

# Utilisation of ashes from co-combustion of peat and wood – Case study of a modern CFB-boiler in Finland

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**Abstract** –Approximately 500 000 tons of peat and biomass ashes are produced yearly in Finland as by-product of energy production. About half of those are utilised and the rest are placed to landfill sites because options for recycling have not been found. From the beginning of the year 2011 the waste tax was extended to fly ashes. Rising of costs forces power plant owners to search new opportunities to recycle ashes. Possibilities to utilise ashes were studied through a case study of a modern peat and wood fuelled CFB-boiler. Ash samples were analysed and their environmental and technical applicability for fertilizers, earth construction and concrete production were evaluated. Refining experiments were also performed to improve ash suitability for recycling and to find new options for ash use. Main results of the project are presented in the paper.

*Keywords: co-combustion of peat and wood, ash utilisation, fly ash, ash refining*

## BACKGROUND

Approximately 500 000 tons of peat and wood ashes are produced yearly in Finland as by product of energy production. Most of those ashes are formed in co-combustion of peat and wood in large scale combined heat and power (CHP) plants utilising fluidized bed technology. It's typical for fluidized bed boilers that 80 – 90 % of ash is discharged as fly ash. Bottom ash consists mainly of bed sand.

Ashes are huge material resource that should be used instead of landfilling. A rough estimation is that about half of the peat-wood ashes are utilised in Finland annually. During the last years the most important utilisation option has been the use of ashes in construction and covering of landfill sites. Peat-wood ashes have also been used in civil engineering applications e.g. in road construction and to some extent as forest fertilizers. About half of the ashes are still landfilled because options for recycling have not been found from the vicinity of power plants.

From the beginning of the year 2011 the waste tax was extended to fly ashes in Finland. Tax of 40 Euros has to be paid for every ton of ash that goes to landfill site in addition to landfilling costs [1]. Landfilling of 30 000 ash tons can cost over 2.5 million Euros to a power plant. Rising of costs forces power plant owners to search new opportunities to recycle ashes.

Coal ashes are regarded as uniform material which can be used e.g. in cement or concrete production. Pure wood ashes are good fertilizers for peatlands. Recycling of mixed peat-wood ashes is more complicated. Properties of ashes differ from a power plant to another depending on e.g. fuels, boiler type and ash recovery system. Ash properties are also varying in a specific power plant in accordance with output of the boiler, fuels, their blends and properties of fuels. Varying properties hinder the material use of co-combustion ashes. No one wants to use material that may cause variations to product quality. Technical applicability of ash for designed use is as important as environmental suitability. It's not enough that ash fulfils the requirements for content and solubility of

substances that are regarded as harmful. There may also be requirements e.g. for particle size and shape or frost susceptibility depending on designed application.

Possibilities to recycle peat-wood ashes produced in Jyväskylä were investigated in a ERDF-project "Recycling of Keljonlahti power plant ashes in Central Finland" in co-operation of ash producers, possible end-users and VTT Technical research centre of Finland. The main goal of the project was to find a sustainable way to recycle Keljonlahti's ashes. Peat-wood ashes were analysed and their environmental and technical applicability for fertilizers, concrete production and civil engineering applications were evaluated. Refining experiments were also performed to improve the suitability of ashes for utilisation.

## **UTILISATION OPTIONS OF PEAT-WOOD ASHES**

Ashes are regarded nowadays as waste and their utilisation is regulated by many laws and decrees. Environmental permission is needed if wastes are utilised with certain exceptions. In addition to traditional utilisation options some possibilities to refine ashes are considered in the following chapters. It needs to keep in mind, that if ashes are regarded as product or by-product according to end-of-waste criteria in future, they need to be registered according to REACH-regulation before commercial use.

### **Utilisation of Ashes as Fertilizers**

In Finland, ash utilisation as fertilizer product is regulated by Fertilizer Product Act (539/2006) and Decree on Fertilizer products (MMMa 24/11). Fly and bottom ashes from combustion of peat and wood can be used as fertilizers if the requirements of legislation are fulfilled. There are limit values for minimum content of nutrients and maximum contents for minor elements. Limit values for ash that can be used as forest fertilizer are represented together with the experimental results in table 1.

Content of nutrients is lower in peat ash than in wood ash, and ash content of peat can be from three to four times higher than that of forest biomass. This results in quite low nutrient content of peat-wood co-combustion ashes, which means higher spreading amount and costs. Sometimes nutrient content of peat-wood ash does not fulfil the minimum requirements of the Fertilizer Decree. Addition of nutrients in the form of mineral fertilizers is allowed to increase nutrient content of granulated ash fertilizers. Another factor that hinders utilisation of peat-wood ash as fertilizer is the arsenic content which often exceeds the limit value of Fertilizer Decree.

