in the chain, so the work can focus on delivering an optimal intermediate product to the next player in the chain.

During the project period, the target was to train 500 machine operators and 225 administrative staff in forestry companies. By May 2010, nearly 1,000 machine operators and 1,005 administrative staff, of which 431 from private forest owners' associations, had completed the training programme. A total of 69 courses have so far been held.



Contact with a large number of interested practitioners in the broad training initiative has given good feedback of knowledge. Skogforsk has published a manual, 'More Efficient Management of Logging Residues (in Swedish)', based on the course material and the experiences gained during the training programmes.

Course evaluations have been very positive (overall score of 83 on a 0-100 scale), but the practical effects of the training initiatives are harder to evaluate. However, spontaneous reports from participating forest owner associations and forest fuel consumers indicate a clear improvement in terms of both increased delivery volumes and their quality. Based on experiences from similar campaigns (e.g. for improved bucking and wood handling), it is reasonable to assume an improvement in efficiency of approximately 5-10 percent as a result of the initiatives. However, experiences show that training initiatives need to be held regularly and to be repeated in order to maintain the positive effect.

Parts of Skogforsk's logging residue training have been incorporated in other campaigns or training initiatives, e.g. in the Swedish Forest Agency's course package, "Bioenergy and Compensation Measures" financed by the Swedish Rural Development Programme. Skogforsk's training course has also attracted interest in other Nordic countries. The course management also received many new experiences from the broad field contacts. Together with the course material, the experiences have been compiled into a manual, "More Efficient Management of Logging Residues" (in Swedish), issued by Skogforsk.

Future development needs

Campaigns of this type need to be repeated in order to maintain the effects. New technology, new methods and new conditions for forest fuel production also means that the training and implementation work needs constant revision.

The working model has been very effective. Similar initiatives will therefore be tested in order to facilitate the introduction of efficient methods for logging of small-dimension trees, pre-commercial thinning for bioenergy and harvesting of stumps.

A corresponding campaign should also be directed towards the fuel users. A project with this aim has been started together with the Swedish District Heating Association (Svensk Fjärrvärmeförening) and the Thermal Engineering Research Institute (Värmeforsk).



WORK ENVIRONMENT AND ERGONOMICS IN FOREST FUEL PRODUCTION

Rolf Björheden, Skogforsk & Ann Hedlund, Dalarna University

A review of work environment and ergonomics indicates that forest fuel operations share many problems with mechanised forestry in general. However, in-depth interviews suggest that forest fuel handling also involves specific risks in the work environment. These risks include high exposure to noise in processing and to dust and spores, particularly during work with stored logging residue fuel. In addition, some of the machines currently used fall short of the recommendations on acceptable working conditions that have been established for forest machine operation.

A large proportion of incidents and accidents in the forestry sector are caused by slipping, tripping, and falling during maintenance and service of the machines, as well as through loss of control over objects or hand-held tools during such work. These causes accounted for nearly 70 percent of the reported occupational accidents in the period 2004-2008, while loss of control of machine or transport equipment during production accounted for just over 10 percent. Consequently, it is important to improve awareness of the risks associated with maintenance work, and to facilitate this work.

Current statistics of occupational injuries do not identify any work environment problems specific to forest fuel production. In order to shed light on the issue, around 25 interviews were held with contractors, experts, and supervisors. The in-depth interviews suggest that activities relating to forest fuel involve greater work environment risks in certain aspects compared with other forest work. The additional risks include high exposure to noise during processing and to dust and spores, particularly when working with stored logging residues. The operator can be exposed to whole-body vibration when removing stumps and transporting wood along unlined striproads. Another possible risk factor is the high mental work-load during logging with an accumulating felling unit in young, dense forest with poor visibility.

In addition, some of the machines used fall a long way short of the recommendations stipulated for acceptable work environments for machine work, for example inappropriately-placed service points. The review concludes that ergonomic analysis and review of relevant work can reduce the problems, increase work efficiency, and make working with forest fuels more attractive.

Work environment in forest fuel operations

A review was carried for the ESS programme by Marit Lundström and the research group Theme Working Life at Dalarna University, under the leadership of Ing-Marie Andersson and Gunnar Rosén. The study shows that it is difficult to identify specific work environment risks in current statistics of occupational injuries. Instead, directed interviews have been held in order to get an overall impression of the work environment situation. The review shows that the work environment risks in forest fuel operations cannot be investigated through the existing statistical groups in ISA (Swedish Information System for Occupational Injuries) nor from the Swedish Work Environment Authority's statistics of occupational injuries reported in accordance with Section 2 of the Swedish Work Environment Ordinance or the Swedish Occupational Injuries Insurance Act. The figures for forest fuel related works are incorporated in figures for forestry in general or with agriculture.

Case studies of work environment and attractiveness

The review has been followed by some case studies by the research group Theme Working Life at Dalarna University, under the leadership of Ann Hedlund. The results show work environment risks shared by mechanised forestry in general, for example monotonous working posture, vibrations, jolting, and solo work. There are specific risks to forest fuel production, for example flying objects and dust. Small cabs with bad noise isolation, defective climate control and without vibration damping occurs. Lack of communication between different operators, and lack of distribution of local knowledge about technical and organizational solutions are also identified. The work is attractive according to most of the 18 deep interviewed persons, owners and employees working with forest fuel production. Freedom to organize work, to be in the forest, to work with machines and to have good management that supports development of both business and employees are things that primary contributes to make the work attractive.

Future R&D needs

In order to improve understanding of the work environment problems in forest fuel operations, measures required include the following:

- Systematic risk assessments of occupational exposure, particularly to mould dust, and exposure to noise and vibration.
- Adaptation of existing statistics in order to distinguish risks in the forest fuel area.

In parallel, systematic initiatives on the work environment should be started, such as:

- Developing a culture of safety and improving risk awareness through increased, systematic exchange of knowledge and experience between contractors.
- Clients making specific demands on suppliers and contractors regarding safety and work environment.

In order to meet the increasing need of skilled work force, further knowledge of and development of work attractiveness is important.



Naturfränsle

PROCUREMENT SYSTEMS FOR LOGGING RESIDUES

Lars Eliasson, Skogforsk

The choice of logging residue procurement system is largely determined by the customer's reception facilities and fuel requirements. Five main systems for logging residue procurement can be identified. The two most common systems are chipping at the landing and trucking of chips to customer and deliveries of loose logging residues to customer, but the share of chipper truck systems are increasing. If the customer demands fuel chips, systems involving chipping at the landing (or cutover) and chipper trucks are appropriate. Systems delivering loose or bundled logging residues requires that the material is sent to a customer or terminal with access to comminution equipment.

Comminution at the landing

Chipping at the landing usually involves using forwarder-mounted chippers that either transfers the chips to a container or onto a pile on the ground, with or without a tarpaulin under the pile. The chips are transported to the recipient using switch-body container trucks or for piled chips a chip trucks fitted with a crane. A major advantage of forwarder-mounted chippers is that they are not dependent on residue piles being placed directly beside the road, and that they do not need to stand on the road during operation. Their main disadvantage is a high cost for relocation between logging sites. They are a competitive option, particularly on larger logging sites and/or where the chip transport distances are long. As an alternative to the forwarder-mounted chippers, large, stationary chippers or grinders can be used on the landing.



Chipping at the landing using forwarder-mounted chippers is common. A disadvantage of the system is the cost of moving the equipment between logging sites.

Loose logging residues

Systems delivering logging residues to the heating plant or terminal are competitive on short to medium-length distances. These systems are favoured by low costs of comminution at the heating plant or terminal, and the absence of relocation costs for chipping equipment. A major drawback is that logging residues are a voluminous material to transport which results in low payloads on logging residue trucks and higher transport costs per km than for other systems.

Presently, the average payload on trucks for transport of loose residues is 22 tonnes which is low considering that the legal payload is between 26 and 30 tonnes depending on truck weight. Nevertheless, compared with the early 1990s, the average payload has increased by about 20 percent. Skogforsk studies at that time showed that payloads could be increased by between 27 and 35 per cent by using the crane to successively compress the residues during loading. To utilise the current potential for greater payloads further compression of the logging residues or increased load volumes



The loose logging residue system is competitive on short to medium-length distances. However, the relatively low payload is a weakness.

are required. An advantage with logging residue trucks is that they can be used for transport of several different

forest energy assortments – logging residues, tree parts, stumps, and bundles.

Chipper Trucks

Integrated systems for chipping and transport are becoming increasingly common. The most common type is the 'chipper truck' – denoting truck equipped with a high-tipping chip bin and rear-mounted chipper, which pulls a chip trailer. The advantages of chipper truck systems are that there are no costs for moving between logging sites and that chipping and loading are integrated. The main disadvantage is that the heavy chipper is mounted on the truck, thereby reducing the maximum payload. On short to medium-length distances, chipper trucks are a competitive option for comminution at the landing.

In order to utilize the advantages and reduce the disadvantages of the

chipper truck system, two hybrid systems have been developed. In one system the chipper is mounted on a link, i.e. a wagon that can be linked between the truck and a chip semi-trailer. The link and chipper can be removed and left at the landing until chipping is completed at the logging site. The other is the container handling chipper truck, where the chipper truck is equipped with a container handling system and chips the wood into containers that may be driven to the recipient by container trucks. Thus, the chipper truck may serve as truck-mounted chipper operating purely at the landing and only used for chip transport when the final load of the day is driven to the recipient.



Chipper truck – a relatively new system.

Bundling

Bundling systems were developed to simplify handling, to increase payload and to enable utilization of standard roundwood vehicles for transport of logging residues in the forest and on roads. Bundled residues also have better storage properties than loose residues or fuel chips.

Bundling is made either on the cutover using forwarders equipped with a bundling unit or at landings using trucks fitted with a bundling unit. Bundling on the cutover considerably reduces forwarding costs compared to forwarding loose logging residues. Consequently, a landing-based bundler must produce bundles considerably cheaper than a forwarder-based bundler in order to be competitive. At present, it is doubtful whether this is the case. Forwarder-based bundlers have a high productivity but are very costly per effective hour. Acceptable bundling costs may be achieved on condition that machine utilization can be kept high. In reality however, the utilization rate can vary greatly between different machines. At present, bundles are transported on logging residue trucks, since the risk of losing material from the bundles during transport makes it impossible



Bundling of logging residues facilitates storage and transport.

to use conventional roundwood trucks safely. As residue trucks are heavier than roundwood trucks, this has led to lower maximum payloads than expected and thereby higher transport costs. Trials are being carried out involving a purpose-built truck for bundle transports that is considerably lighter than a logging residue truck. In addition to high machine utilization rate and high maximum payload, good planning is needed in order to minimize relocation time between logging sites if the bundling systems are to be viable.

Future R&D needs

In the project, existing systems for logging residue procurement have been described, and their advantages and disadvantages examined. For more comprehensive comparisons of forest fuel procurement systems under realistic conditions computer simulations using discrete event methods are needed to realistically estimate effects of interactions between different parts within the procurement system. This will enable more accurate estimates of overall costs and production levels for the procurement systems. Such simulations are now under way.

Chipping on the cutover

Chipping residues on the cutover using forwarder-mounted chippers once was the main system for fuel chip production. Today it is not common since it is not a cost-effective way of producing chips. It may occur to a certain extent during the low season in the summer to provide the chipping contractor with work or in other special circumstances.

Chipping on the cutover is a system that was previously common. Economically it cannot compete with other systems, but may be justified for other reasons.





Systems with no moving costs between sites are very competitive. They are insensitive to tract volume. The container chipper truck is especially versatile since it may work as a landing based chipper for longer transport distances, feeding a team of regular container trucks, who are taking care of transportation.

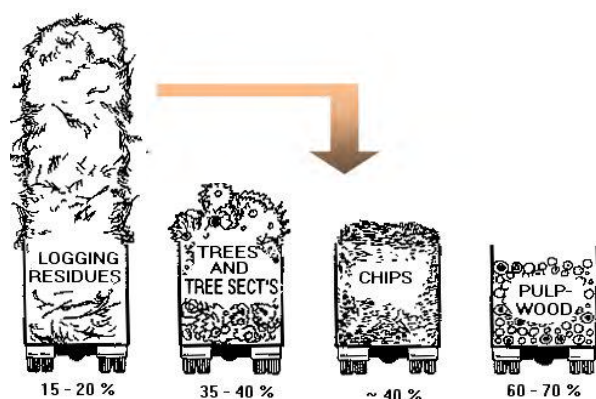


COMMINUTION AND TRANSPORT

– KEYS TO MORE EFFICIENT FOREST FUEL SYSTEMS

Rolf Björheden, Skogforsk

Comminution and transport are major costs in logging residue production. Correct choice of technology and location of the comminution reduces the costs. Improved methods and new technology mean that systems with no cost for moving between sites, e.g. loose logging residue truck or chipper truck, can reduce costs by 20-40 percent on small logging sites compared with chipping at the landing. Such systems are interesting for harvest on cutovers in private forests and in southern Sweden where sites are small. Also on larger logging sites, the loose logging residue and chipper truck systems are competitive for hauling distances under 100-120 km.



SKETCH: SIGURD FALK, BASED ON A CONCEPT OF JAN ERIK MATSSONSON

All loads contain the same amount of biomass. Logging residues are difficult to handle and is very bulky. Comminution at the start of the transport chain, for example using a truck-mounted chipper, reduces the bulk of the material and makes handling easier, but is more expensive than centralised processing.

A great number of combinations of haulage and comminution technologies have been studied and analysed. The analysis shows that the different combinations can be defined as three, principally different types of system. They demonstrate varying sensitivity for hauling distance and size of logging site. The three systems are:

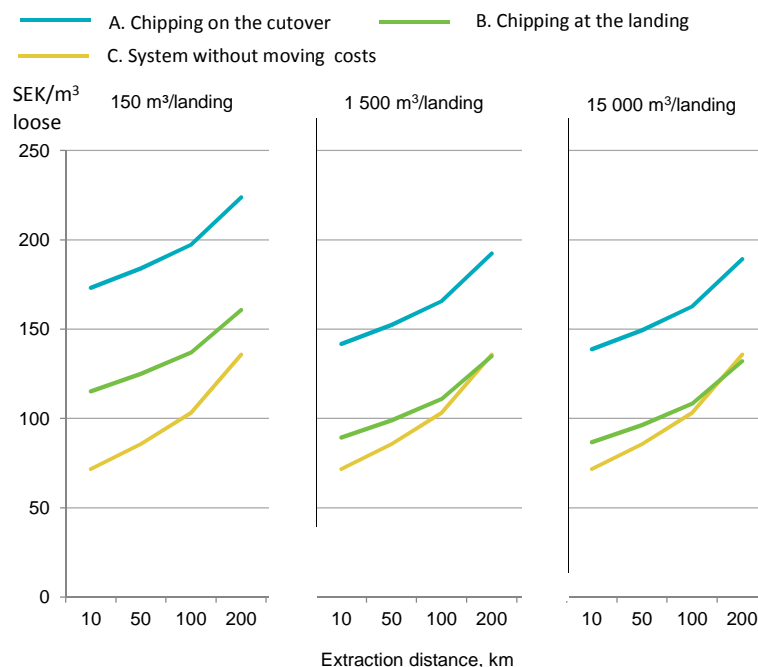
- Systems in which the logging residues are comminuted at the cutover.
- Systems where comminution takes place at the landing by chipper/grinder.
- Systems with no moving costs between sites, i.e. direct transport of loose logging residue or by chips comminuted by chipper truck (or chipper link).

The results show that:

- Comminution at the cutover is expensive and can only be justified on non-economic grounds.
- The system with landing-based chippers can compete over longer extraction distances (>100-120 km). On medium-sized to large logging sites, large chippers or crushers are preferable.

- The systems with no moving cost are superior for most of the raw material, particularly on small logging sites and short-medium hauls.

The systems with no moving cost are very competitive. However, the competitiveness of the loose logging residue system is dependent on good payload utilization of the vehicles. High payloads require experienced operators for loading and effective forwarding/stacking. Naturally, the loose logging residue system also requires that the logging residue can be chipped at the customer's facility or at a terminal. Where chipper trucks with containers (and chipper link, with its removable chipping unit) are used on large logging sites, regular chip/container trucks can work towards the chipper as a team. This should make the system more competitive, but has not yet been studied.



Net cost in SEK/m³ loose for the three systems, at varying sizes of logging site and extraction distance.

Future R&D needs

In the More Efficient Communion project, Skogforsk has studied a large number of combinations of transport and comminution technologies for logging residue. Our analyses indicate that economic forces are driving development towards centralised comminution of forest fuel and towards crushing instead of chipping. This development gives cheaper forest fuel, but also means that the customers must invest in comminution and screening facilities. Consequently, the effects are complex and need to be closely examined. On some logging sites, the forestry company will also want to remove stumps, which will affect the choice of technology and system. Handling the entire forest fuel volume in a single process is desirable. An interesting solution, that we hope to be able to study in the future, is coarse, transport preparatory crushing of both logging residues and stumps at the same landing.





PHOTO: THOMAS ADOLFSEN/SKOCENBIL

FORWARDING FRESH OR DRIED LOGGING RESIDUES

– EFFECTS ON LOGISTICS AND FUEL QUALITY

Rolf Björheden, Skogforsk

There are many advantages of forwarding fresh logging residues at the time of logging compared to after storing and drying in small piles on the cutover. Logging residues are easier to recover, which improves productivity and increases the recovery rate of logging residues from the cutover. The recovery season is extended and, on small logging sites, the same forwarder can be used for transport of both roundwood and logging residues. An expected disadvantage is increased moisture content compared to residues dried on the cutover.

In collaboration with Södra Skogsenergi, SLU and Linnaeus University, Skogforsk has tested forwarding and stacking logging residues at or close to the time of final felling. Drivers for forwarding fresh logging residues without intermediate storing on the cutover are improved logistics, simplified production planning and speed of clearing the cutover, facilitating scarification and planting. Some disadvantages may be higher NO_x concentrations on incineration, and the greater need for ash recycling or vitality fertilization.

The experiment was set up in the 2008-09 season and involved nearly 3,000 tonnes of DM from over 30 logging sites. To include effects of different precipitation regimes, logging sites were chosen in three areas in south Sweden – on the humid west coast, on the South Swedish Upland, and on the drier east coast. All logging residues were stored in covered stacks and chipped for commercial fuel delivery during the period November-January 2009-10. In six sites, both treatments were tested to ensure that orographic

differences would not influence the chemical analyses.

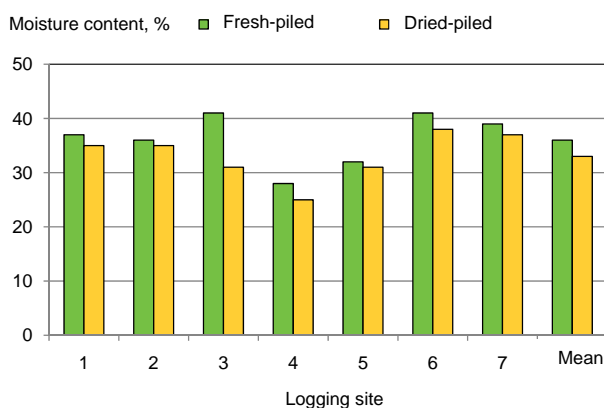
The drying process during storage was monitored by measuring moisture content on three occasions plus a final measurement at the time of delivery. On delivery, the average moisture content of the ‘fresh-stacked’ fuel was moderately higher than for the dried fuel, 36 and 33 per cent, respectively. Another result is that stacks must be placed with the drying conditions in mind, i.e. free-standing, dry and exposed to sun and wind.

The proportion of needles in the ‘fresh’ and ‘dried’ logging residue stacks was investigated. The recorded content of needles was around double for the fresh-stacked residues but the difference in ash content was small. Further chemical analyses revealed logical but minor differences in sodium, potassium, chlorine, carbon, hydrogen and nitrogen. Customers receiving the forest fuel have not reported any problems with fuels from logging residues forwarded fresh.





Forwarding fresh logging residues frees up the cutover earlier, facilitates planning, increases harvest and improves forwarding productivity. Despite a slightly lower fuel quality, it may be advantageous to extract some of the residues in fresh condition.



Comparison of moisture content in fresh-stacked and dried stacked residues on delivery to customer. Columns 1-7 show the differences for each logging site where green logging residue was harvested on half the area, and the rest harvested after storage on the cutover. The mean applies to all logging sites, i.e. includes those where there was comparison by logging site

Fraction	Fresh logging residue, %	Dried-piled residue, stored, %	Fresh-piled residue, stored, %
Branches, sprigs, etc. >3 mm	78	80	74
Fine fraction <3 mm excl. needles	5	16	18
Needles	17	4	8

Fractions in residues forwarded and stacked when fresh and after drying on the cutover and in fresh logging residue of Norway spruce. (Preliminary results from Nilsson, Linnaeus University).

	Reference	Fresh-stacked	Dried-stacked
Chemical analyses:			
Ash % of dry weight	3.3	4.0	3.7
Na mg/kg TS	307.0	193.6	158.8
K mg/kg TS	3 067	3 100	2 670
C % of dry weight	52.50	52.40	52.20
N % of dry weight	1.030	1.100	0.960
H % of dry weight	5.830	5.550	5.550
Cl % of dry weight	0.050	0.036	0.026
Heating values:			
W_{cal} , MJ/kg DM	21.0	20.8	20.8
W_{eff} , MJ/kg DM	19.7	19.6	19.5
W_{eff} , MJ/kg fresh mass	5.8	11.3	11.9

Analyses of material from the 6 sites with both treatments. The reference value is an example of fresh residues. The higher ash content, Na, K and Cl in residues piled green are a logical consequence of a higher proportion of needles. Differences in higher (calorimetric) heating value, W_{cal} , and lower (effective) heating value, W_{eff} , are small between fresh-stacked and dried stacked residues. (Results from Jirjis & Anerud, SLU).

Future R&D needs

Fuel quality and properties of logging residues stacked fresh fuel need to be studied further. There is a lot of technical and chemical engineering knowledge available relating to incineration of these fuels, but these must be disseminated to all users.

Sampling of highly variable materials such as logging residues is difficult and the properties reported cannot be seen as conclusive. The study needs to be followed up. Supplementary field experiments to examine sustainability aspects (nutrient loss, ash recycling, etc) can be needed. In particular, technical and operational issues must be studied in greater depth. Methods and procedures must be designed to fully utilize technical and operational advantages (simpler planning, faster replanting of logging sites, fewer machine relocations, etc) with forwarding of fresh residues.

