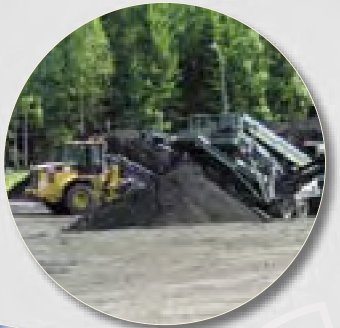
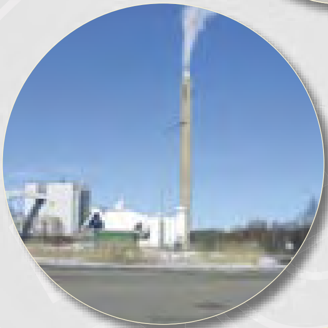
International Handbook

From Extraction of Forest Fuels to Ash Recycling

Produced within RecAsh - a LIFE-enviroment demonstration project- with contribution from the LIFE financial instrument of the European Community.





RecAsh

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Introduction

Extraction of forest harvest residues (small trees, branches and tops) has increased in a number of countries in recent decades. With such whole-tree harvesting, the export of nutrients and acid-buffering substances from the growing site is increased, potentially affecting tree growth and the chemistry of runoff water. There is consequently a long-term need for compensatory fertilisation at many sites in order to maintain the chemical quality of the water in forest streams and lakes. Compensation is particulary important on sites with weak mineralogy, e.g. on organic soils, at severly acidified sites or sites exposed to high nitrogen deposition. Wood ash contains acid-buffering substances as well as most nutrients and is suitable for such compensation.

Since 1998, the Swedish Forest Agency has recommended ash recycling after extraction of harvest residues. Today most wood fuel ash is disposed in landfills. The authorities responsible for managing landfill sites have expressed great interest in decreasing the amount of pure wood fuel ash dumped in landfills. The main obstacles to regular ash recycling have been identified as lack of knowledge and lack of educational handbooks. This handbook was produced within the EU-LIFE project RecAsh [Regular Recycling of Wood Ash to Prevent Waste Production] in order to fill this gap. It describes forest fuel extraction and ash recycling in broad terms and cites examples and experiences from Sweden and Finland. In Sweden the "Recommendations for the extraction of forest fuel and compensation fertilising" will be revised during the autumn of 2006. This handbook refers to the situation before this revision. The examples and recommendations made in this book will lightly need to be modified in countries or areas with different conditions. Nevertheless they can serve as good examples and I hope this handbook will be used to initiate ash recycling activities in new parts of Europe. Regionally adapted use of forest fuels and ash recycling practices can contribute to solving environmental problems concerning energy, climate, water and waste.

Stig Emilsson, Swedish Forest Agency

Reasons for Wood Ash Recycling

The forest ecosystem needs the ash

All extraction of biomass from the forest removes nutrients and acid-buffering capacity from forest soil. Concentrations of such substances are considerably higher in crown foliage and branches than in stemwood. When forest fuel is extracted in the form of harvest residues (small trees, branches and tops), nutrient export increases typically by a factor of 1.5 to 4 over the rotation period. Therefore, extraction of harvest residues may contribute to soil acidification and to reducing nutrient availability.

A degree of acid precipitation is still occurring in parts of Europe and is exacerbating the leaching of certain nutrients, depleting the acid-buffering capacity of the soil and acidifying bodies of water in forests. When a mineral soil becomes more acidic, the leaching of toxic aluminium increase, slowly at first and then more rapidly once the pH in mineral soil drops below 4.4. When the buffering capacity is depleted all the way down to the groundwater level or to the bedrock (whichever is most superficial), such leaching may result in acidification of streams and lakes. Acidification of running streams and lakes leads to poorer water quality and the elimination of sensitive aquatic organisms, including both common and more unusual species (Figure 1). The pH of large lakes can be restored by liming. However, it is very difficult and costly to lime small streams in the forest landscape since the residence time of water in these is short, rapidly declining the desired effects.

Figure 1. Freshwater Pearl Mussel is a threatened species that is sensitive to water acidification

During combustion of pure forest fuel, nutrients and acid-buffering substances are concentrated in the ash. This makes the ash suitable as a compensatory fertiliser to replace the lost nutrients and acid-buffering capacity in forest soil. Only nitrogen is missing, as it is eliminated with flue gases.

Figure 2. Dumping of waste in landfills ought to be reduced. Most forest fuel ash is currently being landfilled.

Climate change must be mitigated

There is growing recognition of the fact that global emissions of greenhouse gases must soon be reduced if we are to avoid climate change with severe consequences for life on earth.
In order to implement the terms of the Kyoto Agreement, the EU has made a commitment to reduce greenhouse gas emissions by 8 % from 1990 levels by 2010. Partly to support the ambition to reduce the use of fossil fuels, the EU has also decided to increase the proportion of renewable energy sources with low net emissions of greenhouse gases in its energy mix. Therefore, the Sixth Environment Action Programme includes the objective of increasing use of energy from renewable sources from 6 % to 12 % of the total energy consumption by 2010. Through ash recycling, more biofuel can be extracted in a long-term sustainable way.

Dumping of waste in landfills ought to be reduced

Ash recycling returns elements to their place of origin and thereby replaces 'linear' element fluxes with 'cyclical' fluxes. Many current environmental problems can be attributed to the translocation of elements by humans from one place to another, causing imbalances and unnatural concentrations, too high in some places and maybe to low in others. The ecological effects of ash recycling on flora, fauna, production capacity as well as water and soil chemistry have been the subject of scientific studies in recent decades. These studies show that pure, non-contaminated and stabilised forest fuel ash can be used to compensate for loss of acid-buffering capacity and nutrients with no negative impact on the environment, provided the ash is applied with site-adapted consideration. Thus, dumping forest fuel ash of high quality in landfills (Figure 2) conflicts with the public effort to reduce the supply of waste to landfills through increased recycling and reuse.

Ash recycling increases forest production

The good fertiliser effect of wood ash on growth of pine on nitrogen-rich peatlands was first demonstrated in studies performed by the Finnish Forest Research Institute in the 1930 : s. Some areas of drained peatland suffer from nutrient imbalance, causing growth disturbance and death of trees. Pure wood ash is a suitable fertiliser for pine stands on eutrophic, nitrogen-rich peatlands in order to prevent phosphorus and potassium deficiency. The fertiliser effect of ash lasts longer than that of artificial fertilisers, at least 30 years. Tree growth has been shown to increase by 2 - 4 m^3 annually on nitrogen-rich peatlands after application of 4 tonnes of ash, dry matter (DM), per hectare.

Moreover, on medium to highly productive mineral soils in southern Sweden, positive effects of ash addition on growth have been demonstrated in several studies. This effect can likely be attributed to the relatively high deposition of nitrogen in this region, likely increasing the availability of nitrogen relative to that of other macronutrients. In regions where surplus nitrogen causes environmental damage, increased nitrogen export through whole-tree harvesting combined with ash recycling may contribute towards reducing this problem

Figure 3. Ash recycling produces an ecocycle.

In those cases where whole-tree harvesting leads to a reduction in tree growth on mineral soils in boreal regions, a reduced supply of available nitrogen is often likely the cause. At sites where tree growth is strongly nitrogen-limited, ash recycling will not improve reduced growth and may even hamper growth somewhat further. On such soils, additional compensation with a nitrogen fertiliser may be considered.

Forest fuel extraction

Figure 4. Loading of harvest residue in forest fuel extraction.

General

Owners of forest land in Sweden are required to notify the authorities in advance when regeneration felling or extraction of forest fuel are planned on their land. As with all other forestry operations, forest fuel extraction must be carried out in a manner that takes natural values and cultural heritage into consideration. Biotopes where conventional logging is prohibited should also be excluded from forest fuel extraction; these include forest wasteland, key habitats, areas of special consideration, wetland forests, buffer zones, etc. A certain proportion of the logging residues should always be left, along with standing dead trees and old fallen trees, in order to promote biodiversity. It is also important that the time and technique of the extraction are chosen wisely in order to minimise the risk of damage to the soil. Particular care should be observed when extracting forest fuel from damp and wet land particularly vulnerable to damage.

In connection with extraction of forest fuel, the risk that insect pests may propagate in forest fuel stacks must be considered. The risk of forest fires must also be considered in warm, dry climates, as large quantities of harvest residues left on the land can constitute a serious fire hazard.

Forest fuel can be extracted in connection with clearing, thinning or final felling. When biomass is taken out of the forest, nutrients and acid-buffering capacity are also exported. When the extraction is extensive or takes place on multiple occasions per forest generation, the need to compensate for the extraction by returning forest fuel ash increases.

