WASTE MANAGEMENT PLAN

Working for the Dublin Region

Dublin Waste to Energy Project

REPORT ON RESIDUES FROM THERMAL TREATMENT

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1 SUMMARY

This report considers the potential environmental impacts from thermal treatment of waste due to disposal of residues and identifies requirements for mitigation measures.

The following treatment methods are dealt with in the report:

- incineration
- pyrolysis/gasification
- vitrification

The report considers various commercially available technologies for waste incineration, pyrolysis and gasification. The environmental impact of handling residues from pyrolysis/gasification and from incineration is in the same range.

The pyrolysis/gasification technologies considered are recent developments and investment and operating costs for these plants are generally higher than for grate incineration.

The residues generated by thermal treatment are:

- Bottom ash (ash and clinker)
- Air pollution control residues (APC residues) including fly ash, etc.
- Wastewater (in case of wet APC- system)

Bottom ash is usually considered a non-hazardous material and has been re-used in construction, for example as structural layer in roads, parking lots, etc. and as backfill in coastal construction works. Strict environmental requirements on content and leaching of heavy metals may demand further treatment prior to using the bottom ash for construction purposes.

Air pollution control (APC) residues, on the other hand, are classified as hazardous waste due to their high content of heavy metals. These residues need to be stabilised prior to final disposal in a controlled landfill.

Bottom ash can be stabilised by different methods. The most feasible with respect to leaching characteristics and economics are CO_2-stabilisation, the Wesphix-process, and stabilisation with bitumen in asphalt.

New stabilisation methods for APC residues (VKI-process, DHR-process and Ferrox-process) have been developed on pilot scale, but it may take 3 - 4 years before these methods receive approval from the authorities. In the meantime, APC residues may be exported to Norway or Germany for final disposal in mineshafts, where there is minimal risk of heavy metals leaching to the surroundings. Norway also operates a facility using APC residues for neutralising acid industrial wastes.

Bottom ash can be used as a valuable aggregate in the construction industry. The reuse of this material and the residue from other thermal treatment processes has been considered with particular emphasis on possibilities for reuse in Ireland.

2 ENVIRONMENTAL IMPACT FROM RESIDUES GENERATED BY THERMAL TREATMENT

The purpose of this report is to assess the potential environmental impacts from the disposal of residues from thermal treatment of waste and to identify requirements for mitigation measures.

The report describes the environmental impact of disposal and use of bottom ash, APC (air pollution control) residues and wastewater from APC systems from thermal solid waste treatment. The economic and environmental estimates are based on the treatment of between 250,000 to 400,000 tonnes of solid waste per year. The report is based on data from Denmark and other European countries. The possibilities for disposal reuse in Ireland are also discussed.

Ireland and Denmark have many similarities in their socio-economic structure. The economies of both countries are based on light industry and agriculture, neither country has mining industry or indigenous coal production, and the patterns of consumption are relatively similar. Therefore, it is assumed here that the waste compositions in Ireland and Denmark are relatively similar. However, the waste management plan for Dublin aims at 60% source separation of waste, which will remove part of the heavy, non-combustible fraction prior to thermal treatment. The amounts of residues from thermal treatment in Dublin may therefore be less than estimated in this report.

The report considers the environmental impact of residues from the following thermal treatment processes:

- Incineration with dry/semidry air pollution control (APC)
- Incineration with wet APC
- Herhof-process (Refuse derived fuel (RDF) based on dry stabilisation with incineration)
- Pyropleq-process (pyrolysis)
- Von Roll Inova process (vitrification)

Table 2.1 shows the different types of residues produced from each of the thermal treatment processes.

Table 2.1: Different types of residues produced from each of the thermal treatment processes

	Bottom ash	Fly ash	Sludge from wastewater treatment
Incineration:			
Dry/semidry APC system	yes	yes	no
Wet APC system	yes	yes	yes, usually mixed with fly ash
RDF:			
Herhof process	yes	yes	no/yes
Pyrolysis:			
Pyropleq process	yes	yes	no
Vitrification:			
Von Roll Inova process	yes (vitrified clinker)	yes	no

3 HANDLING AND DISPOSAL OF BOTTOM ASH AND APC RESIDUES IN A EUROPEAN PERSPECTIVE

Current European regulations require that bottom ash and APC residues be handled separately.

3.1 DISPOSAL OF BOTTOM ASH

Bottom ash is either landfilled or used in construction works. Re-use of bottom ash is the favoured option for final disposal in most European countries. However, most EU-countries have established environmental standards that bottom ash must meet before its re-use in order to minimise the release of contaminants to the environment. Denmark last year implemented very strict standards for using bottom ash for construction works.

In general, bottom ash may be re-used if it has a low environmental risk as defined by its content of organic matter, loss on ignition, content of heavy metals and/or solubility. Bottom ash not fulfilling the requirements for re-use is deposited in a landfill designed to accept this type of material. Some countries (e.g. France, Switzerland, and Germany) use different types of landfills for different ash qualities.

3.2 DISPOSAL OF APC RESIDUES AND FLY ASH

In comparison to the options for handling and disposing of bottom ash, European countries have more strict regulations for APC residues and fly ash. Most countries treat these materials as a hazardous waste, thus limiting their potential re-use.

All countries are aware of the environmental risks from unstabilised APC residues. Therefore, different stabilisation methods are being developed, which may allow future environmentally safe landfilling of the residues. Some promising stabilisation techniques have been developed in Denmark.

Most European countries today dispose unstabilised APC residues in specially designed landfill cells. Deposition can only take place in a landfill, which is lined and has a leachate collection system. The APC residues are stored in large bags (Netherlands, Germany) or are covered with plastic in order to reduce infiltration (Denmark, Sweden). Germany and Norway also dispose APC residues in underground sites such as old salt or ore mines.

Methods to stabilise APC residues and thus minimising their environmental impact are under development. France, UK and Sweden are working with immobilising contaminants by solidifying with hydraulic binders (e.g. cement). Japan and France are also exploring vitrification alternatives.

Denmark is working on different stabilisation methods using chemical agents such as carbon dioxide or ferro-sulphate.

4 ENVIRONMENTAL REQUIREMENTS FOR RESIDUES FROM THERMAL TREATMENT

The report evaluates the environmental impact of residues by applying the national and international environmental standards for handling, using and disposal of solid and wet residues. The Danish standards are used as a benchmark where applicable, having a well-defined set of values against which to compare the residues. The Danish standards are stricter than the current EU-directives.

The following environmental standards are used:

- EU-directive 2000/76/EF (dated 4. December 2000 on thermal treatment) for general guidelines for handling, using and disposing of residues. Furthermore, limits for wastewater discharge from incineration plants with wet APC-system are taken from appendix IV of the directive.
- Danish regulation (no. 921 dated the 08/10/1996 for requirements of discharge of hazardous chemicals to rivers, lakes and marine recipients) for discharge of leachate to marine recipients.
- Danish regulation (no. 655 dated 27/06/2000 on the use of bottom ash for construction works) for limitation on use of residues.
- Danish regulation (no. 619 dated 27/06/2000 on waste) for classifying hazardous waste.
- Danish regulation (no. 733 dated 31. July 2000 on list of hazardous wastes).

The EU-directive 2000/76/EF gives guidance for handling, reuse and disposing of thermal treatment residues. The directive emphasises the following priority actions:

- The volume and environmental impact of residues from incinerators should be reduced as much as possible.
- The residues should be reused, if feasible.
- Before final disposal, the composition and pollution potential of the residues should be measured. This includes measurements of the content of soluble salts and soluble heavy metals in the residues.

The EU-directive sets limits for the discharge of wastewater from thermal treatment plants. These are shown in table 4.1.

Table 4.1: Limits for discharge of wastewater from incineration processes to a recipient. (EU directive 2000/76/EF)

Contaminant	Limits for wastewater from wet APC treatment [mg/l]
Total amount of suspended matter	30 - 45
Hg (total)	0.03
Cd (total)	0.05
Tl (total)	0.05
As (total)	0.15
Pb (total)	0.2
Cr (total)	0.5
Cu (total)	0.5
Ni (total)	0.5
Zn (total)	1.5
Dioxin and furan compounds	0.3 ng/l

Danish regulation no. 655 on use of residues categorises the residual products according to their total content of heavy metals and/or leaching characteristics. Thus, residues are characterised by their total chemical composition and by batch leaching tests with a liquid/solid ratio of 2. Residues in category 1 (equal to virgin materials) may be used outright for construction purposes. Residues in categories 2 and 3 must meet strict requirements with respect to placement of the residues, distances to water supplies and surface waters, etc.

Table 4.2 shows the limits for each of the categories.

Table 4.2: Danish limits for heavy metals in residues. Total content and concentrations in leachate. Category 1 allows immediate use of residues. Categories 2 & 3 are subject to restrictions for their use. (Danish Ministry of Environment and Energy, 2000 a)

Element	Category 1	Category 2	Category 3
	Total content [mg/kg]		
As	0-20	>20	>20
Pb	0-40	>40	>40
Cd	0-0.5	>0.5	>0.5
Cr (total) Cr (VI)	0-500 0-20	>500 >20	>500 >20
Cu	0-500	>500	>500
Hg	0-1	>1	>1
Ni	0-30	>30	>30
Zn	0-500	>500	>500
	Concentrations in leachate (L/S = 2) [µg/l]		
Cl	0-150,000	0-150,000	150,000-300,000
SO_4	0-250,000	0-250,000	250,000-400,000
Na	0-100,000	0-100,000	100,000-150,000
As	0-8	0-8	8-50
Ba	0-300	0-300	300-4,000
Pb	0-10	0-10	10-100
Cd	0-2	0-2	2-40
Cr (total)	0-10	0-10	10-500
Cu	0-45	0-45	45-2,000
Hg	0-0.1	0-0.1	0.1-1
Mn	0-150	0-150	150-1,000
Ni	0-10	0-10	10-70
Zn	0-100	0-100	100-1,500

No residues may be used when classified as hazardous waste. Table 4.3 shows the values for classification as hazardous waste in Denmark.