INTEGRATED HARVEST OF ROUNDWOOD AND LOGGING RESIDUE BUNDLES

Isabelle Bergkvist, Skogforsk



The concept of bundling logging residues parallel with logging of roundwood on a combined harvester/bundler was analysed with positive results already ten years ago. Today, a logging system with direct loading is available - the Besten system - which could make the idea even more interesting. A recent analysis shows that the Besten system with an automated residue bundling unit would reduce costs by around one third. Further, logging residue recovery in such an integrated system, entails only a tenth to a third of the corresponding diesel consumption when the processes are carried out in separate operations.

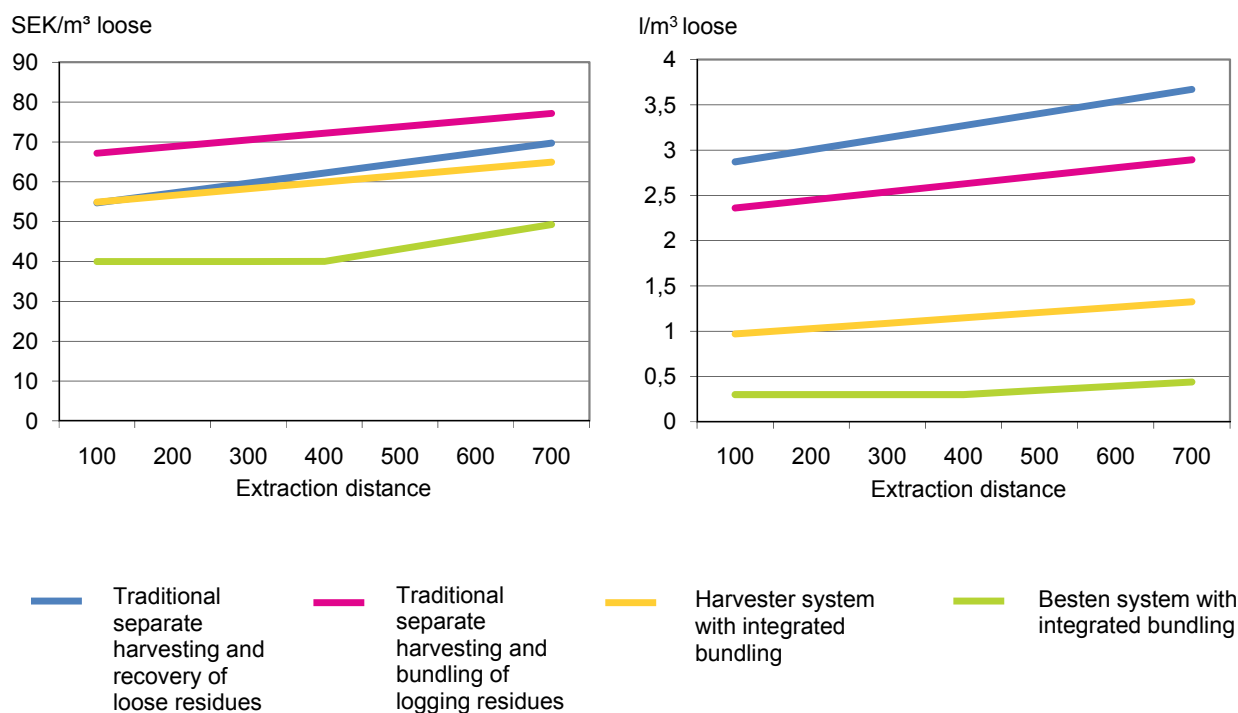
Four systems for logging of roundwood and utilization of logging residues have been compared:

- Separate operations for roundwood logging and utilization of loose logging residues.
- Separate operations for roundwood logging and bundling of loose logging residues.
- Integrated logging: roundwood and bundling of green residues based on a conventional harvester.
- Integrated logging: roundwood and bundling of green residues using the Besten system.

The comparison includes production costs and fuel consumption for the recovery of logging residues including transportation to the landing and the comminution of the fuel assortment. Secondary transport is not included. A marginal cost has been added to the integrated systems to allow for lost production, since performance in roundwood production will decrease as a consequence of fuel handling. However, this effect has been judged to be relatively small. It is also assumed that the logging residues are green when bundled, thereby slightly increasing costs on account of the fuel's higher moisture content, e.g. more expensive

The Besten System

The Besten system consists of an unmanned harvester that is operated by remote control from a courier, which can be described as a forwarder with a slew- and tiltable loading space. The Besten fells and processes the trees, which are loaded directly onto the courier. In most cases, two couriers are used, each of which alternates between logging/loading with the harvester unit and transporting the wood to the landing. The harvester unit has no operator cabin, so there is room for other equipment in the form of a feed table and compressing equipment for bundling loose logging residues. Bundles can be transported cost-effectively, as the shuttles can simply place 2-3 bundles on top of the load when they transport roundwood to the landing.



Left: production cost for utilization of logging residue for different systems and extraction distance to landing, SEK per m³ loose (chips).
 Right: Diesel consumption of the machines for utilization of logging residue, liters per m³ loose.

transports. If bundles are not dried, revenues will decrease as a consequence of the lower heating value compared to stored and dried logging residues.

Integrated bundling with the Besten system had the lowest production cost. Production efficiency was improved through the direct loading and the loading/unloading of bundles was cost effective when shuttles transport roundwood or are on standby.

The system with separate bundling had the highest production cost. It should be noted, however, that bundling simplifies handling and administration in subsequent stages, which has not been included in these calculations.

Fuel consumption in utilization of logging residues can be reduced by using integrated systems. In both integrated systems, diesel consumption per m³ sub forest fuel was considerably lower than in the traditional systems. This is because fewer machines and processes are required on account of the integration and direct loading of the forest fuel.

In the system with separate bundling, fuel consumption was less than in the traditional system with separate logging and loose logging residue handling because bundled logging residue allows more efficient handling, for example in comminution.

Disadvantages of integrating roundwood harvesting with utilization of logging residues are that production rate per machine unit is lower than when producing roundwood and

forest fuel with specialised machines and, in addition, that systems with separate machines are more flexible and less susceptible to down time and low TU (technical utilization). In the integrated systems, productivity of bundling depends on the fuel volume of the trees that are harvested. If the forest fuel volume per stem is low, the bundling unit will not be utilized efficiently, resulting in few bundles per hour compared with separate bundling (where the bundler production rate is much less dependent on the nature of the stand). It was assumed that bundled green residues can be sold as fuel. These disadvantages are to be weighed against the significant strengths of integrated systems, with lower production costs and only a fraction of the fuel consumption, and thereby smaller green house gas load, compared with separate systems.

Future R&D needs

This study only includes analyses of integrated systems for bundling of logging residues. However, systems could be designed whereby chipping of the forest fuel is integrated with harvesting of roundwood. The advantages of such systems are roughly the same as those of the integrated bundling, except that chipping will have a different influence to that of bundling on transport and storage. Skogforsk is also studying systems with integrated logging and chipping.



PRODUCTIVITY STANDARDS FOR FORWARDING OF LOGGING RESIDUES

Torbjörn Brunberg & Lars Eliasson, Skogforsk

Forwarding is an important early step in the procurement chain for logging residues and benchmarking of forwarding efficiency is necessary in order to develop the operation. But in the absence of established, objective productivity models this is virtually impossible. This is why Skogforsk has developed a preliminary productivity standard that allows fair comparisons between different contractors and forestry companies. In combination with improved estimations of logging residue quantities on the cutover using harvester data, on which Skogforsk is also working, the productivity standard will support scheduling and improve the efficiency of utilization of the logging residue harvesters.

Productivity in forwarding of logging residues has increased in the past 15 years. One reason is that payloads have increased from 5-8 tonnes to 8-12 tonnes, through improved design of load bunks of the logging residue forwarders. On the other hand, the permitted payload of most logging residue forwarders is 14-16 tonnes and, thus, load



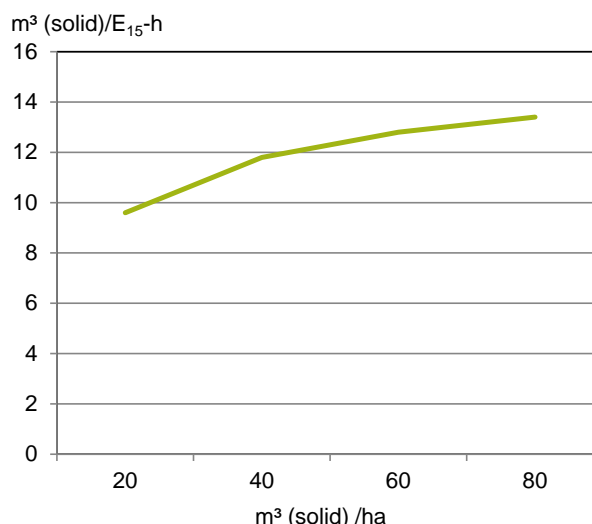
utilization is still low - 65 to 80 per cent. Some contractors still use older technology, thus operating with lower load utilization and lower productivity than is allowed by state of the art technology. Until performance standards have been established it is difficult to make fair productivity comparisons between forwarding contractors, as the variations in payload capacity and work conditions of the logging sites is large and the influence of these important variables is poorly analysed. These variations make it difficult to estimate costs and time consumption for forwarding of a specific site.

In order to produce reliable time and cost estimates for logging residue forwarding, a preliminary productivity standard has been developed based on work statistics. Using the time taken for loading and unloading, transport and other effective time, productivity can be calculated. The variables included in the standard are:

- Density of residues for extraction per hectare
- Terrain transportation and base road transportation distance to the landing
- Surface structure and slope of the logging site
- Average payload

Future R&D needs

Although a first productivity standard is finished, it is a living document and needs updates as work methods and machines evolves. Harvester information on residue harvested areas will enable better estimates of residue concentrations and driving distances in forwarder work statistics. This will improve the quality of input data in future revisions of the productivity model.



Examples in which the productivity standard is used show the influence of logging residue density per ha on forwarding.

The diagram, as an example, illustrates how the density of logging residues influences the expected productivity of residue forwarding. For instance when residue density on the site increases from 20 to 80 m³ per ha, productivity is expected to increase by approximately 30 per cent.

A field study was made to examine if drying of residues prior to forwarding affected forwarder productivity. Results show that there were no differences in productivity measured as dry tonnes per effective hour between forwarding of freshly cut (green) residues and residues that were forwarded after a summers drying on the cutover given the same concentration of residues. However, a conservative estimate based on literature is that at least 10 per cent more dry mass will be recovered when fresh residues are recovered than if they are left to dry on the logging site before recovery.

Combining harvester measurement with biomass functions produces reliable estimations of logging residue density on the cutover. Using this information together with the productivity standard will greatly improve scheduling of logging residue forwarding and thereby simplify efficient utilization of logging residue forwarders. It will also allow fair comparisons between different work teams and between different companies (benchmarking). This will facilitate a broad spread of 'best practice' from the most efficient contractors and machine teams.

FOLLOW-UP OF THE JOHN DEERE LOGGING RESIDUE BUNDLER

Lars Eliasson, Skogforsk

Operation statistics for the John Deere 1490D logging residue bundler have been compiled from 92 logging sites, in total almost 64,500 bundles. The machine produced 28 bundles per hour of effective work (E_0 hour), and had a degree of technical utilization (TU) of 78 per cent. Productivity was comparable to earlier time studies, but the TU was higher which is positive for the cost per bundle. Work in winter conditions decreased productivity by 14 per cent. TU decreased on small sites (i. e. where few bundles could be produced).

The analysed operation statistics apply to one machine with five operators, working on 92 logging sites in 2009. A total of 64,468 bundles of 3 m length were produced. Bundles were produced in February and March 2006 under winter conditions in the north Swedish county of Norrbotten and during April to November in central Sweden under snow-free conditions. Relocation between the logging sites was not recorded and therefore not included in the analyses.

Average productivity was 27.9 bundles per E_0 hour, which is comparable to previous time studies of bundling machines. Productivity increased with size of logging site, while variation in productivity decreased. When bundling took place under snowy winter conditions productivity was 14 per cent lower (25.3 bundles/ E_0 hour) than during summer and autumn conditions (29.3 bundles/ E_0 hour). The causes of between site variability in productivity cannot be deducted from the statistics. More information would be required about each logging site in terms of logging residue quantity per ha, area on which bundling took place, tree species mix, and quality of the logging residue adaptation in final felling. Such data are lacking in the statistics.

The degree of technical utilization (TU, calculated in relation to E_0 time) was 78 per cent, which is high compared to previous studies. Even if there is large variation in TU between logging sites, for the great majority (85 per cent) of



the logging sites TU was between 70 and 90 per cent. Low TU mainly occurred on logging sites where few bundles could be produced. For these sites average relocation time per bundle will be high, which means that the machine's utilization for bundling work will be low. The large variability in productivity and TU for small sites indicates that they need to be planned with extreme care in order to achieve an efficient bundling operation. There were no differences in TU between seasons, nor was it possible to see any link between productivity per E_0 hour and the technical utilization rate of the machine.

High utilization in combination with high productivity means that the bundling cost, including an assumed relocation time of 2.5 hours between sites, is approximately SEK 50 per MWh. If the bundling system is to be competitive in relation to other systems for logging residue procurement, this cost must be balanced by a corresponding reduction of costs for terrain transport, comminution and secondary transport, or by an increased value of the delivered product.



Logging residue bundler – a smart logistics solution

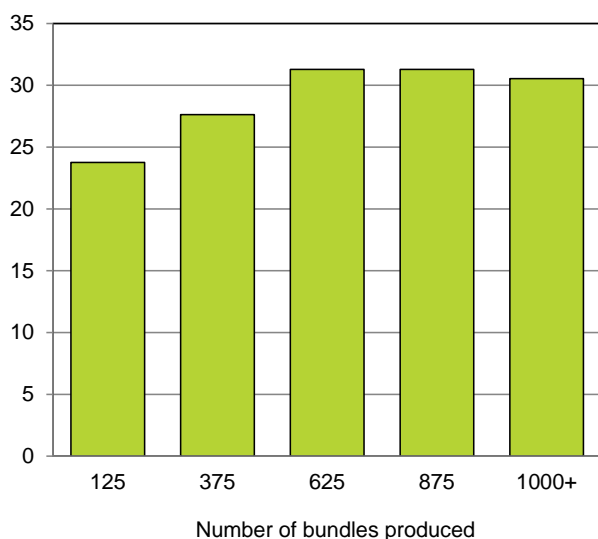
The purpose of logging residue bundlers is to improve the efficiency of transport of logging residues by compressing, bundling and cutting the logging residue into standard handling units. The bundling process of the John Deere bundler is continuous, so the variability of the logging residues, e.g. occurrence of long tops, does not restrict the bundling. The bundler gathers the logging residue using the boom and places it on a feed table. The logging residue is compressed using arms that shape it into a round bundle which is wound together by yarn and cut into suitable lengths, usually 3 m.

The bundles enable efficient handling of logging residues. Bundles can be transported on conventional forwarders and roundwood trucks. In many cases the bundles can be comminuted at the recipient's facility using an electrical crusher, thus reducing environmental impact compared to the standard forest fuel systems where logging residues are chipped on landing using diesel-driven chippers. Bundles dry well and have good storage properties if handled correctly.

Future R&D needs

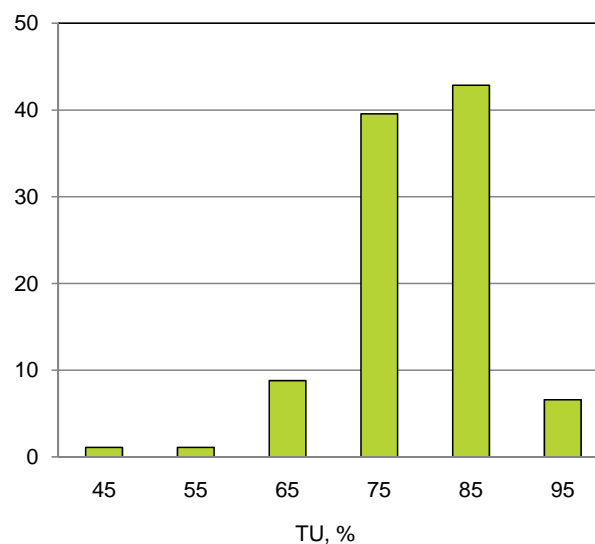
Comparisons between the bundling system and other systems for extraction of logging residues are planned for the near future. Studies further ahead should relate bundler productivity to influencing factors, such as logging residue concentration and type of logging residues. The technical productivity potential of the bundling machine is high, but work management and planning must be carried out with great care and for long periods to ensure a high productivity in practical operations. A relevant question is whether anyone but the large forest companies can manage this.

Bundles per E_0 hour



Average productivity (bundles per E_0 hour) under summer conditions depending on the size of the logging site (total number of bundles produced).

Per cent of logging sites



Variability of technical utilization (TU) for the logging residue bundler. Columns refer to mid-point of class.



CLEANING OF UNDERGROWTH

Lars Eliasson & Tomas Johannesson, Skogforsk

Final felling stands that contain a lot of undergrowth (small unmerchantable trees or small trees not viable for logging) can make logging difficult because the vision of the harvester operator is impaired, preventing efficient utilization of the harvester unit. This can increase time consumption and thereby the logging costs. In order to avoid this, the undergrowth can be cleaned before logging using a brush saw. In the forestry sector, views vary on the necessity of cleaning undergrowth. Some companies do not clean undergrowth at all, while others carry out undergrowth cleaning as soon as the number of small trees per ha exceeds a certain number.

When logging residues are to be extracted after final felling, the harvester operator must use a felling method that leaves tops and branches in stacks alongside the strip road and avoid driving over these stacks with the machine. If the undergrowth on a final felling stand is not cleaned, residue adapted felling for subsequent forwarding is considered harder for the harvester operator compared to when only roundwood is harvested. Also the work of the forwarder operator is made difficult by the undergrowth. For this



reason, there is a greater need for cleaning of undergrowth when the logging operation includes residue extraction than when only roundwood is harvested. In order to investigate how productivity in residue adapted final felling and in forwarding of residues is affected by the undergrowth, these tasks were studied under varying undergrowth densities. The study was carried out in collaboration with SCA Skog AB.

The study shows that both harvesting and residue forwarding are made harder by undergrowth, but cleaning the undergrowth was not economically viable, not even in the site with 3,000 small trees per ha. Compared with sites where all undergrowth was cleaned, the cost of logging in this alternative increased by SEK 1,300 per ha and the cost of residue forwarding increased by SEK 160. The cost of undergrowth cleaning was SEK 1,700 per ha, and the revenue from roundwood decreased by SEK 420. Even if harvest of small trees is not profitable, they are utilized if cut by the harvester and provide a certain volume of small-dimension pulpwood. This is not the case if they are cut when the undergrowth is cleaned. Cleaning of the undergrowth resulted in a net increase of logging costs by SEK 660 per ha.

Number of undergrowth stems	Harvester productivity	Logging residue forwarder productivity
0	100	100
1 000	93	96
2 000	89	96
3 000	85	96

Relative productivity of harvester and logging residue forwarder at different numbers of undergrowth stems.

OPERATOR IMPACT ON STUMP EXTRACTION

Henrik von Hofsten, Skogforsk

Studies show that the operator's working method has a significant influence on both productivity and whole-body vibrations when lifting stumps whereas the type of stump harvester and the size of the excavator are of less importance. The working method is still not settled and in order to develop productivity standards, further research is needed.

The technology used in stump extraction has not undergone any major changes since the 1980s. The few developments in this field are mainly taking place in Finland. Consequently, our studies of stump extraction are mainly aimed at reviewing productivity levels, the most important influencing factors, and the operator's exposure to whole-body vibrations. Another objective has been to lay the foundation for productivity and performance standards.

Today's stump harvesters can be divided into three groups: Fork-type, Shear-type and Root Cutters, each with their advantages and disadvantages. In practical operations, 20-25-tonne crawler excavators are used almost exclusively as base machines. The three types of stump harvesters are represented among the six lifting devices that have been studied.

Fork type

The fork resembles a conventional excavator bucket, but instead of the bucket it has 3-7 long fingers. One finger is often longer than the others to facilitate splitting of the stump before it is lifted. One of the advantages of the fork is that it is lightweight (approx. 800 kg), which makes it easy to manoeuvre. Because the fork doesn't have any moving parts, it is relatively inexpensive to purchase and is easily mounted in the excavators' quick coupler attachment. This allows the bucket cylinder to be used when the stump parts are shaken to remove contaminants. One disadvantage of the fork is that, if the stump comes loose from the ground before it splits, it is very difficult to split it on the ground since it tends to tumble aside.

The studies have primarily been done on the Finnish Aalto fork, but there has been one study done on the Swedish Biorex 30. The Aalto fork is made in northern Finland by a small local manufacturer, and Biorex 30 (later renamed Ecorex 30) is made by Umeå Försäljning AB.



Pallari 140 is a shear-type unit. It is easily mounted in the excavator's bucket quick coupler attachment, and requires no special adaptations before mounting.



In terms of design, the Aalto fork is the simplest of the stump harvesters. It is mounted directly in the quick coupler attachment, and requires no extra hydraulics.

Shear type

Shear-type stump harvesters are available in a number of models. The common design feature for all the models is a powerful frame with two ripper teeth that are placed under the stump to pull them out of the ground. The massive knife shears/splits the most difficult stumps with a force often exceeding 20 tonnes thus removing most dirt and rocks thereby reducing wear and tear on the grinder as well as allowing the stumps to dry to a higher quality fuel. The shear-blade also facilitates picking up and handling stump parts. The disadvantages of the shear-type equipment's are their weight (1,200-2,500 kg) and that they often require a more or less specialised mounting to the base machine, including extra hydraulic outlets in the boom-tip. Depending on how the stump harvester is attached it often leads to a situation where contaminants in the stump wood have to be removed by shaking the entire outer boom, resulting in strong machine vibrations.

The Shear-type units studied include the CBI and the Pallari harvesters. CBI is made in the USA by Continental Biomass Industries, Inc. and sold in Sweden by Allan Bruks AB. The Pallari unit is made in Finland by Tervolan Konepaja OY in Kaisajoki.



The rotary stump cutter loosens the stump by cutting off the lateral roots with the rotating drum.

Root cutters

There is currently only one unit with a practical application. This is the rotary stump cutter, which is currently only a prototype and has not yet been released onto the market.

In addition to reducing ground impact, another advantage of the root cutting unit is that it should be possible to attach it to a base machine that is smaller and more agile than the traditional excavators.

The disadvantage is that the unit's design is more complicated, with more hydraulic functions than fork- and Shear-type heads. Furthermore, the rotary stump cutter yields less stump wood compared with the other units, because the lateral roots are cut off relatively close to the stump.

The rotary stump cutter prototype is made by Lennart Nyman, Trångsviken.