The need for compensation is also high on acidified land and peatland, as well as when forest fuel is taken out green. The latter because concentrations of nutrients and acid-buffering elements are highest in crown foliage. Accordingly, there is a question of whether forest fuel should be taken out before or after the needles have fallen off.

As a long time may elapse between extraction and compensation, there is an advantage to keep track of large extractions so that the magnitude of compensation can be accurately computed. For that reason, forest fuel extraction ought to be documented. The documentation should contain information about the extraction, such as tree species, quantities, date of extraction and whether crown foliage was taken out or left behind.

National laws and recommendations related to the following should be consulted:

- Felling and forest fuel extraction
- Consideration of natural values and cultural heritage
- Consideration of soil and water issues
- Risks related to insect pests
- Risk of forest fires
- Documentation of forest fuel extractions

Extraction in connection with final felling

Extraction of forest fuel in conjunction with final felling not only supplies renewable energy, but also provides higher revenues for forest owners, because regeneration is promoted through removal of harvest residues from the final felled area. Branches and tops equal 20-30% of the biomass above the stumps.

Felling adapted for forest fuel extraction is performed with conventional machinery but according to a special method. When felling, the harvester operator works so that forest fuel, i.e. branches and tops, is gathered into stacks. The trees are felled and tilted over forwards and the fuel stacks, which are laid alongside the driving passage, are made 100-150 cm high. After felling, the stacks are often left on the clearing to shed their crown foliage. The reason for this is that crown foliage contains high concentrations of nutrients that should be left to benefit forest soil. The crown foliage should preferably be spread evenly over the final felled area, but this is difficult to carry out in practice. The stacks are hauled out with a forwarder to a roadside landing, often in the summer after felling. The tractor should be equipped with an open gripper

Figure 5. Consideration of natural and cultural heritage values are importat in connection with extraction of forest fuels.

to avoid bringing up rocks and soil with the load. In order to take large loads, it should also have some kind of extended trailer and loading should be done laterally and back to front. The machinery does not have to be otherwise modified for forest fuel extraction. The fuel should be deposited in stacks at an open, dry place where they can continue to dry. Stacks can also be covered with paper, anchored by a few bundles of harvest residues. Chipping is carried out at the stacks and forest fuel chips are transported onwards mainly with trucks with demountable body systems and containers.

There are a number of different forest fuel extraction systems, which have partially divergent sequences and/or techniques.

- The forest fuel can be transported directly to a heating plant or terminal from the temporary depot in the forest and be chipped or crushed there. One problem with this system is that it is difficult to pack the load sufficiently compactly to make transport financially viable. Technical refinements aimed at solving this problem are being developed.
- Chipping can be carried out in the felled area with a mobile chipper, which then dumps the forest fuel chips in containers parked at a forest roadside or to a shuttle transporter.
- The forest fuel is sometimes hauled out of the felled area to a forest road immediately after felling, while crown foliage is still attached. This method may be preferable on severely acidified soil with high nitrogen deposition, as crown foliage extraction reduces the nitrogen load. Here as well, chipping can be done at the roadside or after transport to a heating plant or terminal. When green forest fuel that has not shed its crown foliage is extracted, the need for ash recycling to compensate for the extraction increases.
- There are also techniques for bundling fresh forest fuel with the crown foliage still attached into log-like bundles that can essentially be handled like round timber. The main advantage of this technique is that standard timber trucks can be used and further transport of timber and forest fuel can be coordinated. The method requires appropriately dimensioned crushers at the heating plant or terminal.

Forest fuel extraction is also possible after motor-manual felling, but collection is then more time-consuming.

Extraction in connection with cleaning and thinning

Integrating forest fuel extraction with a forestry operation such as thinning or clearing is a relatively new practice. Clearing entails a net expenditure for the forest owner and as a result is sometimes neglected, leading to large areas of young forest with high stem numbers that must be dealt with. These stands are ideal for extraction of forest fuel. For cost reasons, extraction is carried out mainly in conjunction with mechanical thinning or clearing. As the extraction volume is less than in connection with final felling, the financial pressure is also greater. An accumulating multi-tree handling harvester is often used, which cuts stems, accumulates them and puts them in bundles alongside the skid road for hauling to a landing. This technique enhances performance considerably compared

Figure 6. Forest fuel from thinning.

to single-tree handling by making hauling easier. The forest fuel can either be chipped at the stack or transported directly to a terminal or boiler plant for processing. Here, as with extraction in conjunction with final felling, there are a number of variants or combinations for the extraction.

- Conventional thinning harvesters are used for thicker stands. The method is similar to that used for mechanical final felling.
- Chipping can be carried out in the stand, preferably along skid roads, after which the chips are dumped in containers.
- One interesting variant is ‘long tops’, a method of thinning in which the harvester cuts the tops at a thicker diameter than normal and the forest fuel is extracted as long, untrimmed tops. This yields more forest fuel at the expense of pulpwood.
- Forest fuel can also be extracted in connection with restoration of meadowlands and pastures, visibility clearing, etc., using technical systems similar to those used for extraction in conjunction with thinning and clearing.

Figure 7. Heden, a district heating plant in Karlstad, Sweden, which uses pure forest fuel.

Production of spreadable ash

General

Ash is a solid, particulate, inorganic residual product of combustion. The ash content of fuels varies widely. In general, ash is composed of 10 - 30 % calcium. Concentrations of potassium and magnesium usually amount to a couple of percent, while the phosphorus content constitutes about 1 % of the total content. Most of these elements are acid-buffering and occur as soluble salts and as more sparingly soluble compounds in the form of oxides, carbonates and silictes.

Ash produced by burning wood generally has a pH between 9 and 13. Calculations show that completely burnt ash may have acid-buffering capacity equal to 50 - 70 % of that of pure limestone.

There is almost no nitrogen in ash because most of it disappears in gaseous form during combustion. However, as trees absorb heavy metals and radioactive substances from both soil and air, those substances are also found in the ash.

The acid-buffering capacity and nutrient content of ash make it suitable as compensation for losses of such elements in forest soil. All extraction of biomass causes these losses, but the losses are proportionately greater when harvest residues is extracted than when only stemwood is extracted. The ash can also be used alone or combined with lime to counteract acidification caused by acid rain. A third application is to increase forest production on drained peatland where phosphorus and potassium rather than nitrogen limit tree growth.

Recycling ash to forest land in Sweden has been regarded mainly as an environmental measure with the main purpose to compensate for the removal of nutrients and acid-buffering capacity and to counteract historical acidification. The dominant purpose in Finland, on the other hand, has been application to increase tree productivity on peatlands.

Ash is often dumped in landfills, even though society is striving to reducing waste deposits to landfills by means of increased recycling and reuse. The EU Landfill Directive (1999/31/EC) has resulted in stricter regulation of landfills. Many of these cannot meet the demands and are consequently being shut down. The cost of running landfills has also increased because of the new regulations. This has made it economically feasible to return forest fuel ash to the forest and in so doing complete the cycle of nutrients and acid-buffering capacity. For this measure to be environmentally sound, the application of ash must not cause the accumulation of any harmful substances in the soil. The recycling of ash should balance the extraction of forest fuel and stemwood. In addition, the application of ash must not cause any harm to ground vegetation or organisms.

Most countries in Europe lack regulations or recommendations concerning this activity. The following sections describe the practical aspects of ash handling and provide examples from Sweden and Finland. However, individual actors have a duty to be cognisant of the national general laws that apply to handling ash.

According to European legislation, ash is regarded as a waste product. Permits or notification are often required for the handling, processing, intermediate storage and disposal of ash. In matters involving storage of ash, regulatory agencies put great emphasis on problems involving leaching to water. The storage site should be dry, at a relatively high elevation in the terrain and at a safe distance from bodies of water.

National laws and recommendations pertaining to the following should be consulted:

- Landfilling and storage of ash
- Processing of ash
- Transport of ash
- Content limits and other standards for spreadable ash
- Nutrient content
- Metals and toxins

Basic requirements for the ash

Ash suitable for processing to an spreadable product should generally meet three requirements:

- The ash should contain all macronutrients (except nitrogen, which is eliminated with flue

Table 1. Minimum content of nutrients in wood fuel ash. From Recommendations for Extraction of Forest Fuel and Compensatory Fertilisation (Swedish Forest Agency, 2002)

Nutrient	Symbol	Minimum content in ash (gram/kg DM)
Calcium	Ca	125
Magnesium	Mg	20
Potassium	K	30
Phosphorus	P	10
Zinc	Zn	1

Table 2.. Maximum content of potentially harmful elements in wood fuel ash. From Recommendations for Extraction of Forest Fuel and Compensatory Fertilisation (Swedish Forest Agency, 2002)

Element	Symbol	Maximum content in ash (mg/kg TS)	Element	Symbol	Maximum content in ash (mg/kg TS)
Boron	B	500	Crom	Cr	100
Copper	Cu	400	Mercury	Hg	3
Zinc	Zn	7 000	Nickel	Ni	70
Arsenic	As	30	Vanadium	V	70
Lead	Pb	300	Polyaromatic hydrocarbons	PAH	2
Cadmium	Cd	30	Radioactivity	Cs-137	10 kBq/kg

gases) in adequate quantities. In Sweden, the ash should contain the minimum concentrations shown in Table 1.