Table 4.3: Limit values for hazardous waste. (Danish Ministry of Environment and Energy, 2000 b and Danish Ministry of Environment and Energy, 2000 c)

Element	Limit values for hazardous waste [mg/kg]
Zn	50,000
Pb	5,000
As	1,000
Cd	1,000
Hg	500
Cu	250,000
Ni	1,000

The Danish regulation no. 921 sets limits for discharge to marine environments of leachate from waste disposal and stabilisation processes (see table 4.4). These limits apply after initial dilution of the leachate in seawater (usually by a factor of 10). The quality requirements of the leachate should therefore be fulfilled after initial dilution of the leachate.

Table 4.4: Limits for discharge of leachate to marine environments. (Danish Ministry of Environment and Energy, 1996)

Element	Limiting value for discharge to marine environment [µg/l]
As	4
Cd	2.5
Hg	0.3
Pb	5.6
Cr	1
Cu	2.9
Ni	8.3
Zn	86

5 ENVIRONMENTAL IMPACTS FROM INCINERATION AND DISPOSAL OF RESIDUES

In the following, the environmental impacts from incineration and disposal of residues are considered.

5.1 RESIDUES

5.1.1 Bottom Ash, Siftings and Boiler Ash

Description

Bottom ash is a heterogeneous material, which, depending on the combustion and cooling processes, can occur as a granulate or as lumps mixed with metals and unburned material. (Hjelmar, 2000).

Siftings include sand, small partially burned particles, and hardened metals, which during combustion melt and seep down through the grate. The siftings can either be collected and mixed with the bottom ash, disposed of separately, or be re-fed to the incinerator for combustion.

Boiler ash consists of relatively coarse ash particles, which are separated from the gas stream when this changes direction between two boiler passes. The boiler ash is normally mixed with the fly ash and disposed of as hazardous waste.

The strict Danish standard for the re-use of bottom ash usually requires stabilisation of the ash prior to use.

The bottom ash is stored for 1-6 months in order to improve its leaching characteristics. By storing the bottom ash, pH is reduced from typically 11-12 down to 8-9 when strong alkalised oxides and hydroxides in the bottom ash carbonise. This pH-reduction during storage reduces the leaching of heavy metals. The pH-reduction results in reduced solubility of Pb and Zn, whereas the solubility of Cd increases slightly. The reduced leaching of Pb and Zn from the bottom ash is partially offset by increased leaching of Cd, but the quantity of this is usually not critical (Hjelmar, 2000). Depots for bottom ash storage should have a watertight membrane, controlled collection of rainwater and be equipped with a wastewater treatment plant to treat the percolate for heavy metals.

In some cases washing with water and CO2 stabilisation are applied as final steps in the ash treatment process. The extent of washing and CO2 stabilisation is dependent on the content and leachability of the heavy metals.

The focus on the heavy metals has caused many WTE plants to search for and locate the main sources for the heavy metals and subsequently restrict their appearance in the waste stream. The result has been a noticeable improvement of the bottom ash.

In Denmark the bottom ash is stored on site or off-site depending on the area available at the thermal treatment plant. The area needed for storing bottom ash in Dublin is estimated at approximately 25,000 - 40,000 m² (see appendix 1). In addition 20,000 m² are needed for containers, fences and personnel facilities etc., i.e. a total area of 45,000 - 60,000 m² would be needed.

Composition

The average chemical composition of bottom ash in Denmark is shown in the following table. It is assumed that waste composition in Dublin will result in a bottom ash of similar quality. This composition has been compared to the strictest limiting values (see table 5.1) for using residues in Denmark.

Table 5.1: Average chemical composition of Danish bottom ash and Danish limits for unrestricted use of bottom ash (category 1)

Element/Compound	Chemical composition of Danish bottom ash [mg/kg][a)]	Danish limits for unrestricted use [mg/kg][b)]
Si	270,000	
Ca	71,000	
Fe	68,000	
Al	50,000	
Na	24,000	100,000
K	12,000	
Ti	4,600	
Cu (total)	2,800	500
Zn	2,300	500
Pb	1,600	40
As	12	20
Cd	1.4	0.5
Hg	<0.08	1
Ni	230	30
Cr (total)	330	500

a) Hjelmar, 2000.
b) Danish Ministry of Environment and Energy, 2000a.

Average Danish bottom ash has higher total concentrations of Cu, Zn, Pb, Cd and Ni than the category 1 limits. Thus, average Danish bottom ash can only be used in construction projects, which ensure only a limited contact of bottom ash to the outer environment (such as under a road base).

Amounts

Bottom ash is the major residue fraction from incinerators. The following table shows the estimated amount of bottom ash from a proposed thermal treatment plant in Dublin assuming intake of mixed waste. However, the amount of bottom ash, as shown in table 5.2, may change if the waste is pre-sorted.

Table 5.2: Amount of bottom ash produced from a proposed thermal treatment plant in Dublin receiving 250,000 - 400,000 tonnes waste per year

Residue Type	Average amount [kg/tonnes waste][a)]	Amount from thermal treatment plant in Dublin [tonnes/yr]
Bottom ash	200	50,000 - 80,000

a) Vestforbrænding, 1999.

Environmental Impact

The main environmental risk from disposing and using bottom ash is leaching of heavy metals, salts and organic compounds to ground or surface water. The immediately soluble part of the bottom ash is in an order of magnitude of 3-7% (w/w). (Hjelmar, 1998).

Tests on leachate from disposed bottom ash show that the leachate usually contains significant amount of salts (sulphates and chlorides of Na, K and Ca) and moderate to low contents of heavy metals. The content of soluble organic matter (DOC or NVOC) in the leachate depends, however, on the quality of the combustion (Hjelmar, 2000).

The results of an accumulated serial column- and batch leaching test conducted on bottom ash, with a liquid-solid ratio (L/S) of 0 - 2 and 2 - 10 l/kg can be seen in the following table 5.3 (Hjelmar, 2000).

Table 5.3: Leaching characteristics of Danish bottom ash, which has undergone accumulated serial column- and batch leaching test with L/S = 0-2 and 2-10 l/kg compared to the Danish limits for unrestricted use and the Danish limits for discharge of leachate to marine environments

Component	Accumulated leached chemical amounts with L/S = 0-2 and 2-10 l/kg [a]	Leachate concentration by assuming L/S=10 l/kg	Danish limits for unrestricted use (category 1)[b]	Danish limits for restricted use (category 3) [c]
Unit	[mg/kg]	[mg/l]	[mg/l]	[mg/l]
Ca	5100	510		
Na	350-2000	35-200	100	1500
K	220 - 780	22-78		
Cl^-	2000 - 3600	200-360	150	3000
SO_4^{2-}	3600 - 11,0000	360-1100	250	4000
As	0.22	0.022	0.008	0.05
Cd	<0.0005 - 0.0093	<0.00005 - 0.00093	0.002	0.04
Cu	0.14 - 3.2	0.014 - 0.32	0.045	2
Pb	<0.02 - 0.69	<0.002 - 0.069	0.01	0.1
Ni	<0.004 - 0.05	<0.0004 - 0.005	0.01	0.07
NVOC	74 - 350	7.4 – 35		

[a] (Hjelmar, 2000)
[b] Danish Ministry of Environment and Energy, 2000a.
[c] Danish Ministry of Environment and Energy, 2000b. The limits shall be met after initial dilution in seawater.

Table 5.3 shows that the leachate concentration, from average Danish bottom ash, exceeds the Danish limits for unrestricted use for some of the chemical components whereas the limits for restricted use are not exceeded. Thus, average Danish bottom ash can only be used in construction for projects outside sensitive areas such as areas with groundwater resources or near surface waters.

5.1.2 APC Residues - Dry and Semidry Treatment of Acid Gases

Description

The air pollution control (APC) residues are a mixture of fly ash and residues from treatment of flue gases.

The fly ash is the very fine ash particles collected in an electrostatic precipitator (ESP) or a baghouse filter. In incineration plants with dry and semidry air pollution control, the fly ash is usually not removed before cleaning the flue gases and therefore mixes with the reaction products from the acid gas treatment.

In the dry and semidry processes, dry lime and slaked lime respectively are blown into the hot gases. The lime reacts with the acid gases and the products $CaCl_2$, CaF_2 and $CaSO_4$ are collected as a fine powder together with the fly ash and excess lime in the ESP or filter bag. The amount of excess lime is normally larger in the dry processes compared to the semidry processes. In order to remove mercury and dioxin, activated carbon is often added to the lime powder. This product will also be found in the APC residues.

Composition

The average chemical composition of dry/semidry APC residues from several countries is shown in the following table 5.4.

Table 5.4 compares this composition to the strictest limits (category 1) for using residues in Denmark and to the Danish limits for hazardous waste.

Table 5.4: The average chemical composition of dry/semidry APC residues and the Danish limits for unrestricted use of the residues and for hazardous waste

Element	Chemical composition of dry/semidry APC residue [mg/kg][a)]	Danish limits for unrestricted use [mg/kg][b)]	Danish limits for hazardous waste [mg/kg][d)]
Ca	230,000		
Cl	180,000		
Si	69,000		
Al	26,000		
K	23,000		
Na	17,000		
Zn	15,000	500	50,000
S	15,000		
Fe	12,000		
Pb	5,400	40	5,000
Ti	3,300		
As	170	20	1,000
Cd	300	0.5	1,000
Hg	15	1	500
Cu	710	500	250,000
Ni	94	30	1,000
Cr (total)	180	500	
Dioxin (semidry process)[c)]	580 ng I-TEQ/kg		

a) Hjelmar, 2000.
b) Danish Ministry of Environment and Energy, 2000a.
c) Value from Amagerforbrænding, Denmark. The measured amount is given in the international toxicity equivalent, i.e. equivalent of Seveso-dioxin (2,3,7,8-TeCDD) (Copenhagen County, 2000)
d) Danish Ministry of Environment and Energy, 2000b.

Table 5.4 shows that dry/semidry APC residue from incinerators has a considerably higher total concentrations of Pb, As, Cd, Hg, Cu and Ni than allowed for unrestricted use of residues under Danish law. Furthermore, according to the Danish regulations on hazardous waste[1], the APC residues are classified as hazardous waste due to their high content of lead (Danish Ministry of Environment and Energy, 2000b). APC residues are not reused in Denmark.