Results from the studies

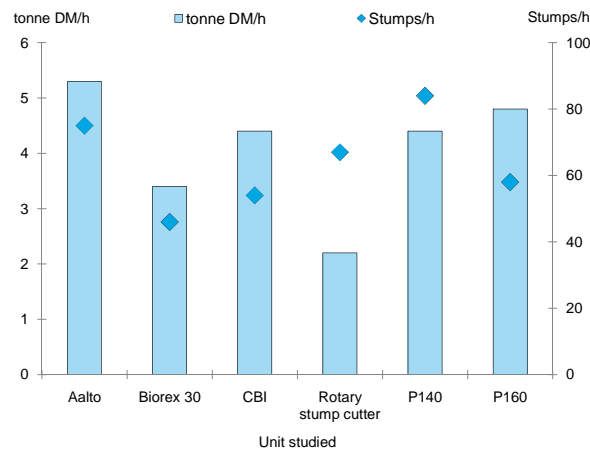
Productivity in stump extraction varied considerably, from 40 to just over 100 stumps per hour. The average was 64 stumps per hour, corresponding to 3.8 tonnes DM/h. In some cases productivity was more than 7 tonnes DM/h and in one case less than 2 tonnes DM/h. The operator had most influence on productivity, while unit and base machine size were less important.

The operator's experience considerably affects not only productivity, but also the exposure to whole-body vibrations. It takes time to learn how to 'read' the stumps and to develop a suitable working method. Incorrect methods require unnecessary use of power and increase the risk of losing grip of the stump, in which case it will result in massive whole body vibrations transmitted through the machine and to the operator. A correctly gripped stump can be removed calmly and without vibrations.

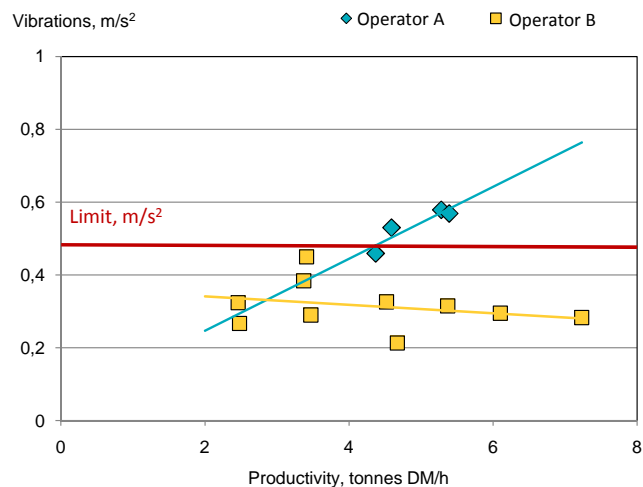
Fair productivity standards can be used as a tool to support method, technology and systems development for stump extraction. These standards can then form the basis for compensation and comparisons between various contractors. The results of the studies are a first stage in the creation of such standards, but more studies and investigations are required.

Name of unit	Type of unit	Number of operators studied	Number of study sites	Min-Max, stumps/h	Mean stumps/h	Min-Max, tonne DM/h	Mean, tonne DM/h
Aalto	Fork	3	10	44–139	75	2.5 – 7.2	5.3
Biorex 30	Fork (with shear blade)	1	2	41–52	46	3.2 – 3.7	3.4
CBI	Shear	1	3	49–65	54	4.2 – 6.0	4.4
Rotary stump cutter	Root cutter	1	4	36–107	67	1.6 – 3.0	2.2
Pallari 140	Shear	2	6	54–153	84	4.0 – 6.1	4.4
Pallari 160	Shear	1	2	48–72	58	4.6 – 5.1	4.8

Studied units and productivity expressed as number of stumps or tonnes of dry matter per hour.



Results of studies of six different units for stump harvest. Productivity is shown both as tonnes of dry matter per hour (tonnes DM/h) and number of stumps per hour. Note that the studies were carried out on different occasions, so direct comparisons should be avoided.



Examples of whole-body vibrations for two operators who worked with the same excavator and stump harvester. Operator A was an experienced forest machine operator, but inexperienced when it comes to stump extraction with crawler excavators. Operator B was more experienced and used to excavator operations. The diagram shows the daily amount of vibrations (m/s^2) to which the operators were exposed in relation to the productivity, tonnes DM/h. The red line shows the limit for daily amount of vibrations ($0.5 m/s^2$). According to the Swedish Work Environment Act, if this level is exceeded, measures must be taken to reduce the exposure. The figure shows clearly that there is no strong link between productivity and the degree of whole-body vibrations. Both of these factors are strongly dependent on the operator.

Future R&D needs

- Supplementary studies of the effects of different types of terrain on productivity.
- Development of productivity standards for stump removal.





PRE-GRINDING STUMPS CAN REDUCE COSTS

Henrik von Hofsten, Skogforsk

Stump parts are difficult to handle as they are bulky and contaminated by soil and stones. Coarse grinding and screening of stump wood on landings reduce these problems and may cut costs by 15-20 per cent. Energy consumption in the process and the risk of damage to trucks are also reduced. Stump extraction productivity can increase, since the operator can reduce time for shaking off contamination's with the excavator crane.

Although the stumps have been split on extraction from the clear cut, the stump parts are irregular and difficult to load on trucks at the landing. The load will contain much air and, in terms of weight, the trucks seldom reach maximum payload. In addition, because the stump parts are hard and can damage the sides of the truck, the truck must be made of strong material, which increases the kerb weight. One way of increasing the payload, minimizing the risk of damage to the trucks, and reducing transport of contaminants, is to coarse-grind the stumps directly on the landing. A system with coarse-grinding of stumps at the landing, including screening of the stump wood, has been studied and compared with a conventional system.

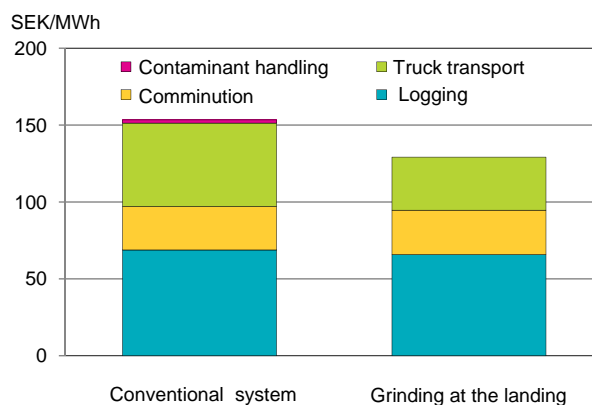
One of the main advantages of coarse-grinding at the landing is more efficient truck transport. Onward transport



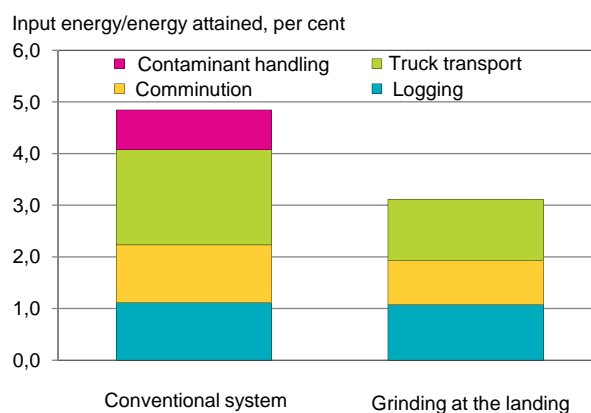
of stump wood from the forest landing to the heating plant is the most expensive measure in the handling chain after the actual stump extraction. Although it has not yet been proved, stump extraction should be made easier because the excavator operator does not need to spend time shaking the stump parts to remove contaminations from the stumps, as screening takes place on the landing. The ash content in the delivered stump wood is decreased, the thermal value increased and less contaminations have to be transported away from the heating plant or terminal.

Our studies have shown that costs can be reduced by 15-20 per cent compared with transporting whole stump parts to the terminal for grinding. Expressed as an energy or fuel value, the costs of a conventional system was calculated to be approximately SEK 150/MWh, and for a coarse-grinding system approximately SEK 125/MWh.

The ratio between input energy (diesel consumption of the machines) and the energy content of the stump wood is also improved. Calculated for the entire chain, from stump extraction on the clear cut to fuel at the terminal, the proportion of input energy in relation to the energy content in the delivered stump wood was 3.1 per cent for the coarse grinding system and 4.1 per cent for the conventional system with grinding at the terminal/heating plant. This does not include transport of contaminants away from the heating plant/terminal which, on account of the big volumes, requires considerably energy in a conventional system.



Net cost for logging (stump extraction and forwarding of stump parts to the landing), comminution and onward transport for a conventional system and a system where coarse-grinding is carried out at the landing, SEK/MWh. Contaminant handling refers to costs for removal of sand, gravel and stones at the heating plant/terminal.



Energy consumption (diesel) from stump extraction to delivery to heating plant/terminal in relation to the energy content of the delivered stump wood, in per cent.

Future R&D needs

Studies of how coarse-grinding at the landing influences productivity of the stump extraction process are lacking. Simultaneous stump extraction and forwarding of stump wood would also be interesting to investigate in this context. A rough estimate is that these two measures could increase production by 20-30 per cent.



FUEL PROPERTIES OF STUMP WOOD IN STORAGE AND HANDLING

Raida Jirjis & Erik Anerud, SLU

Stump wood deliveries contain sand, gravel and stones, which increase wear during comminution, reduce the thermal value, and can cause problems such as sintering on incineration. According to Finnish data, the degree of contamination, measured as ash content, can vary between 1 and 24 per cent. Storage is an effective way of reducing moisture and ash content in the stump wood. Ash content may decrease to levels below 4 per cent for stumps that are harvested in the spring and stored for three months, regardless of the storage method. Storing split stumps in small piles out on the cutover does not show any major improvement in quality compared with storage in larger stacks

High concentrations of inorganic contaminants in the stump wood is one of the reasons why demand for stumps as fuel has previously been low. It is primarily the soil type on the cutover and weather conditions before and during the stump harvest that determines the degree of contamination. Storage not only increases fuel quality of stump wood, but is also often necessary in order to satisfy heating plant demands during the winter.

Stumps that are harvested in the early summer dry quickly. After as little as three months of storage, moisture content may have decreased by 50 per cent. After drying, the degree of contamination falls considerably because of the rough treatment during transport and crushing. Regardless of the storage method, ash content of stumps that have been stored for three months can decrease to levels under 4 percent if the stumps were extracted during the spring. Re-moistening of the stump wood occurs during autumn and winter, though only by a couple of percentage points. In the winter, loose contaminants can be frozen into the wood,

so handling of stumps at temperatures below 0°C should be avoided. Storing split stumps in small piles out on the cutover does not show any major improvement in quality compared with storage in stacks. It can therefore be better to store the stumps in stacks by the forest road directly after extraction in order to facilitate subsequent regeneration work on the cutover.

The lowest moisture and ash contents in stump wood are normally measured in late summer after at least one year of storage. However, due to attack by wood-decomposing fungi, dry matter losses rise as storage time increases. It is therefore important that storage time is considered in relation to both fuel quality and the total energy content in the stored stumps.

In order to improve the drying process, the unit used for stump extraction should be able to split the stump into smaller pieces. A lower moisture content not only gives higher fuel value but also reduces the risk of attack by wood-decomposing fungi. Generally speaking, there are small differences in the stump wood's moisture content, ash content and calorimetric thermal value when the stump is harvested with the two most common types of extraction units – by fork-type or pincer-type technology.

The problem of high ash contents and the long storage times needed to reduce these can be tackled in various ways. One possible approach is to modify the unit so that the cleaning process is made more efficient already at the time of harvest. Another approach is to introduce an extra cleaning stage at the landing.

Future R&D needs

Two projects are currently underway with the aim of reducing contamination after harvest. The principles are based on either coarse-crushing the stump wood, followed by screening, or vibrating to remove contaminants from the stumps.

FORCE REQUIREMENTS IN STUMP EXTRACTION

Tomas Nordfjell, Dimitris Athanassiades
& Ola Lindroos, SLU

The great force needed in stump extraction currently necessitates the use of heavy, powerful excavators, despite their disadvantage of being slower and clumsier in terrain movement than forwarders. However, new results show that force requirements are not so considerable that they cannot be met by the largest harvesters for virtually all stumps.

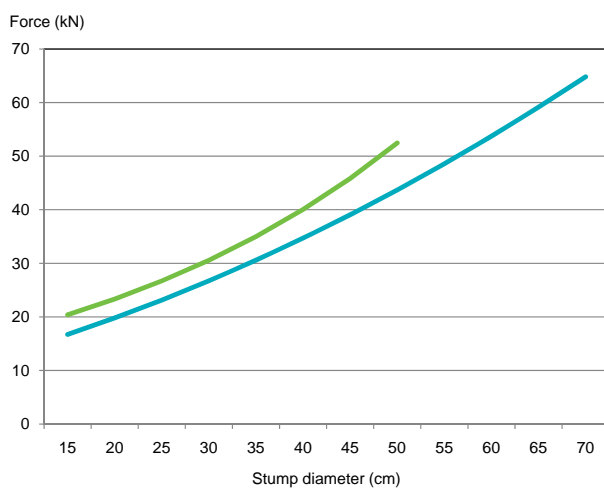


Stumps have greater overall potential for producing forest fuel than logging residues. Greater force is needed for lifting spruce and birch stumps from moraine soil on moist ground than on dry ground. If the stumps are first split in the ground, the force needed to lift them is less than if they are lifted without being split first. If the stump is split before lifting, the market's biggest forwarders have sufficient power to lift stumps up to 35 cm in diameter. Existing stump units weigh approximately 2 tonnes. If the weight of the unit could be reduced to 1 tonne, the same forwarder would be able to lift stumps of at least 45 cm if the stumps are first split in the ground. A rule of thumb is that the force required to lift a 20-cm thick stump is 2 tonnes, and

then increases by about 1 tonne for every 10 cm increase in stump diameter. This rule of thumb applies when the stump is split before lifting. Instead of lifting up the stump, another possible approach is to twist it loose. This will be studied in a planned field experiment (see separate article).

Future R&D needs

Field trials are planned to examine the force needed to twist stumps loose and to study the effect of this on the soil. It is also important to establish which forces apply in lifting or twisting when superficial lateral roots have been cut off.



The maximum force needed (kN) to vertically lift spruce and birch stumps of different diameters (cm). The green upper line applies to stumps that are lifted whole, and the blue lower line for stumps that are first split in the ground. With these forces, 97.5 per cent of all stumps could be lifted on the moraine cutover studied.

STUMP HARVEST TECHNOLOGY TO REDUCE GROUND IMPACT

Tomas Nordfjell, SLU

Current stump harvesting methods involve the stumps being lifted vertically upwards by machines, usually after the stump has been split in the ground. One interesting idea for development is to loosen the stumps by twisting instead. Another is an integrated stump and stem harvest, where the central part of the stump is utilized as part of the stem's butt log. Both these ideas will be studied in efforts to find efficient methods for stump harvest with reduced impact on the ground.

If **stump extraction** is to be given wide application, it must be carried out in forms that society can accept, i.e. without coming into acute conflict with nature conservation, e.g. through excessive soil disturbance. This is necessary to ensure an interest within the thermal power sector in using stump wood to partially cover the increasing need for forest biomass for fuel. It is also necessary if forestry companies and the manufacturers of stump harvesting equipment are to wager substantial investments in developments in the field. It is only if stumps can be harvested on a large scale, i.e. on a significant amount of Sweden's cutovers, that strong development of new technology can be expected.

One interesting concept, where utilization of stump wood need not come into conflict with nature conservation, is to use the central part of the stump (stump core) as an extension of the butt log and let the rest of the stump remain in the ground. As well as reducing ground impact, the number of machine movements to, from and within the site is reduced when roundwood and stumps can be extracted at the same time. It would also be entirely possible to extract the logging residues at the same time. The possible appearance of such a 'multi-harvester' is shown in the design sketch to the right.

Instead of lifting up the stump, another possible ap-

proach is to twist it loose. What needs to be studied is the torque required to loosen stumps. In a planned field experiment, stumps (or trees) will be subjected to rotational forces and the torque will be measured when they come loose. The experiment includes studying how the stump loosens or breaks, and what effects this has on the ground.

When both the force required to lift stumps (which has already been investigated, see separate article), and the processes required to twist them loose are known, there is better support for developing effective technology for stump harvesting.

On the basis of the experiment results, innovators and machine manufacturers should find it easier to develop technology for gentle and effective stump harvesting, which would mean that stump utilization can be a normal operation on a significant proportion of final fellings.



Design sketch of 'stump core harvester', which also produces logging residue bundles directly at the logging site. The stump unit cuts off the tree's lateral roots and then twists and lifts the tree up. On the ground behind the machine are a logging residue bundle and a butt log with associated stump core. Sketch based on a concept by Tomas Nordfjell.

Future R&D needs

In addition to experiments with integrated stump harvesting and twisting loose of stumps, a list of stump harvesting units available on the market will be made. In addition, a simple system analysis of the potential for integrated stump and stem wood harvesting is planned.

The rotary stump cutter is the unit that has the least impact on the ground in stump lifting. It cuts off the lateral roots before the stump is lifted. The rotary stump cutter currently only exists as a prototype.





Thinning small-dimension trees for forest fuel – an operation that must meet silvicultural standards to ensure future development of the forest, but also needs to be very efficient if costs are to be kept at a reasonable level.

YOUNG STANDS

– A GROWING SOURCE OF ENERGY

Tomas Nordfjell, SLU &
Mia Iwarsson Wide, Skogforsk

Thinning or cleaning of young stands is necessary for creating sound and productive future forests. It is expensive, but many dense, young forests can yield sufficient volumes of forest fuel to cover much of the cost or even generate a surplus. In Sweden, nearly three million hectares may be suitable for harvest of forest fuel.

Stands of small-dimension trees are an interesting source of forest fuel. The potential yield of pulpwood is low and the wood is of low quality and divided into a number of assortments. Utilization as forest fuel increases extraction quantities and promotes more efficient handling. A trend for many years has been to reduce cleaning intensity in silvi-

culture. This has had the effect of increasing the proportion of young forests now suitable for forest fuel extraction.

New studies show that the potential is considerably higher than was previously known. In Sweden, there are 2.8 million hectares of young forest with trees shorter than 12 m and more than 30 tonnes DM/ha. Of these, 1.1 million ha are in Norrland and 1.7 million ha in Svealand and Götaland. The mean biomass stock in these stands is 54 tonnes DM/ha. By retaining current management principles with stand thinning (cleaning), but instead using the wood for forest fuel, approximately 2 million tonnes DM per year could be harvested from this type of stand, equivalent to 10 TWh per year. Small-dimension trees are also found along roadsides, the edges of fields, power line corridors and on pastureland.

Data from the Swedish National Forest Inventory shows that the area of final felling, and thereby the supply of logging residues and final felling stumps, will not increase noticeably in the next decade. This makes it extra important that the large volumes in stands of small-dimension trees can be made accessible. Even at the current level of technology, harvest of stands with small-dimension trees for forest fuel already gives considerably higher revenues than if the wood was extracted for use as pulp wood. Better technology and



Roughly delimbed tree parts – a new fuel assortment that is easy to handle and that limits nutrient export from the growing young stand.



systems for utilization must be developed to improve efficiency and to reduce costs. Technology and methods must also be developed with the aim of silvicultural quality, i.e. so that the harvesting does not cause excessive damage to the residual stand.

Extraction of forest fuel in the form of whole trees involves a relatively large loss of nutrients. Harvesting of trees in a growing stand, where competition between

the trees is intense, entails a pronounced risk of direct yield losses compared to when nutrients are removed from a cutover in the form of logging residues. We must learn more about this problem in order to avoid or compensate for any negative effects, for example by recycling ash and applying fertilizer. An alternative that has become more common is to remove forest fuel in the form of roughly delimbed tree parts. This reduces the harvest of forest fuel somewhat but, at the same time, leaves much of the green mass and thereby the nutrients in the stand. Placing branches and tops on the surface of the striproad also reduces the risk of rutting and soil disturbance.

Future R&D needs

Standing stock and yield is considerably greater in young stands of small-dimension trees than was previously thought. However, in order to fully utilize these trees as a source of forest fuel, more and better data is needed. We also need information about how more intensive utilization affects the development of young forests.

Technology and methods must be developed to improve extraction efficiency. Skogforsk is working with the forestry sector on a development tool that will support greater utilization of forest fuel from stands of small-dimension trees.

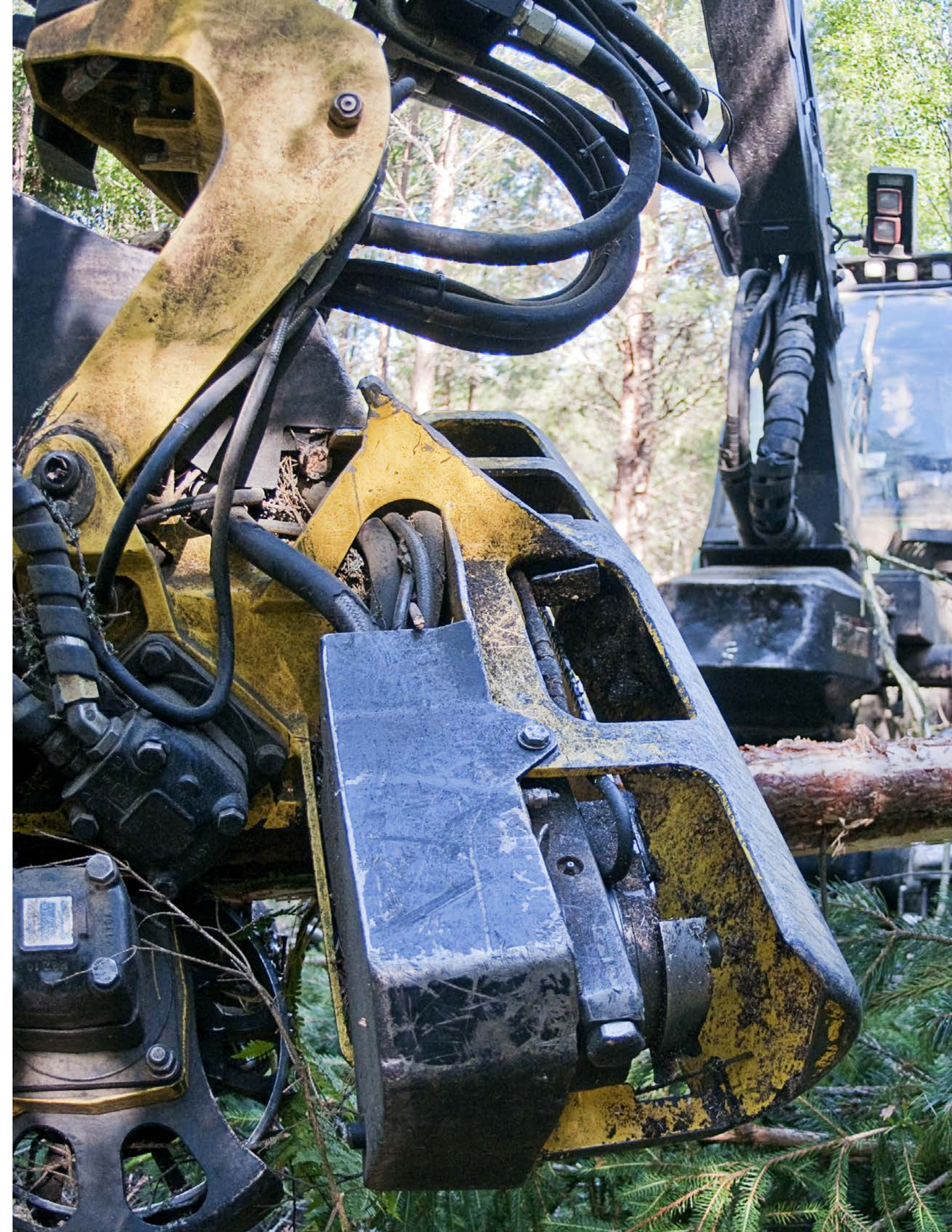
TECHNOLOGY AND METHODS FOR LOGGING IN YOUNG STANDS

Mia Iwarsson Wide, Skogforsk

Multi-tree handling is the key to reduced costs in logging of small-dimension trees. With current technology, productivity can be increased by 15-30 per cent if the number of trees per boom cycle is increased from today's 3 to 6-9. If trees are very thin, the aim should be 8-10 trees. Improved working methods, for example reducing the amount of crane work by cutting trees in the correct order or by working geometrically in boom corridors from the striproad, can further increase productivity without increasing the workload of the operator.

