

## TALLY FRIENDLY USE OF NON-COAL ASHES IN SWEDEN

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### ABSTRACT

The Swedish Thermal Engineering Research Institute (Värmeforsk) has initiated an applied research program "Environmentally friendly use of non-coal ashes", since 2002. The program aims at increasing the knowledge on the by-products of energy producers and their uses, with the goal of formulating technical and environmental guidelines and assessments. It is supported by about 40 authorities and private organisations. The programme has been divided into four areas:

- Recycling of ashes to forests
- Geotechnical uses,
- Uses in landfilling
- Environment and chemistry

Among all results obtained, the following progresses are shown:

- Evidence for the positive effects of spreading ashes on forest growth
- A proposal for environmental guidelines on the utilization of ashes in construction
- Technical and environmental assessments of MSWI bottom ashes in road construction
- A handbook for using non-coal fly ashes in unpaved roads
- Development of the use of ashes with wastewater sludge as a cover for landfills and mine tailings
- Use of ashes from biofuels in concrete
- A method to classify those by-products from combustion that have mirror entries in the EWC as hazardous or non-hazardous.

The Ash Programme has also made it possible to increase knowledge on ashes as materials and their treatment, on quality assurance and on markets for recovered materials.

The Swedish Thermal Engineering Research Institute (Värmeforsk) initiated a research program called "Environmentally friendly use of non-coal ashes" in 2002. In daily talk it is called "The Ash programme". The Ash programme aims at increasing the knowledge on the by-products of energy producers and their uses, with the goal of formulating technical and environmental guidelines and assessments in the fields where there is none. It is supported by about 40 authorities and private organisations.

The Ash Programme is a wide initiative including building up knowledge, working on guidelines, development and communication. During the period 2002-2005, 61 projects have been performed. The programme is planned to continue until 2008.

Work has been carried out in four main areas; recycling ashes to the forests, geotechnical constructions, landfills and environment and chemistry. Sweden produces about 1 million tons of non-coal ashes yearly. In table 1 the amounts of ashes derived from different fuel sources are given. To these amounts should be added soil, clay and sand that follow e.g. both peat and woodchips. All non-coal ashes in Sweden are rich in calcium and therefore has a high pH. An estimation of ash production in Sweden 2003 is presented in table 2.

Table 1  
Amount of ashes, in percent, derived from different fuel sources in Sweden

Fuel source	Amount of ashes
Municipal waste	25
Peat	5 <sup>a</sup>
Sludge from paper ind.	50-90
Bark	2-4
Pure wood	0,3-0,5

<sup>a</sup> This amount can be much greater

Table 2  
An estimation of ash production in Sweden 2003. The unit is tons per annum.

Boiler	Fuel	Bottom ash	Fly ash
Grate-fired combustion boiler, incineration	Wastes household + ind.	400 000	70 000
	Coal + rubber	15 000	10 000
	Paper industry	100 000	60 000
	Wastes from buildings	15 000	5 000
	Woodchips/peat	20 000	5 000
Powder combustion	Sawmill industry	20 000	10 000
	Coal	10 000	30 000
Fluid Bed combustion CFBC, BFBC	Woodchips/peat etc	25 000	60 000
	Woodchips/peat	25 000	25 000
	Paper industry	30 000	70 000
	Wastes household + ind.	20 000	30 000
	Wastes from buildings	15 000	15 000
	Coal (PCFBC)	20 000	20 000
Total		730 000	435 000

In Sweden we have a lot of different grate-fired combustion boilers and incinerators for most different fuels like wastes from households and industry, waste from building materials, sludge from the paper industry, peat, bark, woodchips and chipped tyres. Elderly boilers have a lot of unburnt material in their ashes, but ashes from modern grate boilers hold only 3-5 % unburnt. Burning temperature is about 1 100 °C.

Powder boilers burn less and less coal and more and more peat, pellets from the sawmill industry and woodchips. Due to the high taxes on nitrogen oxides the content of air during combustion is held to a minimum. Therefore the powder boiler ashes can contain a lot of unburnt. The temperature is about 1 200 °C.