Quantities

The following table shows the amounts of dry and semidry APC residue from a proposed thermal treatment plant in Dublin.

Table 5.5: The amounts of dry and semidry APC residues from a proposed thermal treatment plant in Dublin receiving 250,000 - 400,000 tonnes waste per year

Residue Type	Amount [kg/tonnes waste][a)]	Amount from incinerator in Dublin [tonnes/yr]
Dry APC residue	20 - 50	5,000 - 20,000
Semidry APC residue	15 - 40	3,750 - 16,000

a) (Hjelmar, 2000)

[1] APC residues are also classified as hazardous waste in EU-directive 94/904/EC.

Environmental Impact

The APC residues are characterised by a high content of soluble salts, a significant amount of lime, and trace elements/heavy metals. The main environmental problem from the APC residues is the risk of leaching of salts and heavy metals to ground- or surface water. The percolate from deposited fly ash and residues from the APC systems have a very high initial content of salt and significant initial content of trace elements/heavy metals. – Dry/semidry APC residues have the greatest potential for leaching of salts and trace elements compared to the other residues (Hjelmar, 1998).

Dioxin is generated in all combustion processes and many heating processes when chlorides are present. Current standards for thermal treatment specify limits for dioxin emissions. These limits are met by injection of activated carbon into the gas stream. Dioxin adsorbs strongly to particles and adsorption seems not to be affected by changes in pH or redox conditions. It is generally accepted, that dioxin only to a minor extent will leach from disposed APC residue. (Copenhagen County, 2000). The minuscule amount of dioxins that dissolves in the leachate can subsequently be removed in wastewater treatment plants (Noma et al, 1999).

The following table shows the results of an accelerated combined column and batch-leaching- test with dry/semidry APC product with a liquid-solid ratio of 0-25 l/kg. (Hjelmar, 2000) With a L/S ratio of 25 l/kg, leaching for a time period of thousands of years is taken into account, thus representing the total leachable fraction of heavy metals and salts. In table 5.6, the chemical concentration in the percolate is estimated by assuming that most of the chemicals have already leached out after about 100 years, i.e. a L/S ratio of 2 l/kg is assumed.

Table 5.6: Leaching characteristics of dry/semidry APC residue which has undergone accumulated combined column- and batch leaching test with L/S = 0-25 l/kg. The table furthermore shows the concentration in the percolate by assuming L/S = 2 l/kg and the Danish limits for discharge of leachate to marine environments

Component	Accumulated leached chemical amounts with L/S = 0-25 l/kg [a)]	Concentration in percolate by assuming L/S = 2 l/kg	Danish limits for leachate discharge to marine environments [b)]
Unit	[mg/kg]	[mg/l]	[mg/l]
Ca	61,000 - 109,000	30,500 - 54,500	
Na	12,000 - 17,000	6,000 - 8,500	
K	17,000 - 29,000	8,500 - 14,500	
Cl^-	116,000 - 200,000	58,000 - 100,000	
SO_4^{2-}	470 - 3,100	235 - 1,550	
As	<0.02 - 0.04	<0.01 - 0.02	0.004
Cd	0.03 - 0.44	0.015 - 0.22	0.0025
Cu	0.13 - 22	0.065 - 11	0.0029
Cr	<0.6 - 2.4	<0.3 - 1.2	0.001
Pb	220 - 3,400	110 - 1,700	0.0056
Hg	<0.003	<0.0015	0.0003
Ni	<0.2	<0.1	0.0083
Zn	45 - 340	22.5 - 170	0.086
NVOC	71 - 780	35.5 - 390	

a) Hjelmar, 2000 (Danish APC residues)

b Danish Ministry of Environment and Energy, 2000a. The limits assume initial dilution of the leachate in seawater.

Table 5.6 shows that the percolate from dry/semidry APC residues has high concentration of lead, but also of copper, chromium and zinc compared to the Danish limits for leachate discharge to marine recipients.

If APC residues are stored intermediately, prior to final disposal, the percolate must be collected and treated for heavy metals before discharge to a marine recipient in order to meet Danish requirements for wastewater discharge.

For final disposal the residues shall be stabilised and disposed at locations where they are of no harm to the environment (see section 5.3.2).

5.1.3 APC Residues - Wet Treatment of Acid Gases

Description

Several thermal treatment plants use wet treatment of acid gases with subsequent treatment of the wastewater generated from the wet acid gas treatment.

The APC residues from wet gas scrubbing consist of fly ash and residues from treatment of flue gases (sludge from wastewater treatment). The fly ash is collected as a separate residue upstream of the scrubber. The residues from the wet treatment process are collected, when the wastewater from the scrubbers is neutralised and treated for heavy metals/trace elements.

Fly ash and sludge may be handled separately or mixed together prior to disposal (the "Bamberg model"). The latter solution reduces the water content of the sludge and the leaching of trace elements from the fly ash.

The wastewater is traditionally treated by adding lime mixed with an organic sulphide compound (often tri-mercaptotriazin) to the water. The process produces wastewater and chemical sludge with high contents of trace elements/heavy metals.

The following table 5.7 shows the chemical composition of the fly ash and sludge from wet treatment of gases. The concentrations are based on analyses from several countries.

Table 5.7: The average chemical composition of wet APC residue and the limits for unrestricted use of residues

Element	Chemical content in fly ash [a]	Chemical content in sludge [a]	Danish limits for unrestricted use [b]
Unit	[mg/kg]	[mg/kg]	[mg/kg]
Ca	107,000	150,000	
Cl	74,000	36,000	
Si	160,000	78,000	
Fe	25,000	54,000	
Al	71,000	28,000	
K	36,000	3,900	
Na	31,000	1,900	
Zn	28,000	31,000	500
Pb	11,000	11,000	40
Ti	8,700	2,600	
Cu	1,200	1,200	500
Hg	8	650	1
Cd	390	630	0.5
Ni	140	62	30
As	130	89	20
Cr (total)	650	240	500
Dioxin [c]	1240 ng I-TEQ/kg		

[a] Hjelmar, 2000.
[b] Danish Ministry of Environment and Energy, 2000b.
[c] Value from Vestforbrænding, Denmark. The amount measured is shown in the international toxicity equivalent, i.e. equivalent of Seveso-dioxin (2,3,7,8-TeCDD) (Copenhagen County, 2000)

The table shows that fly ash and wet APC residues have considerably higher total concentrations of Zn, Pb, Cu, Hg, Cd and Ni than the Danish limits for unrestricted use.

Amounts

The following table 5.8 shows the amount of wet APC residue (fly ash and sludge mixed together) from a proposed thermal treatment plant in Dublin.

Table 5.8: Amount of wet APC residue from proposed thermal treatment plant in Dublin receiving 250,000 - 400,000 tonnes waste per year

Residue Type	Amount [kg/tonnes waste][a)]	Tonnes/yr
Fly Ash	10 - 30	2,500 - 12,000
Sludge	1-3	250 - 1,200
Wet APC product [2]	11 - 33	2,750 - 13,200

Environmental impact

The APC residues from the wet treatment processes are like the APC residues from dry/semidry treatment characterised by a high content of soluble salts and a significant amount of trace elements/heavy metals. However, the APC residues from wet treatment leach significantly less heavy metals than residues from the dry/semidry treatment. (Hjelmar, 2000).

The following table 5.9 shows the results of an accelerated combined column and batch-leaching-test with wet APC residue[3] with a liquid-solid ratio of 0-25 l/kg. (Hjelmar, 2000) With a L/S ratio of 25 l/kg, leaching for a time period of thousands of years is taken into account, thus representing the total leachable fraction of heavy metals and salts. In table 5.9, the chemical concentration in the percolate is estimated by assuming that most of the chemicals already have leached out after about 100 years, i.e. a L/S ratio of 2 l/kg is assumed.

Table 5.9: Leaching characteristics of Danish wet APC residue which has undergone accumulated combined column- and batch leaching test with L/S = 0-25 l/kg. The table furthermore shows the concentration in the percolate by assuming L/S = 2 l/kg and the Danish limits for discharge of leachate to marine environments

Component	Accumulated leached chemical amounts with L/S = 0-25 l/kg[a)]	Concentration in percolate with L/S = 2 l/kg	Danish limits for discharge of leachate to marine environments[b)]
Unit	[mg/kg]	[mg/l]	[mg/l]
Ca	17,000	8,500	
Na	21,000	10,500	
K	21,000	10,500	
Cl^-	56,000	28,000	
SO_4^{2-}	32,000	16,000	
As	0.28	0.14	0.004
Cd	<0.0006	<0.0003	0.0025
Cr (total)	0.52	0.26	0.001
Cu	<0.004	<0.002	0.0029
Pb	<0.0011	<0.00055	0.0056
Zn	0.15	0.075	0.086
Ni	<0.2	<0.1	0.0083
Hg	<0.001	<0.0005	0.0003
NVOC	78	39	

a) Hjelmar, 2000
b Danish Ministry of Environment and Energy, 2000a. The limiting value is given prior to initial dilution of the leachate with seawater.

[2] Wet APC product in this context is a product with fly ash and sludge mixed together.

Table 5.9 shows that the percolate from wet APC residues has relatively high concentration of arsenic and chromium compared to the Danish limits for discharge of leachate to marine environments.

If APC residues are stored intermediately, prior to final disposal, the percolate shall be collected and treated for heavy metals before discharge to a marine recipient in order to meet the Danish requirements for wastewater discharge.

For final disposal the residues shall be stabilised and disposed at locations where they are of no harm to the environment (see section 5.3.2).

5.2 WASTEWATER

As described in section 5.1.3, wastewater generated in the wet APC system has to undergo treatment.

Amounts

The following table shows the amount of wastewater generated from a proposed thermal treatment plant in Dublin using a wet APC process.

Table 5.10: Amounts of wastewater produced from a proposed thermal treatment plant with wet treatment

Residue Type	Amount [m^3/tonnes waste][a)]	Amount from thermal treatment plant in Dublin [m^3/yr]
Wastewater	0.3 - 0.5	75,000 - 200,000

a) (Hjelmar, 1998)

Environmental Impacts

The wastewater must be treated to meet the limits set in EU Directive 2000/76/EF from 4. December 2000 before it is discharged to a recipient (see sections 3.1. – Section 5.3.3 describes the means of treating the wastewater.