Forest fuel can be extracted from young, dense stands in various ways – as whole trees, as roughly delimbed tree parts (energy wood) and in combination with pulpwood. The fuel is high quality thanks to a high proportion of stem wood. It is relatively easy to handle in storage, comminution and transport. A large part of the biomass in young stands is found in branches and tops. Compared with traditional pulpwood logging in early first-thinnings the extracted volume increases by at least 50 per cent in forest fuel operations. This increases revenues. Normally, handling is easier if only forest fuel is extracted while combined extraction of pulpwood and forest fuel increases the costs of logging, because several small-volume assortments must then be handled. But, depending on price relationships, the circumstances of the forest owner, and characteristics of the stand, simultaneous extraction of pulpwood and forest fuel can sometimes be preferable.

Small trees are expensive to harvest. The biggest cost factor is felling-piling, which accounts for 60-75 per cent of the costs. Three technical solutions are used for felling small trees: shears, circular saw, or chain saw. Each has its advantages and disadvantages, but the most important aspect is the performance of the unit as a whole, not least how the trees are handled after felling. A suitable unit should be capable of felling and bunching several trees in each boom cycle, hold the bunch together, and be able to compact and, when necessary, feed and buck the bunch into lengths suitable for transportation. In addition, the unit should preferably be able to fell and bundle the trees during boom movement. The units on the market today differ in their abilities to meet these requirements, and also have varying potential for development.





Bracke C16. Felling head with circular saw. The unit lacks feeder rollers. The accumulation function is relatively reliable.



Naarva-Grip 1500-40E. Felling head with shears. The unit lacks feeder rollers. The accumulation function is reliable.



Log Max 4000. Harvester head with circular saw and feeder rollers. The accumulator function is reliable.

Technology and work methods are mainly determined by the density of the stand and mean diameter of the trees, but also by whether only forest fuel is to be extracted or whether this is to be combined with pulpwood. For extraction of whole trees along roads and edges of fields, felling heads (without feeder rollers) are used. They can also operate in young stands of very small-dimension trees with a mean height of up to 7-8 meters. However, in very dense forest, piling can be extra difficult for a felling head with no feeder rollers. The tree bunch easily sticks to the crowns of residual trees. The problem increases in stands where the mean height is over 7-8 meters. A felling head with feeder rollers can use the wheels to pull down accumulated trees. Piling is also simplified by feeder rollers since they can be used for part of the transport, eliminating excessive boom movement.

An accumulating harvester head can alternate between felling pulpwood and forest fuel, thereby offering great flexibility. The capability to compact and roughly delimb tree parts is necessary in order to achieve high payloads for for-

warding and onward transport. The risk of future increment losses is less when trees are roughly delimbed because much of the nutrient-filled limbs and needles are left in the stand. Furthermore, risks of ground damage are reduced when the harvester can place branches and tops on road surfaces in sensitive areas.

Multi-tree handling is vital to efficiency in the utilization of small trees and is the key to profitability. Currently, the potential of this technology is not fully exploited. Even with today's technology, productivity can be increased by 15-30 per cent by raising the accumulation rate from the current 3 trees per boom cycle to 6-9. In stands where the trees are very small, the aim should be 8-10 trees per cycle. To ensure reliable handling of the bunched trees, a relatively long distance between the lowest grip arms on the unit and the upper accumulation arms is an advantage. Limbing knives and feeder rollers can help to stabilize the tree bundle.

The working pattern of the harvester is very important. Felling the trees in an order that minimizes boom movement

increases productivity. Instead of thinning selectively, which is the conventional way in Swedish forestry, geometric thinning patterns can be applied. All the trees are then felled in boom corridors extending from the edge of the striproad. This increases productivity and reduces workload for the operator, who does not have to make a decision about every individual tree. Geometric working patterns are probably best suited in dense, homogeneous stands. For dense thickets with very small trees, the swath method (felling during continual boom movement) with a circular saw mounted on the unit works relatively well.

For efficient forwarding, it is important that the felled trees are concentrated into a few, large piles along the striproad. The productivity in forwarding of small-dimension, delimbed tree sections is nearly as great (approximately 95 per cent) as in pulpwood forwarding. The slightly lower payload is due to greater air content in the load because of the very small-dimension wood. Corresponding figures for roughly delimbed tree parts are 80-90 per cent, and for uncompacted tree sections and whole trees approximately 65 per cent.

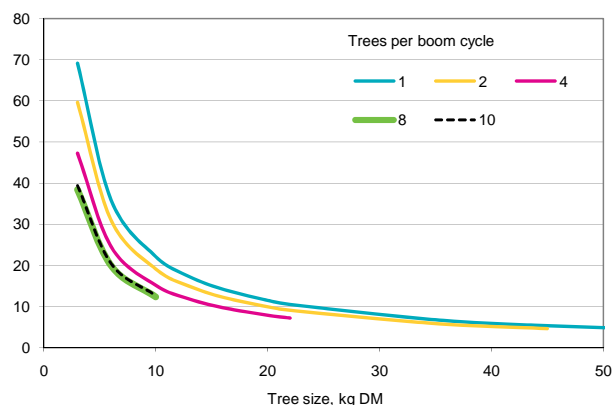
Pre-commercial thinning of the smallest trees (<4 cm dbh) increases the mean volume in the harvest, and thereby the productivity of logging. Pre-commercial thinning costs approximately SEK 2,000/ha. This is a standard measure and is often carried out even though it is not always financially viable. However, where there is a very dense undergrowth of spruce, and when the logging is to take place in darkness or during periods of deep snow, pre-commercial thinning can be necessary in terms of both work environment and financial viability.

Productivity and thereby profitability are strongly dependent on the volume that can be harvested, i.e. the number of trees and their size. With today's systems, relatively large harvests are needed, approximately 2,000 trees per hectare with a mean diameter at breast height of approximately 8 cm, to ensure a net profit, corresponding to a harvest of approximately 50 m³solid/ha.

Comminution and transport are major cost factors. Fully- and roughly delimbed small-dimension tree sections can be transported in conventional roundwood trucks. This makes direct transport of unchipped material cost-effective, also over longer distances. However, the truck's loading bunk should be covered to ensure that material does not fall out during transport. Forest fuel from small-dimension trees has good storage properties and can, after transport, be piled up as a strategic fuel store at terminals or at the end customer's facility.



Felling-accumulation, min/ton DM



Felling time is considerably reduced if more than one tree can be felled per boom cycle. However, the effect decreases with greater degree of accumulation.

Future R&D needs

In the short term, system analyses are needed of the entire supply chain, with the aim of finding the most efficient and profitable solutions under varying conditions.

More method studies are needed in order to identify and develop optimal working methods and patterns.

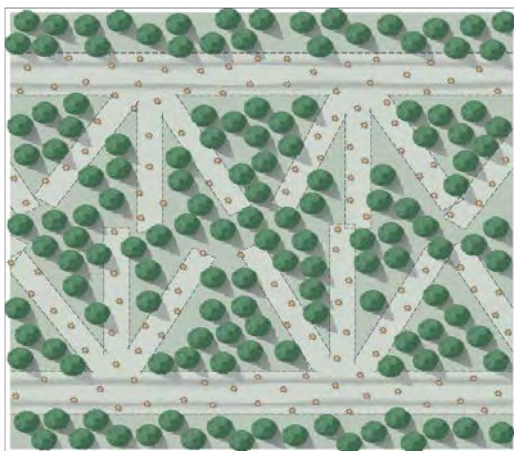
In the longer term, solutions must be developed for continuous felling- accumulation of small trees if the efficiency in small-dimension tree handling is to be increased further.

GEOMETRIC THINNING OF YOUNG, DENSE STANDS

Tomas Nordfjell, SLU & Dan Bergström, SLU

A way to substantially increase productivity when thinning dense young stands is to employ some form of geometric harvest between the striproads, i.e. felling all the trees in narrow boom corridors extending from the striproad. The corridors can be harvested with a felling head that can accumulate trees upright. In comparison with conventional, selective thinning, studies show that boom corridor thinning using current technology increases productivity and profitability, and that more forest fuel can be harvested. With further development, boom corridor thinning can become even more competitive and may be applied in even lower diameter stands of even thinner trees with no loss of profitability. Visually, it is hard to see any difference between geometric and selective thinning in the residual stand.

In conventional thinning, a network of striproads is laid out in the stand, with a spacing of approximately 20 m. In the roads all trees are felled, while in the area between the striproads, the intermediate zone, the trees are selectively thinned. If thinning of dense stands of small trees (< 8 cm) is to be more productive and profitable, some sort of geometric harvest is needed in the intermediate zone. This can be done by clearing narrow passages, boom corridors, from the striproad into the intermediate zone. The logging machine would preferably have a felling head that can fell and handle all the trees in a boom corridor in one continuous movement.



Thinned stand with fan-pattern boom corridors (drawing by Per Thorneus, SKOGEN 11-06).

On a field excursion, a stand thinned by boom corridors was demonstrated. Before thinning, the stand contained 90 tonnes DM/ha. When the stand was thinned by boom corridors in a perpendicular pattern, 45 tonnes DM/ha was extracted. When a fan-shaped boom corridor pattern was used, the harvest was as high as 59 tonnes DM/ha. Observers participating in the excursion found it difficult to distinguish between boom corridor thinning and conventional, selective thinning in the residual stand.

In an extensive field study (16 experimental areas divided into 8 blocks), selective and geometric thinning were compared in terms of logging productivity. An important conclusion from this study is that, even with current technology, geometric thinning can be applied and thereby clearly higher productivity attained.

With suitable compaction equipment on the haulage rig, the load utilization for untrimmed small-dimension trees can be 75 per cent of the maximum payload, compared with 55-60 per cent without compaction. Compaction equipment in the boom tip can compact the wood even better, at the same time as a large proportion of nutrient-rich fine fractions, needles and thin branches, are removed. This reduces the ash content when the material is incinerated. Between 11 and 18 per cent of the total mass of the material is removed, and the ash content decreases from approximately 0.8 per cent down to 0.4-0.5 per cent.

Today's technology allows trees to be felled continually in a 0.8 m wide boom corridor, at a speed of at least 0.4 m/s.

Studies have shown that continual felling at speeds of up to 1.0-1.4 m/s is theoretically possible, depending on the diameter of the trees. There are proposals for new technical solutions to achieve high productivity for logging in stands of very small trees. In Sweden there is a market for somewhere between 130 and 300 special machines for boom corridor thinning, depending on the degree of specialization of the machines. The calculation is based on an estimated annual harvest of approximately 2.6 million tonnes DM, a production capacity of 4-10 tonnes DM/h, and a machine utilization of 2,000 h/yr. With current technology, corridor thinning can be profitable if the stand's mean diameter is slightly over 8 cm (45 trees/tonne DM). With more advanced technology, the limit would be closer to 6 cm. However, if special machines are to be developed, thinning of dense young forest must become a standard procedure, thus establishing a firm demand for efficient small-tree felling technology.

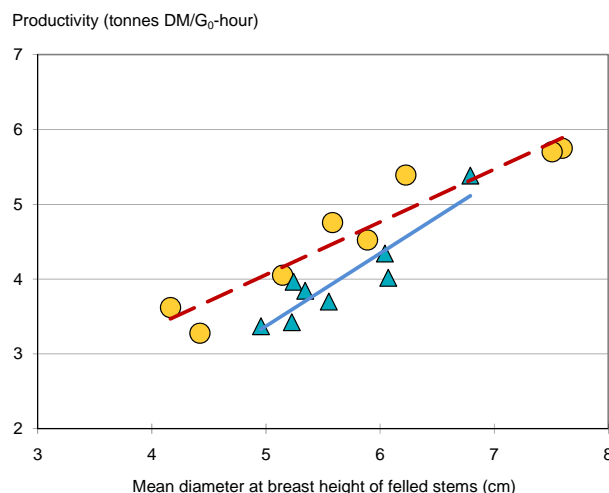
The trials show that, if appropriate technology is developed, geometric thinning in dense stands of young forest has great potential to improve productivity. The studies also show how much biomass per ha dense young forests actually contain. A conclusion from the trials is also that the very small trees (< 2 cm in diameter) should be totally omitted from operation if high productivity is to be attained. For dense stands with dbh under 9-10 cm, the gross value of thinning is 2.5-3 times higher for forest fuel harvest than for conventional pulpwood harvest. After harvesting of full, compacted trees, it is technically possible to separate pulpwood from the harvested biomass in an industrial facility, if there is an economic incentive for this.



Concept sketch of a specialized boom corridor harvester that would enable profitable operation even in stands with mean diameters as low as approximately 6 cm dbh.



An early model of the Bracke C16a, the market's perhaps most advanced felling head for geometrical harvest in young, dense stands. Using this unit for felling and accumulation in stands with very thin trees, production can already reach approximately 4.5 tonnes DM/G₀-hour (9 m³ solid biomass/G₀-hour and 500 trees/G₀-hour). PHOTO: Tomas Nordfjell, SLU.



Productivity as a function of tree size for selective thinning (full line) and for geometric boom corridor thinning (dashed line).

Future R&D needs

Research to date into thinning has been comprehensive, but should be followed up by development of methods and of specialized commercial machines. More in-depth knowledge is also needed about forwarding to the landing, including compaction and bucking of tall trees. It is uncertain which processes are best carried out during felling/accumulation and which during forwarding. Furthermore, the question remains about whether the material should be bundled and, if so, where and when this should take place.

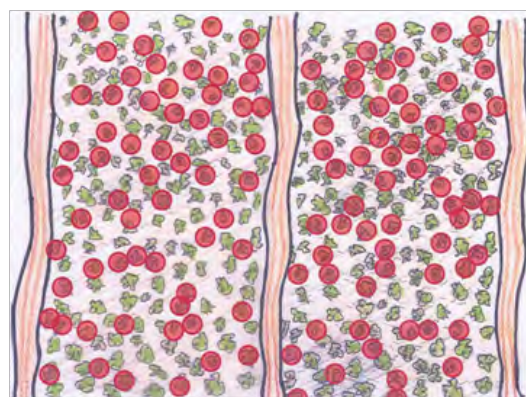
CORRIDOR THINNING FOR HARVEST OF TREE SECTIONS

Isabelle Bergkvist, Skogforsk

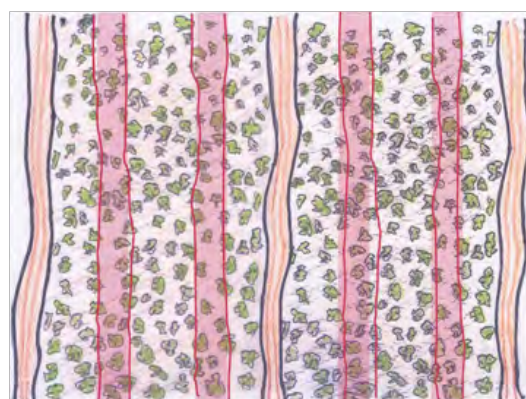
In pole stage stands most forest fuel is harvested using conventional methods. An alternative is corridor thinning, where the trees between the striproads are felled in passages instead of selectively. Corridor thinning has been studied in detail and tested in cleaning of young forest (without extracting biomass). A comparative study of the two methods in a first thinning (11,5 cm dbh) showed a 10-15 per cent higher productivity for corridor thinning. In lower diameter stands, the difference would probably be greater, which planned, further studies may show.

Increasing demand and price for forest fuel in combination with the prospect of an early net profit and new technology for utilization have increased interest in harvesting forest fuel in cleaning of young forest and in first thinnings. In Sweden, forest fuel extraction from such stands may add 5-10 TWh to the annual energy supply. Today, forest fuel from these forests is harvested using conventional methods, with striproads spaced by approximately 20 m and selective thinning between the roads. An alternative to this is corridor thinning where the stand between the striproads is thinned by cutting all trees in passages or corridors.

The two methods were compared in a time study to evaluate the potential of corridor thinning in terms of productivity and costs. The study was carried out in collaboration with Sveaskog Förvaltnings AB in a pine-dominated first-thinning stand. The mean tree volume was 0.07 m³ (solid volume, including tops, branches and needles). The stand was a bit too tall for optimal harvest of tree sections; with



Layout sketch showing selective thinning and corridor thinning between striproads, respectively. The pictures are drawn to scale for a stand with approximately 7,500 stems/ha.



a mean height of 14 m all stems had to be bucked to allow efficient forwarding.

The striproad spacing was 20 m. In corridor thinning, the idea is to fell two corridors between the striproads and leave the intermediate zones undisturbed. The distance between corridors and corridor-striproad will then be about 7 meters. The trees are felled towards the striproads which are used



Tree species	Stems/ha	Mean diameter	Mean height	Mean tree volume	Terrain
Pine-dominated	2 850	11.5 cm	14 m	0.07 m ³	1–1–3

Stand data for the study.

for collection and forwarding. For the comparison, corridor thinning was simulated by using study data from felling of trees in the striproad to calculate productivity and volumes for the corridor thinning. The machines studied in the thinning were a Valmet 901 with a Bracke C16 felling head and a Valmet 901 with a Silvaro harvester head, both heads with accumulation arms for multi-tree handling. The Silvaro was used in a part of the stand where the trees were slightly smaller. The site conditions were easy for the machines (carrying capacity- surface-slope, 1-1-3). The felling of 100-200 trees per striproad was studied.

The harvest of forest fuel was similar for both methods – approximately 105 m³ solid volume (biomass) per ha. The productivity of the machine with the Bracke C16 was 14.7 m³solid/h in conventional thinning and 16.5 m³solid/h in corridor thinning. The corresponding figures for the machine with a Silvaro head were 15.8 m³solid/h and 17.1 m³solid/h respectively. Overall, this means that corridor thinning had a 10-15 per cent higher productivity than conventional, selective thinning. In lower diameter stands, the difference can be expected to be even higher.

Future R&D needs

This is a pilot study with more comprehensive investigations planned of various methods to harvest forest fuel in the form of tree sections. It is expected that corridor thinning is even more advantageous in even denser stands with smaller trees than the case in this study, but this remains to be proved. Other important issues are:

- What volumes and net revenues are possible under different stand conditions?
- How can silvicultural regimes be adapted to promote forest fuel extraction?
- What are the suitable corridor-/striproad distances under different biological and economic conditions?
- How is the stand's future development affected by corridor thinning?
- What technical development is needed in order to improve and refine the method?

FOREST FUEL HARVEST



FROM ROADSIDES

Mia Iwarsson Wide, Skogforsk



Felling small trees and bushes along roadsides has traditionally been regarded as part of road maintenance, and thereby only involving cost but no revenue. Up to now, very little roadside vegetation has been utilized, largely because profitability has been poor. However, with rising prices and increasing demand for forest fuel, interest has grown in utilizing this resource and developing effective methods and technology.

Skogforsk carried out two studies of forest fuel extraction along roadsides. In the first study, a Ponsse Dual forwarder with a multi-tree handling, shear felling head (EH25) was examined. Felled trees and bushes were loaded directly and forwarded to stacks. In the other study, a Valmet 911 equipped with a Bracke C16 circular saw accumulating felling head was used. Trees and bushes were harvested together, and placed in piles at the roadside. The aim of the studies was to investigate harvest volumes, productivity, and costs and revenues relating to felling and utilization of roadside trees using different felling systems.

In the study parcels, the number of stems per hectare varied between 4,300 and 7,000, and the harvest between 39 and 52 tonnes DM per hectare. The mean tree volumes in the two studies were 5 and 12 kg DM per tree respectively. The mean productivity in logging and forwarding varied from 2.6 to 3.7 tonnes DM per G₀-hour.

Clearing roadsides of small trees is an overlooked source of forest fuel. The supply varies greatly, from stretches of road with no small trees and bushes to parts with many tens of thousands of stems per ha. Our studies include a variation from 4,000 to 20,000 stems per ha, with a biomass extraction of between 40 and 110 tonnes DM/ha. The mean productivity was 2.6-3.7 tonnes DM/ G₀-hour. Profitability was relatively good, with a net profit of over SEK 10,000 per km road. If annually five percent of the 213,000 km of forest roads in Sweden, i.e. approximately 10,000 km, is assumed to be suitable for harvest of roadside trees, this would correspond to over 2 TWh energy/year.

	Bracke C16	Ponsse EH25
Stem total per ha	7 000	4 300
Mean dbh (basal area weighted), cm	7	9.9
Mean height, m	5.5	9.2
Tonnes DM / ha	39	51.8
Tonnes DM / km	54.7	46.6
Kg DM per tree	5	12.4
Logging width per roadside, m	7	4.5
Number of trees per boom cycle	4.3	3.6
Trees per G ₀ -h	490	303
Logging, tonnes DM/G ₀ -h	2.6	
Logging & forwarding, tonnes DM/G ₀ -h		3.7
Cost of logging SEK/km	20 500	13 100
Revenue, SEK/km	46 700	36 800
Cost of chipping, transport, SEK/km	15 700	10 700
Total net (SEK per km)	10 500	13 000

Parameters and results of two studies of utilization of forest fuel on roadsides.