- The ash should contain sufficiently low concentrations of heavy metals or other harmful substances in order to avoid net accumulation of these substances in soil after application. The concentration limits presented in Table 2 apply in Sweden. They were developed according to the principle that application of ash should not exceed the element concentrations exported in connection with the extraction of forest fuel and stemwood. The uptake of heavy metals in trees varies with both tree species and bedrock type. As a result, the values in Table 2 should be applied conservatively - they may serve as examples, but national conditions should determine suitable concentrations.
- The ash must not cause direct harm when it is spread. For the ash to be suitable for application, it must be possible to process so that reactivity declines and solubility can be adapted to the application site. The content of uncombus-

ted carbon is the main source of problems. If the content of uncombusted carbon is too high the ash does not harden, and consequently, the ash product may be too reactive to be distributed. This because it may cause burn injuries to vegetation, especially mosses. It may also lead to higher leaching of nutrients and harmful, rapid elevations of pH in small bodies of water. However, the connection between uncombusted carbon content and reactivity is not fully known, and more research is needed in order to determine the extent of this problem.

These requirements are needed because ash is not a uniform residual product. Its composition varies depending on fuel, combustion technique, boiler type and flue gas cleaning equipment. Ash is classified into various types or groups based on fuel, boiler type, or where in the combustion process it is extracted. The properties of ash types and their suitability as compensation fertiliser vary.

Types of ash

Classification based on fuel

An initial division may be made between ash from renewable and non-renewable fuels. Non-renewable fuels consist of fossilised organic materials such as coal, oil and natural gas. Ash from non-renewable fuels is considered hazardous waste and may not be applied to forest soil. Peat is an intermediate class but is not considered a biofuel from the climate perspective because it is renewed very slowly.

The renewables are various types of biofuels, which yield biofuel ash when combusted. Biofuels can be further categorised into e.g. reeds, straw, recycled paper, wood fuel and organic household waste. Ash from household waste incineration contains high concentrations of metals, is classified as hazardous waste, and is disposed of in landfills.

Wood fuel is the most interesting category for ash recycling for reasons of quantity, quality and ecology. Wood fuel is divided into forest fuel, short-rotation forest fuel and recovered wood fuel. Forest fuel may consist of harvest residues, timber that has no industrial use, such as biomass from neglected young forest, or industrial byproducts and waste, such as bark and sawdust. Forest fuel ash is usually suitable for further processing into a spreadable ash product.

Ash from short-rotation forest for energy use

Figure 8. Different types of forest fuels stacked outside Sannaverket, a District Heating Plant (DHP) in Kristinehamn, Sweden.

Figure 9. A stoker-fired boiler during cleaning. The grates in the base of the boiler transport the fuel during combustion.

can in certain cases be unsuitable for spreading because of its high content of cadmium, a toxic heavy metal. Several Salix clones (various forms of willow or osier) used in short-rotation forestry have the capacity to accumulate cadmium in the wood.

Ash from recovered wood fuel can also be problematic because the fuel often contains impregnated or treated timber, which may produce ash with unacceptably high concentrations of e.g. arsenic, chromium or lead. In addition to high concentrations of individual substances, ash from recovered wood may contain solid impurities such as nails, screws and glass, which constitute a hazard in connection with application. Recovered wood fuels were combusted in many large district heating plants (DHP) in both Sweden and Finland until the end of 2005. The EU Directive on waste combustion (2000/76/EU) came into force at the beginning of 2006 and in future the combustion of recovered wood fuels will probably be concentrated to only a few heating plants.

Unfortunately, several types of fuel are often mixed during combustion, resulting in various forms of mixed ash. Some clean forest fuel boilers are fired with oil during start-up, but fuel oil produces very small quantities of ash, so the percentage of oil ash in the mix is negligible in this case. A higher percentage of oil in the mix cause elevated concentrations of nickel and vanadium in the ash.

Wood ash is produced in most power plants of the pulp and paper industry, where wood, bark and wood-based sludge are used as fuel. Forest fuel mixed with a certain amount of peat is another common combination in both DHP plants and municipal plants. This combination is thought to produce less coating in the boiler. The nutrient content of peat ash is lower than that of forest fuel ash, while the concentrations of some heavy metals are usually higher.

In smaller district heating plants in Finland, peat and wood are often used seasonally, peat in winter and wood during the rest of the year. Separation of peat and wood ash is therefore easier in these smaller plants. In larger plants, peat and wood are combusted together. During the warmer seasons, the proportion of wood fuel increases and the proportion of wood ash is high. In winter, the proportion of peat fuel and thus also of peat ash is greater. In addition, the ash content of peat is higher (on average 5%) than that of wood (on average 2%), which increases the proportion of peat ash in the ash mix.

In summary, it can be said that ash intended to be applied to forest land should mainly come from forest fuel, as the fundamental idea behind the application is to complete the ecocycle and make forestry and energy production sustainable over the long term. From that perspective, pure ash produced by combustion of forest fuel alone is the most appropriate to use. Forest fuel ash is also preferable with regard to concentrations of heavy metals and toxic substances. However, ash of good quality originating from combustion of a mix of wood and peat should be able to use on peatland.

Classification based on boiler type

The boilers in Swedish and Finnish heating plants are based on various technologies, but are basically either combustion or gasification systems.

During combustion, the air supply is so great that complete combustion takes place in the boiler. The simplest combustion boiler, which is most similar to an ordinary household wood-fired boiler, is the stoker-fired boiler, in which the fuel is burnt on a grate (Figure 9). The simplest type of grate is flat, permanently attached and found mainly in small boiler systems. There are also slanted or stepped grates where the fuel is burnt as it slides down the gradient. The wander grate variant consists of a chain conveyer that feeds the fuel into the boiler. The combustion temperature in a stoker-fired boiler is 1 000 - 1 150 °C.

Powder furnaces are used in some systems. A powder-fired boiler is similar to an oil-fired boiler with a furnace. Instead of oil, a fine powder consisting of wood, peat or coal is injected. The combustion temperature is about 1200 ºC.

The circulating fluidised bed (CFB) is another boiler type commonly found in large plants. In a CFB, fuel and bed material (most commonly sand) circulate during combustion and the bed and fuel mix behaves like a fluid.

The bubbling fluidised bed (BFB) is of similar construction. In a BFB, the bed material does not circulate, but only ‘hovers’ above the boiler base. Fluid bed boilers are particularly well-suited for combustion of moist fuels such as forest fuel. The combustion temperature is 850 - 900 °C.

In gasification systems, the fuel is heated under oxygen-free conditions, producing a gas which later is combusted. The technology is interesting and highly efficient, especially in connection with biofuel-based power production. However it is still in the trial phase. The ash quality depends on how the technology is developed. The main problems so far have been insufficient concentrations of potassium, phosphorus and certain trace elements as well as excessive concentrations of PAH (polyaromatic hydrocarbons, environmental pollutants that are difficult to degrade).

Fly ash and bottom ash

All boiler types are equipped with some form of flue gas cleaning. Ash taken out of the boiler itself is called bottom ash, whereas ash taken out of the flue gas cleaning section is called fly ash. The flue gas cleaning section can consist of a cyclone separator, an electrical filter and a fabric barrier filter. The various stages or methods of flue gas cleaning also produce fractions with

Figure 10. Wet outfeed ash at Sannaverket in Kristinehamn, Sweden.

different granule sizes. The cyclone separator captures the coarsest and the fabric barrier filters the finest particles in fly ash. The relative proportions of bottom and fly ash produced vary widely between different types of boilers. Fly ash is generally finer than bottom ash. The concentrations of volatile metals such as mercury and cadmium are often lower in bottom ash than in fly ash and higher in fine-grained fractions than in coarse-grained fractions. If contaminated fractions are eliminated, the opportunity exists to use the remaining ash.

The quality of fly and bottom ash varies between different boiler types. Bottom ash from CFB or BFB boilers should not be applied to forest soil as it consists mainly of bed material, whereas the fly ash from these boilers has suitable characteristics as it is completely combusted and uniform. Contamination of fly ash with bed material lowers the nutrient content, increases the costs of handling and application as well as entails a risk of mechanical injury to tree stems. With stoker-fired boilers, on the other hand, the bottom ash is more suitable as it is more thoroughly combusted and has lower concentrations of metals than the fly ash. Bottom and fly ash are often mixed in smaller combustion plants.