5.3 OPTIONS FOR HANDLING, USE AND DISPOSAL OF BOTTOM ASH, APC RESIDUES AND WASTEWATER

APC residues and wastewater from wet APC systems pose a potential risk to the environment. However, different options for reducing the risk are available by treating the incineration residues prior to use or disposal and by treating the wastewater prior to discharge. The stabilisation techniques described in this section are based on the different methods used in Europe.

The main objectives of treating the incineration residues are:

- reduce the potential leaching of elements and compounds before re-using bottom ash or disposing APC residues.
- improve the functional characteristics of the residues, e.g. the compressive strength and mechanical cohesive force before using or disposing the incineration residues.
- extract specific components from the residues prior to use.

The most significant treatment principles for residues in general are:

- Separation processes.
- Stabilisation processes.
- Thermal treatment processes.

These processes and their advantages and disadvantages are described in the following section for each type of incineration residue.

5.3.1 Bottom Ash

General

Bottom ash has been used extensively in the past in Denmark and elsewhere in Europe, particularly for road construction. As an example, the Danish incineration plant Vestforbrænding disposes of its bottom ash to a number of small projects such as construction of parking lots, roads, bicycle paths etc. where it is used as base material. Bottom ash is also used in larger projects such as land reclamation for an extension of Copenhagen harbour (150,000 tonnes of bottom ash have been used in this ongoing project) and for a similar project in Nakskov. There is a preference for using the bottom ash in larger projects since the environmental authorities must approve the use of ash in each project.

EU directive 2000/76/EF on waste incineration as implemented in the Danish regulation 655 on use of incineration residues, restricts the use of bottom ash in order to protect sensitive areas.

General quality criteria recommended for bottom ash to be used for construction purpose are as follows:

- The bottom ash shall have low contents of TOC, heavy metals, trace elements, easily soluble salts and potentially toxic organic matter in order to protect the environment.
- Hard, well-graded ash with low content of fine particles and good compressive strength is preferred.

To achieve this the bottom ash has to undergo further treatment.

Separation

Separation is the simplest of all the treatment processes. The bottom ash typically contains 7-10% by weight of scrap iron and 1-2% by weight of non-magnetic metals. The metals may be separated before using the ash. Standard treatment of bottom ash from Danish incinerators includes coarse sieving, magnetic separation and additional screening at 45 - 50 mm. In some cases, lumps of bottom ash are crushed before the final screening. At some incinerators, the processes mentioned above are supplemented with an eddy-current process collecting non-magnetic metals from the ash. The treatment of the bottom ash may also begin with a washing process where a significant part of the soluble salts (especially the chlorides) are transferred to the liquid phase.

The environmental problems related to the use of this method are leaching of heavy metals from the bottom ash and discharge of wastewater if the ash is washed.

Stabilisation

Stabilisation processes reduce the leaching of heavy metals and are applied to the bottom ash prior to use. Stabilisation can be a physical/mechanic stabilisation or chemical stabilisation.

Chemical stabilisation adds hydraulic binding agents, e.g. cement (5-10% w/w) and other additives to the bottom ash. This produces a product with great strength and slower leaching properties. (Hjelmar, 1998).

The use of bitumen as a pore-filling additive in bottom ash blended asphalt is an example of physical/mechanical stabilisation. The use of bitumen reduces the leaching of inorganic components from the ash and increases its strength.

The Wesphix-process is an example of chemical stabilisation of bottom ash. Phosphoric acid is added to the bottom ash, thus binding most of the trace elements, especially Pb and Cd. (Hjelmar, 1998).

Furthermore, the bottom ash may be stabilised by means of CO_2-stabilisation, where the heavy metals in the bottom ash are bound to carbonates (Faulstich et al, 2000).

The carbonisation that occurs when the bottom ash is stored can also be designated as a sort of chemical stabilisation. (Hjelmar, 1998).

Thermal treatment

Thermal treatment of bottom ash uses different temperature levels. Sintering occurs typically at 400 - 600º C, when rearrangement of chemical solid phases takes place in the bottom ash. This results in reduced accessibility for components to leach. (Hjelmar, 1998).

Melting/vitrification occurs at 1100 - 1500º C. If aggregates are added in the vitrification process, an amorphous phase is generated. Otherwise, crystalline or heterogeneous products are produced. Leaching from these products occurs very slowly.

The entire mass balance has to be considered when evaluating thermal treatment, since some of the ingredients of the bottom ash will evaporate and need to be treated again. Thermal treatment normally ensures that the bottom ash does not contain any toxic organic compounds. (Hjelmar, 1998).

Thermal treatment of bottom ash is usually very expensive and energy demanding compared to other treatment methods available.

The leaching of heavy metals from the bottom ash matrix is best reduced by means of thermal treatment compared to the other methods mentioned. However, air emissions of CO_2 and NO_x have to be taken into account due to the use of fuel in the process.

Landfill Solution

Bottom ash may be disposed of in landfills if its use is not environmentally acceptable or immediately possible. Usually bottom ash is stored in landfills only on a temporary basis.

Bottom ash may normally be disposed without any measures of stabilisation. EU-directive no. 99/31/EF dated the 26. April 1999 classifies bottom ash as non-hazardous waste. This means that the disposal site has to fulfil requirements with respect to permeability and thickness of bottom layers (clay layer and plastic liner) in order to protect the groundwater. Furthermore, leachate from the site must be collected. The leachate can be discharged directly to a recipient if it meets the requirements for leachate discharge.

5.3.2 APC Residues

At present, no environmentally safe methods for use of APC residues have been developed. Due to the risk of leaching of heavy metals and salts, the APC residues require extensive treatment prior to disposal in an environmentally proper way.

The following describes methods of handling, use and disposing of APC residues:

Natural stabilisation implies disposing the APC residues without any pre-treatment measures at all. Salts and heavy metals, which leach from the residues, must be collected and the leachate treated. Depending on topcover, layer thickness etc. it will take approximately 100 years before leaching of L/S = 2 l/kg is achieved by means of natural precipitation. Leachate treatment will therefore be required for a very long time. Natural stabilisation is not considered a feasible stabilisation method for APC residues.

Forced stabilisation involves washing of the APC residue in-situ, which accelerates the dissolution of salts and heavy metals. Forced stabilisation is continued until the contents of salts and heavy metals in the leachate have reached a prescribed level (in Denmark according to regulation no. 921), after which the landfill can be operated passively. The washing water from the forced stabilisation must be collected and treated and the residues from the treatment should be suitable for disposal at a special waste disposal site for hazardous waste, since the heavy metals will be bound to heavily soluble compounds. Thus, the risk of leaching from landfilling of the APC residues is reduced. Furthermore, the time frame of percolate treatment is reduced by means of this method compared to natural stabilisation.

The environmental risks connected with leaching of salts and heavy metals from the stabilised residues in the passive phase of both natural and forced stabilisation are relatively high compared to other stabilisation methods. There are technical risks with forced stabilisation. Thus, forced and natural stabilisations are not considered sustainable options.

Stabilisation

A number of different stabilisation methods for APC residues are available or at the experimental stage.

Cement based stabilisation mixes the APC residues with cement. This is followed by one of the following three methods:

1. Casting of blocks, which are disposed after hardening.
2. Direct disposal in landfill cells, where the mixture is allowed to harden.
3. Use of the mixture for reinforcement or sealing of mine passages.

Cement based stabilisation reduces the contact between water and APC residue and minimises the leaching of salts and heavy metals from the residues. Experience with this method has been gained in Germany, Netherlands, Sweden and Switzerland. – Methods no. 1 and 2 may cause environmental problems if leaching of salts and heavy metals occur due to cracks forming in the cement in the long term. These methods are therefore not considered feasible.

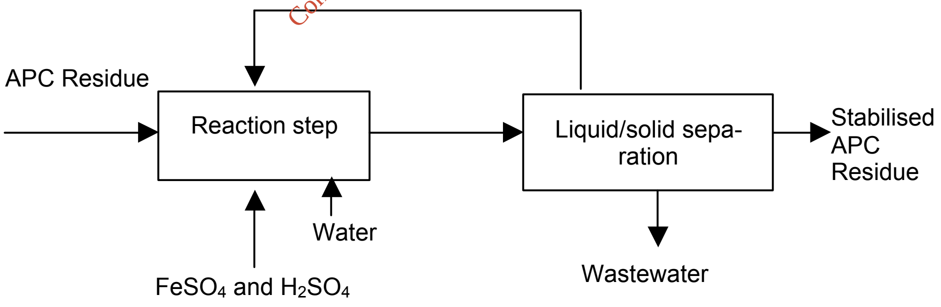
Transporting residues abroad (to Germany or Norway) for sealing mine passages (method 3) will produce some emissions to the air from the use of fuel. However, the impact on the environment is considered minimal.

Chemical Stabilisation

The ferrox process is based on chemical binding of heavy metals by means of ferrous-sulphate.

The ferrox-process is under development in Denmark. A pilot plant was built in 1999 and this method is expected to be ready for full-scale implementation around 2004.

The process diagram below gives an overview of the principles behind the method.