Stem densities and tree size differed between the two studies. This affects profitability. The vegetation along the stretches of roadside varies greatly. Some stretches of road were very densely vegetated, while others virtually lacked vegetation for felling. The dimensions of the roadside trees also varied greatly. This probably applies for the entire forest road network in Sweden, making it difficult to estimate extraction volumes, and net profit for forest fuel extraction based on this limited study.

To ensure profitability, it is very important that only trees on roadsides that contain sufficient volumes are felled. Extraction should be at least 40 tonnes DM per km road. If a large proportion of the stems are 3 cm or less in diameter at breast height, combining felling with verge cutting should

be considered. In that case, the larger dimension stems are felled first and utilized. The remaining vegetation is then cut down with a verge cutter, which considerably reduces the cost of felling brush and plant size trees.

Often, the aim is to remove all vegetation along the roadside to improve visibility, but also because leaving vegetation adds nutrients to the soil, thereby promoting new growth. What is needed, and what is currently lacking on the market, is a broad-felling machine that can fell and utilize both 'larger' dimension stems (6-12 cm) and brushwood (<6 cm) in a single operation.

Normal road maintenance includes regular cleaning of vegetation along roadsides. If bushes and small trees on the roadside are allowed to grow freely, this reduces visibility and



Small-dimension trees

Forwarding of forest fuel after roadside cutting and direct loading by Ponsse Dual forwarder fitted with the EH25 multi-tree handling shear felling head.

Estimated forest fuel potential along Sweden's forest roads

In Sweden today, there are approximately 213,000 km of forest roads, i.e. roads without government grants. Assuming that five per cent of this road length is suitable for biomass extraction, and that the mean harvestable biomass is 40 tonnes DM /km at 10 m harvest width, this corresponds to approximately 425,000 tonnes DM per year. With an effective energy value of 4.7 MWh per ton DM, this corresponds to approximately 2 TWh/year.

Future R&D needs

Methods for assessing extractable volumes along road-sides are needed. At present there are discussions about the possibility of using laser data and remote sensing to assess the volumes.

More studies are needed to study the efficiency of alternative technologies and methods under different circumstances.

Studies of different systems and methods are also needed, e.g. studies of separate logging and forwarding to stacks for later chipping, direct loading at logging and forwarding to stacks for later chipping, felling and placing of trees and bushes at the roadside with subsequent chipping with a chipper truck that operates on roadsides.

moisture gets into the road structure and causes damage. Cleaning is usually done as part of verge cutting, and the cost is approximately SEK 2,500 per km. This cost must be weighed against the net profit generated by utilization of the vegetation. Our studies indicate that extraction of forest fuel along roadsides may be relatively profitable. Under the conditions of this study profit varied from 10,500 to 13,000 SEK per km for the respective systems.

The cost of verge cutting depends a lot on the speed of the machine, which in turn depends on the number and dimension of the trees that are to be cut down. If the trees are less than 4 cm at the stump, the verge cutter can maintain a speed of approximately 3 km/h and the cost is approximately SEK 1,000 per km. However, if the stump diameter

on many of the trees is around 10 cm, the machine cannot work faster than approximately 1 km/h and the verge cutting then costs approximately SEK 3,500 per km. If many of the trees are even larger, the cost increases considerably. Consequently, it may be economically favorable for the road maintainer to utilize the forest fuel instead of just cutting it down. The problem is that the 'profitable' road stretches are embedded in the less densely vegetated stretches, and there is no good method for assessing and recognizing these more profitable stretches of road.

GRINDERS AT THE LANDING

– WORK ORGANISATION CRITICAL

Lars Eliasson & Berndt Nordén, Skogforsk



Studies of large grinders used for producing hog fuel from stumps and logging residues at normal-sized landings on forest roads show that it is difficult to utilize the high production potential of the grinder due to lack of space for material and machinery. Furthermore, the material properties have a significant effect on the productivity level. The relative productivity compared to chipping of roundwood, was reduced to 25-30 per cent when dried (brown) residues were ground and to 35-45 per cent when stumps were ground.

In 2007 and 2008, medium- to large sized grinders was studied when grinding forest fuel on landings beside forest roads. The studied machines were usually employed at large landings and terminals. Results indicate that, under 'normal' conditions on forest roads, there are major difficulties in organising the work around a large grinder in order to efficiently utilise its potential productivity. Due to limited space it is difficult for the loader to feed the grinder with sufficient material and to handle the fuel produced. Disturbances to loading and transport of the fuel produced might also be

caused by the limited space, as it limits the possibilities for simultaneous grinding and loading of the chip truck. In order to minimise the cost for relocation of the grinder operation per unit of hog fuel produced, large quantities of raw material are required at each landing. Altogether, this means that it is very difficult to efficiently utilize large crushers on normal forest road landings.

The studies show that material properties are crucial for grinder productivity. Under favourable conditions the productivity relative to chipping of roundwood, with the same machine, were 25-30 per cent when dried logging residues and 35-45 per cent when stumps were ground. Feeding of the grinder becomes a bottleneck to an efficient operation when grinding logging residues, due to their bulkiness and low proportion of solid mass.

Future R&D needs

More studies of comminution technology, machine size and different forest fuel assortments are needed in order to thoroughly investigate the effects of comminution on productivity, cost and energy efficiency of forest fuel supply chains.





CHIPPER TRUCKS INCREASINGLY COMMON

Lars Eliasson, Skogforsk

Chipper trucks combine chipping and chip transport. Chipper trucks with a switch-body system for chip containers have become more common in recent years. Compared with traditional chipper trucks, their advantages include better utilization of the chipper. An alternative to the chipper truck is the chipper link, with the chipper mounted on a removable link. Thus, the chipper can be left on the site until work is complete and does not impact on the maximum payload. To make optimal use of the chipper link, the system should contain at least two chip transport trucks depending on the transport distance.



Maneuvering chip containers at the landing.

Chipper trucks, i.e. chip transport trucks with permanently mounted chippers, have been shown to be a profitable alternative to traditional forwarder-mounted chippers. In recent years, container handling chipper trucks (CCT) have become more common. The wood is chipped straight into containers that are then transported to the recipient by one or more container trucks, i.e. switch-body trucks without chipper mounts. Compared with a traditional chipper truck, the CCT has the advantage that both chipper utilization and the chip payload in containers are increased when container trucks are used for the transports. This makes the CCT system more competitive on large logging sites and where extraction distances are longer. The disadvantage of the container system is that container handling is time consuming and that the CCT can be standing idle due to the lack of empty

Work process	Minutes/ton DM)
Chipping	3.68
Transport & maneuvering	1.27
Σ Effective time (G_0)	4.96
Maintenance time	0.42
Organizational down time	0.56
Σ Work time	5.94

Observed time factors for chipping with a chipper truck with switch-body and containers.

containers. In collaboration with Stora Enso Bioenergi AB and the Italian research institute CNR/IVALSA, a study was carried out to determine the productivity and work time distributions for a CCT.

The productivity of the CCT was 10.1 tonnes DM per effective hour, at a distance of 250 m between the logging residue stack and the container trans-loading site. Approximately one-sixth of the effective time was spent on maintenance and organizational down time (waiting for container, time taken to maneuver the switch-body trucks, etc).

The organizational down time could be reduced through better planning. Most of the organizational down times occurred during one of the study days when the chip transport distance to the recipient was long, i.e. the CCT had to wait for an unusually long time for empty containers to return. Apart from this day, the organizational down time was 0.35 minutes per tonne DM. This loss of time is equivalent to a productivity decrease of just under 4 per cent per effective hour for the CCT. It is unrealistic to believe that the organizational down time can be completely eliminated. The down time caused by trucks being forced to wait to allow others to pass on the landing is unavoidable, and some waiting time for the chipper truck caused by lack of containers will always occur.

The factors that determine which system is most advantageous to choose – a CCT system or forwarder-mounted chipper with chip bucket and chip truck with crane and bucket – are primarily the amount of residues on the landing and the distance between the logging residue stack and the loading point. The forwarder-mounted chipper has a relatively high relocation cost, thus large landings where this cost can be distributed over a large quantity of forest fuel are advantageous. The CCT system is less affected by the amount of residues on the landing as the relocation cost is low due to the high mobility of the system.



Chipper link at work (left) and standing idle at the landing, waiting for the chip truck to return after a delivery(right).

The longer the distance between the residue stack and the point where trucks can collect the chipped material, the less competitive the forwarder-mounted chipper is in comparison. This is because the forwarder is considerably slower than the CCT. The main disadvantages of the CCT are that the logging residues must be piled within reach from the roadside, and that the truck stands on the road during chipping, completely or partly blocking the road. It is also unavoidable that chaff and chips are spilt on the road during operation. A forwarder-mounted chipper can handle logging residue stacks that are placed some distance from the road, and do not have to stand on the road when chipping a residue pile that is beside a road, leaving the road free for traffic.

Chipper link

ToMo AB has built a chipper system that consists of a truck, a link with a chipper and a chip semitrailer. On the link, i.e. a wagon that fits between the truck and the trailer, a Bruks-Klöckner 805 CT chipper and a loader is mounted and powered by a separate 331 kW engine. The link can be uncoupled from the truck and left at the landing until the chipping is completed at the site. When the system arrives to the landing, the chipper link is uncoupled and placed by the logging residue stack, and the truck with trailer is placed beside it to enable the chipper to blow the chips directly into the semitrailer. By leaving the heavy link on the landing, the legal payload of the truck and trailer can be fully utilized for wood chips. When chipping is completed on a logging site, the link is reattached to the truck before the landing is left. The link is equipped with four supporting legs that can be maneuvered separately using hydraulics, making it possible to move the chipper link sideways over the ditch between the road and the logging residue stack, thereby increasing its reach and enabling traffic on the road.

The chipper link has been studied in chipping of stored, covered logging residues of spruce. Chipping productivity was $68 \text{ m}^3 \text{ loose} / \text{E}_0\text{-hour}$, which is comparable with the productivity level of a conventional chipper truck. In the study, the distance to the recipient was relatively short, 25 km. The round trip took 1.5 to 2 hours per load, i.e. longer than it took to chip a full load. This indicates that, if the chipper link is to be used efficiently, two transport units should be used in the system.

Like chipper trucks, the chipper link system is dependent on the logging residue stack being placed close to the road, but the chipper link's capacity to move sideways increases its reach. If only one truck is used for chip transport, the payload capacity of the chipper link system and the utilization of the chipper is approximately the same as for a conventional chipper truck. More chip transport trucks in the system increase utilization of the chipper. Because the chipper link can serve several chip trucks, the chipper link concept can be interesting for large logging sites with middle to long transport distances to the recipient. The concept does not depend on comminution with a chipper. Equipping the link with a small grinder in order to handle both logging residues and stumps is an interesting possibility.

Future R&D needs

In addition to comminution productivity, the total cost of various truck-mounted chipping systems is affected by a number of other factors, such as machine utilization, payload, transport distance and how the work is organized. In order to calculate and compare the costs of different systems under varying conditions, system analyses should be carried out of all chipper truck systems.

The chipper link was studied when the system was relatively new. The system should be followed up when it has been in practical operation for a while.



A NEW GRAPPLE WITH POTENTIAL TO INCREASE PRODUCTIVITY

Lars Eliasson & Berndt Nordin, Skogforsk

A new, asymmetrical grapple with one short and one long pair of arms, has been studied in forwarding of roundwood, of partly delimbed tree sections and of logging residues, and feeding of logging residues into a chipper. For roundwood and partly delimbed tree sections, differences were small in comparison with an ordinary wood grapple. In logging residue forwarding, productivity was nearly 10 per cent higher with the A-Grip than with a conventional residue grapple. However, a conventional residue grapple was more effective than the A-Grip for feeding loose logging residues into a chipper.



Three types of grapples were studied. Above the asymmetric grapple (AG), below from left a log grapple (LG) and an residue grapple (RG).



During 2009 Skogforsk made a series of studies of an asymmetric grapple (Figure 1) manufactured by Hultdins AB in a variety of work tasks. In order to investigate whether the asymmetric grapple was more efficient than conventional grapples in handling forest fuel, a series of experiments were carried out in collaboration with Stora Enso Bioenergi AB and Sydved AB. The grapple was studied as mounted on forwarders forwarding traditional round wood, partly delimbed energy wood, and logging residues as well as mounted on cranes feeding chippers with residues piled on landing.

The studies show that the asymmetric grapple (AG) increased forwarding performance by 1.4 per cent for round wood, 0 per cent for energy logs compared to the performance with a log grapple (LG) and 9.1 per cent for residues compared to a residue grapple (RG). The changes in time consumption occurred when loading and unloading (table 1). In the study, it was noted that loading residues with the A-Grip produced sheaf-like grapple loads, arranging the residues in parallel as the grapple pinched material from a logging residue pile. These residue sheaves retained their shape in the load, which made unloading easier. Compared to the standard grapples on the studied forwarders, no increase in the amount of soil contaminations of log and fuel assortments was recorded for the new grapple.

A residue grapple was a more effective tool than the asymmetric grapple when feeding chippers, partly because it was easier to get a good grip of residues from the stack and partly because it was easier to pick up the last residues on the landing with a residue grapple. However, residues forwarded and piled with the A-grapple were significantly faster to chip, because piled residues were more co-oriented and less entangled in each other within the pile than after piling with a residue grapple (cf. figure 2).

There was a large difference between chipper operators in how well they were able to adapt to the new grapple and thus how efficient their work was. An observation is that the

Type of work	Comparison	Effect on time consumption
Forwarding of saw logs and pulpwood in a late thinning.	AG / LG	AG 1.3 per cent faster when loading (not significant), and 4.3 per cent faster when unloading.
Forwarding of partly delimbed energy wood (~slender pulpwood with some branches).	AG / LG	No observed differences between grapple types.
Forwarding of branches and tops (logging residues).	AG / RG	AG 11.4 per cent faster for loading and 17.2 per cent faster for unloading.
Feeding a chipper when chipping branches and tops.	AG / RG	Chipping up to 50 per cent slower when an AG was used. Residues forwarded with an AG equipped forwarder were 20 per cent faster to chip than residues forwarded with a RG equipped forwarder.

Results of the separate studies; AG = assymetric grapple, LG = Log grapple, RG residue grapple.

operator has to expect that a different grapple than the one he is used to will have other properties due to differences in grapple design and geometry. Therefore, training is important and so is the operator's willingness to adapt his way of work in order to maximise the advantages of a new piece of equipment.

Conclusions

- Mounted on a forwarder, the asymmetric grapple is a versatile tool that was as good as or better than the standard grapples for all assortments forwarded.
- A chipper preferably should be fed by a residue grapple equipped loader but the residues chipped should have been forwarded by a forwarder with an asymmetric grapple.
- The possibility to use the same forwarder for forwarding both round wood and residues with an equal or increased performance opens up for substantial reductions of total harvesting costs. The effect is particularly strong for small logging areas, where machine relocation costs constitute a large part of the total harvesting costs.



When loading logging residues the assymetric grapple forces the residues to form a sheaf-like, structured bundle.

Future R&D needs

New technology for forest fuel handling should be constantly evaluated. Further studies may be needed of use of the asymmetric grapple for extraction of tree sections and partly delimbed material in first thinnings.



Willibald 5000 grinding logging residues.



FUEL CONSUMPTION IN COMMINUTION OF FOREST FUEL

Paul Granlund, Granlund LB-Teknik

Diesel accounts for much of the contractor's costs in comminution of forest fuel, but has not previously been studied in detail. The fuel consumption of several comminution machines has therefore been studied. Comminution involves either chippers or crushers (grinders). The chippers cannot be used for stumps, while the crushers can be used for all materials. The results show that an efficient comminution machine produces approximately 200-300 times more energy in the form of forest fuel than is consumed in the form of diesel. The results also suggest that, when comminuting logging residues, chippers use less fuel than crushers, which is logical in view of the comminution principle.

Today, utilization and transport of forest fuel involves machines and trucks driven by diesel engines of varying sizes. The price of vehicle fuel is increasing, and today comprises a major part of the contractor's costs. Fuel consumption of the machine in relation to the energy it produces (efficiency) is therefore very important for profitability.

Comminution of forest fuel using chippers gives a more consistent chip. But chippers are sensitive to contaminants in the material and cannot be used for stumps. Crushers can be used for all material. The users have declared fuel consumption of the crushers to be 'high', but more precise information is lacking. Six different machines were studied – an electric stationary crusher, a diesel-run chipper truck and four diesel-run crushers. The studies includes comminution of various materials – logging residues, stumps

or roundwood. Two of the crushers, the CBI 8400 and the Komptech Crambo 6000, have been studied for comminution of various types of forest fuel. At the time of the study, Willibald and Komptech had worn crushing tools that did not give an acceptable result in terms of productivity and quality.

The results show that an efficient comminution machine should give approximately 200-300 times more energy in the form of processed forest fuel than the energy used in the form of diesel to produce it. With the exception of the electric stationary crusher, the results suggest that chippers are more efficient than crushers in comminuting logging residues. However, because only one chipper was studied, more studies are needed in order for this to be confirmed.



CBI 8400 grinding roundwood.



Chipper truck with Bruks's 805 chipper working with logging residues.

Future R&D needs

The project has not yet been completed. The next stage involves repeated studies of the Komptech Crambo 6000 using a fresh crushing tools. In addition to the machines already studied, a number of other machines will be included in the study.

Machine	Engine strength, KW	Comminution	Material	Energy consumption, kW diesel (el) /tonne DM	Fuel consumption, l/h	Energy ratio out/energy in
Willibald 5000	338	Side-fed crusher	Logging residues	56.3	40.1	94.1
Doppstadt DW-3060 (coarse crushing)	321	Top-fed crusher	Stumps	23.3	36.8	222
Svedala electric (fine crushing)	800	Side-fed crusher	Crushed stumps	4.7	–	1094
CBI 8400 (fine crushing)	783	Side-fed crusher	Stumps	25.0	97	207
CBI 8400	783	Side-fed crusher	Logging residues	19.6	113	271
CBI 8400 (fine crushing)	783	Side-fed crusher	Roundwood	22.9	186	226
Truck-mounted chipper, Bruks 805	412	Side-fed chipper	Logging residues	18.9	48.7	280
Komptech Crambo 6000	328	Top-fed crusher	Logging residues	87.7	87.0	60.4
Komptech (coarse crushing)	328	Top-fed crusher	Fresh stumps	80.8	60.2	64.1
Komptech (coarse crushing)	328	Top-fed crusher	Dry stumps	33.2	61.4	156

Studied comminution machine/material combinations. The energy input/output ratio is a measure of the machine's efficiency, and shows the relationship between the energy in the processed forest fuel and the energy in the diesel (electricity) that was used for comminution.

INCREASED RAILWAY TRANSPORT OF FOREST FUEL

Johanna Enström, Skogforsk

Areas with large supplies of forest fuel and areas of big demand can be linked together through long-distance transports. But in order to prevent the costs being excessive, effective transport solutions are needed. A calculation tool developed by Skogforsk has identified the most important cost-influencing factors in railway transport of forest fuel. We have also reviewed possible recipients of railway transports of forest fuel in Sweden. Only 6 of the 44 heating plants that produce at least 100 GWh from forest fuel annually have direct rail connections. As unloading from trains directly at the heating plant is usually not an option, greater efficiency in the combination truck-train-truck is important for developing the potential for long-distance transport.

Long-distance transport of forest fuel by train or boat is an interesting option, particularly for major users who have difficulty in supplying their boilers from local sources. Igelstaverket CHP (combined heat and power plant) in Södertälje and Hedensbyverken CHP plant in Skellefteå are examples of facilities that have chosen to buy their forest fuel outside their local region and transport it by train and boat. In Sweden, today there are regular train transports of wood chips in containers. According to our information, volumes now correspond to 1 TWh annually. Economically viable long-distance transport balances out the price of forest fuel and also makes fuel extraction profitable on more sites and in larger regions. But in order to increase long-distance transports of forest fuel, the efficiency of the rail transport system must be improved.

The economic aspects of railway transport are difficult to overview because the conditions, and thereby the costs, vary considerably. In order to illustrate what factors that influence the costs, Skogforsk has developed a calculation tool for making economic analyses of various transport options on railways. The economic analyses and practical studies show that the following factors have the greatest influence on the costs of railway transport:

- Number of deliveries that a train unit makes per time unit
- Utilization of load capacity
- Transport distance
- Terminal handling (loading and unloading)
- Conditions for train shunting at terminal points (electricity connection)

The fixed costs are high for railway transports (50-60 per cent). In order to reduce the proportion of fixed costs, they must be spread over a large volume, i.e. maximizing utilization of the load capacity of the railway trucks.

The graph shows how the transport cost for two transport distances are affected by the number of deliveries per week.

The transport distance has a direct influence on the variable costs, but distance also influences the number of deliveries that can be made per week, which is more conclusive. The time for handling processes at the terminal also affects the number of possible deliveries per week. Efficient handling at the terminals is therefore important, and can be achieved through well-planned internal logistics that minimize, for example, the distance moved by the machines when loading and unloading.

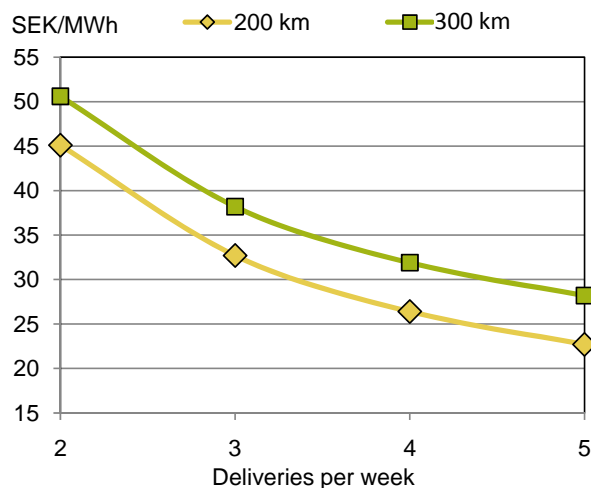
In a master's thesis possible Swedish recipients of forest fuel via railway transport were examined. The map shows the 44 heating plants in Sweden that produce >100 GWh from forest fuel annually. The study showed that only six plants have direct railway connections, while approximately 20 have railway tracks close to the plant. At the majority of the heating plants forest fuel trains cannot be unloaded directly. This accentuates the need to improve the efficiency of the combination truck-train-truck, including the intermodality of transfers between them, if the scale is to be increased.

Currently, we are analyzing the full chain of rail transport system together with the earlier tiers of the logistics chain, i.e. from forest over railway terminal to the end users. It is important to investigate when and to what extent the diversion via the terminal is offset by the more efficient onward transport and comminution of the forest fuel that can be arranged at a terminal.

In order to increase efficiency in connecting transports to the railway, we are also investigating whether larger trucks can be used for chip transport. Current provisions for permitted width and payload of transported containers are more generous for rail than for road transports. If the payloads for container trucks could be increased, whole containers could be transferred with better use of the train's transport capacity.