Dry and wet outfeed ash

The method of ash removal from the boiler also affects its suitability for future use. The ash can either be taken out directly (dry outfeed) or be dampened with water when it is taken out (wet outfeed, Figure 10). Dry outfeed ash is easy to process but is dusty and can cause work environment problems including injuries to e.g. the skin and eyes. Dry outfeed ash with a high carbon content is also highly flammable if taken out or stored inappropriately. Wet outfeed ash is easier and less unpleasant to handle, but if hardening starts spontaneously it is difficult to produce a uniform product.

Amount of ashes in Finland and Sweden

In Finland, power and heating plants produce over 600 000 tonnes of peat and wood ash annually. Of this, wood ash represents about 150 000 tonnes per year (25 %). In 2003, the amount of wood ash from the pulp and paper industry was almost 110 000 tonnes, of which over half was utilised. Other plants with fluidised bed boilers produce about 310 000 tonnes of peat and wood ash as fly ash, and over 70 000 tonnes as bottom ash. Thirty percent of fly ash and 70 % of bottom ash are generally utilised in some way. In 2004, about

27 000 tonnes were used for forest fertilisation in Finland.

In Sweden, 800 000 tonnes of ash are produced annually. Of this, 300 000 tonnes consist of pure wood ash that is capable of being recycled. This originates as one third each from the power and heating plants, pulp and paper industry and sawmill industry. Approximately 15 000 tonnes are recycled annually to forest land in Sweden.

Pre-processing measures

Sampling

Analysis is required to determine whether the ash is suitable to use as a raw material for the production of a spreadable product. Analysis of the finished product could also be necessary (se page 27). For these analyses to be accurate, sampling must be performed correctly. It is believed that the majority of the uncertainty associated with analysis is due to sampling error. The ash may be heterogeneous and originate from different occasions during the firing season with different fuel mixes. A standard method should be used for sampling, to minimise the risk of incorrect analytical results. A European standard for sampling [CEN/TS 14778-1 Solid Biofuels Sampling Part 1. Methods for Sampling] has been compiled but is not yet published. As the title indicates, the standard is actually adapted to fuels but should serve equally well for ash. It describes both manual and mechanical methods for sampling of solid biofuels from stationary or moving material. The apparatus for sampling is specified and the size and number of the increments needed to provide a representative sample are defined.

In general, samples should be taken from lots of 250 - 500 tonnes of ash, or at least once per firing season. Sampling may be less frequent at large combustion plants that use pure forest fuel, but should be carried out more frequently at plants whose choices of fuel and operating conditions are more varied.

Each plant should establish a sampling procedure which should function as instructions for the person taking the samples. The procedure should specify the time and place of sampling, the material to be sampled, the reasons for sampling and the standard to be applied.

A number of partial samples are usually taken and then carefully mixed to form a pooled sample. If samples are to be taken from vehicles, piles or containers, it should be noted that the sample may vary with the distance from the surface layer and samples should be taken at varying depths. The pooled sample should be stored in a dry, clean and corrosion-proof receptacle. The sample must not be changed in any respect while it is in storage or before the analysis. The sampling must be documented and a reference sample should be kept for three years along with the results of the analysis.

Ash analysis

Many of the analyses performed both before and after processing are complex and require costly laboratory equipment and apparatus. To ensure optimum analytical results, the service should be contracted out to an accredited laboratory. Accreditation is proof of expertise according to European and international standards. It is based on a review of documentation describing the laboratory’s quality management system e.g.

Figure 11. Many of the analyses are complex. To ensure reliable results, the service should be contracted out to an accredited laboratory.

organisation, procedures, methods and employee expertise. The accreditation process also includes examination of how operations are run in practice. It is important for the client to document the analyses and to specify requirements for documentation when analytical services are purchased. The analysis report must always specify the method, date, measurement uncertainty and name of the person who performed the analysis.

Content of uncombusted material

A high content of uncombusted material usually leads to difficulty in hardening the ash. The uncombusted content should preferably be below 2-3% and should not exceed 10%. The content may be roughly interpreted as the total carbon content of the ash and provides a measurement of combustion efficiency. There is no European standard that is fully equivalent to that used in Sweden, but SIS-CEN/TS 14 775 Solid Biofuels. Method for the Determination of Ash Content comes closest. If the charcoal content is high, the ash can possibly be combusted again. If combustion regularly produces high-charcoal ash, the entire combustion process should be reviewed. Optimisation of combustion should result in both financial and environmental gains.

Total concentrations

An analysis of total concentrations of macronutrients and trace elements should be performed before processing to determine whether the ash is suitable as a raw material for production of a spreadable product. It may also be performed after processing to guarantee that the ash product is of the correct quality and element content.
If only one analysis is performed, it is most cost-effective to do it before processing. The ash producer needs the analysis to obtain an accurate picture of the combustion plant and for the annual environmental statement. Ash processing does not normally add any foreign elements, so raw ash that has been tested and approved with regard to concentrations should yield an acceptable final product. In Sweden, two American standards are recommended:

- ASTM D 3682 Standard Test Method for Major and Minor Elements in Combustion Residues from Coal Utilisation Processes
- ASTM D 3683 Standard Test Method for Trace Elements in Coal and Coke Ash by Atomic Absorption

Polyaromatic hydrocarbons (PAH)

Polyaromatic hydrocarbons are a group consisting of large organic molecules of varied toxicity. They are fat-soluble, can accumulate in food chains and are considered carcinogenic. Analysis of the 16 most toxic PAH (EPA 16) is usually performed. Concentrations of PAH are normally low in combustion ash from pure forest fuel but are often higher in gasification ash. However, if stabilisation and land application of gasification ash is planned, the ash should be analysed for PAH before processing. High concentrations of PAH in gasification ash can be reduced through recombustion.

Radioactive caesium

Forest fuel ash contains radioactive substances from both human activity and natural sources. The majority of the former consist of caesium-137, from nuclear weapons testing and the Chernobyl accident of 1986, which contaminated forested areas in northern Europe. Radioactive caesium-137 was absorbed by the trees to a certain extent and when contaminated forest raw products is combusted as fuel, the radioactive caesium in the ash is enriched. Other radioactive substances are not absorbed to any great extent by trees and the total radioactivity of forest fuel ash is usually low. It is thus important to check the radioactivity of the ash if the forest fuel comes from a contaminated area. Radioactivity measurement is carried out according to ISO 11 932 Activity Measurements of Solid Materials Considered for Recycling, Reuse or Disposal as Non-radioactive Waste. Ash must have a radioactivity content below 10 kBq Cs/kg to be applied to forest land in Sweden.

Ash processing

Risks associated with unprocessed ash

Only ash of good quality can be spread in forests. Unprocessed forest fuel ash is dominated by oxides, has high pH and is very reactive. If ash is to be applied to forest land with long-term fertilisation effects and without causing damage to vegetation and soil fauna, it must be processed before spreading. The aim of processing is to stabilise the ash and make it as homogeneous as possible and to minimise the proportion of fine fractions. Alkaline shock effects on ground vegetation can thus be prevented. Ash products of homogeneous quality are also more easily spread in forests.

Stabilisation takes place both chemically through hardening and physically through agglomeration. Chemical hardening is based on oxides present in the ash first being converted to hydroxides through the addition of water and eventually to carbonates through reaction with atmospheric carbon dioxide. Carbonates are relatively sparingly soluble, which reduces the rate of leaching and acid neutralisation after application. Both these reactions are normally followed by a complex chemical change of carbonate interacting with other contaminants, such as gypsum.

Processing begins with wetting

There are currently three main methods for processing ash: self-hardening and crushing; compaction; and granulation. All are based on first wetting the ash with water so that chemical hardening takes place. The amounts of water required and control requirements vary among the methods.

Figure 12. A crusher breaking up self-hardened ash at Borås, Sweden.

Several types of machines are available for the wetting process. One type is the rotating cement mixer, which has the advantage of being cheap, easily available and easily modified for the purpose. Another type corresponds to the screw conveyer in the outfeed, a horizontal cylindrical vessel with a rotating axle to which shovels or blades are attached. There are also paddle systems, in which ash and water are mixed with shovels or blades. The intensive mixer is similar to the cement mixer but has been equipped with knives that chop any aggregates formed. All of the techniques are dependent on the quality of the ash, mainly the completeness of combustion.

