CHAPTER 21 - UTILISATION

21.1 INTRODUCTION

Utilisation of MSW incinerator residues is being conducted or considered for a variety of applications in many countries. Interest in utilisation principally is motivated by the potential for extending existing ash landfill capacity, and thus reduces disposal costs, and in some regions the substitution for natural aggregates. The relative importance of each of these factors varies considerably from country to country and between regions within a country.

Primary applications include use as:

- an aggregate substitute in paving applications, including as compacted base, or in bituminous pavement,
- an aggregate in terrestrial Portland cement applications, including cement block and prefabricated or field erected forms
- an aggregate substitute in Portland cement-based marine applications such as artificial reefs and shoreline protection
- daily cover for municipal waste landfills, or
- granular fill material for embankments.

Bottom ash is the primary material being utilised or considered for utilisation in construction applications. However, there are some notable exceptions, for example, a small percentage of fly ash has been used as a fine aggregate filler in asphalt in The Netherlands and the use of combined ash has been considered in the United States. Almost all of these applications, except use as daily landfill cover, would involve some degree of ash processing, either physical and/or chemical. For example, most applications would require screening of ash to achieve a desired particle size gradation or would result in ash encapsulation in another matrix. Utilisation through recovery of chemical constituents (e.g., $CaCl_2$) and recycling of ferrous and nonferrous metal is discussed in Chapter 17 (separation processes).

A typical pavement consists of the following layers or a subset combinations of layers depending on design (listed from the top driving surface down): a shim/levelling course, a wearing/surface course, a binder course, a base course, a sub-base course, a compacted subgrade, and a natural subgrade. The shim/levelling course is placed on the surface to level ruts and depression and typically consists of a fine grain sand. The wearing/surface course is the top 1 to 5 cm and the binder course is below the binder course. The binder course serves as the bottom portion of the roadbed if needed. Otherwise, it will be placed between the wearing course and the base course. The base course is normally the lower portion of the pavement. However, a sub-base may be required and is place directly below the base. The pavement is built from the bottom to the top on a subgrade that has been prepared by compaction. The entire roadbed is placed on natural subgrade or fill.

Applications in the marine environment include shoreline protection and artificial reefs. These involve the use of the residues mixed with Portland cement to form concrete structures. Shoreline protection is the process of creating physical resistance to disruptions, such as storm events, natural erosion, and boat wakes. Examples of shoreline protection are bulkheads, sea walls, breakwaters, jetties, and piers. Artificial reefs are constructed to provide structures for the growth of marine organisms and attraction of fish while additionally serving as shoreline protection. All of the above applications require a final product which has a high degree of physical durability.

21.2 CURRENT AND PLANNED PROJECTS

The following sections provide a summary of current and planned utilisation projects and testing programs in several countries at the time of writing.

21.2.1 Canada

Because of the availability of landfill and the modest production of incinerator ash, there is little incentive, either economic or environmental, to pursue ash utilisation applications in Canada. The only example of ash utilisation is the use of bottom ash from the Burnaby Incinerator facility to construct access roads within a landfill. As utilisation becomes more wide spread in other countries, it is expected that the practice will be considered more seriously in Canada.

21.2.2 Denmark

Danish incinerator facilities produce approximately 420,000 tons of bottom ash annually (including grate siftings and boiler ash which in most cases are mixed with the bottom ash) the overwhelming majority of which is utilised. Since 1974, screened and sorted bottom ash has been utilised in Denmark for civil engineering purposes, particularly as subbase material at parking lots, bicycling paths, and paved/unpaved residential and major roads (Hjelmar, 1992). As a subbase material, the bottom ash is usually substituted for the diminishing supplies of natural gravel in various parts of Denmark. Thus, the incentives for utilisation include both natural resource conservation and economic benefit. A substantial portion of the economic benefit is derived from the avoided costs of landfilling, which is typically $150 (US) per tonne.

21.2.3 Germany

In 1991, the 48 German incinerators in operation produced 2.56 million tonnes (Tg) of bottom ash. About one half of the annual production was utilised (1.2 Tg) and almost 0.2 Tg of scrap ferrous was recovered for recycling. The remaining amount (about 1.2 Tg) was landfilled (Johnke, 1993). The bottom ash is sieved and ferrous metal is removed prior to utilisation. The primary uses reported were as aggregate for compacted roadbase and embankments, primarily in demonstration projects. The extent of utilisation varied considerably from state to state. There remains strong opposition against the use of bottom ash even though positive results have been obtained from demonstration projects. Following an inquiry of 176 municipalities with >10,000 inhabitants, only 6 make use of bottom ash on a regular basis, with another 11 making use of it on a limited basis.