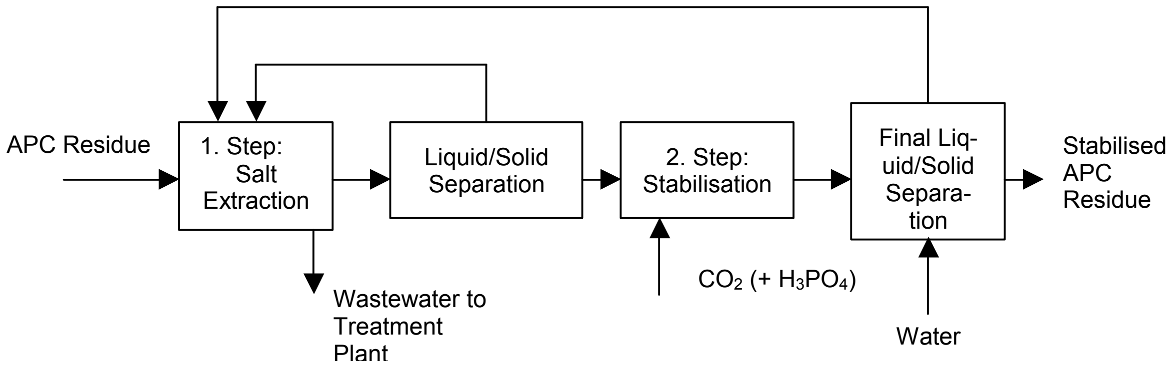
Ferrous-sulphate is mixed with APC residues and a part of the salt contents of the residues is dissolved in the mixture. The ferrous-ions in the ferrous-sulphate solution precipitate and adsorb to the residue particles. These iron compounds adsorb both the heavy metals that dissolve in the liquid and the heavy metals contained in the residue particles. By aerating and stirring the process water, the iron compounds are oxidised to iron oxides, which are stable and strongly bind heavy metals. Thus, heavy metals are unlikely to leach from the treated residues. Finally, the process water with high salt concentrations is separated from the residues. The stabilised APC residues may subsequently be disposed and the wastewater discharged to a marine recipient after treatment.

Leaching from the stabilised residues and discharge of the wastewater are considered the main environmental risks. The ferrox method is, however, thought to attain the best degree of stabilisation with existing technology.

The VKI- and DRH processes[5] are both based on stabilisation of APC residues with carbon dioxide.

These treatment methods have been tested on pilot-scale and it is expected that the methods will be fully implemented around 2004.

The process diagram below gives an overview of the principles behind both methods.



Both methods initially wash the APC residues in order to dissolve salts and heavy metals, after which the process water is separated from the residues. In both methods carbon dioxide is mixed with the residues and in the VKI-process phosphoric is added. This causes the heavy metals to react with the heavily soluble carbonate- (and phosphate) compounds and reduces pH. The result is a more stable product with better leaching properties. The process water from the stabilisation step is reused in the initial washing of the residues and the wastewater can be treated to allow discharge to recipients under EU-directive 2000/76/EF.

Both methods produce three kinds of end products: stabilised APC residues; sludge from wastewater treatment, ready for disposal; and wastewater to be released to a marine recipient. Leaching of chemical components from the stabilised APC residues and discharge of treated wastewater are the main environmental concerns with respect to both processes. However, the degree of stabilisation of residues achieved in both processes is the best attainable with present technology.

Final Disposal in Mine

This method is based on cement stabilisation of the APC residues (see description above) with subsequent injection into mine passages under the groundwater table.

Several mines in Germany receive and handle APC residues in a responsible way. The main environmental impact from final disposal in mine passages is the emissions to the atmosphere resulting from the transport of the residues.

Table 5.11 shows the total emissions from transporting APC residues from Dublin to Germany. The quantities for emissions to the atmosphere are shown in appendix 2 whereas appendix 3 shows the emissions to the air of CO_2, NO_x particles, CO and hydrocarbons for transportation to Germany for all methods of transport.

Table 5.11: Total air emissions from transporting APC residues to Germany

	Transport to Germany	
Emissions	**CO_2 [tonnes/yr]**	**NO_x [tonnes/yr]**
Total emission to air from truck transport	938.7	21
Total emission to air from coaster transport	483.3	19

[5] VKI = Vand Kvalitets Instituttet (Water Quality Institute)
DRH = Dansk Restprodukt Håndtering (Danish APC Management System)

Final disposal in mine shafts is considered not to affect the groundwater resources since disposal occurs at depths around 1000 m below ground surface, where the high water pressure will prevent/limit leaching.

There may also be abandoned mines in England that could receive the residues. At present this is not practised in England and further investigations are needed to determine whether this may become a feasible option in the future.

Use/Final Disposal

This method is based on neutralisation of the residues with waste acid and final disposal in a limestone quarry on the Langøya Island in Oslo Bay in Norway. In Norway, the residues are mixed with sulphuric acid and iron sulphate, which will adsorb the heavy metals from the residues. The mixture of acid and residues is subsequently disposed in a closed limestone quarry. Experience with this method is gained from residues from Danish thermal treatment plants. The major impact on the environment is the emissions to the atmosphere from the transportation to Norway.

The following table shows the approximate air emissions from transporting the residues from Dublin to Oslo. Appendix 3 shows the air emissions for transportation to Norway for all methods of transport.

Table 5.12: CO2 and NO_x emissions from transporting APC residues to Norway

	Transport to Norway	
Emissions	**CO_2 [tonnes/yr]**	**NO_x [tonnes/yr]**
Total emission to the air by sea transport	398.7	17

A comparison of the emissions to the atmosphere from transporting residues to Norway or Germany shows that emissions are less for transport to Norway.

Discharge of treated wastewater to the marine recipient at Oslo bay and leaching of contaminants from disposed residue represent only a marginal risk to the environment since the disposal site at Langøya has no or only very limited hydraulic contact to any aquifers. (COWI, 2001a).

5.3.3 Wastewater from wet APC system

On-site wastewater treatment for thermal treatment plants with wet APC systems includes the precipitation and removal of heavy metals. After treatment the wastewater is discharged to either a marine recipient or via the sewage system to a municipal sewage treatment plant. Usually, discharge to a natural recipient will require better treatment than discharge to a municipal sewer, because a modern municipal sewage treatment plant with mechanical, biological and possibly chemical treatment performs an effective final removal of most heavy metals.

When discharging to a marine recipient, an environmental impact assessment is usually required to evaluate the environmental consequences for the recipient. Discharge to a freshwater recipient is usually not an acceptable option, as the salt concentrations in the wastewater are fairly high.

Discharge to a municipal sewer requires an assessment of the consequences of both the salt and heavy metal content on the municipal sewage treatment process. The salt content may have an inhibiting effect on the microbiological processes, and the heavy metals in the surplus sludge will increase. If the sewage sludge is used for agricultural purposes, this increase may become critical.

To meet the standards set in the EU-directive, the wastewater should be treated for heavy metals at the thermal treatment plant, either by means of traditional precipitation treatment or by use of fluid bed treatment.

Traditional precipitation treatment involves:

- pH adjustment with $CaCO_3$ in order to increase pH and thereby decrease the mobilisation of heavy metals
- Gas-stripping

- Precipitation of heavy metals with calcium oxides and precipitation of mercury with TMT
- Flocculation
- Lamella separation
- Sand-filter where residual lumps are separated
- Final treatment in the form of activated carbon filters, ion exchange, membrane filtration etc. is sometimes added

Traditional wastewater treatment is relatively expensive with respect to both construction and operation costs. (COWI, 2000b)

Alternatively, fluid bed treatment may be used. This technology is based on adsorption of heavy metals to ferric/manganese oxides in a fluid bed reactor. Iron/manganese is oxidised under controlled conditions by adding oxygen, hydrogen peroxide or potassium hydroxides to the water. This produces a surface coating of iron/manganese hydroxide on a medium (typically quartz sand) to which the heavy metals adsorb. The fluid bed process is combined with a filtration step to separate particulate (containing heavy metals) from the wastewater. (COWI, 2000b).

A fluid bed process usually obtains a better treatment than the traditional precipitation process.

Fluid-bed wastewater treatment is relatively expensive to build, but inexpensive to operate. (COWI, 2000b).

6 CONCLUSION ON IMPACTS FROM WASTE INCINERATION RESIDUES

This chapter provides a short summary on the environmental impacts from incineration residues and a comparison between the different options for handling, use and disposal of residues.

The main strategy in EU is that bottom ash shall be stabilised before use, whereas APC residues shall be stabilised before final disposal in a controlled landfill. In some EU member countries, such as Denmark, there is a move towards stricter requirements regarding to the locations, where bottom ash may be reused.

Some stabilisation methods for APC residues have been developed based on the use of chemicals, but these methods are not expected to be approved until 4-5 years.

6.1 BOTTOM ASH

The more stringent requirements regarding bottom ash is relatively new and the stabilisation processes to meet these requirements are therefore in the development phase. Only limited information is available on these processes.

Table 6.1 provides a general comparative evaluation of the alternative stabilisation methods for bottom ash with respect to environmental impact, time horizon and cost of the methods.

Table 6.1: General comparative evaluation of alternative methods of stabilising bottom ash - is below average, 0 is average and + is better than average

	Stabilisation with cement	Stabilisation with bitumen	CO_2 stabilisation	Wesphix process	Thermal treatment
Time horizon	0 - 1 year	0 - 1 year	1 - 2 years	1 - 2 years	0 - 1 year
Environmental impact	-	0	0	0	+
Economy	+	+	0	0	-

Thermal treatment of bottom ash is very expensive and not a feasible option at present. Stabilisation with cement is not considered an acceptable option, as the cement undergoes ageing processes and may crack resulting in leaching of heavy metals. This leaves stabilisation with bitumen in asphalt, with CO_2 or through the Wesphix process as the most feasible option.

6.2 APC RESIDUES

Better waste separation and other changes of the waste composition may in the future result in APC residues that are suitable for reuse. However, at present the APC residues must be treated prior to final disposal because of their high content of heavy metals and salts.

Table 6.2 summarises the principles, environmental impacts, time horizon and costs of the stabilisation methods for APC residues mentioned in section 5.3.2.

The leachate from APC residues, stabilised by means of forced stabilisation, has a higher concentration of heavy metals than when the VKI, DRH or the Ferrox methods are used. Usually, forced stabilisation is only applied to APC residues already disposed. Otherwise, forced stabilisation is not considered a feasible option.

Table 6.2: Alternative methods for handling and final disposal of APC residues

	Ferrox-process	VKI/DRH-processes	Export to Germany	Export to Norway
Time horizon	Fully developed around 2004	Fully developed around 2004	App. 12 months	App. 12 months
Environmental impact	Min. leaching in passive operation	Min. leaching in pas-sive operation	Air emissions from transportation	Air emissions from transportation, CO_2 emission from neutralisation
Construction costs	IR£ 5-10 M	IR£ 5-10 M	None	None
Operating costs	60 IR£/tonne	70 IR£/tonne	100 IR£/tonne	100 IR£/tonne
Other costs	Final disposal	Final disposal	None	None

6.2.1 Short-term Solutions

Until the stabilisation methods presently under development are approved and operational the only solution appears to be export of the APC residues to Norway or Germany. The APC residues may also be stored temporarily in Ireland until a suitable stabilisation method is approved.