Granulation and compaction are often more costly techniques than self-hardening and crushing but they yield a more uniform final product. A uniform final product with a lower proportion of fine-grained fraction is desirable, as the reactivity of the ash with respect to pH and salinisation is reduced when the degree of hardening and granule size are increased. This in turn reduces the risk of damage to fauna and flora as a result of high pH values and disrupted osmotic reactions. Uniform products are also easier to apply, especially by helicopter, as there are machines designed for forest fertilisation that work well with granulated ash products.

It is advantageous to process the ash at a depot where measures have already been taken to collect and treat run-off water. This also prevents problems and time delays that can easily arise in connection with processing of permits or notification of temporary storage or processing sites.

Self-hardening and screening

Self-hardening and screening is the most widely practised technique in Sweden, mainly because it is cheap and requires little ancillary equipment. In Finland, the self-hardening has been used for some years in the Äänevoima Oy power plant situated next to the Äänekoski pulp and paper mill.

First, the ash is wetted in a mixer (large cement mixers have been used with good results). An amount of water sufficient to wet all particle surfaces (approx. 40 % for fly ash and 15 % for bottom ash, computed as water ratio) is then added. Water and ash must be mixed very carefully and in the right ratios, for instance by a pan mixer or by a mixing screw in the ash silo in the power plant. The wetted ash is spread on a paved surface, where it is allowed to self-harden. The quality of the finished product can be improved by laying the ash in thin layers (max 40 cm high at a time), in a loafshaped pile. Each layer is packed by repeatedly driving over it with a tractor. The packing makes the ash product harder and more sparingly soluble and the amount of fine fraction produced in connection with crushing is reduced.

After packing, it is important that the ash is left undisturbed long enough for chemical hardening to occur. The time required depends on several factors including temperature and ash quantity, but with proper handling and good ash quality, the winter's production should be fully hardened by late spring or early summer.

Once the ash has hardened, the ash loaf is broken up. If the pile has hardened well at depth, the best way to break it is with an excavator. The ash is later crushed down to a spreadable fraction. Crushing can be done with a crusher or sieving bucket, a tractor-mounted bucket with rotating crushing cylinders fitted in the base (Figure 13). The crushed product can often be dumped directly into a container or dump truck for transport out into the forest. If crushing yields a great deal of fine fraction, the ash may need to be screened before application. The granule size after crushing and screening should be such that no more than 30 % passes through a screen with 0.25-mm mesh width in wet screening.

Figure 13. Crushing with a sieving bucket, a tractor-mounted bucket with rotating crushing cylinders fitted in the base.

Processed ash is sensitive to rewetting and dehydration, so it should be covered if there is a risk of heavy precipitation or if it is going to be stored for a long period before application. The ash should be wetted if necessary before loading into application machinery, so that it does not create dust during application. The amount of water that should be added varies, but the dust is usually bound if the water ratio is increased by 5 %.

It is difficult to specify the cost of self-hardening of ash, especially for large plants with their own depots, as several aspects of handling are performed when the ash is deposited. The steps for which costs can be estimated are mixing

Figure 14. Peter Mellbo from Kalmar Högskola pictured with cylinder compaction equipment at Kalmar DHP. Photo Sirkku Sarenbo.

with water, spreading and compaction, breaking of the loaf and crushing. The approximate cost is €5-11/tonne for mixing with water and €4.7/tonne for crushing and screening or €2-5 for crushing with a sieving bucket.

Compaction

In the compaction process, large granules are formed from the ash-water mix through some kind of pressing method. For example, the wetted ash can be pressed between cylinders in a process known as cylinder compaction (Figure 14). Binding agents such as cement can be added during compaction to produce extra-stable products or to bind ash with poor self-hardening capacity.

A Swedish compaction example

A variety of cylinder compaction techniques have been developed in Sweden within the Adaptation of Bioash to the Ecocycle project. The project tested full-scale cylinder pelletisation at the Fors and Frövi pulp and paper mills. A total of 1 500 tonnes of pellets were produced in the project, mainly from ash, but pellets made from mixtures of ash-green liquor sludge and ash-lime sludge were also tested.

In the cylinder compaction technique, the wetted ash is compacted into strings under a grooved press cylinder. The cylinder can be made with grooves of any width. The strings can thereafter be cut to the desired length. The technique is robust and can be adapted to accommodate extensive automation. The cylinder pelletisation equipment is built into a 20 - foot container and equipped with a complete set of controls. It is entirely mobile and easy to transport and install. An electricity supply and instruments are required for installation and the installed container should be covered by a roof. As cylinder pelletisation requires homogeneously wetted ash, there must also be good opportunities to control the water mixture. The project used a Fejmert ash mixer, which was connected to a control system in Fors. This provided good opportunities to influence batch size, water addition and mixing time. The mixer was controlled manually in Frövi.

It takes two people a couple of days to carry out the installation and adjustment. The normal capacity is 5 tonnes/hour. During the term of the project, production was increased to 10 tonnes/hour for a brief period with no operating problems. After pelletisation, the product was allowed to harden for one month. The fully hardened pellets can be handled, shovelled and reloaded without breaking down to any appreciable extent.

In leaching tests, the pellets proved to have good leaching properties. One explanation for the good results may be that cylinder pelletisation provides nearly optimal conditions for chemical hardening, as the compaction of the material increases the contact between water and ash. A thoroughly hardened cylinder-pelletised ash product can probably also be spread in the felling phase, without risk of damage to ground vegetation. The risk for increased nitrification or nitrate leaching is negligible with such a product.

The project calculated the total cost (operations + transport) for cylinder pelletisation to be €9.5/tonne DM or €6.6/tonne wetted ash. In addition, the system requires a capital investment of €3-8.7/tonne of ash, depending on the depreciation schedule and production.

Granulation

Granulation involves rolling the ash-water mixture in a drum or on a plate; granules are formed and dried in hot air so that they do not stick together. Handling of granulated ash is cleaner than handling of self-hardened ash but it is more expensive. Granulation has been carried out in full scale in Finland. In Sweden, the method has been used in scientific projects. The technique has mainly produced very hard particles with a slow leaching rate. The main objection to the technique is its cost, due to drying of the granules. Granulation techniques now exist both in Sweden and Finland where the granules self-dry, which reduces the cost. Various types of binding agents can also be added in the granulation process to make the final product even more stable. The granules can also be coated with a dense surface layer, e.g. of lignin or stearate, to further lower the leaching rate.

Figure 15. Granulation unit comprising plate granulator and drum type post-granulator at Enotuhka Oy, Stora Enso´s Enocell pulp and paper plant. Enocell owns the equipment, Enotuhka Oy is responsible for its operation and Astera Ky designed and manufactured the post-granulation unit. The volume of granulation is 4 000-5 000 tonnes annually, but production capacity is much greater. Photo Samuli Rinne, VTT Processes.

A Swedish granulation example

A company called Renoma, in Helsingborg, Sweden, has developed a granulation method where the granules self-dry. The method has been in use since 1997. The current mixing/granulation process is based on a throughput mixer of the same kind as is used for mixing of asphalt. With only limited conversion of the equipment, a capacity of 15 - 20 tonnes/hour can be achieved. The type of paddle mixer currently used for wetting ash at heating plants could easily be rebuilt to handle granulation.

The quality-controlled ash material is loaded

Figure 16. Ash granules.

into a feeder pocket over a coarse grid, which screens out material >50 mm. The rejected material is collected, run over a crusher and remixed into the ash. The amount of rejected material varies for different types of ash. Based on experience, Renoma assumes 15 % rejected material as a basis for production estimates.

The material is transported via a belt from the feeder pocket to the mixer in a continuous process. Dose rate is controlled via the belt speed and the belt weigher. Any binding agents are dosed via a screw, belt or pump to the mixer. The reactivity of the ash affects the choice of binding agent type and quantity. Liming material and supplementary nutrients, etc. are added if required. There is a separate hopper for each type of material and total dose rate is controlled by the central control computer of the mixing system.

The size and screen curve of the granules are controlled as a combination of factors including mixing speed, moisture ratio, particle composition, binding agent and blade angle. Daily production of granules is 150 - 200 tonnes. The price varies between €8-12/tonne of finished granules. The largest cost is for set-up and adjustment of the system, while the limit cost per manufactured tonne i.e. the cost per tonne (after the first day) can end up at around €3.8 - 4.6/tonne.

In granulation with the Renoma method, the finished material is stored in stacks until it is applied. If time in storage exceeds 1-2 months, the stack is covered with silage plastic to reduce the risk of dehydration of the outer layer and consequent risk of dust production. This applies first and foremost to the upper part of the stack.