### **Utilisation of Ashes in Civil Engineering Applications**

Fly and bottom ashes can also be utilised in certain earth construction applications by notification procedure if requirements of Government Decree on recovery of certain wastes in earth construction (VNa 591/2006) are fulfilled. The Decree covers e.g. following construction applications: public roads, streets, bicycle lanes, pavements, parking areas, sports areas, storage fields and roads in industrial areas. There are limit values for total content of harmful substances and maximum values for their leaching for the use in covered and paved structures. If the limit values are exceeded, the utilisation in earth construction applications is still possible with environmental permission. Limit values for utilisation without environmental permit are presented in Tables 1 and 2 together with experimental results.

Ashes can replace non-renewable natural resources in earth construction. Notification procedure was created to facilitate ash use, but actually biomass ashes have difficulties to fulfil the criteria. Environmental permission procedure takes long time and therefore ashes can't compete against natural materials. Other barriers for ash utilisation in earth construction are quality variation and uncertainty of availability, environmental and technical applicability. Most of ashes are formed during wintertime when plants operate high loads and road construction has to be done during summertime. Ashes have to be carefully stored to maintain their quality.

Ashes can be used in massive structures or as stabilisation agents in earth construction applications. There are no exact technical requirements for ashes to be utilised in road construction [2]. Different structures have their own requirements that can be used as basis for measures of ash applicability. First preliminary estimate of technical applicability can be based on particle size distribution. Maximum dry density and optimum water content are also important basic properties. Most significant properties in many cases are frost-susceptibility and thermal conductivity.

### **Utilisation of Ashes in Concrete Production**

Fly ashes can be used in concrete production as binder material or as aggregates. Binder materials must have pozzolanic properties and aggregates suitable particle size distribution.

Coal fly ashes are commonly used in concrete production and their utilisation is regulated by the standard EN 450-1. Biomass ashes can't be used in concrete production because there is no official quality control system for biomass ash available. Applicability of biomass ashes can be estimated by comparison of ash properties to the limit values of coal ash. There are limit values for e.g. loss on ignition, sulphur and chlorine compounds, and for free calcium oxide content.

Uniform quality is absolute demand for ashes to be used in concrete. This requirement may be challenging for co-combustion ashes. Peat-wood ashes may also cause swelling of concrete and reduce strength against frost. They may also have effect on concrete colour.

### **Refining of Ashes**

Refining of ashes should be considered if ashes can't be utilised as such. The goal of refining can be to improve environmental or technical applicability, or to even out quality variations. Refining can be performed e.g. by using suitable methods of separation technology.

Stockpiling is a simple method to refine ashes. Solubility of fly ashes changes during storage due to weathering. Oxides of ash are reacting with moisture and carbon dioxide of air, which results to formation of carbonates. Carbonation causes reduction in pH-value which in turn has strong effect on solubility of harmful metals. Solubility of substances usually decreases, but may also increase depending on element and predominant conditions. Stockpiling reduces also ash reactivity.

Harmful substances of fuels are vaporised in combustion chamber and condensate to surfaces of fly ash particles during cooling stages of flue gases. As a consequence concentration of harmful substances becomes higher in smaller particles. In certain cases it's possible to separate coarser, cleaner fraction from fly ash and utilise it. Harmful substances are concentrated to finer fraction which can be landfilled. Air classification is a method that can be used for classifying very fine particles.

Ultranat Ltd has developed a method in which ashes are used as raw material for nutrient solution [3]. Nutrient solution can be used e.g. as forest fertilizer. Advantages of the method in forest use are for example smaller spreading amount of nutrient solution compared to fly ash as such and low amount of heavy metals in solution. Most of the ash remains in solid state after the process and that residual ash fraction can also be utilised depending on its environmental and technical properties (e.g. in earth construction applications).

## **MATERIALS AND METHODS**

### **Keljonlahti Combined Heat and Power Plant**

Jyväskylän Voima Oy's Keljonlahti power plant is milled peat and wood fuelled CHP plant, which started up during the spring 2010. It serves district heat for Jyväskylä City and produces electricity to the grid. The thermal capacity of the circulating fluidized bed boiler (CFB) is 465 MW. Electricity capacity is 210 MW in condensing mode and 160 MW in CHP-mode with 260 MW district heat.