Future R&D needs

- Further studies of the possibility to transfer material directly between truck and train.
- Solve technical problems such as increasing chip compaction and preventing chips from freezing in the containers.
- Analysis of the coordinating role of the terminals in improving efficiency and optimization of storage, transport, comminution, measurement and sorting of forest fuel.
- Increased collaboration between the players to create efficient flows, e.g. finding return loads.



Examples of costs for railway transport of chips over different distances and numbers of deliveries per week, SEK/MWh.



Heating plants that use at least 100 GWh of forest fuel annually. The Swedish railway network is indicated on the map.



GREATER EFFICIENCY IN RAILWAY TRANSPORT OF FOREST FUEL

Johanna Enström, Skogforsk

High transport cost is the most limiting factor to improved availability of forest fuel. Effective transport solutions are therefore one of the most important issues for development. Efficient systems for loading, unloading and transfer of load between truck and train can be part of the solution. The type of container largely steers which technology can be used for loading and unloading of chips. Three systems for transport of chips on railways have been studied – Innofreight's system, standard container systems with switch-body units, and Kockum's turntable wagon. All three systems have advantages and disadvantages.

In all studies the chips were loaded from a pile on the ground at the terminal with a wheel loader or a material handler with a bucket. The chips were loaded into containers that were already in position on the railway wagons and not lifted off the train until they were unloaded at the recipient's facility. During the train transport, all containers were open-topped. Chip transport by rail in Sweden does not require the load to be covered. Time consumption and machine resources for loading varied greatly, primarily because of the placement of the piles of chips and the distance to the railway track. The highest productivity recorded during the studies was with a wheel loader that loaded approximately 550 m³ chips per hour.

The Innofreight system

Large containers (46 or 53 m³) are emptied by inverting with a fork-lift truck. This system is used for plants that receive chips transported by rail several times a week.

- + Specially-adapted containers mean greater volumes of chips per railway truck.
- + Effective unloading through forklift truck with turntable forks.
- Specialized system. The unloading truck has few other areas of application and therefore has low utilization.
- The loader's forks are specially designed for these containers and cannot handle other standard containers.



Conventional container system for switch-body trucks

The containers can be used on both roads and railways, providing there are fork tunnels under the containers. A smaller fork-lift truck lifts the containers down from the railway wagon. A truck with a hook then pulls them onto the vehicle and empties the load by tipping the container backwards. Containers can also be pulled over to a trailer that is connected to the vehicle if the containers are to be transported some distance before emptying.

- + Because the containers stand on a truck, a longer distance to the point of emptying is not a major problem.
- + Only includes standard components.
- Somewhat longer time taken for unloading compared with the Innofreight system (can be shortened with more road trucks).

- A conventional chip container cannot fully utilize the train's full load capacity. The weight limit of the truck on public roads is approx-

imately 14 tonnes/container, and the train wagon's limit is approximately 20 tonnes/container. The permitted width of containers is also greater on trains.



Conventional truck container where the tunnels for the forks can be seen under the container.

Kockums turntable wagon

This is a technology that is used to transfer standard truck containers directly between the railway wagon and a road truck. By a rotating plate on the railway wagon under each container, the truck can drag the container to its trailer or push an emptied container back to the railway wagon. Even though it is yet not practically applied, the method could be used for loading filled containers at a terminal.

- + Greater flexibility because no extra machines are needed for loading and unloading.
- + The containers and trucks are of standard design and no extra equipment is needed on the trucks.
- The railway wagons are purpose-built and approximately 20 per cent more expensive to purchase than normal railway wagons. As yet, they are not massproduced.
- High time consumption for unloading (approximately 10 minutes/container from train to road truck).
- The standard containers do not fully utilize the payload capacity of the railway wagons.



Future R&D needs

An interesting question is how normal systems for container management (according to ISO standard) used in other sectors would work for forest fuel. Such container management in combination with fixed installations at the recipient's facility is worth examining. These questions are particularly interesting if they also include the possibility of transporting forest fuel by boat. Boat transports open up an international market for forest fuel. Furthermore, it is important that competitive, flexible transport solutions for small volumes of forest fuel are also developed.



Train loaded with crane loader



INLANDSBANAN

– A POSSIBLE TRANSPORT ROUTE FOR FOREST FUEL

Johanna Enström, Skogforsk

Inlandsbanan is a 1,400-km railway line between Gällivare in the north and Kristinehamn in the south with potential to become an important transport route for forest fuel. Almost one-third of Sweden's productive forest (6.9 million ha) lies within 50 km of Inlandsbanan. The energy from the forest fuel that could be extracted in the area corresponds to nearly 6 TWh.

An accessible and well-maintained railway network is a prerequisite for increasing the potential for long-distance transport of forest fuel. Today, there are bottlenecks in the railway network that make it sensitive to disruption. There are also lines that could be used for forest fuel transport but that have fallen into decay and now require renovation in order to handle goods traffic.

Inlandsbanan is a 1,400 km-long railway line between Gällivare in the north and Kristinehamn in the south, mostly trafficable for freight trains but in certain parts requiring renovation. The potential for the Inlandsbanan to serve as a transport route for forest fuel and so promote utilization of large forest fuel resources in the interior of Norrland was investigated. A number of lines to/from the coast connect with or cross Inlandsbanan. Consequently, there is potential to transport forest fuel both southwards to the Mälardalen region and the major users there, or to the ports along the

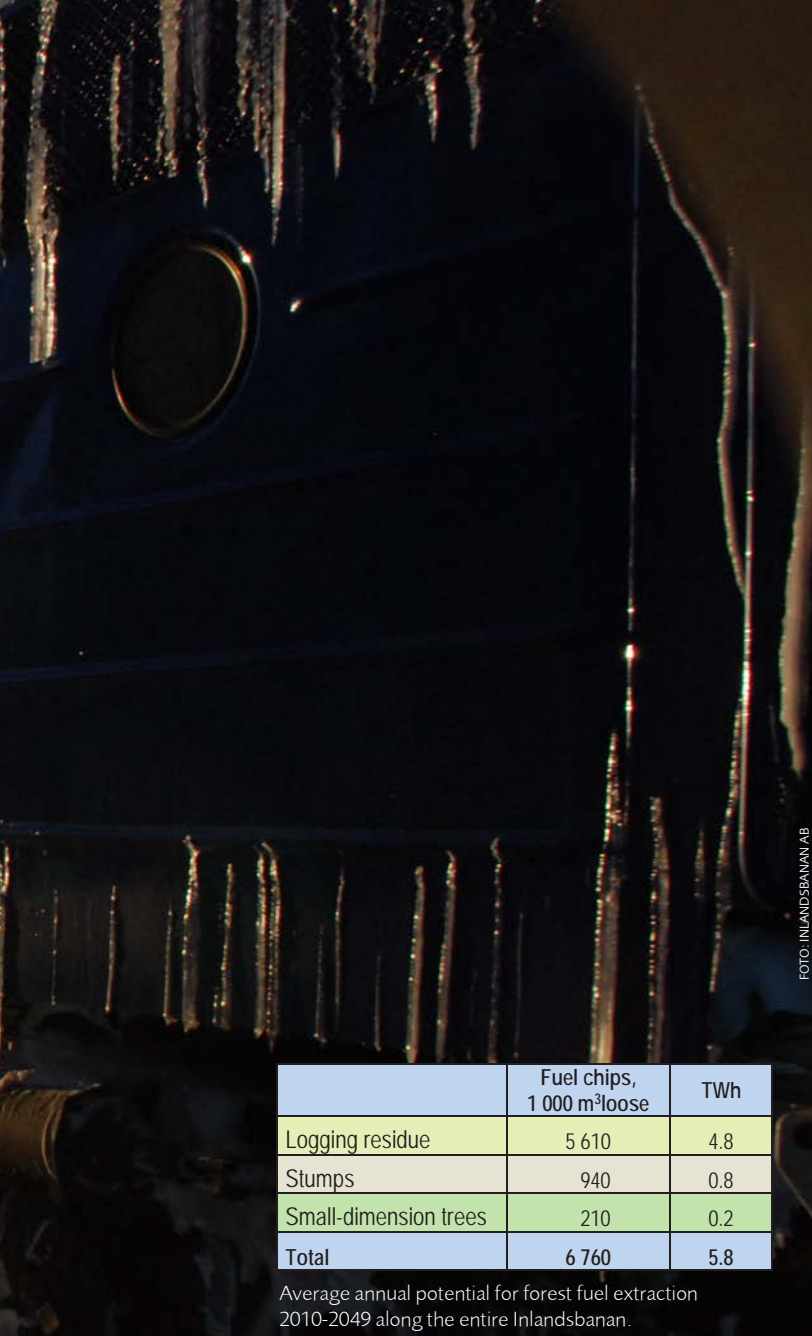


FOTO: INLANDSBANAN AB

	Fuel chips, 1 000 m ³ loose	TWh
Logging residue	5 610	4.8
Stumps	940	0.8
Small-dimension trees	210	0.2
Total	6 760	5.8

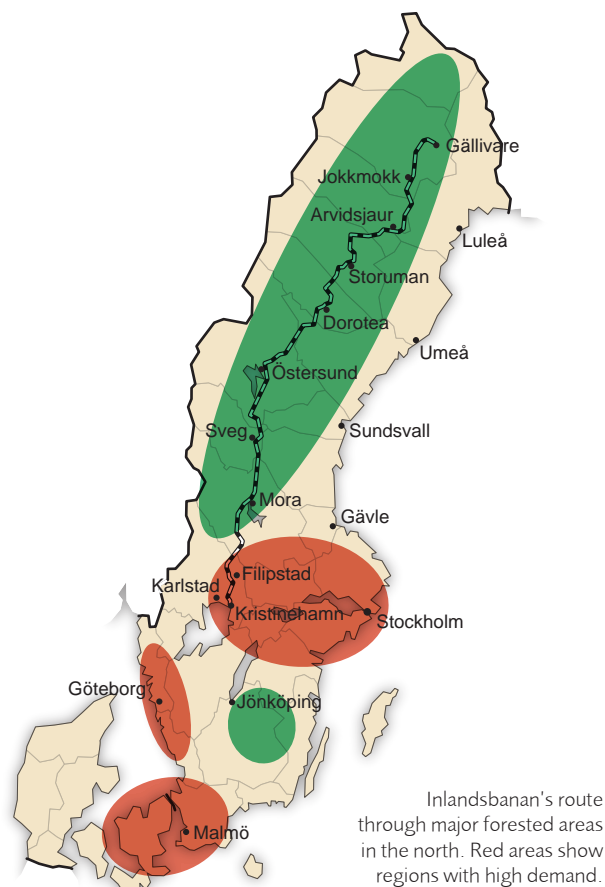
Average annual potential for forest fuel extraction 2010-2049 along the entire Inlandsbanan.

Norrland coast. Not all the perpendicular lines are currently trafficable, and the main line is only open for goods trains between Mora and Arvidsjaur.

Almost a third of Sweden's productive forest, 6.9 million ha, lies within 50 km of Inlandsbanan. This area contains approximately one-fourth of the Swedish wood supply.

Trend projections have been made to calculate the annual quantity of forest fuel that could be extracted along the line in the coming 40 years. The following assumptions were made for the calculation:

- Extraction of 80 per cent of the logging residues on 70 per cent of the final logging area.
- Extraction of 70 per cent of the stumps on 10 per cent of the final logging area.
- Extraction of small-dimension trees on 30 per cent of the area of early thinning in the form of part delimbed tree sections meaning that 25 per cent of the branches are included.



Future R&D needs

Accessibility on the Swedish rail network strongly affects the potential for increasing transports of forest fuel by rail. Today, many rail sections are classed as overloaded, which makes the system sensitive for disruption. The scale of the limitations, and how this affects the conditions for transport of forest fuel, therefore needs to be studied further.

In total, the annual extraction of forest fuel along the Inlandsbanan could be close to 7 million m³ chips, corresponding to an energy content of just under 6 TWh. The local use of forest fuel along the Inlandsbanan is currently approximately 1.8 TWh per year. Apart from forest fuel, this figure also includes peat and sawmill by products. Consequently, the surplus of forest fuels in the area corresponds to over 4 TWh/year. Transporting this volume of forest fuel by rail would require approximately 2,000 full system train hauls.

There is no shortage of locations for terminals along the Inlandsbanan that limit the line's potential, but the closed line sections limit the connection possibilities to the coast and southwards. The traffic control system would also need to be modernized if the traffic on the line were to increase substantially.

SIMULATION – A TOOL FOR SYSTEM COMPARISONS

Petrus Jönsson & Lars Eliasson, Skogforsk

Skogforsk has developed a simulation model to allow evaluation and comparison of logging residue procurement systems under identical conditions. Currently, the model is being validated and it will be used for analyses of the most common procurement chains for logging residues. Future use includes studies of cost, utilization rate, competitiveness, etc. for proposed procurement systems that currently are in a concept stage.

Simulation technology allows experimental comparative analyses of different procurement systems under equivalent conditions. This enables study where alternative procurement systems is compared in terms of, for example, productivity, costs and machine utilization when they are used on the same logging sites, with the same volumes, extraction distances, etc. The model enables us to include conceptual or proposed procurement systems into our analyses. Thus, we can estimate e.g. which capacity, cost, utilization rate, and shift forms that are required in a new system in order for it to be competitive with established procurement systems. In the simulation model, pre-programmed components in the systems, such as transport and comminution machines, may be substituted in order to customize the procurement system to a company's specific conditions, e.g. location, site conditions, distance to recipients, technical utilization rate of machines, etc. The competitiveness of different logging residue procurement systems can also be analyzed over a long time span and for different regions of the country.

So far, the following procurement systems have been included in the simulation model:

Loose logging residue

Forwarding of logging residues, transport of loose logging residues by truck to recipients, comminution of residues at the recipient's facility.

Tractor-mounted chipper + container

Forwarding of logging residues, chipping at the landing and tipping of chips into a container, transport by container truck to recipients.

Tractor-mounted chipper + chip truck with bucket

Forwarding of logging residues, chipping into a pile at the landing, loading and transport by chip truck (with crane and bucket) to the recipient.

Chipper truck

Forwarding of logging residues, chipping at the landing and transport to the recipient by chipper truck.

Chipper truck + container

Forwarding of logging residues, chipping into containers at the landing, transport by the chipper truck or by container trucks to the recipient.

Bundlers

Bundling on the logging site, forwarding of bundles, truck transport of bundles to the recipient, comminution at the recipient's facility.

Chipping at the cutover

Chipping at the cutover, tipping of chips into a container at the landing, transport by container trucks to the recipient.

Currently, model validation and a first evaluation of some of the systems – **loose logging residue**, **tractor-mounted chipper + chip truck with bucket**, and **chipper truck + container** are under way.



The simulation model has been used to examine the effects on overall system costs for the alternatives to tip chips into a container or onto the ground. If containers are used, the interaction between the chipper and the container truck must be smooth for the work to be efficient. If the chips are tipped onto the ground, the chipper can operate independently from onward transport of the chips, but the risk of chips being left at the site and of contamination with soil is greater.

Future R&D needs

The simulation model can be developed for evaluation of a multitude of procurement systems, for example, railway transport and terminal handling, and also for evaluation of biofuel flows at regional or national level. Since the model allows general cost-effective comparisons of systems, and not just forest fuel systems, it will be a valuable research tool in the future.

MARGINAL COST ANALYSES SUPPORT REGIONAL SYSTEM DEVELOPMENT

Dimitris Athanassiades, SLU

Marginal cost analyses show what quantities of forest fuel are available at a given cost level. A model for calculating the marginal costs has been developed. In a first test of the model, the marginal cost of logging residues and stumps at national level has been calculated. The calculation shows, for example, that at a marginal cost of SEK 1,000 per ton dry matter, we may extract all available logging residue in Sweden and approximately half of the final felling stumps. But the national average does not reflect the varying conditions in the country. These must be known in order to develop regionally optimized forest fuel systems. In deepened studies, the regional perspective will be emphasized.



The **Hugin simulation system** was used to calculate the potential quantity of forest fuel (logging residues and stumps) in final felling at national level. Conditions for forest fuel sites in terms of size, extraction and secondary transport distances, etc. were determined based on data from the Swedish National Forest Inventory, notifications of final felling site sizes submitted to the Swedish Forest Agency and GIS analyses of transport distances. For harvest of logging residues and stumps, the currently dominating systems were chosen. For logging residues, this was forwarding, chipping at the landing and truck transport to heating plants. For stumps, the system involved splitting and removal from the ground, forwarding, and transport to heating plant for comminution with a stationary crusher. The costs used in the analyses are based on experience and studies of the machines used in the systems. Costs include compensation to land-owners and administrative costs.

An example of the results is shown in the diagram. It can be seen, for example, that at a maximum marginal cost of SEK 1,000 per ton DM, in principle all logging residues is accessible as well as about half of all stumps. It can also be seen that only limited quantities of forest fuel incur extreme marginal costs. The most important factors for increasing marginal cost are the size of the felling site, the amount of logging residues and stumps in it and terrain transport distance (cost of terrain transportation). Thus, the graph shows that most final felling sites have an acceptable size and logging residue and stumps quantity and that the road network in Sweden is relatively well developed.

In order to prioritize the measures when developing efficient forest fuel systems, it is necessary to be aware of regional variations in terms of quantities, costs and other conditions. Deepened studies include several different forest fuel systems as well as a regional perspective. In addition to logging residues and stump wood, these studies will also include small-dimension trees from cleaning and thinning stands. The studies will involve regional calculations of the quantity of logging residues, stumps and small-dimension

trees resulting from logging sites in the period 2010 to 2019. Costs of extraction for logging residues, stumps and small-dimension trees will be calculated for most machine systems currently used in Sweden. Landowner compensation, administrative costs and costs of moving machines will be included in the calculations. The following systems will be included:

Logging residues. Forwarding to the landing, comminution at the landing or at the terminal/heating plant, and road transport of chips or uncomminuted logging residues to the terminal/heating plant.

Stumps. Stump removal, forwarding of stump parts to the landing, road transport of stump parts to, and comminution at, terminal/heating plant, or coarse crushing at the landing and road transport of crushed stump parts to terminal/heating plant.

Small-dimension trees. Logging with multi-tree handling harvesting units, and forwarding of roughly delimbed tree parts to landing, comminution at the landing and road transport to the terminal/heating plant.

The differences in marginal cost levels that are expected between the three fuel assortments are partly due to differences in experience with the systems, so they vary in how far they have been developed. In particular, harvest of stumps will become more efficient as experience grows and technology advances. New technologies, new system solutions or new conditions in, for example, infrastructure, may change the internal order between the fuel assortments. In future, the marginal cost levels can be expected to fall, while the principal appearance of the marginal cost function will remain stable.

Calculation of forest fuel volumes using Hugin

Hugin is a simulation system that can be used to forecast the future state of a forest on the basis of the increment of individual trees. The software can calculate the total forest inventory by region and for the country as a whole, at present and for various future time periods. The gross forest inventory was used as the basis for calculating the potential forest fuel quantities. From this volume, deductions were made for forest that grows on land where there are ecological restrictions according to the Swedish Forest Agency's current recommendations, and for areas that were judged inaccessible for technological or economic reasons.

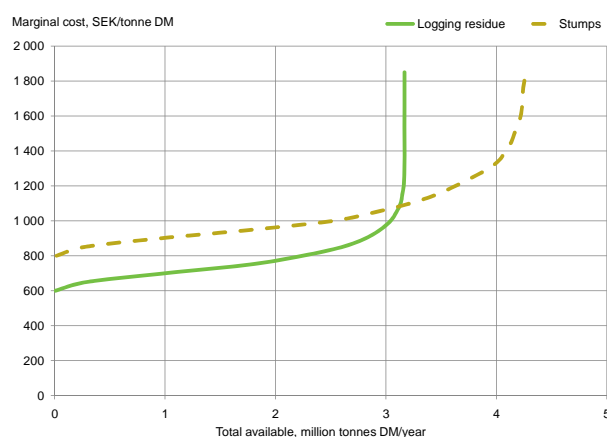
Future R&D needs

Studies will be made of marginal costs for extraction of logging residues, stumps and small-dimension trees on the basis of regional conditions.



PHOTO: MAGNUS MATSSONS, SLU

Forwarding of logging residues with conventional forwarder.



Swedish marginal costs for extraction of logging residues and stump wood from final felling.





AN INTERACTIVE TOOL FOR SYSTEMS ANALYSES

Henrik von Hofsten, Skogforsk

It is difficult to calculate and allocate the production costs of forest fuels, but such information is needed for decisions on machine investments as well as in many other situations. The FLIS Excel program can be used for simple machine cost calculations, but also for more comprehensive analyses of entire forest fuel systems. FLIS is regularly being developed to become more user-friendly.

FLIS is an Excel-based calculation tool developed by Skogforsk. The program was originally created to enable calculations, at a strategic level, of the total cost per cubic meter (m^3 loose chips) for different forest fuel systems. Since then, the software has been revised and expanded. Today, a few clicks of the mouse allow calculation of the costs for

both the entire forest fuel system or for individual machines, for example to see how the total cost is affected when machines are added or removed.

The calculations are divided into four cost areas:

- Transport costs in the forest
- Costs at the landing, and road and railroad transport
- Costs at the terminal/heating plant
- Optional indirect costs

Within each of the three direct cost areas, a choice can be made from a number of different machines. The results are productivity and cost figures for each machine. The user can review and change pre-set values if required.

FLIS has been a great benefit in R&D work, and has also been used by several large forest fuel producers when analyzing their own systems and identifying areas for improvement.

Future R&D needs

Calculations and functionality in FLIS have been developed in several stages. The program has recently been expanded to also include railway transport. The next stage will address its user-friendliness. FLIS was originally developed when forest fuel handling was still in its infancy. In the past five years, the range of machines has increased considerably and, as a result, FLIS has become somewhat difficult to overview. A future step may be to translate the software to English.

LONG-TERM ECONOMY OF FOREST FUEL HARVEST

– CALCULATION TOOL FOR FOREST OWNERS

Staffan Jacobson, Skogforsk

Forest owners should consider the long-term effects when extracting forest fuels. Most noticeable is the risk of increment losses. Skogforsk has developed a user-friendly calculation tool to support the forest owner in assessment and economic evaluation of the short- and long-term effects of forest fuel extraction. The calculations can help in decisions on extraction and any compensation measures and is available on the Skogforsk website.