Fluid beds are flexible boilers and incinerators. The content of unburnt is mostly very low. Temperature of combustion is about 850 °C. District heating is the main purpose for the Swedish combustion plants even if complementary production of electricity is coming strongly.

An estimation of uses of ashes in Sweden in 2003 is given in table 3.

Table 3  
Estimation of uses of ashes in Sweden 2005

Forestry	14 000 ton Mostly CFBC wood fly ashes
Road building,	20 000 ton CFBC peat/wood fly ashes,
Parking places + other surfaces	40 000 ton MSWI <sup>b</sup> bottom ashes
Parking places +other surfaces	90 000 ton Powder <sup>c</sup> peat/coal + other fly ashes
Surfaces for drying slimes	40 000 ton Fly ashes, some bottom ashes
Filling of former oil storage-cavern	20 000 ton Wastes fly ashes + other CFBC
Covering mine tailings	14 000 ton CFBC fly ashes
Stabilization of hazardous fly ashes	30 000 ton PCFBC <sup>d</sup> coal ashes
Construction material for landfilling	300 000 ton MSWI bottom ashes and other ashes
Other	32 000 ton
Total	600 000 ton

<sup>b</sup> MSWI = Municipal Solid Waste Incineration (grate kiln)

<sup>c</sup> Powder = Powder boiler

<sup>d</sup> PCFBC = Pressurized Circulation Fluid Bed Combustion

Reference: Estimation by C. Ribbing April 2006

## 2. ASHES TO FORESTS

### 2.1 Acid rains and low buffering capacity

In Sweden we are concerned by acidification of the ground from rains containing sulphuric acid and nitric acid, especially in the Southwest part of Sweden. The outtake of timber as well as tops and branches from the forests for production of energy will also contribute to the acidification of the ground. The forests can so far resist the

and lakes are sensitive to it due to low buffering capacity. Models show that when both timber, branches and treetops are harvested, not even mineralogical soils are able to balance the outtake of cationic nutrients. The Swedish National Board of Forestry (2002) strongly recommend recycling of ashes when energy is harvested from forests. This is an important issue as the production of bioenergy must increase in order to reduce the release of climate gases. Heavy metals are allowed in the ashes but not to a higher extent than has already been taken out during one harvest period. The ashes must be matured to disturb the balance of nitrogen in the soil etc as little as possible.

## 2.2 Recycling of ashes

Ashes suitable for recycling to the forest shall have wood as the main fuel. Ashes from trees hold a lot of CaO and less of SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub>. Ordinary mineral soils in Sweden hold a lot of SiO<sub>2</sub>, somewhat of Al<sub>2</sub>O<sub>3</sub> and very little of CaO. As seen in the diagram in figure 1 most bioashes reside between soil and pure woodashes, i.e we can imagine how much of the ashes coming from wood and how much that comes from other fuels as peat and impurities, according to Ribbing and Bjurström (2006). As seen from table 4 pure wood holds heavy metals. Bio fly ashes from grate boilers hold mostly a lot of desired K and P but more than what is allowed of Cd. But the bottom ashes can hold less than 0,75 mg Cd/kg dry weight and are then allowed for agriculture as a complex Ca-fertilizer. Fly ashes from fluid beds are often so diluted that the content of heavy metals is OK but the content of desired nutrients are also less than desired.