Milled peat is the main fuel of Keljonlahti power plant. Share of wood fuel varies with its availability and output of the boiler. Wood fuels include forest chips, sawdust and bark. Lime is used for desulphurisation and ammonia water for reduction of nitrogen oxides if needed. Amount of lime used depends on fuel share of peat. Fly ash is collected by 3-stage electrostatic precipitator (ESP). Approximation is that about 41 000 tons of fly ash and 9 000 tons of bottom ash are produced annually in Keljonlahti power plant. Ashes are utilised if possible, otherwise they have to be placed to landfill site.

During the project several ash samples were analysed from Keljonlahti power plant. One larger sample (~ 4 000 kg) was taken from ash silo and other samples from the first ash hopper of ESP. Weekly ash samples were combined from daily samples that were taken by the power plant staff. For comparison, some samples were also taken from other peat and wood fuelled power plants with bubbling fluidized bed boilers (BFB) or CFB boilers.

Ash samples were first characterized by determining their particle size distribution, elemental composition and leaching properties. After characterisation the utilisation options were evaluated by comparing analysis results to limit values of different uses. Some tests were also conducted to get

information on ash technical suitability to civil engineering applications. Refining tests were performed to improve ash suitability for recycling.

### **Characterization Methods**

Content of unburnt material in ash samples was evaluated by measuring loss on ignition (LOI) at 550°C. Particle size distributions were measured by using Malvern Mastersizer 2000 analyser. Measurements were done from dry ash samples.

Inductively coupled plasma mass spectrometry (ICP-MS) and inductively coupled plasma optical emission spectrometry (ICP-OES) were used to measure the content of minor elements from ash samples. Ash samples were prepared by using microwave assisted HF-HNO<sub>3</sub>-HCl -acid digestion according to the standard SFS-EN 13656. Content of major elements in ash samples were determined by using Philips PW2404 X-ray fluorescence (XRF) spectrometer with semiquantitative SemiQ-software. Handheld Niton XL3t 900S GOLDD XRF spectrometer was used to determine elemental concentrations of weekly fly ash samples.

Two stage batch leaching test according to the standard EN12457-3 was used to evaluate solubility of elements from the fly ash.

### **Evaluation of technical properties**

Basic geotechnical properties were determined to fly ash for evaluation of technical applicability to civil engineering applications. Measured properties were solid density, maximum dry density, optimum water content, height of capillary raise, thermal conductivity as frozen and unfrozen, California bearing ratio (CBR), water permeability and frost coefficient. Height of capillary raise and frost coefficient give information about ash frost-susceptibility. CBR value measures carrying capacity and thermal conductivity insulation properties of ash.

Full scale granulation test was performed by FA Forest Ltd to evaluate fly ash technical applicability for fertilizer use.

### **Refining Experiments**

Air classification tests were done to divide original fly ash to finer and coarser fraction. Properties of fractions were analysed and suitability for recycling evaluated.

Stockpiling tests were done in outdoor conditions for 6 months to investigate the effect of storage on ash properties. Two stage batch leaching test was performed before and after the storage.

Nutrient solution was prepared from fly ash by Ultramat® method. Properties of nutrient solution and residual ash fraction were determined.

## **RESULTS AND DISCUSSIONS**

Research was focused on fly ash, because of its large volume. Bottom ash was characterized, but research was not continued. Bottom ash consisted mainly of bed sand and it fulfilled the requirements of Government Decree on recovery of certain wastes in earth construction. It was supposed that bottom ash can be utilised in earth construction without further processing and therefore technical applicability was not tested.

### **Characterization of Fly Ash**

The particle size of Keljonlahti power plant's fly ash was really fine, which is typical for CFB-boilers (Figure 1). Half of the particles were smaller than 20 micrometres and about 40% smaller than 10 micrometres. The colour of fly ash was caramel which indicates low concentration of unburnt carbon. Loss on ignition was really low, under 0.5% in all the measured samples. Average total concentrations of major and minor elements in fly ash are represented in table 1. Values are compared to limit values of Fertilizer Decree and Earth construction Decree.

Leaching of harmful substances is important issue if ashes are utilised in civil engineering applications or are landfilled. Average leaching values of harmful substances from Keljonlahti peat-wood fly ash samples are presented in Table 2. Values are compared to limit values of Earth construction Decree. The results of leaching tests were typical for peat-wood fly ashes.