Air pollution control residues, including fly ash and scrubber residues, are undergoing pilot-scale and provisional evaluation for use in the coal mining industry as filling and sealing materials for excavation cavities, and as aggregate substitute in grouts (Plate, 1992). The hard coal mines of Ruhrkohle AG (RAG) consume approximately 1.5 million tonnes of grout per year and the potential capacity to incorporate APC residues in grouts is approximately 20,000 tonnes/yr. Approximately 50,000 tonnes of APC residue has been used for a pilot test of mine filling and sealing operations. Scrubber residues also are being considered for use in alinite cement (Oberste-Padtberg, 1992). In this case, scrubber residue is used as a substitute for lime as a raw material. Scrubber residues are pelletised with other raw materials and about 20% water, and then treated in a rotary kiln to form an alinite cement clinker which is subsequently ground into cement.

21.2.4 The Netherlands

Approximately 600,000 tons of bottom ash and 80,000 tons of fly ash are produced annually (1988) in The Netherlands (Born, 1994). Ferrous scrap, representing about 70,000 tonnes/yr, is separated magnetically at all facilities and recycled in the steel industry. The government policy is to achieve utilisation of more than 80% of incinerator residues. In practice, approximately 95% of the bottom ash is currently utilised (Born, 1994). The principal motivation for utilisation in the Netherlands is the shortage of suitable natural aggregate and the lack of available landfill space. The primary use of bottom ash is in the following applications:

- road base material for roads and industrial sites
- material for embankments, noise and wind barriers
- aggregate in concrete and concrete products, and
- aggregate in asphalt concrete

A total of more than 2 million tons of bottom ash has been used in the listed applications. In addition, 30-40% of the fly ash produced since 1984 has been used as a fine aggregate filler in asphalt concrete. The following is a summary description of several major ash utilisation projects:

Caland Wind barrier - This project carried out in 1985 used more than 650,000 tons of bottom ash in an embankment with a length of 700m and a height of 15m. The ashes are covered with a primary cover layer of 0.5m compacted clay with a sand drainage layer (0.5m) and top soil (1.0m) overlaying the clay layer. The slope of the compacted ash is 1:2 and 1:2.5. The mean compaction factor was 97.5% with a wet density of 1840 kg/m^3. Groundwater quality is monitored on both sides of the embankment.

Highway A-15 Rotterdam - Approximately 400,000 tons of bottom ash was used in an embankment for this major roadway construction. Ash is covered with a compacted sand-bentonite mixture with a minimum thickness of 20 cm to reduce water infiltration.

Road Base Material - Several projects with bottom ash as road base material have been carried out in Rotterdam and North Holland. In Rotterdam, primarily a mixture of ash, crushed rubble aggregate and additive (50%-50%-10%) has been used. The base thickness is 25-30 cm.

Concrete Paving Blocks - A project in Keilehaven carried out in 1984 used more than 300,000 concrete paving blocks in which the coarse aggregate was replaced up to 40% with the 5-8 mm fraction from bottom ash. After five years of traffic, it was concluded that there was no difference in physical properties between standard concrete paving blocks and those using bottom ash as the coarse aggregate replacement (Leenders, 1988). Laboratory investigations of environmental properties of concrete paving blocks with 20% replacement of the coarse aggregate by bottom ash indicated no significant difference from conventional paving blocks (KEMA, 1986).

Hartel Canal Pilot Project - A pilot project with asphalt containing bottom ash was carried out in 1987 along the banks of the Hartel Canal. A length of approximately 50 m was coated with about 100 tonnes of asphalt containing 30% bottom ash. It was found that the mixture temperature was required to be 40°C higher and the bitumen content 3% higher than traditional material.

21.2.5 Sweden

Current utilisation of incinerator residues in Sweden is very limited due to the regulations for licensing the use of any residual products in a specified manner (under the Environmental Protection Act). This also applies to controlled tipping.

Uncertainty with regard to whether or not a license is obligatory under the Environment Protection Act for the utilisation of residues has resulted in essentially no full-scale utilisation of incinerator residues through 1993. However this uncertainty is supposed to be resolved within a short time frame (e.g., 2 years) with the overall intent to increase utilisation of waste materials. New regulations are likely to require quality control based on environmental parameters. It is unclear if incinerator bottom ash will be deemed acceptable since these parameters have not been established.

The legal, environmental and engineering aspects of utilising incinerator bottom ash have been studied in a comprehensive project (Lundgren & Hartlén, 1991). The results based on field and laboratory tests indicated that sorted bottom ash can be used as embankment fill, base course material in low traffic roads and under light buildings and floor structures. Recommendations included that the use of bottom ash should be restricted to applications where the ash is covered by a low permeability material, such as asphalt, and deposited away from the groundwater table or ground water catchment areas. It was also recommended that the thickness of a deposit should be limited to 3.0 m and the ash placed well above the ground water table until further experience is gained.