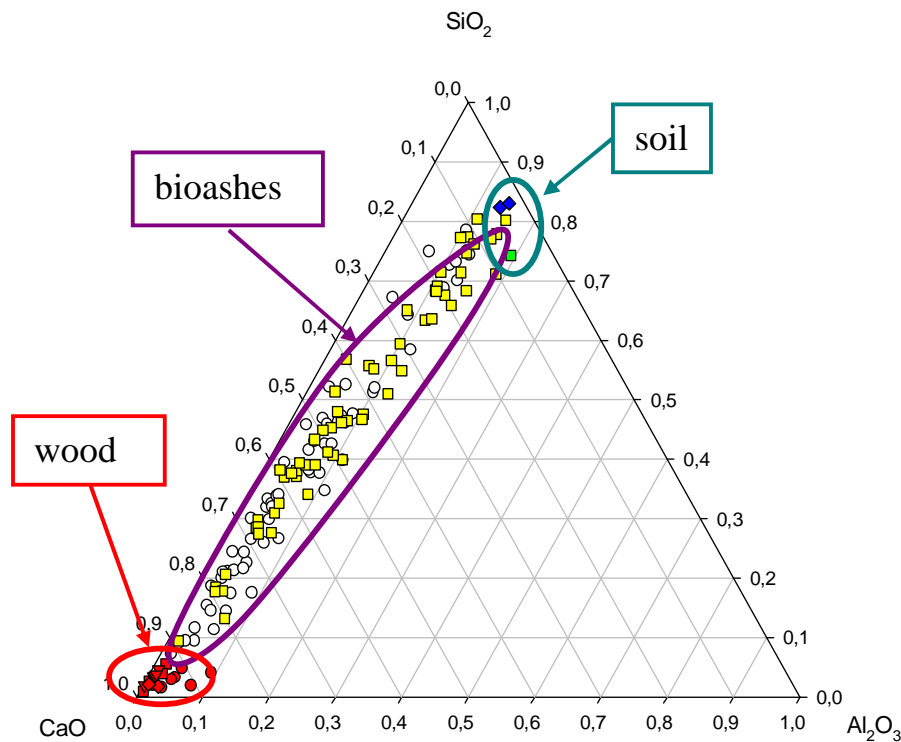


Figure 1. Ternary diagram of the composition of bioashes from a grate boiler.

elements in the unit mg/kg or in percent

mg/kg	Swedish Forest Agency	Pure wood	Bark	Soil	Bottom ashes MSWI	Fly ashes MSWI
Al	-	0,15-0,7 %	0,3-2 %	6-7 %	-	-
As	Ö30	5	2	-	1-80	40-120
B	Ö0,05 %	0,28 %	0,18 %	-	-	-
Ca	× 12,5 %	34-44 %	41-44 %	1,5%	5-10 %	5-10 %
Cd	Ö30	33	27	1	Ö0,5-10	50-1 000
Cr	Ö100	105	43	51	100-1 200	0,01-0,1 %
Cu	Ö0,04 %	490	182	26	250-4 500	50-5 000
Fe	-	0,15-0,8 %	0,3-0,6 %	2-3 %	5-15 %	3,0-6,0 %
Hg	Öß	-	-	-	Ö1	1-30
K	× 3,0 %	14-17 %	13-17 %	2,5 %	0,2-1,5 %	0,4-4 %
Mg	× 2,0 %	3,6-8 %	4,5-6 %	0,6 %	0,5-2 %	1-4 %
Mn	-	1,5-7 %	45 %	0,05 %	0,04-0,1 %	0,08-0,15 %
Na	-	0,3-2 %	0,2-0,5 %	0,05 %	0,8-4 %	1-4%
Ni	Ö70	73	110	18	50-800	100-300
P	× 1,0 %	0,9-2,7 %	2,6-3 %	0,03%	-	-
Pb	Ö300	42	49	14	350-5 000	2 500-12 000
Si	-	0,5-3 %	0,4-0,8 %	34 %	-	-
Zn	Ö 1 000-7 000	6 000	9 000	61	800-6 000	5 000-80 000

Recycling of ashes is actually not as common as one would expect. The Ash program has therefore strived at increasing interest for spreading ashes on forest soils by providing evidence for also short-term profit. The Ash program has contributed with some projects and some of these are presented below:

Thelin (2006) has shown that better health and a higher growth rate are achieved for spruce pine on minerogenic soils in South West of Sweden by spreading ashes and lime.