The cost of the export option may be competitive with stabilisation by means of the Ferrox-, VKI- or the DRH- processes, when taking the cost of local, final disposal into consideration.

Transporting the waste to Norway or Germany will result in air emissions of CO_2, NO_x, CO and hydro-carbons due to the use of fuel. The potential of leaching of heavy metals and salts in the receiving countries is considered minimal in both countries.

6.2.2 Long-term Solutions

In the long term, when the following processes have obtained the necessary approvals, these may be the most acceptable processes with respect to environmental impact:

- The VKI/DRH- processes
- The Ferrox-process

These processes all offer effective stabilisation and the costs of the processes are considered similar.

6.2.3 Wastewater Treatment

Technology is available to treat the wastewater from incineration plants with wet APC systems to the standards required in EU 2000/76/EF (see section 5.3.3).

7 ENVIRONMENTAL IMPACT FROM PYROLYSIS

Pyrolysis is a thermal treatment technology, which transforms waste into a gas and a char fraction. It is generally followed by a combustion step. Some plants are in operation or under development in Europe and may become commercially available. The Pyropleq (Technip) method, which is dealt with in section 8, is a pyrolysis process to be used in combination with other treatment processes.

The first step in the pyrolysis process produces less dioxins and furans due to the absence of oxygen. If the gas and char are subsequently burned dioxin and furans will be produced. A pyrolysis process may generate less flue gas and have better retention of contaminants in the ash. However, the oil/tars contain toxic and carcinogenic compounds, which may be partially or fully decomposed during the ensuing combustion process.

The following sections provide the general amounts and environmental impacts from the products of pyrolysis processes.

7.1 GASES AND LIQUIDS

Hot gas and/or liquids are formed in the pyrolysis process and secondary catalytic processes.

The following table shows the amounts of gas and liquids that could be produced from a pyrolysis plant in Dublin.

Table 7.1: Amounts of gas and liquids from a proposed pyrolysis plant in Dublin. receiving 250,000 - 400,000 tonnes waste per year

Product	Percentage (w/w)[a)]	Amount [tonnes/yr]
Gas and liquids	50 - 60%	125,000 - 240,000

a) M.C. O´Sullivan & COWI, 1998

The gas may be used as a fuel in kilns or in boilers to generate steam for electricity and heat production.

7.2 CHAR

Char (coke) is formed in the pyrolysis process and consists of carbon and ash. It usually contains a considerable quantity of glass and metals.

The following table shows the amounts of char produced from a proposed pyrolysis plant in Dublin.

Table 7.2: Amounts of char from a proposed pyrolysis plant in Dublin receiving 250,000 - 400,000 tonnes waste per year

Product	Percentage (w/w)[a)]	Amount [tonnes/yr]
Char	30 - 40%	75,000 - 160,000

a) M.C. O´Sullivan & COWI, 1998

The char may be used as a fuel (similar to coal), but the combustion plant will need a flue gas scrubbing system similar to an incineration plant. As an alternative the char may be used as a low quality activated carbon for wastewater and flue gas cleaning for removal of mercury and dioxin. The poor quality compared to commercially activated carbon products may though prevent its marketability.

7.3 RESIDUES

The residues consist of ash, glass and metals with a considerable quantity of carbon mixed in.

The following table shows the amounts of residues that could be produced from a pyrolysis plant in Dublin.

Table 7.3: Amounts of residues from a proposed pyrolysis plant in Dublin receiving 250,000 - 400,000 tonnes waste per year

Product	Percentage (w/w)[a)]	Amount [tonnes/yr]
Residues	10%	25,000 - 40,000
Inerts from the char	10%	25,000 - 40,000
Total	20%	50,000 - 80,000

This assumes that there is a market for the char as a readily useable fuel. Otherwise the amount of residues to landfill will be higher.

If the residues are landfilled the main environmental impact is leaching of heavy metals and salts from disposal sites of residues.

7.4 OPTIONS FOR HANDLING, USE AND DISPOSAL OF RESIDUES

The char and residues from pyrolysis usually retain more heavy metals than the residues from incineration since the heavy metals are more closely bound to the carbon of the char compared to the mineral ash in the incineration residues.

Char may be used as a fuel or as activated carbon if of high enough quality. Alternatively, the char may be disposed of in worked out mines (Germany).

The char will require the same treatment methods as mentioned for incineration residues for further stabilisation (see chapter 5).

Because the amount of char is low for certain plastic and oil containing wastes and tyres and shredder waste pyrolysis may be suitable for the treatment of such pre-sorted waste fractions.

8 ENVIRONMENTAL IMPACTS FROM THE PYROPLEQ-PROCESS

The Pyropleq process may combine pyrolysis with an existing or proposed coal fired power plant.

One full-scale plant designed for 35,000 tonnes/yr and applying some of the features later developed into the Pyropleq system, is in operation in Germany. The first Pyropleq plant is presently under construction in combination with a coal fired power plant.

8.1 RESIDUES

The outputs of the Pyropleq process are gas and char (coke) fuels, metallic residues and coarse inert matter. The solid fractions will be partially mixed.

The amount of solid fraction generated from a proposed Pyropleq plant in Dublin is shown in the following table. The information is calculated based on a special waste stream (taken from a German plant under construction). It is not representative of Dublin municipal solid waste.

Table 8.1: Amount of solid residue from the pyrolysis process of a proposed Pyropleq plant in Dublin receiving 250,000 - 400,000 tonnes waste per year (COWI, 2001b)

Residue type	Amount (kg/tonne) [a)]	Amount in Dublin [tonnes]
Fe metals	67	16.750 - 26.800
Non Fe metals	16	4000 - 6400
Inert material	67	16.750 - 26.800

[a)] Depending on the content in the processed waste.

8.2 OPTIONS FOR HANDLING, USE AND DISPOSAL OF RESIDUES

Thermal waste treatment using the Pyropleq process is in the construction phase and no experience has yet been gained.

Pyropleq claims some advantages over incineration with respect to better use of residues. The metallic residues and coarse inert matter may be recovered and recycled to a high quality. It should be noted, however that the separation of inerts and coke is incomplete. The char and fuel gases generated in the pyrolysis may subsequently be combusted in an existing, adjacent coal-fired power plant with high electricity generating efficiency. It is unknown whether the acid content in the gases will contribute to high temperature corrosion of the boiler. The generation of dioxins and furans in the combustion process may demand the addition of more sophisticated pollution control equipment to the power plant boilers.

Assuming that the plant can be combined with an existing coal-fired power station and use its infrastructure and mechanical plant (boilers, turbines, gas cleaning plant, etc.) the additional capital investment and operation costs are relatively low (Bracker, von Christen & Stadtmüller, 1998).

9 VON ROLL INOVA - PROCESS

The von Roll Inova process was developed as an improved incineration process. The residues are treated to become marketable (metal alloys) or readily disposable (vitrified ash and clinker) with little environmental impact.

The Von Roll Inova process includes:

- sub-stoichiometric combustion of waste on a grate using oxygen as combustion air
- total oxidation and melting of the ash using oxygen injection (Recycled Clean Products (RCP) process)
- optional clinker vitrification for improving the leaching characteristics of the ash (HSR process)
- post combustion of the gases in a boiler or circulating fluidised bed

A small-scale pilot plant is in operation in Bremerhaven. In Nürnberg, bottom ash melting and treatment modules have been added to a waste incineration plant. (Frey & Stammbach, 1999).

9.1 RESIDUES

The residues produced from the Von Roll Inova process are melted metal alloys for recycling and vitrified ash including clinker and flue gas cleaning residue. Metal alloys are produced as 1-m3 blocks weighing approx. 12 tonnes. Vitrified ash and clinker are taken out separately as a granulate through a water bath.

The amount and composition of residues will depend on the composition of the waste received to the plant.

The following table shows leaching characteristics of melted clinker with and without high temperature clinker reduction (HSR).

Table 9.1: Leaching of heavy metals from RCP clinker and heavy metal content in HSR clinker compared to untreated bottom ash from incineration. The table is based on incineration/von Roll Inova processing of German waste. (Frey & Stammbach, 1999)

Element	Leaching from RCP clinker	Leaching from waste incineration bottom ash [b)]	Content in HSR clinker	Content in waste incineration bottom ash [b)]
Unit	[mg/l]	[mg/l]	[mg/kg]	[mg/kg]
Hg	<0.0002	0.002	0.1	0.4
Cd	<0.001	<0.01	0.5	30
Pb	<0.006	1.08	75	1800
Zn	<0.01	1.5	400	4000
Cu	<0.01	0.98	400	8400
Ni	<0.01	0.01	50	1000
Cr	<0.01	<0.05	2000[a)]	1500

a) The content of chromium is higher in the HSR clinker due to the use of chromium magnetite refraction material in the process.
b) Data obtained from German untreated raw bottom ash from conventional municipal waste incineration.

The table shows that the leaching characteristics of the bottom ash may be improved considerably by means of RCP melting of the clinker and the heavy metal content can be reduced significantly by means of HSR treatment. (Frey & Stammbach, 1999).

9.2 OPTIONS FOR HANDLING, USE AND DISPOSAL OF RESIDUES

Clinker Melting

In the RCP process, the clinker is melted and the easily vaporised heavy metals (mercury, cadmium and arsenic) are removed together with zinc and lead. The remainder of the heavy metals (copper, nickel and chromium) are fixed in the vitrified clinker. Additional treatment or intermediate storage is not necessary prior to the use of the clinker.

Clinker Treatment

In the integrated high temperature clinker reduction (HSR), the heavier metals are extracted from the liquid clinker.

The volatile heavy metals, evaporated in the clinker treatment may be recovered from the fly ash by means of:

- heavy metals extraction applying an acidic fly ash extraction followed by recovery in the zinc recycling industry.
- pH adjusted carbonate leaching followed by recovery in the zinc recycling industry.

Most of the industrial fly ash extraction operations exist in Switzerland.