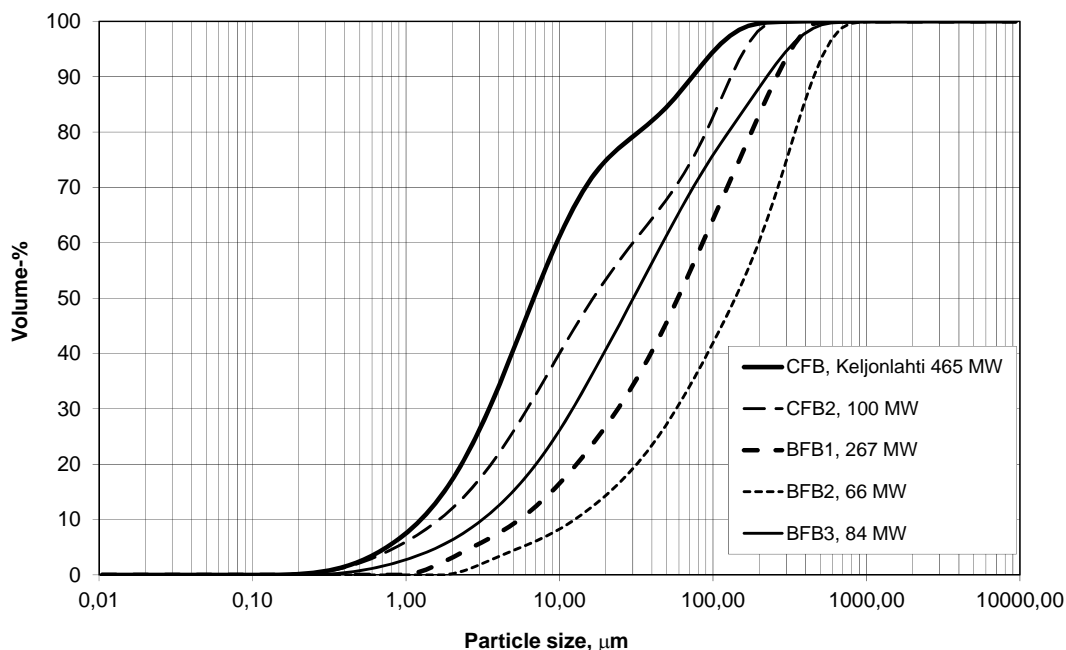


Figure 1. Particle size distributions of fly ash samples from different peat and wood fuelled circulating fluidized bed boilers (CFB) and bubbling fluidized bed boilers (BFB).

Table 1. Average total concentrations of minor and major elements in fly ash from peat-wood fuelled CFB-boiler. Limit values of Fertilizer Decree (MMMa 24/11) and Earth construction Decree (VNa 591/2006) are given for comparison.

		Fly ash	Ash Fertilizers for forest use MMMa 24/11	Earth construction VNa 591/2006
<b>Minor element, mg/kg db.</b>	Arsenic, As	30...60	40	50
	Barium, Ba	1200...2100		3000
	Cadmium, Cd	2	25	15
	Chromium, Cr	50...70	300	400
	Copper, Cu	100...300	700	400
	Lead, Pb	40...70	150	300
	Molybdenum, Mo	10...20		50
	Nickel, Ni	30...50	150	
	Vanadium, V	80...130		400
	Zinc, Zn	200...400	4500	2000
<b>Major element or nutrient, %</b>	Calcium, Ca	10...20	min 8 %	
	Potassium, K	2	P+K min 2 %	
	Phosphorus, P	1		
	Silicon, Si	16...24		
	Iron, Fe	7		
	Aluminium, Al	7		

Table 2. Average leaching of harmful substances from peat-wood fly ash. Limit values of notification procedure for earth construction are given for comparison. Two stage batch leaching test EN 12457-3 was used in solubility tests. Results are calculated to liquid solid ratio 10 and given in mg/kg db. pH of filtrate was 12.6.