Hånell and Magnusson (2005) have shown that there are about 200 000 ha of land in Sweden suitable for an economical fertilizing of organic forest soils with ashes. Ashes are often essential to increase the growth rate on organic forest soils.

Bonding of CO<sub>2</sub> can be bigger than the release of climate gases when fertilizing organic forest soils with ashes. It is, however, too early to make any firm conclusions, according to Sikström (2006).

At the website of RecAsh, [www.recash.info.se](http://www.recash.info.se), you will find more information about recycling of ashes to forests, written in both English and Swedish.

### 3. GEOTECHNICAL USES

The large potential market for ashes produced in Swedish combustion plants is in construction, which consumes about 100 million tons of materials each year. The most

roads and surfaces in landfills or as ballast or filler in concrete.

The most important barriers for using the material in e.g. road construction have been the absence of a method to assess the impact of the use of ashes in a construction on the environment, as well as the absence of relevant testing methods for the geotechnical properties of ashes. Both these barriers were addressed in some parallel projects.

### **3.1 Bottom ashes in roads**

The tests used today to determine the geotechnical properties of materials aim primarily at checking if these keep within given specifications. As for other recovered materials, normal material tests must be replaced by somewhat different tests to ascertain that bottom ashes can be used to provide a function. (Arvidsson and Loorents, 2005, and von Bahr et al., 2006)

Dynamic cyclic triaxial tests and other tests have been made on wood based and coal based ashes from grate boilers and MSWI bottom ashes. With material parameters such as low density and good bearing capacity they are particularly adaptable in some construction applications in the sub-base of roads. MSWI ashes have a good bearing capacity. Coal bottom ashes give a very light construction. Wood bottom ashes can have nearly the same bearing capacity as the MSWI ashes if the amount of unburnt is moderately low and the particle size distribution is not too fine. One peat/wood bottom ash from powder combustion had a low bearing capacity. The properties related to moisture may sometimes become critical for grate bottom ashes. The results are given by Arvidsson and Loorents (2005) and by von Bahr et al. (2006).

Earlier studies show that MSWI bottom ashes cause a higher stiffness, which is good, than natural gravel and less stiffness than crushed rock in the sub-base of newly build roads. Now some years later, two test roads show an equal or a somewhat bigger difference to the reference roads with crushed stone, according to falling weight deflectometer tests by Arm (2005).

### **3.2 Bio fly ashes in concrete and as replacement for Portland cement**

All bio fly ashes has too much CaO and too little SiO<sub>2</sub> to be able to meet the demands of EN 450 which is valid for silica rich coal fly ashes from powder combustion. But even bio fly ashes give a tribute to the strength in concrete but are more seen as a replacement of fillers than of Portland cement. The bio fly ashes are self hardening, i.e. there are enough of free CaO and SiO<sub>2</sub> to yield puzzolanic reactions in moist ashes. Unburnt and e.g. Pb and Zn retard the puzzolanic reactions. Unburnt acts otherwise more like ballast in the concrete. Chlorides limit the possibilities for many bio fly ashes, too much chlorides corrode the reinforcing bars.

Fly ashes from a peat/wood powder boiler have been proved to have good rheological properties in concrete. The program has identified an interesting possibility for powder fly ashes as a hardening filler to replace limestone fillers and some Portland cement in concrete with crushed stone as ballast. If the amount of water is increased, good rheological results can also be achieved by fly ashes from fluid bed boilers, according to Sundblom (2004).

ry, both from a grate boiler and a CFBC, has been proved to be able to replace 50% of Portland cement in stoop mining. (Nordström, Holmström and Sandström, 2004) A full scale test has been performed in the autumn of 2005 with successful results.