Clinker melting and clinker treatment may also be added to existing conventional incineration plants. The disadvantage of post-installation is lower energy recovery efficiency and higher investment costs. To this should be added the high cost for carbon electrodes used in the HSR-process.

The energy demand of the clinker melting process is very high, so the energy recovery from the process is substantially reduced.

10 HERHOF-PROCESS

The Herhof process produces a Refuse Derived Fuel (RDF) based on pre-separation of iron with subsequent composting of the residual waste in special composting boxes. The heat produced during the composting process will reduce the moisture content in the residual waste. This reduces the mass of the waste and increases its heat value. A post-separation stage follows where the residues are separated in the following fractions:

- Dry stabilate (refuse-derived fuel, RDF), which can be temporarily stored and later used as a fuel.
- Mixed plastic fraction (optional)
- Usable materials (Fe and non-Fe metals, inert substances (such as minerals, ceramics and glass)
- Contaminants (e.g. batteries)

By separating the amount of recyclable materials from the RDF, the amount of bottom ash from incineration is reduced from typically 200 kg/tonne to about 100 kg/tonne. This corresponds approximately to the results achieved from source segregation.

A full-scale Herhof plant has been in operation in Rennerod in Germany which opened in 2000 and treats 100,000 tonnes per year. Four Herhof plants are now in operation and a contract has just been signed for Osnabrück. Only one plant includes on-site combustion of the RDF produced. The RDF produced at the other plants has to be transported to an incineration plant or to a landfill for final disposal.

10.1 RESIDUES

The residues generated from the Herhof process are ash, RDF and fractions of glass and metals, which may be used in industry. The amounts of residues generated from a proposed plant in Dublin will depend on the incoming waste quantities and composition. This in turn will reflect the effect of the planned source segregation to be implemented in Dublin.

The Rennerod plant delivers the pre-sorted recyclable materials for further sorting and incineration at a nearby facility in Asslar.

10.2 OPTIONS FOR HANDLING, USE AND DISPOSAL OF RESIDUES

Thermal waste treatment using the Herhof process is relatively new. However, the Herhof process may offer an alternative to the planned source segregation under the Dublin Waste Management Plan. The RDF can be used in energy production and because of the extensive pre-separation the quality of bottom ash will be less than from an incineration plant burning unsorted waste.

In comparison to the combined source segregation scheme and conventional thermal treatment proposed for Dublin the difference might be negligible.

The total operation cost for both solutions will depend on the market prices for recycled residues.

11 MARKETS FOR THERMAL TREATMENT RESIDUES

11.1 INTRODUCTION

Bottom Ash can be used as a valuable aggregate in the construction industry, and has in fact been used for this purpose throughout Europe over the last number of years. However, there have recently been some concerns raised regarding the recycling and reuse of incinerator bottom ash, particularly in light of recent activities in Byker, Newcastle.

EU Directive 2000/76/EF on waste incineration restricts the use of bottom ash in order to protect environmentally sensitive areas. However, the use of bottom ash for construction purposes is permitted by the directive provided it meets the following criteria:

1. Quantities of TOC, heavy metals, trace elements, easily soluble salts and potential toxic organic matter should not exceed concentrations set by the directive.
2. The bottom ash should comprise hard, well graded material with a low fines component and should have good compressive strength.

In order to meet the above criteria the bottom ash must be treated. Alternative treatment processes are describes in section 5.3.1.

Once the bottom ash is proven to be environmentally safe it can be reused in the construction industry. This reuse of bottom ash has several environmental advantages:

1. It avoids the need to transfer and dispose of ash to landfill.
2. It reduces the need to quarry aggregates, often from environmentally sensitive areas.
3. Processed ash from waste to energy plants can be treated as a useful material rather than as waste.

The National Hazardous Waste Plan 2001 refers to residues from the thermal treatment of waste of which there is a hazardous component. The Plan states that reuse of thermal treatment residues may be a viable option but it points out that applications to date in other countries have been limited. It also says that development of a hazardous waste landfill may be required in the event of a hazardous or municipal waste thermal treatment facility being developed.

An estimated 75,000 – 120,000 tonnes per annum of bottom ash will be produced by the proposed Dublin Waste to Energy Plant. Recoverable metals will be removed including iron, aluminium, copper, lead and zinc, these account for 13% of the bottom ash. This effectively means that 65,000 to 105,000 tonnes per annum of treated bottom ash will be available from the proposed waste to energy plant. Where markets are not developed this material must be stockpiled or disposed of in landfill.

11.2 APPLICATIONS/MARKETS

1. Reuse of Bottom Ash in Fill and Road Works

In Ireland, materials that can be used in the construction of roads and motorways are set out and described in detail in the National Roads Authority's 'Manual of Contract documents for Road Construction, Vol. 1, Specification for Roadwork's' which was last published in March 2000. Additions and amendments to the specification will only be made following a period of testing and proving.

Tests have, in the past, been carried out by Local Authorities for various recycled materials as aggregates in road construction. It is feasible that similar tests could be carried out on the use of bottom ash as an aggregate. However, since a period of testing and proving is necessary, it would be advisable to start such tests as soon as possible. It would first be necessary to establish the mechanical and geotechnical properties of the treated bottom ash. With this information it should be possible to agree on a means of progress with local authorities and the NRA.

Treated bottom ash can be used as replacement for virgin aggregates in 'hotmix' bituminous materials. A blend of granite 70% and ash 30% can have a 10% fines value of 140 kN. Approximately 4000 tonnes of bottom ash could be used in the road base of 1 km of motorway.

2. Reuse of Bottom Ash in Concrete Construction

Use of bottom ash in concrete construction has gained acceptance as a replacement for primary aggregates in the U.K and other countries. Applications for incinerator bottom ash include the following:

- As an aggregate in cement bound materials – seven day strengths up to $22N/mm^2$
- As an aggregate in foamed concrete
- As an aggregate in low strength concrete
- As a pipe bedding or drainage media

The current standards which apply to concrete materials are contained in IS 326 1995, this allows the use of fly ash as an aggregate in concrete. However, it does not refer to incinerator residues in particular. This standard is currently being upgraded to the European standard EN206.

European committee, CEN 154, are presently revising standards for aggregates in concrete materials. A sub committee has also been established and will be dealing with the use of recycled aggregates including thermal treatment residues and construction/demolition waste. The final report is expected in about two years from now.

In the present situation in Ireland, fly-ash can be used to decrease the cement requirement in concrete. Quantities used depend on the quality of the concrete demanded by the customer. Incinerator bottom ash may be permitted in the future once methods of treatment are found to be acceptable.

3. Reuse of Thermally Treated Bottom Ash

Bottom ash can be vitrified to produce glass or glass ceramic products. Applications include shingles, road base fill, sand blasting grit and aggregate for asphalt. Thermal treatment of bottom ash is expensive when compared to other handling methods. However, vitrified bottom ash is much more stable and less prone to leaching.

The vitrified mineral materials produced in the von Roll INOVA process, as described in section 9, can be used as an additive to concrete in the following forms:

- In crushed form, directly on the construction site, as a partial replacement for cement in the making of concrete and as a filler material.
- As an additive for concrete with partial or complete replacement of an additive fraction.
- As a frost proofing layer (substructure material) in highway construction or in bituminous highway surfaces.

Again the use of vitrified materials derived from waste in construction would have to be approved and included in the relevant specifications.

4. Reuse of residues from Pyrolysis/Gasification

Char

Char is formed as a result of the pyrolysis process and consists of carbon and ash. The main potential market for char is for use as a fuel in cement kilns. However there are certain problems associated with this;

- The manufacture of cement is highly sensitive to chlorine and alkali metals as they form a swelling gel with silica which can cause micro-cracks in the concrete.

- The use char in a cement kiln will be seen as the use of treated waste. This means that the emission standards and monitoring related to thermal waste treatment processes would be required. In addition to this the necessary licences would be required.

Any benefits to the cement industry from using such alternative fuels will be weighed against the above considerations with anticipated public perception also having a significant input. The process of burning char in cement kilns is technically sound but barriers may exist with reluctance from the cement industry to use a product which may not be hugely beneficial to them.

As an alternative to fossil fuels (i.e. coke) the use of pyrolysis char residues would represent a reduction in CO_2 emissions. The cement industry is significant source of CO_2 gases and therefore may be interested in such waste derived fuels as a means of achieving reductions in CO_2 emissions. The possibilities in this regard will only become clear when the government implements it's planned carbon tax policy.

11.3 EXPERIENCE IN OTHER COUNTRIES

11.3.1 UK

The Energy from Waste Association (EWA) in the UK is a non-profit making organisation who draws its members from developers, operators and other companies with a role in the energy from waste industry. One of the member companies is 'Ballast Phoenix' who handles the bottom ash for four of the waste to energy plants in the UK. This recycling business has been in operation for five years.

90% of the bottom ash is reused, including recovered metals, and the residual is deposited in a landfill facility. According to the company's experience, establishing a market, which can absorb such quantities of treated bottom ash will take a number of years. It is necessary to demonstrate material performance and safety as an aggregate. In addition it will take some time for such products to gain widespread acceptance as viable alternative materials.

Applications to date have included use as a sub-base in a 4 km stretch of bypass, 12,000 tonnes of treated bottom ash were used in the project. Other applications include 25-30% granite and limestone replacement and also drainage and pipe laying applications.

The EWA has been working with the UK's DETR, the Environment Agency and the Highways Agency in preparing an EA Policy Document for the use of recycled incinerator bottom ash. The document deals with specific applications and has taken into account the environmental impacts of bottom ash. (Still in draft form)

11.3.2 Denmark

Bottom ash from Danish waste incineration plants is used extensively for construction works. The bottom ash is purchased from the waste incineration plants by private entrepreneurs for various projects.

As an example, the Danish incineration plant Vestforbrænding disposes of its bottom ash for a number of small projects such as construction of parking lots, roads, bicycle paths etc. where it is used as base material. Bottom ash is also used in larger projects such as land reclamation for an extension of Copenhagen harbour (150.000 tonnes of bottom ash are used in this ongoing project) and for a similar project in Nakskov. There is a preference for using the bottom ash in larger projects since the environmental authorities must approve the use of ash in each project.