Stationary and mobile granulation in Finland

In Finland, ash is granulated in two stationary granulation plants in Northern Karelia: Enotuhka Oy, founded in 1997 at Stora Enso´s Enocell pulp and paper plant in Uimaharju; and FA-Forest in Liperi, founded in 2005. The Enotuhka Oy granulation system can be a cost-effective and clean solution in large plants, producing several thousands of tonnes of ash granules annually (Figure 15). For smaller plants, transportable granulation units are one alternative in addition to self-hardening. Prototypes of transportable units have been demonstrated in the RecAsh project. To get granules that are sufficiently durable for transportation and spreading, it is best to use clean wood ash. In practice, the availability of wood ash is rather restricted today in Finland compared to mixed ash. According to tests with a concrete mixer carried out by VTT Processes, mixed wood-peat ash can be granulated into quite hard granules even with only 15 % wood ash. However, granules made of pure peat ash tend to be very fragile after they have dried. These tests also showed that granulation does not succeed very well if the ash contains a lot of unburned carbon. Full-scale testing by VTT Processes using portable granulation test equipment produced the same result as the small-scale experiments, namely that mixed wood and peat ash can be granulated.

Post-processing analysis

It is important that ash products do not cause direct damage to vegetation after application. Mosses, spaghnum mosses in particular, are sensitive to damage, as are lichens. It is the dust-like fine fraction of the ash that is mainly causing damage. The particle size of ash is usually determined by wet or dry screening through standard screens in which the product is separated into different size fractions. The coarser fractions usually have a longer dissolution time than the more fine-grained fractions. Ideally the stabilised ash should dissolve over a period of 5 - 25 years in the field. Slow dissolution are required when the ash is applied during the felling phase and faster dissoulution is suitable during the thinning and clearing phases. There is no standard method for measuring dissolution rate and it is complicated to translate laboratory trials to long-term conditions in the field. The Swedish Forest Agency is currently developing a Swedish method.

The compensation fertiliser dosages are usually calculated on a dry matter basis and moisture content is accordingly an important parameter for calculating the correct dose. The moisture content of the finished ash product can be determined according to CEN/TS 14 774 - 2: Solid Biofuels - Methods for the Determination of Moisture Content – Oven Dry Method – Part 2: Total Moisture – Simplified Method.

Figure 17. Mobile granulation plant, Finland. Photo Samuli Rinne, VTT Processes.

Product declaration for ash

There is currently no standard for product declaration of processed ash. It would be a good idea to rapidly create such a standard by agreement among the actors in the ash recycling chain. The declaration should state the origin of the ash and contain a rough description of the fuel. Total concentrations of nutrients and metals should be included, along with the results of a stability test. The laboratory that performed the analyses and the name of the person who was responsible for the analyses should be specified. The declaration should also contain a description of particle size and moisture content.

Planning and performance of application

Figure 18. It is important that ash products do not cause direct damage to vegetation in conjunction with or after application. Mosses, white mosses in particular, are sensitive, as are lichens.

General

Ash recycling has slightly different focus in Sweden compared to Finland. In Sweden, it is mainly seen as an environmental measure on mineral soils and is well summarised by the general guidelines concerning section 30 of the Swedish Forestry Act:

‘When ash is used for forest vitality fertilisation and compensatory fertilisation, the quantity, form and composition of the ash and the time at which measures are carried out should be chosen so that nitrogen leaching and losses of added nutrients are limited, in order to prevent or limit damage to the environment. For instance, the ash should have originated from biofuel and be stabilised and slowly soluble. In addition, the total supply of hazardous substances (e.g. heavy metals) should not exceed the export of such substances that takes place through the total biomass extraction during the rotation period of the stand. For compensatory fertilisation, no more than three tonnes of ash DM (dry matter) per hectare should be applied during the rotation period of a stand.’

In Finland, it is more common to use ash recycling as a method to increase forest growth on drained peatlands. These differences originate from historical causes such as different soil distributions, acidification problems in Sweden and shortage of wood after World War II in Finland. Nevertheless, the methods used for processing the ash and spreading are similar in the two countries. From an European point of view, these differences in focus increase the opportunities to introduce ash recycling as a method to reuse wood fuel ash.

The application of ash to forest land is essentially a new activity in large parts of Europe. Accordingly, there are often no specific rules and recommendations regarding such programmes, although waste management regulations usually provide limits regarding the actions permitted.

National laws and recommendations pertaining to the following should be consulted:

- Application of ash
- Consideration of natural values and cultural heritage
- Concentration limits and other requirements for spreadable ash

Overall organisation of application

One fundamental problem with the use of ash as a compensatory fertiliser on forest land is the number of actors involved in the chain from forest fuel extraction to application of the stabilised ash. The landowner hires a forestry company to manage forest fuel extraction, the forestry company sells the material to a forest fuel supplier and the supplier has a contract with one or more heating plants where the ash is produced. One contractor carries out the stabilisation and another returns the stabilised product to the forest land from which the fuel was extracted. A few different models have been developed in Sweden.

- In south-eastern Sweden, the Swedish Forest Agency takes responsibility for organising stabilisation and application of ash on a contractual basis. Heating plants pay for the ash to be removed and private forest owners pay a nominal sum to receive it. The Swedish Forest Agency carries out the planning and arranges contracts with landowners and subcontractors.
- In a few cases, heating plants have initiated ash recycling and identified landowners who are willing to receive ash. Another option for heating plants that are concerned about protecting the ecocycle or that are required by regulatory authorities to recycle ash is to include a requirement in the contractual terms of delivery with forest fuel suppliers that the latter must ensure that the ash is returned to the forest. In this way, the responsibility is shifted to actors closer to the landowners.
- Several large forest fuel suppliers have also taken on the task of organising ash recycling. In those cases, the ash is recycled to their own forest or to the land from which the suppliers have purchased the forest fuel. In this case, the connection between the extraction and compensatory fertilisation is also clear.
- In Finland, the pulp and paper industry has fertilised forests belonging to its own companies with ash since the late 1990s. However, there has been little use of ash in privately-owned forests to date, but this is becoming

Table 3. Recommended application dosage with the nutrient balance method. Habitat index is a measure of the production capacity of a site. It consists of a combination of a letter and figure. The letter stands for the typical variety of tree on the site, G=Spruce, T=Pine and B= Birch. The figure stand for the predicted average height of the trees at an age of 100 year. From ”Recommendations for Extraction of Forest Fuel and Compensatory Fertilisation” (Swedish Forest Agency, 2002).

Extraction		Habitat index. Compensation dosage, tonnes ashes DM/ha and rotation						
		G18	G26	G34	T18	T26	B18	B26
All stemwood during rotation		1,5	2	2,5	0,8	1,2	1,4	2,1
Final felling	Logging residue without needels/leaves	0,7	0,8	0,9	0,2	0,3	0,4	0,5
	Logging residue with needles/leaves	1,1	1,3	1,4	0,3	0,4		
Cleaning/Thinning	Delayed cleaning	0,4	0,5	0,6	0,2	0,3	0,3	0,6
	All thinning without needles/leaves	0,3	0,6	0,8	0,1	0,2	0,2	0,3
	All thinning with needles/leaves	0,6	1	1,3	0,2	0,3		

Table 4. Recommended application dosage with the standardised method. From ”Recommendations for Extraction of Forest Fuel and Compensatory Fertilisation” (Swedish Forest Agency, 2002).

Species of tree	Tonnes of ashes DM/ha and rotation (poor soil -fertile soil)
Spruce	1-2
Pine	0,7-1,5
Birch/other trees	1,2

Table 5. Nutrient and heavy metal contents of Finnish wood and peat ash in comparison to the concentrations stipulated by the Swedish recommendations.

mg/kg	Recommendations	Wood ash	Peat ash
Kalium	>30000	17000-26500[1])	2800[3])
Calcium	>125000	150000-295 000[1])	44000[3])
Potassium	>10000	11000-25000[1])	6700[3])
Cadmium	<30	0,4-40[2])	0,5-5[2])
Copper	<400	15-300[2])	60-160[2])
Lead	<300	15-1000[2])	75-970[2])
Zinc	<7000	40-5100[2])	20-540[2])

[1]) Wood ashes of power plants in the RecAsh-project
[2]) Source. Ranta, J. & Wahlström, M. 2002
[3]) An sample of peat ash

more common with help of projects promoting wood ash use (such as RecAsh), where knowledge about the benefits of ash is disseminated, and forest owners’ associations and other stakeholders in the chain of ash utilisation are activated. The new updated fetilisation law and related acts also encourage to wood ash application and give clear rules and operation methods.

Ash dose rate for compensatory fertilisation

Compensatory fertilisation usually takes place after extraction of forest fuel. It may also be suitable to compensate for stemwood extraction, especially in acidified areas. A high degree of extraction requires higher compensation, as the fundamental precept is that ash recycling is an ecological measure.