### **3.3 Fly ashes in roads**

The thesis written by Lahtinen 2001 about frost heave resistant low-volume roads with fly ash from peat/biofuels in the reinforcing layer has been tested in practice with good results. All tested variants of the ashes from different types of combustion plants, with and without mixes of gravel, crushed stone, old road materials and cement, result in stiff and frost heave resistant light weight roads. The roads can be soft and have low bearing capacity if it rains a lot or if it is freezing when the roads are constructed. But they all have been very good after they have dried up. The more gravel, the lesser or no problems in the green stage. Cement shortens the greens stage and increases the frost resistant which can be important if the amount of fly ash is lower than 30 %. The impact on the environment from the test roads have been very low. The road authorities are beginning to be more and more interested in using the good utilities of the fly ashes to stabilize weak materials in the line and be able to use them as good road construction materials. A mixture of 9,5 % fly ash and 0,5 % Portland cement seems to give good results. (Lahtinen et al., 2005)

It takes a very long time to get the first drops of water passing trough a gravel road mixed with fly ashes. That makes us suggest, when making environmental leaching tests in the laboratories, that you should let the fly ashes harden for at least 28 days before the test is performed.

The compressive strength of the tested ashes correlates well with the Kihlstedts formula  $T = k/e^2$  where  $k$  is the specific strength coefficient for the material,  $e$  is the pore number, i.e. the volume of pores divided by the volume of solids (Kihlstedt, 1973). The coefficient  $k$  indicates having about the same value for different ashes, especially after a long time of hardening. But the compaction characteristics differ for different ashes. The differences in compaction explain most of the differences in compression strength for fly ashes, concluded Mácsik et al. (2004)

The Finnish and Swedish results with bio/peat fly ashes have been put together in a handbook containing guidelines for building unpaved roads using fly ashes, written by Munde et al. (2006).

### **3.4 Surfaces**

Both fly ashes and bottom ashes are used to construct surfaces. Mostly they are used for parking places, areas for storing biofuels or for drying sludge from the paper industry. The ashes are often covered by asphalt.

### **3.5 Fluid bed bottom ashes in trenches**

Bottom ashes from fluid bed boilers have been proven to meet the demands for filling materials in district heating pipe trenches. But if the fuels contain flame retardant plastics, the leaching of antimony is a problem, concluded Pettersson, Suér and Rogbeck (2004).

Loss of ignition, LOI, is a reliable method for measuring unburnt material for fresh and dry ashes from powder combustion. But LOI is not a good method for measuring unburnt for ashes that can hold chemically bonded water e.g. in  $\text{Ca}(\text{OH})_2$ ,  $\text{CO}_2$  in form of carbonates as  $\text{Ca}(\text{CO}_3)$ , or chlorides and sulphur. Bjurström and Suér (2006) have shown that TOC, due to EN 13 137, is the best method for measuring unburnt in non-coal ashes.

## 4. LANDFILLS

### 4.1 Liners in landfills

In Sweden many landfills will close during the following 10 to 15 years. Tham and Ifwer (2006) summarize the present use of secondary construction material in waste management with a focus on incineration ash. The overall results show that incineration ash is a suitable material for use in liner constructions, either alone or mixed with sewage sludge. Data from water percolating below the liner has indicated that the liners can meet permeability requirements.

The main thrust in the Ash Programme together with other organisations in this domain is on liners using fly ash and sludge from municipal wastewater treatment. The purpose of the liner is, together with the total construction, to reduce the amount of water through the landfill. Ashes provide the liner with a high pH value that hinders biological degradation of the sludge as well as increase the mechanical stability.

In two parallel alleys by Mácsik et al. (2005) and Carling et al. (2006), projects have investigated mixing proportions between ash and digested sludge on landfills in four pilot surfaces, with satisfactory results. These projects have been complemented with an investigation of the chemical stability of the digested sludge, which stability may be decreased by the high value of the pH. However, the degradation of the sludge was shown to be limited. Wikman et al. (2005) concluded that 50/50 blends of ash and digested sludge, on dry weight, seem to be optimal. It causes a low percolation, none or very low biodegradation, good shear strength, flexibility and is easy to repair and capable of resisting subsidences. The durability is long, at least as long as for most of the alternative methods.