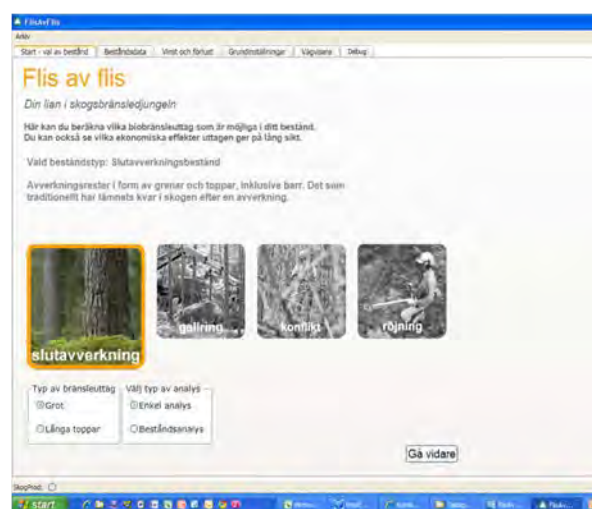
Harvest of large quantities of green and fine tree fractions (logging residues, roughly delimbed tree sections) result in increment losses. This applies to harvest in cleaning and thinning stands, as well as after final felling. Losses in the order of 5-15 percent during a 10-20-year period are reasonable estimates under Swedish conditions. Removal of logging residues after final felling also has positive effects, facilitating the establishment of a new stand, primarily through easier and cheaper ground preparation and a somewhat cheaper cost of planting. Both positive and negative effects must be included in the balance sheet. For the extraction of small trees in cleaning/thinning stands, some other effects also arise, e.g. early placement of strip roads, which indirectly affects the development and total production of the stand.

An economic calculation tool has been developed to support the forest owner's decision on forest fuel delivery. Economic consequences of increment losses in relation to simplified stand establishment after forest fuel harvest are evaluated at stand level. The analyses show what revenues are required from the forest fuel sale in order to balance future increment losses and what any compensation measures may cost. The results are illustrated in the form of present net values at differing calculative rates of interest. The tool also

estimates the size of the harvest in terms of MWh, m³ loose and tonnes DM per hectare.

Due to the complexity of problems, and the variability of conditions, a tool of this type must allow the user to vary the conditions and assumptions. In order for the user to gain an overview of the tool, and to make it easy to use, a guide is provided using informative texts and linked background documents. Consequently, it can also be used as an aid in training.

The software is available for free download from the Skogforsk website and on Kunskap Direkt. The latter is an Internet-based advice tool about forestry that is produced by Skogforsk in collaboration with the Swedish Forest Agency and LRF (Swedish Federation of Forest Owners).



Future R&D needs

The tool will be continually updated as new knowledge becomes available.



PHOTO © CORAN BACKSTROM / SCIENCE



ChipOpt – FLOW OPTIMIZATION FOR FOREST FUEL

Mikael Frisk, Skogforsk

Logistics are critical in the production of forest fuel. In the ChipOpt project, Skogforsk's computer-based tool for analysis of roundwood flow, FlowOpt, has been adapted for forest fuel logistics. Much of the development took place in conjunction with a study by Sveaskog, where the aim was to establish the optimal localization of terminals for forest fuel, as well as methods of comminution and transport. Some interesting results from the study were that the average extraction distance could be shortened and that several of the 15 terminals included in the study were not used by an optimal solution. It could also be seen that certain recipients of forest fuel were considerably more profitable than others.

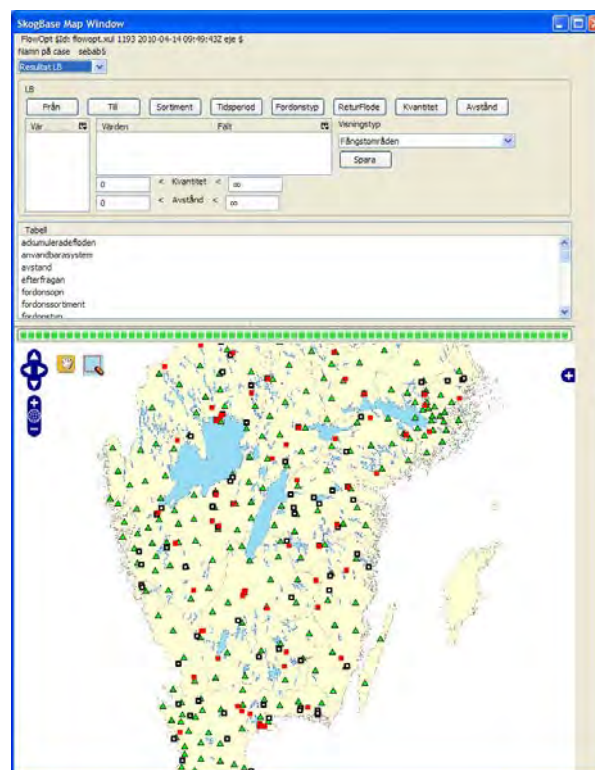


For several years, Skogforsk has developed FlowOpt, which is a tool for analysis of wood flows. It has been validated through around twenty studies in order to analyze optimal catchment areas, back haulage potentials, timber exchanges and cost-effective train and terminal systems. ChipOpt is a further development of the tool making it suitable for optimizing forest fuel production, including decision-support for selection of technology for comminution. The tool has developed from being a pure logistics optimization tool into one for business optimization. Both purchase and selling price are included in the optimization, maximizing contribution margin (revenues minus costs). This makes it possible to calculate profitability of

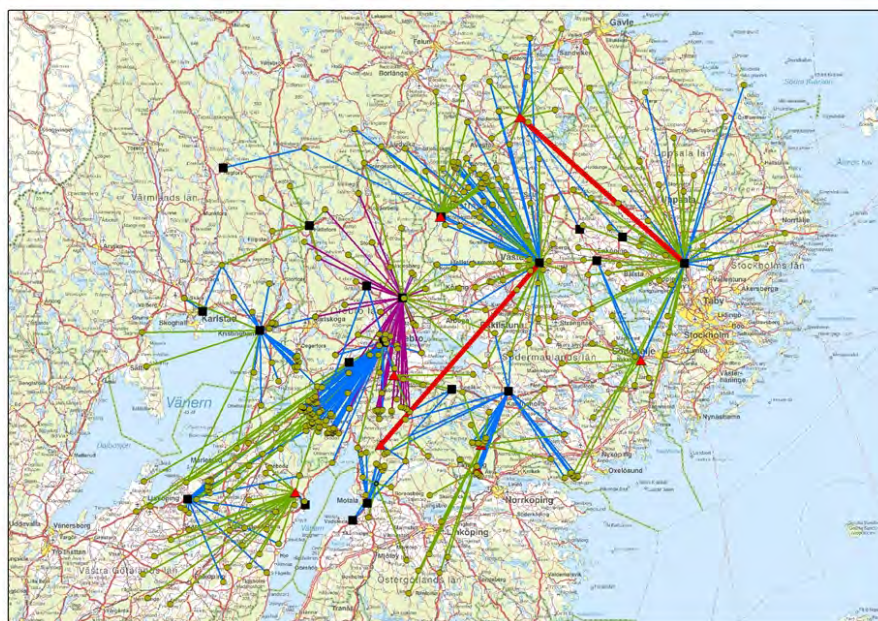
deliveries to different customers. The model also presents data supporting base decisions on: Which comminution technology is best for logging residues on a particular site? Which heating plant should receive which forest fuel?

In addition to a new optimization model that is considerably more comprehensive than the original FlowOpt model, a new interface has been developed. It is based on easy-to-use programs with an open source code for database and map management. By including variations in supply and demand over the year, and limitations in production and transport capacity, FlowOpt can calculate and optimize the need for storage, e.g. ahead of the winter months.

There is great interest in ChipOpt. In addition to the study at Sveaskog, presented below, the tool was used in 2010 in a study carried out together with Stora Enso Bioenergi AB. The aim has been to optimize localization and use of terminals, determine which type of transport and comminution system is most profitable, and to analyze the nature of the customer structure.



The new interface for FlowOpt includes a map section. The diagram shows terminals (red squares), recipients (open, black squares) and central points of municipalities (green triangles). The upper part contains menus for selecting which flows are to be shown on the map.



Example from the optimization of forest fuel flows at Sveaskog. On the map, each line shows a delivery to a customer, and each color represents a forest fuel assortment.

Optimization study of forest fuel flows

Much of the development work for ChipOpt, mainly adapting the FlowOpt tool for forest fuel assortments, was carried out during a study for Sveaskog in 2008. The study analyzed localization of terminals for storage and comminution of forest fuel, terminals for transfer to trains, best destination (recipient), and methods of comminution and transport. The input data to the study was the forest fuel flows for 2007 and comprised:

- 650 GWh logging residues, energy wood (roundwood) and tree sections, from 400 sites in central Sweden. For each assortment, a purchase price per MWh was stated, regardless of whether the volume came from the company's own forest or from private forest owners.
- Several different systems for comminution and transport: Tractor-mounted chipper, chipper trucks, grinder and logging residue bundler, and roundwood truck, logging residue truck, chip truck and train. For each machine and transport type, there was information about productivity, annual capacity, and cost.
- 21 recipients, mainly heating plants. For each recipient, there was information about contracted volume and the price paid for different assortments.
- 15 terminals, both existing and not yet established. The terminals were used for comminution and storage, and/or transfer from truck to train.

In the optimal solution, the average transport distances shortened. Several of the 15 terminals were not used. It could also be seen that certain recipients were considerably more profitable than others. Some even proved to be unprofitable when the costs of purchase, comminution and transport were totaled, and then compared with what the customer pays. This can depend on binding agreements and/or that not all conditions were taken into account in the optimization. For example, seasonal variations in demand were not included.

Future R&D needs

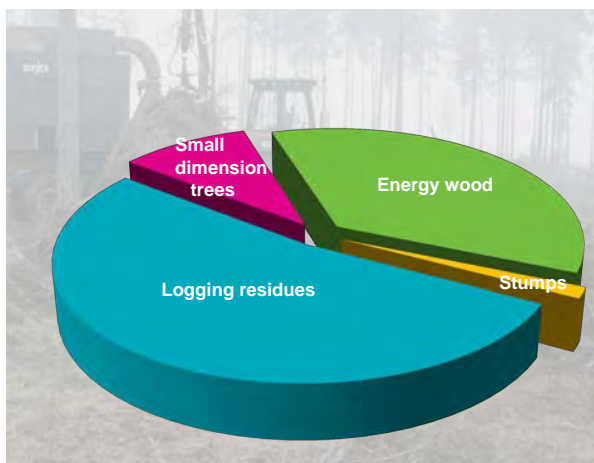
FlowOpt has been used as a research tool and by researchers on a commission basis to help Skogforsk's member companies with different analyses. An implementation project was started in 2010, with the aim to install FlowOpt in Södra Skogsägarna, a member company, so that they can use the tool itself. Refining the interface and simplifying the use for such companies that are interested in using FlowOpt will be important in this project.



FOREST FUEL SURVEY

Torbjörn Brunberg, Skogforsk

For a long time, Swedish statistics on costs, methods, systems and assortments for forest fuel have been inadequate. A survey covering these topics has been carried out through a questionnaire and show, for 2009, an average cost of SEK 170 per m³ loose chips at end customer for production and transport of forest fuel. Logging residues and energy wood are the major assortments. More than 80 per cent of the logging residues were chipped at the landing before transport to the customer.



Forest fuel is growing in terms of volume and is becoming increasingly important for the forestry sector. This increases demands on the operation to be run efficiently and undergo constant development. In order to improve forest fuel operations, we need to follow volume changes and developments in technology and methods, as well as costs and revenues. The individual company usually has a good understanding of these, but comparable information is often lacking at regional or national level. This is needed for long-term planning and for benchmarking between companies.

In order to meet the outlined need for general statistics, a questionnaire was issued to gather information from various forest fuel producers in Sweden, on model of the 'logging and forest management questionnaire' that Skogforsk has

regularly collected, compiled and presented in summary form in its publication series, 'Resultat', for several decades.

The new forest fuel questionnaire contains questions about:

- Technology and methods for harvest, forest transport, comminution and secondary transport.
- Costs of harvest, forest transport, chipping and secondary transport.
- Costs of logging residues, tree sections, stumps and energy wood.

The questionnaire was sent to all the major producers of forest fuel in Sweden. Before the questionnaire was sent out, the contents and the degree of detail was discussed with the recipients. The questionnaire was sent out in the first quarter





of 2010, and the questions related to conditions in 2009. The response frequency was good, representing approximately 13 million m³ loose of forest fuel, corresponding to 80 percent of the total production.

The responses have not yet been fully analyzed, but preliminary results show that, of the approximately 13 million m³ loose of forest fuel, just over 50 per cent comprised logging residues, just under 40 per cent energy wood, and 10 per cent small-dimension trees from cleaning and thinnings. Stumps accounted for only 1 per cent. The forest transport distance averaged approximately 350 m. The difference in extraction distance between the different forest fuel assortments was marginal.

More than 80 per cent of logging residues, the largest forest fuel assortment, was chipped before onward transport to the customer. Extraction of whole, loose residues accounted for approximately 15 percent of the volume, and bundling on the cutover for 5 percent. Logging residues were mainly comminuted through chipping (approximately 90 per cent), while 10 per cent of the volume was crushed by grinders. The average cost in Sweden in 2009 for production and transport of forest fuel to end consumer was approximately SEK 170 per m³ loose.

Future R&D needs

The questionnaire on forest fuel is planned to be repeated annually, and results will be presented in the Skogforsk publication series, 'Resultat'.

ADVISORY PORTAL NOW INCLUDES FOREST FUEL

Mats Hannerz, Silvinformation AB

Skogforsk's advisory portal, Kunskap Direkt (Direct Knowledge), was extended in December 2009 with a comprehensive section on forest fuel. In this section, forest owners, contractors, buyers and users of forest fuel can find both simple guidelines and in-depth information about extraction of energy from forests. The web service also includes calculation tools and films about forest fuel.

Kunskap Direkt Forest Fuel is intended as a support for anyone planning extraction of forest fuel. It gives answers to such questions as: How much energy is there in the stand? How do I plan for forest fuel extraction? How will the environment be affected? What does it cost to harvest logging residues, stumps or small-dimension trees?

However, it does not give the answer to how much a forest owner is paid for forest fuel. Pricing is a matter for buyer and seller, and varies greatly depending on market situation and other conditions.

Production of Kunskap Direkt Forest Fuel was financed by the Swedish Research Council Formas. The content was compiled by researchers in the ESS program from ongoing projects about forest fuel. It contains approximately 120 pages. The emphasis is on practical issues of logging residue extraction, but stumps and small-dimension trees are also covered. More general aspects are also taken up, such as environment measures and Sweden's energy supply as a whole.

The section, 'Count on forest fuel', provides decision support and calculation tools for estimating the energy content in various assortments, the quantity of forest fuel in a stand, and costs for extraction of forest fuel. Six short video clips from the Swedish Forest Agency, provides a quick introduction about logging residue extraction and ash recycling.

Kunskap Direkt in brief

Kunskap Direkt is an advice portal about forest management and nature conservation in forestry, produced by Skogforsk in collaboration with LRF Swedish Federation of Forest Owners and the Swedish Forest Agency. The site was launched in 1999 and initially concerned hardwood forest management. Since then, the portal has been extended to over 1,700 web pages, with 45 sophisticated calculation tools and approximately 40 instruction films. The users can also test their knowledge and simulate forest management with interactive examples. Today, the portal spans the entire field of forest management and nature conservation, including water and cultural heritage conservation. There are also sections on forestry roads.

Use of Kunskap Direkt is free and it is reached via the Skogforsk website, or via the direct address www.kunskapdirekt.se. The primary target group is forest owners and their advisors. For Kunskap Direkt Forest Fuel, contractors and buyers of forest fuel are also important target groups.

KUNSKAP DIREKT

- Startsida
- Hälsyn
- Skötsel av lövskog
- Skötsel av barrskog
- Vägar
- Verktyg



Kunskap Direkt om skogsbränsle

Kunskap Direkt Skogsbränsle är ett kunskapssystem under utveckling.

Kunskap Direkt Skogsbränsle vänder sig i första hand till dig som är skogsägare och funderar på att sälja skogsbränsle. Här finns också information för dig som är entreprenör eller planeringsansvarig i skogsbruket eller på energiföretag, och som vill veta mer om skörd, transport, ekonomi och miljöeffekter.



- Vad är för och nackdelarna med uttag av grovt lövsnitt och toppar?
- Hur mycket energi finns det i beståndet?
- Hur planerar jag ett grovtuttag?
- Vilken naturhänsyn ska ta vid grovtuttaget?
- Ska jag utrotta stubbarna?
- Vad är skillnaden skogsbränsle?
- Vad har skogsbränslet för kvävet?
- Vad kostar det att ta ut skogsbränsle?



Filmer om skogsbränsle

Hur går bränsleuttag till, och varför ska man återföra aska? Sex kortfilmer ur Skogstjänstens film "Grotuttag och askåterföring".

Läs mer »





GROTSPORRE IMPROVES PROFITABILITY

Petrus Jönsson, Karin Westlund, Patrik Flisberg och Mikael Rönqvist, Skogforsk

Forwarding accounts for over 20 per cent of the costs of logging residues. Profitability in extraction of logging residues therefore largely concerns the ability to decide which parts of a logging site should be adapted for logging residue extraction and which should be left on account of the cost. GROTSPORRE is a tool that, on a map, suggests optimal forwarding routes and shows, at a given price level, which parts of the site are not viable for forest fuel extraction. When there are several landings, it also shows the landing to which the fuel is to be forwarded.

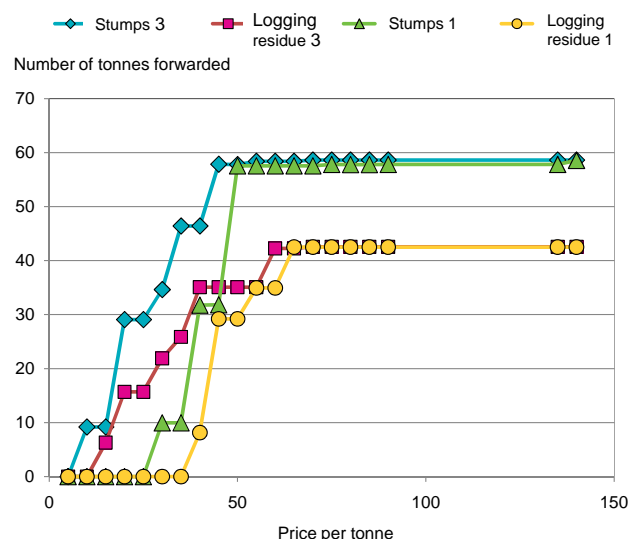
SPORRE (*Planning and Reporting of Forwarding in Real Time*) is a tool developed by Skogforsk to optimize forwarding of roundwood. A similar tool for utilization of forest fuel, GROTSPORRE, is now under development. It builds upon the system for harvester reporting of forest fuel that was developed within the ESS program (see separate article). In harvester reporting, information about individual trees is stored in the harvester's computer. This is used in GROTSPORRE to show, on maps, volumes and distribution of the logging residues on the cutover. The tool can analogously be used for to optimize stump extraction operations.

In GROTSPORRE, the extraction is optimized for the forwarding at a given cost (SEK/tonne). Varying this figure allows price sensitivity to be studied, i.e. how much more logging residues (or stumps) can be extracted if the price is increased, and the volume that is lost if the price falls. The diagram to the right shows price sensitivity for logging residues and stumps in the interval 0-140 SEK/tonne. At a price level of 40 SEK/tonne (stumps) and 60 SEK/tonne (logging residues) in principle the entire site can be forwarded. The effects of using one or several landings can also be seen. In order to forward 20 tonnes of logging residues on this site, there is a difference of about SEK 10/tonne for using one or three landings.

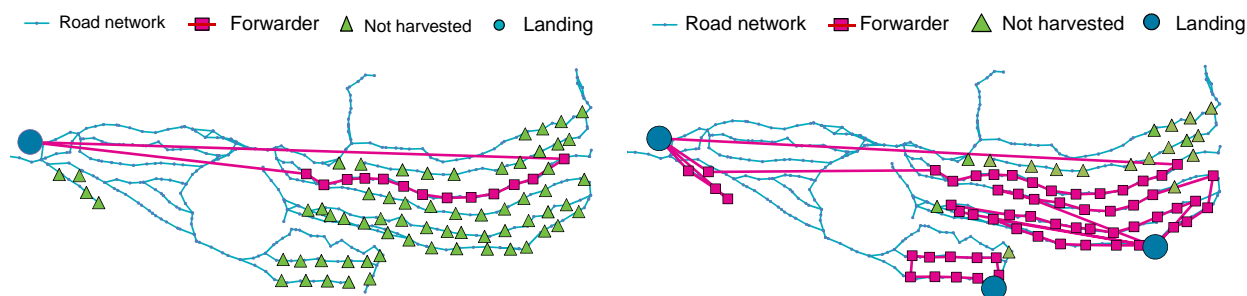
A field study from Korsnäs AB illustrates the potential of the new tool. The cutover where the study was carried out was 6 ha. On the site, there were 40.5 tonnes of logging residues and 58.6 tonnes of stumps. Three possible landings could be used. The extraction distance on the cutover and localization of the forest fuel was obtained through GPS coordinates from the harvester.

GROTSPORRE makes it possible to determine the parts of the cutover from which forest fuel should be extracted and which transport routes to use. The figure below shows which routes are optimal at a forwarding price of 35 SEK/tonne using one and three landings respectively in the example stand.

When GROTSPORRE is ready to use as practical support, the most efficient transport route can be calculated in advance and presented graphically for the logging crew, together with the stand directive. In addition, unprofitable parts of the cutover for logging residues and stump harvest can be identified and exempted.



Quantity (tonnes) of stumps and logging residues that is profitable to forward at various price levels. Two different scenarios, with one and three landings respectively, are shown in the diagram.



The figure illustrate which routes are to be used to optimize the extraction of forest fuel at a forwarding price of 35 SEK/tonne. The left figure shows the situation when one landing is used, and the right figure when three landings are used.

Future R&D needs

The case study shows that GROTSPORRE enables calculation of optimal transport routes and the volumes of forest fuel that are profitable to extract. However, before the calculation program can be used in practice, more tests are needed and probably also greater detail in terms of parameters included.

Greater detail about price elasticity of the fuel raw material that can be obtained through analyses with GROTSPORRE should, in the future, be usable in conjunction with supply planning, decisions about greater use of forest fuel, etc.

MEASUREMENT OF ENERGY WOOD

Frans Larsson & Mats Nylinder, SLU

Low grade roundwood used as fuel, energy wood, is a very important constituent of today's forest fuel. For accurate evaluation of a forest fuel assortment, the material's effective energy content needs to be established, e.g. by measuring dry content. Currently, there are no reliable, simple methods of measuring this for unprocessed assortments; instead, the same measurement method is used for energy wood as for pulpwood. Studies have therefore been started to see whether simplified measurement methods can be developed.