There are two methods in Sweden for calculating the dose: the standardised method and the nutrient balance method. Table 4 shows the recommended doses according to the standardised method. This method is used when there is no information available about previous forest fuel extractions or when compensation is being made for stemwood extractions during the current rotation period. Compensation usually takes place once per rotation period. The upper part of the range given in Table 4 indicates fertile land/southern Sweden, while the lower part indicates infertile land/northern Sweden.

The nutrient balance method (Table 3) yields more precise amounts for compensatory fertilisation. The dosages are calculated on the basis of the amount of nutrients and acid-buffering capacity exported in connection with the extraction and so as to ensure that the quantities of heavy metals will not increase in the soil. The guidelines were developed for mineral soils but can also be used on peatland. The maximum permitted dose in Sweden is three tonnes of ash DM per hectare and rotation period

Ash dose rate for forest fertilisation

Some of the most important nutrients and heavy metals in wood/peat ash for forest fertilisation in Finland are presented in Table 5 and compared to the Swedish recommendations. The comparison is based on results of studies carried out by VTT Processes in heat and power plants. The conclusion is that power plants must ensure that wood and peat fuels do not contain any polluted items, such as lead-contaminated demolition wood. This since even small amounts of contaminated fuel fractions will cause high concentrations of heavy metals in the ash.

Determination of the ash dose (tonnes/ha) is based on the amount of phosphorus present, which should be 45 kg per hectare. The amount of potassium should be 70 kg per hectare, but the phosphorus content is decisive if the nutrient ratio is different from above. The nutrient ratio is usually suitable in wood ash but there is insufficient potassium in peat ash and in mixed ash dominated by peat. Potassium can be added for example as biotite, which is a byproduct of the apatite concentration process. Studies by the Finnish Forest Research Institute have shown that the fertiliser effect of peat ash is as large as that of wood ash if biotite is added.

Spreading on mineral soils in Sweden

As ash application is regarded as an ecological and compensatory fertilisation measure, ash should primarily be applied to forest which has been, or is intended to be, used for extraction of forest fuel. Compensation for stemwood extraction is also beneficial, especially on sites with heavy nitrogen deposition. However, forest wasteland, key habitats, areas of special consideration, buffer zones around wetlands, lakes and streams, etc. are not suitable for ash application, for reasons of nature conservation. There is no general rule concerning the width of buffer zones. In Sweden, the same regulations as for nitrogen fertilisers are applied, i.e. 50 m from sources of water supply, rivers and lakes, buildings, farmyards and gardens, 20 m from tarns, ponds and streams and 10 m from public roads and other people’s land. Dry, poor land such as lichen habitats should also be avoided, as the application of ash on such land has proved to cause a decline in tree growth, at least in the short term. Damp and wet land should also be excluded from both forest fuel extraction and application of ash because of the risk of damage to the land. It is never appropriate to apply ash during the spring thaw or after heavy rains, as the risk of damage to the soil is imminent. It is also important, as in all forestry activities, to be particularly careful in areas with cultural heritage landmarks.

One general rule is that compensatory fertilisation is particularly important on productive soil, because the forest fuel extraction rate is higher there. Further, compensatory fertilisation has often been found to increase productivity on these sites. Compensatory fertilisation should always be carried out on severely acidified land and peatland after extraction of forest fuel.

Forest fuel extraction may have a positive impact on severely nitrogen-loaded land because nitrogen is removed with the forest fuel, the amount of leachable nitrogen declines and it is easier for vegetation to establish itself on the felled area. In these situations, it is a good idea to extract forest fuel with its crown foliage, as nitrogen concentrations are higher in crown foliage than in branches and tops.

Stand types

With regard to the forest phase, the general recommendation is that application should not be performed within five years before or after final felling. The reason for this is that ash application on bare soil increases the risk of nitrification and leaching of potassium and nitrate from the cutted area.

Further research is required regarding the effects of stabilised ash products of varying hardness. It should be possible to apply granulated or cylinder-pelletised ash with a long or very long dissolution time to felled areas, preferably in conjunction with site preparation or planting. If the ash is well stabilised, application can be carried out when the vegetation has grown sufficiently large to inhibit leaching, but not so large that application is made difficult (5-8 years after felling).

Application to felled areas is appealing for financial reasons, as machines with larger application swathes can be used. Ash with a short dissolution time may be applied only in closed stands, preferably in thinning stands where existing skid roads can be used. Application within stands should be avoided when sap is rising, as bark damage can easily arise.

Spreading on peatlands in Finland

The good fertiliser effect of wood ash on growth of pine on nitrogen-rich peatlands has long been known, based on studies performed by the Finnish Forest Research Institute in the 1930s. Ash fertilisation research in Finland has historically focused on peatlands due to a period of shortage of wood after World War II when stem volume productivity recived high priority. Furthermore, there were large areas of drained peatland suitable for ash fertilisation and the authorities provided subsidies for additional forest drainage to increase growth. A considerable increase in forest volume was achieved. A number of research studies on ash recycling have been performed, especially in the 1980s and the late 1990s, including effects on tree stand growth, foliar analyses, vegetation, peat analyses, micro-organisms, berries, mushrooms, leaching, heavy metals and carbon balance.

Nowadays in Finland, ash is used mainly for vitality fertilisation of peatlands and the Finnish government subsidises such fertilisation by paying part of the cost involved. Some areas of drained peatlands suffer from nutrient imbalance, causing growth disturbances and death of trees. Wood ash is suitable for vitality fertilisation of pine stands on eutrophic, nitrogen-rich peatlands, to prevent phosphorus and potassium deficiency. Ash also decreases the acidity of peatlands (the pH value can increase by up to 2 - 3 units) and increases microbial activity. The fertiliser effect of ash lasts longer than that of artificial fertilisers, at least 30 years. Tree growth has been shown to increase by 2 - 4 m^3 annually on nitrogen-rich peatlands after application of 4 tonnes of ash DM per hectare. Wood ash is more suitable for forest fertilisation than peat ash, because peat ash contains fewer nutrients than wood ash. The use of mixed peat and wood fuels is common in Finland. Mixed peat and wood ash can be used as a fertiliser if the quality of the mixed ash is adequate for forest fertilisation. The dose rate of wood ash in Finland is generally 3 - 5 tonnes per hectare, while for mixed peat and wood ash the rate per hectare is 1 - 3 tonnes higher. According to studies carried out by the Finnish Forest Research Institute, normal doses of ash do not increase the cadmium content of e.g. forest berries or mushrooms.

The Finnish government subsidises wood ash fertilisation on sites with adequate drainage but where forest growth is low due to nutrient deficiency. The subsidy is 40 - 55% of the cost and the amount of the subsidy depends on the location of the fertilised forest, with it being higher in northern Finland than in southern Finland. For a forest owner to be entitled to subsidies, a needle analysis or demonstration of clearly visible nutrient deficiency symptoms on tree crowns in the stand is required. For needle analysis, the needles are collected during tree dormancy in winter. A sample contains 1 or 2 shoots from the south side of the tree top of the biggest and healthiest trees, not growing by a ditch. About 5 - 10 samples are collected and analysed.

Figure 19. In Finland, ash is now used mainly for vitality fertilisation of peatlands. Photo: Samuli Rinne.

Procedure for ash fertilisation

The procedure for vitality fertilisation of peatland forests with ash consists of the following steps:

- Plans for forestry (thinning plan and drainage maintenance plan)
- Needle sampling
- Needle analysis and calculation of ash fertiliser requirement
- Thinning
- Fertilisation
- Drainage maintenance

In Finland, ash is classified as a waste product and an environmental permit is always needed. Permits are issued by the environmental protection agency or the regional environmental agency. The permit includes both the use of ash (spreading) and the area where the ash will be spread. The quality of ash must be analysed and the permit application must include a declaration from an accredited analytical laboratory. Ash must also be stabilised to prevent dust formation. There are also some recommendations for spreading ash related to buffer zones and protection distances near lakes and streams, forest ditches and groundwater areas. The authorities check the situation case by case. The permit procedure could be shortened considerably if the status of ash could be changed from waste status to product status. The waste designation currently restricts the use of ash as a forest fertiliser.

Methods of spreading

Ash is applied either with a ground spreader, often a converted tractor, or by helicopter. Both techniques are used, but ground application is considerably more common. Good experiences with helicopter application of nitrogenous fertiliser may eventually make the helicopter a viable alternative. At present, ground application is the most economical method.