### 4.2 Covering mine tailings

Other types of waste impoundments have been studied in two projects regarding tailings from mining. In the first project, digested sludge is used as support for vegetation on the tailing ponds. The second role filled by the sludge is to prevent oxygen from reaching the sulphide rich tailings. To prevent roots from the vegetation to reach the tailings, an intermediate layer with ash has been placed below the vegetation support layer. The high pH value due to the ashes, its content of salts and its hardness yield an effective barrier. Trials with about a 40 cm bottom layer of fly ashes and 40 cm of municipal sludge seem very promising. Both layers hold water, which prevents oxygen to penetrate the layers down to the tailings. (Greger, Neuschütz and Isaksson (2006)).

m and Karlsson (2006), the effect of covering mine tailings with a mixture of ash and digested sludge on leaching from the tailings has been monitored. The goal for the covering has been reached, i.e. reducing leakage through the surface into the mound and an ugly sterile acid surface has been converted to a green, useful surface as can be seen in figure 2.



Figure 2. Vegetation on the surface of mine tailings that has been covered with ashes and municipal sludge.

## 5. ENVIRONMENT AND CHEMISTRY

### 5.1 Environmental guidelines for use of ashes for construction purposes

The aim with this project by Bendz, Wik et al. (2006) is to get a general environmental recommendation how to use ashes for road construction. It takes in account the total impact of MSWI bottom ashes and ashes from burning biofuel and wastes from construction in roads, including the building and destruction of the roads.

One piece of background information comes from a project that has excavated and analysed an 18-year-old badly maintained MSWI slag-road on heavy metal release. (Bendz, Flyhammar et al., 2006).

The first goal of achieving general environmental guidelines must be to provide a boundary between *ösmall risksö*, i.e. the materials may be used without any restrictions and without any comprehensive permitting procedure, and *örisksö*, where an assessment must be made from case to case. The method to be used and the assessment must be coherent with the principles for polluted soil or the waste acceptance criteria for landfills, even though the physical situations may be different. Guidelines with general limit values for road construction have been proposed. This work has also yielded an unexpected result; leaching of metals from ashes to soil and water is usually not the big

e. However, highly soluble salts may be a cause for restrictions how the construction shall be made. Although one should interpret results from calculations with cautiousness, it seems that dust from the roads settling on vegetables in the vicinity of a road is a more serious problem than leaching of metals. Even so the results indicate the risks are small when MSWI bottom ashes and ashes from building materials are used in roads below a layer of asphalt or concrete. Ashes from wood and peat can also be used in gravel roads at a small risk. But they should not be placed in the top layer as dusting must be avoided.

## ***5.2 Hazardous wastes***

An important issue is the classification of combustion by-products according to the Swedish waste regulations SFS 2001:1063. This requires a deep knowledge on the specification of elements which is a very complex area. A simplified method has been developed by starting from present knowledge of the chemistry and thermodynamics of ashes and its elements. A conservative selection of compounds was then made for the elements found in the analysis. The regulations are then applied on ashes to determine whether they are or are not hazardous. Metals in ashes can occur in many different forms. To make it possible to make classifications, they have suggested that they occur in possible reference substances. They have been chosen in a conservative way so that the hazard for health and environment will not be underestimated. (Adler, Haglund and Sjöblom, 2004)

There are several important questions arising about the limits for ecological toxicity. Too narrow limits can give the astounding result that even pure wood ashes can be regarded as hazardous wastes, especially when EU classified ZnO as an ecotoxic substance from November 1<sup>st</sup> 2005. There are no regulations for H14 regarding the ecotoxic elements and it is well known that it is not the amount but the effect of the elements that makes ashes ecotoxic or not. And in nature, only parts of the metal ions are available to be ecotoxic. Most of them are complex bonded etc. (Olsson and Gustafsson., 2005) E.g. Lindeström (2002) has analyzed how mother Nature can withstand 600 years of ongoing environment disaster from Falun sulphide Mine and the roasting of the ore. Comparing with chemical regulations it might be theoretical correct to say that a sum of 0,25 % ecotoxic elements should make a waste hazardous. But e.g. zink in wet ashes is not in the form of ZnO particles of 0,6 micrometers in pure water and so on. While waiting for regulations for H14, the Ash programme has suggested a recommendation on condition that the reference substances are chosen in a conservative way; if the amount of ecotoxic elements exceeds 2,5 % in the ashes, they shall be regarded as hazardous and we regard this to be a conservative recommendation.