	Fly ash	Earth construction VNa 591/2006	
		Covered structure	Coated structure
Arsenic, As	0.01	0.5	1.5
Barium, Ba	5...120	20	60
Cadmium, Cd	0.002	0.04	0.04
Chrome, Cr	0.08...1,6	0.5	3
Copper, Cu	0.02	2	6
Mercury, Hg	<0.002	0.01	0.01
Molybdenum, Mo	0.5...2.5	0.5	6
Nickel, Ni	0.001	0.4	1.2
Lead, Pb	0.03...0.09	0.5	1.5
Antimony, Sb	<0.01	0.06	0.18
Selenium, Se	0.02...0.05	0.1	0.5
Vanadium, V	0.02	2	3
Zinc, Zn	0.05...0.1	4	12
Chlorine, Cl <sup>-</sup>	700	800	2400
Fluoride, F <sup>-</sup>	12...22	10	50
Sulphate, SO <sub>4</sub> <sup>2-</sup>	40...4000	1000	10000
Dissolved organic compounds	2	500	500

### Suitability for Fertilizer Use

Total content of minor elements was low in fly ash (Table 1). Arsenic is the only harmful element which in some fly ash samples exceeds the limit value for fertilizer use and blocks the use of fly ash as fertilizer. Contents of nutrients were higher than expected for ash which is formed mainly from peat. High concentration of potassium in fly ash may partly derive from bed sand, which is ground during intensive circulation in the boiler. It has to be pointed out that nutrients were analysed by XRF, which is not the standard method to specify nutrient content of ash to be used as fertilizer product.

Arsenic content of peat is greater than that of wood based fuels and therefore arsenic concentration of fly ash depends on fuel share of peat. Fly ash quality and especially arsenic concentration was monitored by collecting and measuring weekly samples for 36 weeks. Arsenic concentration and fuel share of peat in a 14 week period are plotted to the figure 2.

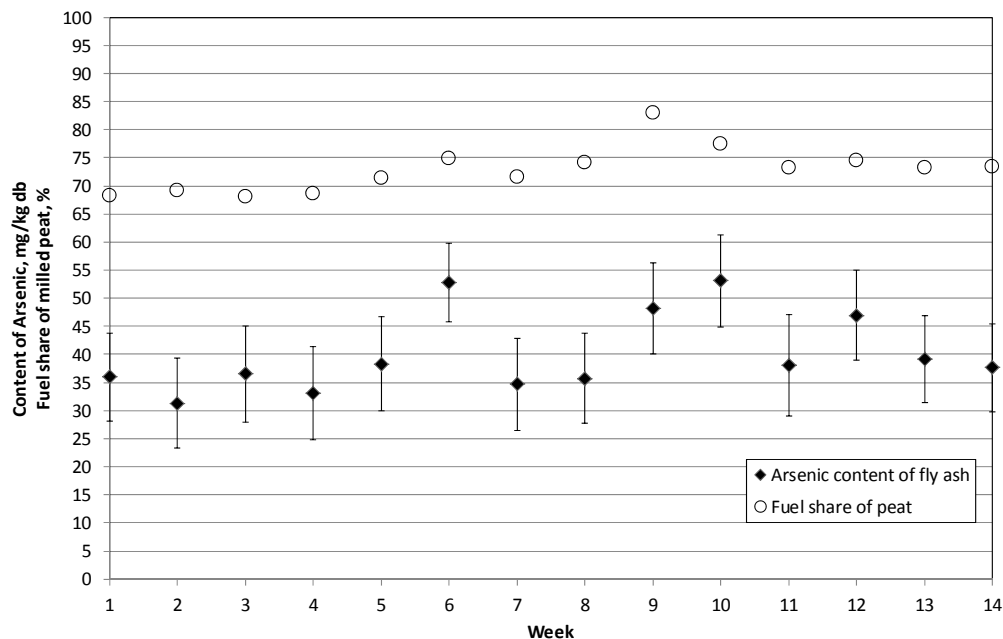


Figure 2. Concentration of arsenic in weekly peat-wood fly ash samples and fuel share of peat in the boiler. Arsenic concentrations were measured with portable Niton XRF-analyser and peat proportion was calculated from fuels delivery reports of the power plant.

Monitoring of arsenic concentration revealed that the maximum value of Fertilizer Decree for arsenic (40 mg/kg db.) is really difficult to reach with the fuels and fuel shares used during the research. Fly ash is technically suitable for fertilizer use. Full scale granulation test proved that hard granules can be obtained.

### Environmental and Technical Suitability for Civil Engineering Applications

In some samples solubility of barium exceeded the limit value of notification procedure for earth construction. Therefore environmental permission may be required for fly ash use in all applications of earth construction.

Frost coefficient of Keljonlahti's fly ash was noticed to be about  $4.5 \text{ mm}^2/\text{Kh}$  that means strong frost-susceptibility. For comparison, corresponding peat-wood fly ash samples from BFB1 and BFB2 boilers were proved to be frost-resistant. Fly ashes from BFB combustion are coarser, so fine particle size and quite narrow particle size distribution probably makes the CFB fly ash frost-susceptible. According to these tests the Keljonlahti's fly ash is not technically applicable to be used in construction layers of roads or pedestrian and bicycle ways. Frost-susceptibility of ash can be decreased by stabilisation e.g. with cement, but functioning of the method should be tested with freezing-thawing tests. Profitability of cement use should be calculated case by case. Preliminary tests indicated that fly ash can also be used as stabilisation agent in layer stabilisation.