Ground application

Ash is usually applied in growing stands as the requirements for the degree of ash stabilisation are lower than for application on felled areas. Ground spreaders can drive on skid roads. These may be 2.6-metre wide forwarders with a load capacity of up to six tonnes, with the ash loaded by the forwarder’s grapple loader. The application swathe is approximately 25 metres. Smaller tractors, usually farm tractors of various types, can be driven into the stand without using skid roads (Figure 20). Their load capacity is two to three tonnes, the width 1.8 metres and the application swathe 18 - 20 metres. A forwarder can spread 40 - 80 tonnes a day, whereas a smaller machine can manage 20 - 40 tonnes. The spreader consists of a container with a feeder belt in the bottom. There is a hatch towards the rear of the belt through which the ash is dropped onto one or two spreader plates that broadcast the ash in a fan shape in both directions.

The dose is determined by belt speed and hatch size. On more sophisticated machines, belt speed

Figure 20. Ground spreading in an 8-year-old clear-cut area in Sweden.

is linked to vehicle driving speed. This kind of speed-dependent application is not considered particularly worthwhile as regards application to forest land. Driving speed is usually steady at 50 m/min, which results in uniform application even without this device. Bark damage has been observed on a few occasions after ground application in stands. If ash is applied to wet ground, in association with precipitation or at the wrong time of year, the spreding vehicle may cause machine tracks and root damage.

Unfortunately there are currently no studies of application to felled areas, which is a pity as that type of application would most likely improve the cost/benefit ratio since the application swathe can be increased, leading to less driving. Application to felled areas is possible until the new trees have attained a height of 0.7 m but requires

Figure 21. Helicopter changing ash spreading containers and Bobcat loader using sieve scoop for loading ash. Photo: Samuli Rinne.

a hard-stabilised ash product. Application of ash with a tractor on forest land (in stands) costs €14 - 22/tonne of ash product plus €5 - 11/tonne for transport of the ash to the application site (within 60 km).

Helicopter application

Helicopter spreading is more flexible than ground spreading in that it avoids problems concerning the bearing capacity of the soil, a thick snow layer or narrow skid roads in old thinning stands. Helicopter application can also be a viable option in dense stands where there are no roads, where the land slopes steeply or on other rough country where spreading with a ground spreaders is difficult. However, the cost of helicopter spreading is many times that of ground spreading.

Ash to be transported to a forest site is loaded into a spreading container by e.g. Bobcat loader, which at the same time sieves and crushes any oversized ash granules. There can be two spreading containers, one being loaded while the other is being used for spreading (Figure 21). The loading capacity is about 500 kg. Global positioning system (GPS) can be used to determine the route of the helicopter and display it on a screen in the cockpit. Based on this system, the pilot chooses the flight route for every spreading event. The typical ash spreading capacity by helicopter is 100 tonnes per day in one shift. It can be difficult to form a clear picture of the application pattern when helicopters are used, especially when crushed ash with a great deal of fine fraction is used. Figure 22 shows a helicopter spreading ash.

The helicopter becomes more competitive at smaller doses and when granulated ash is used. Granulated ash allows more reliable application and less wind drift. Helicopter application also becomes a more competitive option when there are very large objects or many small objects within a limited area because ground or parking costs for helicopter application are high, while operating costs are more modest.

Nitrogen supplementation

Nitrogen is normally the element that limits growth on forest land. At present, the atmospheric deposition of nitrogen compounds, mainly caused by human activity, is very large in central Europe. Deposition in southern Germany often exceeds 20 kg N per hectare annually, which may be compared to approximately 3 kg per hectare annually in northern Sweden. The nitrogen deposited is likely to promote forest production, but it has also been proven that forest soil has great potential to store nitrogen after nitrogenous fertilisation. So far no increase in leaching from growing forests has been noticed. On the other hand, it has been noted that leaching increases during the harvesting phase if nitrogen has been added to the site earlier during the rotation period. Nitrogen fertilising has also been found to increase nitrogen thriving field flora.

It would be reasonable to conclude that increased leaching in the harvesting phase should be expected from land with a surplus of nitrogen. This arises when the supply of nitrogen during the rotation period is greater than the export via harvesting and normal leaching. Increased supply of ammonia to the soil increases the risk of nitrification, which in turn contributes to acidification if the vegetation cannot absorb the nitrate formed sufficiently rapidly. Increased nitrate leaching speeds up the export of acid-buffering capacity from the soil and may increase nitrous oxide formation in discharge areas. The formation of nitrous oxide is to be avoided since the gas contributes to the greenhouse effect. Another problem is increased

Figure 22. Helicopter spreading ash on growing forest. Photo: Samuli Rinne.

Figure 23. As a result of comprehensive restrictions on sulphur emissions, large areas of forest land affected by acid rain will probably recover, but recovery of the most severely acidified land will take a very long time.

nitrogen concentrations in coastal areas which lead to eutrophication problems in neighbouring seas. Thus, even though trees grow better when they have a greater supply of nitrogen, increased nitrogen concentrations may cause serious environmental problems

Schematic calculations show that land of moderate quality where forest fuel extraction is carried out during both thinning and final felling may need nitrogen compensation if the annual nitrogen deposition is below 5 kg per hectare. For higher site productivity classes, the limit is at a somewhat higher deposition and for lower site productivity classes at somewhat lower deposition. There is some uncertainty in these budget estimations which future research hopefully will help to reduce.

Compensatory addition of nitrogen must not exceed the levels specified in regulations regarding nitrogenous fertilisation. The nitrogen fertiliser may be spread simultaneously with the ash, provided that the proportions of ash product and fertiliser are such that an even application pattern can be achieved and that the products are sufficiently stable to prevent ammonia formation and dissipation. Joint application of this kind should also be performed in a vigorously growing stand, e.g. in thinning forest.

If nitrogen is added to wood ash, the use of ash can be extended to fertilisation of mineral soils. VTT Processes has studied the granulation of wood ash and wood-based biosludge of pulp and paper mills, resulting in nitrogen rich granules. The growth rate of birch and pine plants in greenhouse studies at the Finnish Forest Research Institute after fertilisation with ash-biosludge granules was equivalent to the growth rate after fertilisation with artificial fertilisers.

Lime supplementation

Acidification of land and water has been one of the most serious environmental problems in northern Europe since the late 1960s. In areas with low buffering capacity in the soils, the acid deposition caused inreased concentrations of toxic inorganic aluminium in both groundwater and surface water. This has led to a negative impact on biodiversity in streams and lakes. As a result of comprehensive restrictions on sulphur emissions, large areas of forest land will probably recover, but recovery of the most severely acidified land is going to be a slow process. Compensation for intensive harvesting is particularly important in these severely acidified areas. The use of a mixture of ash and lime may be appropriate on land that is expected not to recover within 20 - 25 years.

The main method for remediation of acidified land in Sweden is based on applying a mixture of two tonnes of ash and two tonnes of lime. The lime should consist of carbonate limestone and/or dolomite and have a granule size distribution that allows slow dissolution. The treatment should probably be carried out per catchment and may also be applied independently of forest fuel extraction. Lime should not be added in catchments where the run-off water is acidic as a result of natural causes.

Logistics

Transport constitutes a high cost in connection with extraction of forest fuel and ash recycling. Round-trip transport is one way to reduce costs. Large bags have been tried but are rarely used, probably because the cost of the bags and expensive handling due to filling. Lift dumper systems of the type used for household waste or demountable body system trucks seem to work best. These systems use relatively light vehicles, which yields a high utility load. It is easy to park containers in the forest even if the ground is uneven and the small base area makes loading easier. Promising trials of dumping on wire gauze cloth or thick tarpaulins have also been carried out.

Figure 24. Lift dumper systems or demountable body system trucks are often used for transport of stabilised ashes.

The distance between the ash container and the application tract is critical, as tractor spreaders have a low top speed even when running

Figure 25. Modern GPS-based monitoring systems are now available.

empty. Application tracts further than 1 km from a depot site make application considerably more expensive. Careful planning of application with container depot sites nearby forest roads and application tracts yields cost-effective application.

Monitoring

Older manual methods for monitoring dose and uniformity of application are often very time-consuming and provide relatively limited information about the application. Modern GPS-based monitoring systems are now available (Figure 25). They are based on recalculation of the application pattern with a mathematical function, which combined with GPS data about the positions of the spreader during the application provides information about dose and coverage. After application, the total dose, dose/area unit and quantity of fertiliser that ended up outside the application area can be calculated

Application should preferably be documented. One way is that the application contractor document necessary information such as date, dose, product, etc. on a form designed for that purpose. A map is appended to the form which then is handed to the landowner to be filed with the property's forestry plan, and to relevant regulatory agencies if so required. If application was carried out in conjunction with extraction of logging fuel (branches and tops), this could also be documented, specifying e.g. amount, tree species, whether or not crown foliage was left behind and the date of the extraction.

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