Before 1999, approximately 80 % of the bottom ash was reused. In year 2001, a new Statutory Order on reuse of incineration residues was coming into force in Denmark. The Order restricts the reuse of bottom ash in order to protect sensitive areas. The implementation of this regulation has resulted in reduced reuse of the bottom ash.

11.4 ECONOMIC EVALUATION

Although it is technically feasible to reuse residues in the construction industry, it is important also to determine the economic feasibility. Recycled construction materials have a limited value in Ireland as virgin materials are relatively cheap and readily available. In this respect it may be difficult to establish a market for combustion residues, particularly if they have no technical advantage over virgin materials.

There are significant costs associated with the disposal of thermal treatment residues in landfill facilities. Therefore when the avoided costs of landfill are considered, the economic standing of recycling materials is improved.

The local authorities could play a key role in developing a market for treated bottom ash with the benefits being twinfold i.e. reduction in requirements for natural materials and less dependence on landfill disposal.

Critical to the development of the market is environmental and technical proving of treated bottom ash. The technical aspects do appear to be acceptable while debate is ongoing with regard to environmental issues and acceptable safety standards.

12 CONCLUSION

The total quantities of residues from all the Waste to Energy processes considered in this report are of the same magnitude for incoming waste of the same quality.

The quality of the residues will vary according to the front end and post treatments applied.

The von Roll INOVA process delivers a residue of very high quality, but at a very high cost and with high energy consumption.

The mixed residue products from pyrolysis processes – char and inerts – may be suitable for down-stream separation of ferrous and non-ferrous metals of good quality, but the balance of the residues will probably contain a high level of unburnt and putrescible material. There is at present no operating experience to confirm either suggestion.

The bottom ash from RDF material – such as produced by the Herhof method – will be less because most of the inert materials have been separated from the fuel in the pre-sorting process. The residues will instead occur in unburnt form and may be marketable. The combustion of RDF however may produce higher levels of NOx and dioxins than is the case for conventional thermal treatment.

Conventional grate type incineration plants will produce a completely burned out bottom ash, but depending on pre-sorting (source segregation) it may contain levels of heavy metals that demand additional treatment prior to its use for construction purposes etc. Ferrous metals will be separated from the bottom ash, but will be of less value due to their exposure to high temperatures.

Long term experience is needed to ascertain whether some of the emerging technologies may eventually offer a real reduction of environmental impact compared to proven waste to energy technologies with comparable energy efficiency and at an acceptable cost.

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APPENDIX A

CALCULATION OF AREA NECESSARY FOR STORING BOTTOM ASH

Calculation of area necessary for storing bottom ash

The following assumptions are made:

Density of the bottom ash = 1.7 tonnes/m^3
Amount of bottom ash = 75,000 - 120,000 tonnes/yr
The bottom is assumed to be put up in 4-m high and 8 m wide triangle. Thereby there are 16 m^3/8 m^2 = 2 m^3/m^2.

Thus, the amount of bottom ash per m^2 is:

1.7 tonnes/m^3 ·2 m^3/m^2 = 3.4 tonnes/m^2.

Therefore, the area needed for 75,000 tonnes/yr of bottom ash is:

75,000 tonnes/yr / 3.4 tonnes/m^2 = 25,000 m^2/yr

With an average storage period of 1 year, the minimum required area for storage of bottom ash is 25,000 m^2.

APPENDIX B

QUANTITIES OF AIR EMISSIONS FROM TRANSPORTATION

Quantities of air emissions from transportation

The following table shows the quantities of air emissions from different means of transportation. It is assumed that the truck is in EURO II class (i.e. it is registered after the 1st of October 1996).

Table Ap 2.1: Quantities for air emissions from trucks, ferry and coaster

Cargo Weight	CO_2	NO_x	Particles	CO	HC
Trucks 0% [a)]	613 g/km	6.7 g/km	0.27 g/km	1.16 g/km	0.45 g/km
Trucks 100% [b)]	1157 g/km	10.4 g/km	0.28 g/km	1.16 g/km	0.49 g/km
Ferry	48 g/tonne pr. tour	775.5 g/tonne pr. tour	31 g/tonne pr. tour	144.5 g/tonne pr. tour	45 g/tonne pr. tour
Coaster	21.77 g/tonne km	0.4 g/tonne km	0.005 g/tonne km	0.053 g/tonne km	0.018 g/tonne km

[a)] 0% corresponds to a cargo weight of 0 - 4 tonnes

[b)] 100% corresponds to a cargo weight of 28 - 32 tonnes

(COWI, 2000a)

APPENDIX C

AIR EMISSIONS OF CO_2, NO_X, PARTICLES, CO AND HC FROM TRANSPORTATION OF APC RESIDUES TO GERMANY

Air emissions of CO_2, NO_x, particles, CO and HC from transportation of APC residues to Germany

In the following calculations the median amount of APC residues of 10,000 tonnes/yr is assumed to be valid for a mass burn incineration plant in Dublin. Since the interval for the amount of residue is so big, the calculations of air emissions are inaccurate and can be seen as guide values for comparative purposes only.

The following assumptions are taken into account for transportation to a mineshaft in Germany by transporting the residues with a truck:

The total distance from Dublin to the mineshaft (which is assumed to be close to Dresden) is approximately 1750 km. The total route is divided into:

- 1640 km with a truck (through the English channel)
- 110 km with a ferry (from Dublin to Holyhead in England)

The following assumptions are taken into account for transportation to a mineshaft in Germany by transporting the residues with a coaster and a truck:

The total distance from Dublin to the mineshaft are divided into:

- approximately 1300 km with a coaster (from Dublin to Hamburg)
- approximately 800 km with a truck (from Hamburg to Dresden)

The following general assumptions are taken into account for the calculations:

The key numbers for the air emissions are shown in appendix 2.

It is assumed that 40 tonnes trucks with maximum cargo of 32 tonnes are used for the transportation. Thereby, there is need for roughly 320 trucks per year to transport the residues. This corresponds to a one way distance of 530,000 km/yr for transporting the waste to Germany.

It is furthermore assumed that the trucks drive on a highway with an average velocity of 70 km/h. The total emissions in the table are given for a route with full cargo from Dublin to the destination and no cargo on the way back to Dublin.

In the calculations for the emission of the ferry (from Dublin to Holyhead), the total weight of the truck and the residues (40 tonnes) are taken into account. On the way back (Holyhead to Dublin) it is assumed that the truck is empty.

Table Ap 3.1: Air emissions from transporting APC residues to Dresden in Germany or northern England

	Transportation to Germany (truck)		**Transportation to Germany (coaster)**	
Cargo Weight	**CO_2 [tonnes/yr]**	**NO_x [tonnes/yr]**	**CO_2 [tonnes/yr]**	**NO_x [tonnes/yr]**
Trucks:				
0%	325	3.6	2.6	2.8
100 %	613	5.5	481	4.3
Ferry:				
total cargo for both ways	0.7	11.9	0.7	11.9
Total	938.7	21	484.3	19

The following table shows the air emissions of particles, CO and HC from transportation of APC residues to mineshaft in Germany.

Table Ap 3.2: Air emissions of particles, CO and HC from transportation of APC residues to mineshaft in Germany. It should be noted that the air emissions for truck transportation are given on the left side of the slash and the air emissions for coaster transportation are given on the right side of the slash

	Transportation to Germany (truck/coaster)		
Cargo Weight	**Particles**	**CO**	**HC**
Trucks:			
0 - 4 tonnes [tonnes/yr]	0.2/0.1	0.6/0.5	0.3/0.2
28-32 tonnes [tonnes/yr]	0.2/0.1	0.6/0.5	0.3/0.2
Ferry:			
[tonnes/yr]	0.5/0.5	2.2/2.2	0.7/0.7
Total [tonnes/yr]	0.9/0.7	3.4/3.2	1.3/1.1

APPENDIX D

AIR EMISSIONS OF CO_2, NO_X, PARTICLES, CO & HC FROM TRANSPORTATION OF APC RESIDUES TO NORWAY

Air emissions of CO_2, NO_x, particles, CO & HC from transportation of APC residues to Norway

The same general assumptions for trucks and ferry are made as in appendix 3.

In the calculations it is assumed that the residues are transported:

- 110 km on a ferry from Dublin to Holyhead in England
- 385 km from Holyhead to Newcastle in a truck
- Approximately 800 km on a coaster from Newcastle to Oslo

The total one way distance with a truck is therefore approximately 123,000 km. It is assumed that the ship transportation occurs with a coaster.

The following table shows the air emissions from transporting residues to Norway.

Table Ap 4.1: Air emissions from transporting APC residues to Oslo Bay in Norway

Cargo Weight	CO_2 [tonnes/yr]	NO_x [tonnes/yr]	Particles	CO	HC
Trucks:					
0%	75.4	0.8	0.03	0.14	0.06
100%	142.3	1.3	0.03	0.14	0.06
Ferry:	0.7	11.9	0.5	2.2	0.7
Coaster:	180	3	0.07	0.3	0.09
Total [tonnes/yr]	398.4	17	0.63	2.78	0.91

APPENDIX E

CALCULATION OF COSTS FOR EXPORT OF APC RESIDUES

Calculation of costs for export of APC residues

The costs for transportation by ferry and through the Eurotunnel are estimated and should only be regarded as guiding values. The other costs are based on experiences from exportation from Denmark. Transportation of residues is regarded for a dry product.

Table Ap 5.1: Costs for export of APC residues

Costs	Unit costs	Germany truck	Germany coaster	England	Norway
Unit		IR£/tonne	IR£//tonne	IR£//tonne	IR£//tonne
Transportation by truck	0.05 IR£//tonne/km	82	40	9.5	19.2
Transportation by ferry	500 IR£//tour	32		32	32
Transportation by coaster	0.015 IR£//tonne/km		19.5		12
Eurotunnel	1000 IR£//tour	64			
Transfer	3.5 IR£//tonne		7		7
Handling of waste	1.5 IR£//tonne	1.5	1.5	1.5	1.5
Receiving of waste	40 IR£//tonne	40	40	40	40
Administration, research, service etc.	5 IR£//tonne	5	5	5	5
Total		224.5	113	88	116.7