In order to determine price, forest fuel in the form of roundwood is currently measured by calculating the solid volume by the same method as for pulpwood. Measurement is done by the Wood Measurement Society through a qualified estimate and using a guidance table. For pulpwood, we know that the estimate is relatively accurate as the guidance table is designed for this assortment. However, there are often significant differences between pulpwood and energy wood. Energy fuel contains unusual tree species, the wood is more crooked, and often has a greater diameter variation than pulpwood.

An important property for the heating plants that is currently not measured for unprocessed energy wood is the dry matter content. This is because there is no established method for measuring the dry matter content in unprocessed assortments. When the assortment is comminuted (chipped or crushed), it is relatively simple to take a sample from the fuel, which is weighed before and after drying to determine the dry matter content.

For fuel materials that have not yet been comminuted, measurement and sampling is more difficult. Energy wood is one example. It is currently the second largest forest fuel assortment, but measurement techniques must be improved. In order to investigate how this can be done, the following questions need to be addressed:

- How well can the measurement staff estimate the volume of stacked energy wood when its properties differ from those of traditional pulpwood (log taper, straightness, diameter range)?
- Can stack estimates be further developed?
- How should the bark proportion be considered when measuring energy wood?
- Can a simple method be developed for reliable sampling of dry matter content for unprocessed forest fuel assortments?



Dry matter content is measured, for example, in random samples of the chipped material.



Control measurement of an energy wood pile.

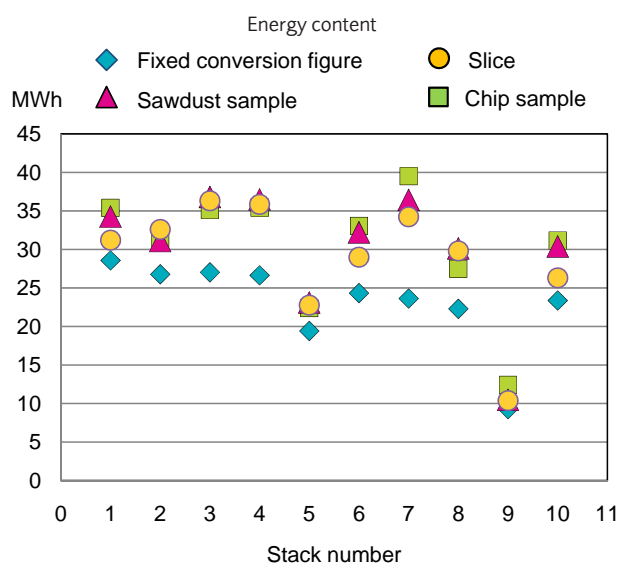
A field study involving four repetitions was carried out with the wood measurement association VMF Qbera and Fortum. The study included 20 stacks of energy wood. The volume of every stack is estimated by the timber measurement staff, and then control measured by VMF Qbera.

Dry matter content samples are then taken using three different methods:

- Sawdust from a motor saw.
- Slices cut from logs in the stack.
- Samples of chips after the stack has been chipped.

In conjunction with chipping, the stack is weighed and the chipped volume determined. The field work was completed in autumn 2010.

Preliminary results show that when the pulpwood template for solid volume assessment is used correctly, the volume is estimated accurately. The average deviation was -0.7 percentage points, with a standard deviation of 3.36. However, the diagram shows that existing conversion figures are less suitable for conversion from volume to energy units.



Results from the first ten stacks measured. In the diagram, the energy content (MWh), using a fixed conversion figure, is compared with calculations based on the tested methods for determining dry matter content. Using current Swedish fixed conversion factor (according to SDC) from m³ sub to tonnes DM for the energy wood assortment, the energy content was underestimated by 21 per cent.

Measurement of dry matter content with double energy X-ray

In evaluation of fuel chips and for incineration process management, correct measurement of the moisture content is of great importance. This is why there are calls for an efficient method to quickly determine the moisture content for both individual samples and for continual measurement, for example when feeding chips into a boiler. The Mantex company has developed a measurement method based on a variation of an X-ray examination. The method works well for measuring the moisture content of sawmill chips. Measurement of the moisture content of logging residue chips was tested in spring 2010.

Future R&D needs

The forest fuel business is developing rapidly. This will increase the need for accurate determinations of fuel volume and quality. Further, forest fuel will fall under the provisions of the Timber Measurement Act. Consequently, the following is required:

- Basic development of measurement technology for both processed and unprocessed fuel assortments.
- Implementation of new measurement procedures and reporting systems in the forest fuel area.
- Information and training initiatives to disseminate knowledge of these procedures and how they are to be used.

ASSORTMENT STANDARDS AND CONVERSION FIGURES NEEDED

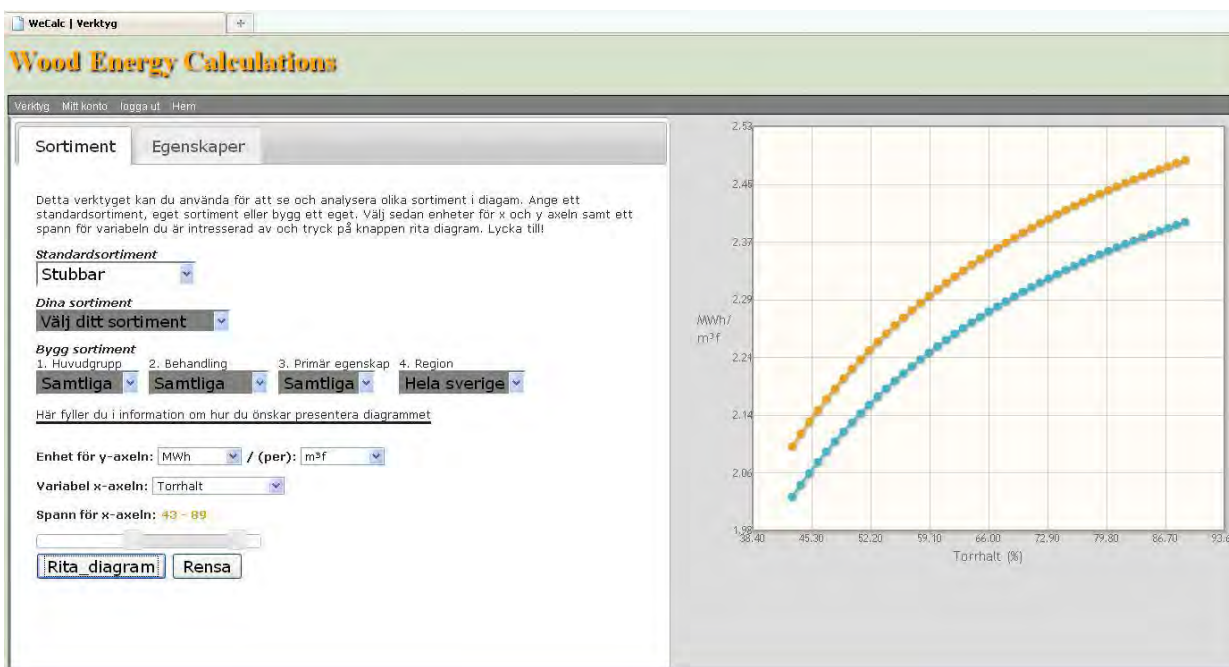
Frans Larsson, SLU

Forest fuel is measured and evaluated in different units on its journey from the forest to the fuel customer. The heating plant uses MWh, the hauliers talk in terms of tonnes, and the forest sales staff mainly use volumes, such as m³solid or m³ loose chips. The various concepts lead to misunderstandings. In order to avoid this, and to promote a smooth-running trading system, it is important to have reliable conversion rates between the units. In collaboration with relevant players, a Web tool for converting between units has been developed. The aim is to eventually establish a common standard on these matters.

A strongly growing market means that forest fuel has now become a forest assortment in a class with pulpwood and saw timber. This has also increased the need for accurate conversion rates between different units, for example between tonnes and megawatt hours. Conversion rates are needed for transactions between sellers and buyers in the supply chain, for monitoring, for planning and for technical auditing, such as stock valuation. Forest fuels have different origins and vary in form, so they have very different properties, for example in terms of ash content or density, which the players may want to emphasize. At the same time, it is very important that every player can use units that are relevant and that they feel comfortable with.

Together, this means that there is a need to critically review the classification that is used today for the different forest fuel assortments. In collaboration with sector representatives in wood measurement and auditing, as well as buyers and sellers on the market, a Web tool has been developed for conversion rates.

The conversion rates for the different forest fuel assortments are steered by a number of wood and fuel properties, relating to where the tree grew, the tree species or tree species mix, the parts of the tree that are included, when the assortment was harvested, how it has been stored, and so on. Consequently, the statistical conversion rates that are applied today do not give accurate values for every individual batch,



WeCalc allows graphical presentation and analysis of how various properties influence the conversion rates. WeCalc is available on the Internet for testing, and has quickly become appreciated and well-used. <http://biofuelcalc.sites.djangeurope.com/>

but instead reflect an average condition for each assortment. In order to cover the needs of the market, a fuel assortment must therefore be specified more precisely than that indicated by the statistical conversion rate, for example by incorporating tree species and codes for properties. The conversion rates are kept up to date by the wood measurement societies, and are used by the forestry sector's central data unit, SDC, in a wood management system that automatically applies the conversion rate to measured assortments.

The work to develop more reliable conversion rates was started with a compilation of knowledge in the field, primarily through literature studies. A new model has been developed for practical work with conversion rates for the forest fuel assortments. The model involves using nine identifiable standard assortments that, if necessary, can be modified through the properties that steer the conversion rates. This means that wood species and property codes can be specified and continuously refined by the parties themselves.

This approach also forms the basis of the WeCalc Web tool, which makes it easy to adapt the conversion rates to applicable wood and fuel properties. In addition to providing the sector with improved conversion rates, the tool can help to create understanding and consensus about how the different units relate to each other, and how they are to be calculated, which is necessary if a universal standard is to be developed. In the future, data generated through WECalc

can be used in agreements and integrated into the companies' and SDC's wood auditing systems.

In order to ensure quality and relevance, the project is run in collaboration with a biofuel committee appointed by the wood measurement societies. So far the project has resulted in an updating of the statistical conversion rates used by the wood measurement societies and SDC, and creation of conversion rates for assortments that previously had no conversion rates.

Future R&D needs

Knowledge about wood properties in the forest fuel assortments must be improved through basic research initiatives.

The Web tool allows further tools to be added, such as

- Geographical optimization support for forest fuel assortments.
- Cost calculations for refinement chains.
- Models for how handling affects the properties of forest fuel.



MULTI-TREE MEASUREMENT BY THE HARVESTER

John Arlinger, Skogforsk

Dense stands of small-dimension trees for thinning contain large quantities of raw materials suitable for fuel, but logging is expensive. Extraction can be made more efficient through multi-tree harvesting. But an impediment to this development is the lack of a reliable method for determining the volume of stems in bunches. This makes calculation of the contractor's remuneration and the size of the harvested stock uncertain. Based on actual data from harvesters adapted for multi-tree harvesting, a common method to determine the volume of multi-tree harvested assortments is now being developed.

A method for determining the volume of trees that are felled and accumulated in the harvester head for subsequent bunch processing is being developed and tested. An expected effect is greater extraction of volumes in thinning of small-dimension trees, which will mainly be used as forest fuel.

The new method, together with the updated standard, will generate data that can promote more effective planning and monitoring of stocks, and that can be used for calculating payments to machine crews and contractors.

The aims were to:

- Evaluate the methods for stem and volume calculation that the machine manufacturers have introduced on their harvesters.
- Develop a method for determining the number of felled stems, the total volume, and volume per assortment in multi-tree harvesting.
- Adapt and develop StanForD (standard for data communication with forestry machines) for multi-tree harvesting.
- Test the new method together with 2-3 member companies and some machine manufacturers.
- Assist machine and software manufacturers with implementation of the method developed.

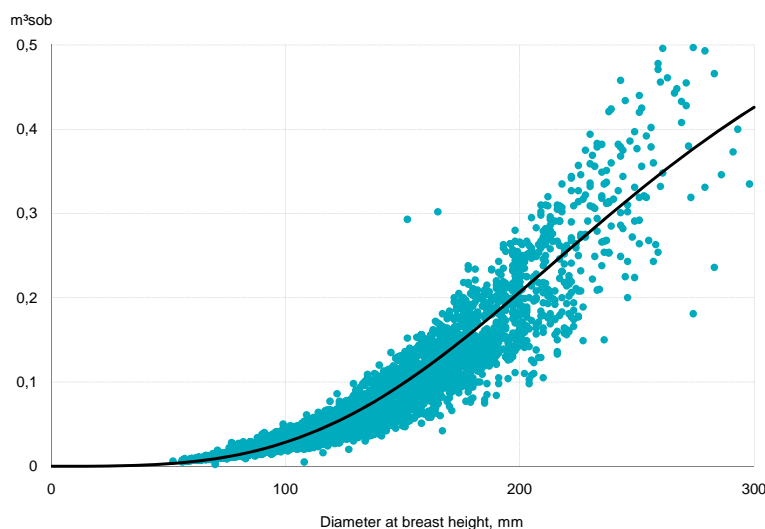
A first version of the software has been developed. This allows determination of the volumes of multi-tree harvested stems using the data that is continually recorded by the harvester. The method is based on the known relationship between the diameter at breast height and volume of individual stems (see diagram below). For all stems, both individually and multi-tree harvested, the diameter at breast height is recorded, but in multi-tree harvesting only the diameter of the first stem felled is recorded. The other stems in the bunch are given the same diameter as the first, and only the number of stems is recorded. The relationship between diameter at breast height and stem volume is used to calculate and to allocate the same volume to all the stems in the bunch.



A total of six different practical tests were carried out in order to evaluate the proposed method. In each test estimated volumes from calculation were compared with control volumes based on manual measurement using caliper. The results are promising. The calculation method seems to work well if two conditions are fulfilled:

- that the machine is well calibrated for diameter measurement
- felling is carried out in random sequence, i. e. without systematic choice of a “thick” or “thin” tree as the first tree felled.

Under such conditions, the accuracy of the proposed method is about ± 10 per cent from control volume during the tests so far. If the diameter variation was left uncorrected, the volume difference was around ± 25 per cent in the ongoing trials.



The relationship between diameter at breast height and volume of individual stems is shown by the unbroken line, which is achieved from regression analysis or from calculation of median volumes in diameter classes. The relationship is used to calculate the volume of multi-tree harvested stems. If, for example, the first of several multi-tree harvested stems has a diameter of 10 cm at breast height, this corresponds to a volume of approximately 0.025 m³ sob. This volume is then multiplied by the number of stems in the bunch.

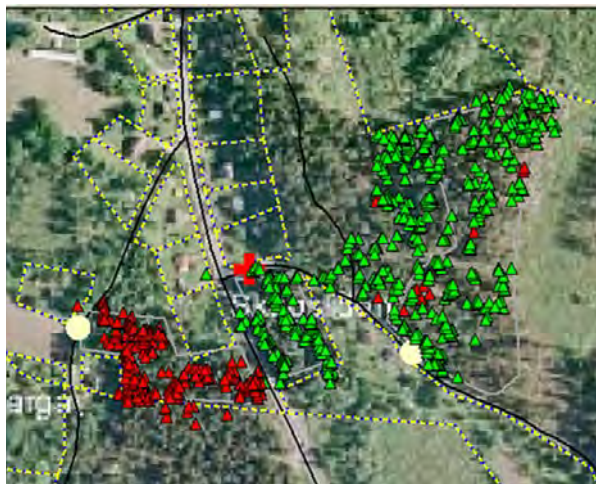
Future R&D needs

It is important to develop a calibration method which handles possible systematical differences between the first stem in a stem bunch and the rest of the stems in the bunch.

HARVESTER REPORTING OF LOGGING RESIDUES AND STUMPS

Johan Möller, Björn Hannrup, William Larsson, John Arlinger,
Andreas Barth & Lars Wilhelmsson, Skogforsk

In practice, information about the amount of forest fuel from logging sites is mainly obtained through subjective assessments and figures based on experience. Working together with forestry companies, SDC, energy companies and forest machinery manufacturers, Skogforsk has developed a system for calculating and locating on maps available quantities of forest fuel. Input data is the harvesters' measurement of individual trees. Using biomass functions, quantity of forest fuel per tree is calculated, and positioning determined via GPS. The evaluations show good correspondence between actual and calculated quantities.



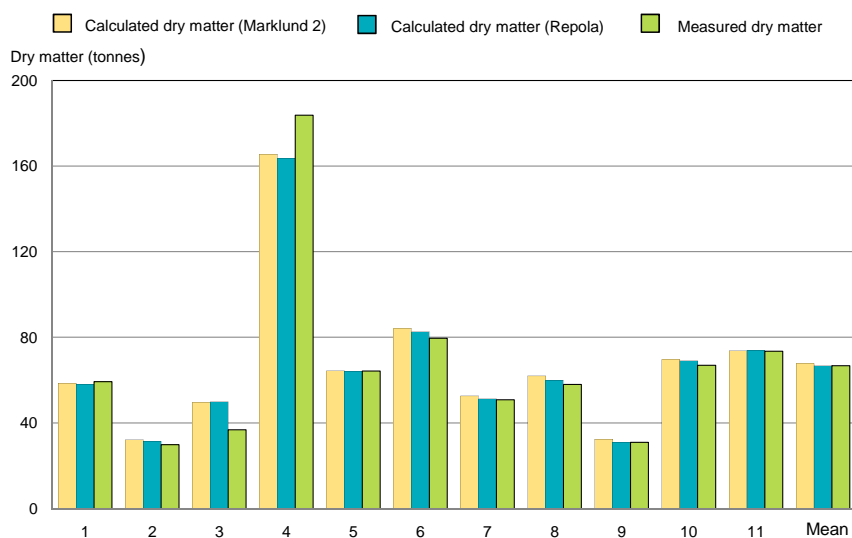
Map generated by the calculation system showing location of logging residue piled for extraction (green triangles) and logging residue that should not be collected (red triangles).

Access to detailed information about the quantity of forest fuel from logging sites is very valuable in planning of production, stocks and flows. However, standardized systems have been lacking for produced quantities of forest fuel in conjunction with logging. Such information has previously been based on subjective assessments and figures based on experience. Skogforsk has now developed a system for calculating the quantity of forest fuel, divided into branches, tops, needles and any stem wood and stumps.

Data is fed into the system from the harvesters' computers, which store information about individual trees. Using biomass functions per tree, the quantity of forest fuel is calculated. The system also contains two components for distinguishing between extractable forest fuel and that left on the logging site:

- One function enables separate accounting of logging residues that are not to be extracted as forest fuel, i.e. for environmental reasons or because the logging residues are to be used to reinforce logging roads and transport routes.
- A function for forecasting the proportion of the logging residues that the harvester operator has placed in piles that will also be forwarded for stacking.

Practical evaluations of the system show that it works well, and that it does not increase the workload of the harvester operator during logging. The evaluation also tested various existing biomass functions for calculating logging residues and stump volumes. Harvester data was collected from 38 test areas, placed on ordinary final felling sites in seven parts of Sweden, from Småland to Norrbotten. On the test areas, all logging residues were utilized and the quantity of dry matter was determined through weighing and moisture content measurement at heating plants or terminals. The theoretical quantity according to two of the most commonly-used biomass functions (Marklund's and Repola's) corresponded well with measured quantities after some slight adjustment (regional level mode).



Comparison of the calculated quantity of forest fuel according to the two most common biomass functions, and the quantity that was measured on eleven different logging sites.

At a general level, the system was evaluated by measuring, at heating plants, all logging residues from 11 logging sites and comparing the results with calculated values. The results showed very good correspondence between the measured quantity and the quantity calculated on the basis of harvester data. The mean figure for the measured quantity of dry matter on the 11 sites was 67 tonnes, while corresponding quantities according to each biomass function were 68 and 67 tonnes. The evaluation shows that the system could be applied in practical operation without risk of any major systematic bias. In a subsequent project, the system is being implemented at SDC and the forestry companies SCA Skog AB and Stora Enso Skog. The calculation tool is also a basis for developing GROTSPORE, a tactical route optimization tool for forest fuel forwarding (see separate article).

Future R&D needs


- The system for reporting and handling of the harvesters' production files (pri / hpr) to the forestry companies and SDC must be improved. This work is going on.
- The function for registration by tree through harvesters' computers, whether or not logging is adapted to logging residues, must be implemented on more harvesters. From 2010, software versions from the market's leading manufacturers of harvester computers are able to do this.
- The software in forwarders' computers will be adapted so that it shows the position of the logging residue piles on a map. Such software has already been tested in the project with good results.
- If the stump harvest increases in scale, the stump functions should also be validated in large, practical tests.

A photograph of a pile of snow and sticks. The snow is white and piled up, with several sticks and branches protruding from it. The sticks are brown and dry. The background is a clear blue sky. The text "DEFINITIONS AND ABBREVIATIONS" is overlaid in the center of the image in a bold, black, sans-serif font.

DEFINITIONS AND ABBREVIATIONS

Forest energy operations are a recent, rapidly growing activity in forestry. Many new types of machines and operations are introduced and tested and many of the terms may be new. To simplify reading of this publication, a list of terms and abbreviations used in the report are explained below.

chips	forest fuel cut into particles. (Also comminuted material in general)
chipper	comminution machine with cutting function
chipper truck	a mobile chipper mounted on a truck for bulk cargo transport
chip truck	a truck for bulk cargo transport (e.g. chips, hog fuel)
container chipper truck	an chipper truck with a container handling system
container truck	a truck for bulk cargo transport with container and switch-body system
dbh	diameter at breast height (1,3 m above ground)
DM	dry matter
GHG	greenhouse gas (often carbon dioxide)
grinder	comminution machine with grinding or crushing function
hog fuel	forest fuel ground or crushed into particles with a blunt tool
logging residue	branches, tops and small trees from logging operations
m ³ s	cubic meter, solid (physical) volume of all biomass
m ³ s ub	cubic meter under bark, volume of stemwood excluding bark
m ³ s ob	cubic meter over bark, volume of stemwood including bark
m ³ loose	cubic meter bulk measure, i. e. including air between particles
MWh	see TWh
residue forwarder	forwarder, e.g. with grapple and load space adapted for residue transport
residue truck	bulk transport truck with closed load space to avoid spilling material
roundwood	tree, delimbed and cut to length
tree section	tree, cut to length, undelimbed or roughly delimbed
truck-mounted chipper	a mobile chipper mounted on a truck
TU	degree of technical utilization, as percentage of utilized time
TWh	Tera (10 ¹²)Watt hours, cf. kWh (10 ³), MWh, (10 ⁶) and GWh (10 ⁹)



Project reports from the research
programme "Efficient forest fuel
Supply Systems" are available in
Swedish at:

skogforsk.se/ess-rapport

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