Fly ashes of Keljonlahti power plant can certainly be utilised in secondary civil engineering applications. Ashes that have low technical applicability can be utilised e.g. in construction of noise barrier walls.

### Suitability for Concrete Production

Keljonlahti's peat-wood fly ash is too fine to be used as aggregate in concrete production and its' activity is too low to be used as binder material. The content of free calcium oxide exceeds the limit value of EN 450-1 for coal fly ash. Fly ash contains also lot of sulphur compounds, which may cause swelling of concrete. Conclusion was that studied fly ash is not applicable to concrete production as such.

### Refining of Fly Ash

Stockpiling tests indicated that solubility of barium decreases to acceptable level, but the solubility of sulphates increases after six months storage. pH of fly ash decreased from 12.6 to 9.7 during the storage.

Air classification was not applicable method to refine Keljonlahti's fly ash. It was not possible to separate fractions with different properties from totally uniform and fine fly ash.

Fly ash was applicable to raw material of nutrient solution produced by Ultramat method, but the fineness of fly ash complicates the utilisation of remaining mass fraction. Leaching properties of mass fraction are excellent, but it's strongly frost-susceptible and therefore not applicable to road construction. Utilisation options for mass fraction are still under development.

## CONCLUSIONS

Keljonlahti power plant ashes were typical peat-wood ashes. The properties that may prevent the fly ash utilisation were noticed to be arsenic content, high content of free calcium oxide and fine particle size. Arsenic content of fly ash depends on fuel share of peat, and naturally on the arsenic content of peat bog from which the peat is originating. High concentration of free calcium is consequence of lime used for desulphurisation. Fine particle size distribution of fly ash originates from circulating fluidized bed combustion technology. The cyclone, that returns bed sand and larger particles back to the boiler, controls the fly ash particle size also. Only particles that are smaller than the cut-size of cyclone will exit the boiler as fly ash.

It is not possible to affect on fly ash particle size, but the arsenic content of fly ash slightly decreases if share of wood fuels is increased. Increase in biomass fuels will also decrease the need of desulphurisation lime. The share of wood based fuels varied from 10% to 30% during the research. An empirical estimation is that the share of wood based fuels should be increased up to 60 - 70% to decrease arsenic content to a level lower than 40 mg/kg db, which is the current limit value for fertilizer use. It has to be point out, that arsenic content of soil varies regionally, which naturally has considerable effect on arsenic content of peat and wood fuels, and finally on fly ash.

Some experiments were performed to improve the suitability of fly ash for recycling. Storage decreased pH of fly ash, but the positive effect on leaching properties was not clear. Ultramat method seems to be promising option, but mass fraction has to be utilised some way to get the method profitable.

One more challenge for ash utilisation arises from huge yearly amount of fly ash, which for example in Keljonlahti case is approximately 40 000 t. Up to hundred road kilometres should be constructed or repaired in the vicinity of the power plant to utilise whole ash amount. Fertilizer use of whole fly ash would double the area of yearly ash fertilized forests in Finland. There should be several potential uses for ash to reach high utilisation rate.

The most reasonable way to use peat-wood ashes would be the fertilizer use. The valuable nutrients of fly ash should be recycled back to nature to ensure biomass fuel production for future needs. Unfortunately most of peat-wood ashes do not fulfil the requirements of the present fertilizer decree, although they are composed of peat and untreated wood fuels.

The Finnish Fertilizer Decree was revised in September 2011. Among other things the limit value of arsenic for "Forest ash" was raised from 30 to 40 mg/kg db. This raise of limit did not resolve utilisation of Keljonlahti power plant ashes. Arsenic content of analysed fly ash samples is fluctuating around the limit value, so it's very risky to use it as fertilizer in the light of Fertilizer Decree. Fertilizer use would necessitate really tight fly ash quality control at the plant.

The experimental research was done during the first operational year of the new power plant, mainly during the high output winter period. Therefore it is difficult to evaluate, for example, seasonal variation of ash quality and the effect of higher variation in fuels. Basic data was collected in this research, but still lot of work is needed to continue research in the utilisation applications that were noticed to be most promising.

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