## ***5.3 Allaska database show properties of ashes***

To disseminate information about the properties of ashes, the data obtained within the Ash Programme have been collected in a database, Allaska. This database may be reached on the Internet site of the Ash Programme, [www.askprogrammet.com](http://www.askprogrammet.com), but it is written in Swedish. At the end of 2005, data for 244 samples have been recorded.

In the project SMAK, the selective mobilization of critical elements in ashes was studied. A non-hazardous MSWI slag and a hazardous fly ash from a CFBC incinerator were investigated. Parameters in the experiments were ultrasonic pre-treatment, pre-treatment with carbonation, L/S-ratio, pH, time and temperature. The treatment with optimal parameter settings did not change the classification according to the Council decision on acceptance criteria at landfills of neither ash. For the bottom ash, Sb, Mo and Cr exceeded the limit values for landfilling as inert waste according to the Council decision on acceptance criteria at landfills. Only Cr exceeded the limit value for landfilling the fly ash for non-hazardous landfill. (Svensson et al., 2005).

Kärman et al (2005) has made a model for environmental systems analysis for the beneficial use of ashes in constructions. It was concluded that the developed method for environmental systems analysis has a potential to be a tool for strategic environmental assessments in regional natural resources plans and municipal planning. A weakness with this study is that water emissions are mostly based on laboratory leachate tests while data from full-scale studies would have been more relevant. Full-scale tests are however rare and must be used with precaution since they are very dependant on local conditions.

### ***5.5 Development of hydrogen***

When incineration ashes are wetted, hydrogen can be produced and cause explosions. Arm et al. (2006) have found that it is nearly only metallic alumina that causes the development of hydrogen. Metallic Al is most common in FBC fly ashes and grate bottom ashes. It normally occurs in very low concentrations in grate fly ashes but the ashes can have high amounts if the fuel contains a lot of Al foil. A tool for measuring the gas generation in the laboratory has been developed.

## **6. CONCLUSIONS AND FUTURE RESEARCH**

Among all results obtained in the applied research programme "Environmentally friendly uses of non-coal ashes in Sweden" the following progresses are shown:

- Evidence for the positive effects of spreading ashes on forest growth
- A proposal for environmental guidelines on the utilization of ashes in construction
- A handbook for using non-coal fly ashes in unpaved roads
- Continued development of the use of ashes together with wastewater sludge as a cover for landfills and mine tailings
- Use of ashes from biofuels in concrete
- A method to classify those by-products from combustion that have mirror entries in the EWC as hazardous or non-hazardous.

The Ash Programme has also made it possible to increase knowledge on ashes as materials and their treatment, on quality assurance and on markets for recovered materials.

Today about 50 % of the ashes produced in Sweden are used for different purposes. However, we need to do a lot more work to keep and increase that level. The Ash program will therefore continue for at least three more years. The main focus is to



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ated, monitor experiences in the field, get users of ashes more involved and augment communication. (Bjurström, 2006)

The aim is:

At the end of 2008 there shall be knowledge enough to bring 90 % of the Swedish ashes into environmentally friendly uses.

## **ACKNOWLEDGEMENTS**

I thank all the great people and organisations involved in the Ash programme who has made this interesting program possible.

Most of the references used for this paper are written in Swedish. The reports from Värmeforsk have always a summary written in English and all the diagrams, charts and figures are explained in English as well. These reports can be loaded down or ordered through their website [www.varmeforsk.se](http://www.varmeforsk.se).

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