21.2.6 United States

In the United States, several factors have influenced the possible uses for incinerator residues in construction applications. The shortage of existing landfill space and the difficulty of securing new sites has created a situation in which either disposal fees are costly, disposal space must be sought in distant locations, or disposal will not be possible. Hence, recycling and reuse of residual wastes has been suggested as the preferred management option.

A detailed summary of planned and ongoing demonstration projects utilising municipal solid waste incineration residues in the U.S. has been prepared by Hoffman (1993). The following paragraphs and Table 21.1 highlight summary information for project parameters.

Type and Distribution of Application: Approximately half of the 23 identified projects utilising residues are concrete applications. Of those 11 projects, 5 involve using residues in concrete blocks for buildings, 4 marine application, and 2 are used for landfill functions. Six of the remaining 12 projects are asphalt road paving applications. The most common initially proposed was in the road wearing surface. Project plans have been substantially modified in several cases, resulting in more road sub-surface demonstrations. Other projects include utilisation of loose MSW residue aggregate as the base layer underlying a paved parking lot, commercial scale substitution of fly ash for a raw material in cement production and fill material for inactive salt mines. Plans for the remaining three projects do not contain specific identification of use.

Table 21.1
Summary of Incinerator Ash Utilisation Projects in the United States

Project	MSWI Facility Type	Ash Type
Asphaltic Applications		
Hennepin County, Minnesota Pavement Demonstration	Mass Burn/DS-FF	Combined
Hillsborough County Department of Solid Waste Municipal Incinerator Ash Reuse, Research Development and Demonstration Project, Florida	Mass Burn/ESP	Combined
McKaynite Demonstration, Acline Street, Florida	Mass Burn/ESP	Combined
McKaynite Demonstration, Ruskin, Florida	Mass Burn/ESP Mass Burn/DS-FF	Bottom Bottom
New Hampshire Bottom Ash Paving Project	Mass Burn/DS-FF	Bottom, Combined
NYSERDA - Phase IIa, New Jersey	Mass Burn/DS-FF	Bottom, Combined
Concrete/Cement		
Ash Management Building, OH (Montgomery County)	Mass Burn/ESP	Bottom
Center for Innovative Technology, VA	Mass Burn/DS-FF	Bottom, Combined
Commerce Refuse-to-Energy Ash Treatment and Reuse, Los Angeles County, CA.	Mass Burn/DS-FF	Combined
Fly Ash Stabilisation Building, OH (Montgomery County)	Mass Burn/ESP	Bottom
Islip, Blydenburgh Landfill, Long Island N.Y.	Mass Burn/DS-FF	Combined
Pinellas County, Florida Artificial Reef	Mass Burn/DS-FF	Scrubber, Bottom
Residential Foundation, New York	RDF/ESP	Bottom
SEMASS Administration Building Project, MA	RDF/DS/ESP	Bottom
SUNY Artificial Reef Demonstrations	Mass Burn/ESP Mass Burn/DS-FF	Combined Combined
SUNY Boathouse Demonstration	Mass Burn/ESP	Bottom, Combined
Other		
Commercial Grade Cement Production (Tacoma, Washington) (shale replacement)	RDF/FF	Fly Ash
City of Albany, NY, Parking Lot Demonstration (loose aggregate)	RDF/ESP	Bottom
Hawaii: Field Tests of Use as Landfill Cover	RDF/ESP	Bottom
Metropolitan Washington, D.C. Demonstration	Mass Burn/DS-FF	Bottom, Combined
NYSERDA - Phase II B - New York City	Mass Burn/DS-FF	Bottom, Combined

RDF	Refuse Derived Fuel	DS	Dry Scrubber
ESP	Electrostatic Precipitator	FF	Fabric Filter

Geographic Distribution: The majority of projects cluster in two areas - Northeastern United States (New England, N.Y., and N.J.), and Florida. Additional locations include Los Angeles County, California and Honolulu, Hawaii. Factors influencing this distribution are lack of landfill space, availability of natural aggregate, and vendor and government interest in utilisation.

Type of Incineration Facility: All but five of the sources of incinerator residue for the demonstration projects are mass burn facilities. Of those five, four employ refuse derived fuel (RDF) in a conventional boiler. The fifth also uses RDF, but co-combusts it with coal and wood waste in a fluidised bed burner.

Slightly more than half of the incineration facilities supplying residue for the projects are equipped with a scrubber and fabric filter combination. One of this group is equipped with an additional lime injection system in the furnace, and one is fitted with a de-NOx treatment system. Eight are equipped with ESPs only.

Incinerator Residue Fraction: Six projects propose using only bottom ash, and one uses only fly ash or APC residues. The others either use bottom and combined ash in the experimental design or are debating which residue streams to employ. The trend is toward bottom ash use, rather than combined ash.

Incinerator Residue Processing: In each project, the incinerator residue is processed to some degree before it is substituted for natural materials in asphalt and concrete media. Pre-combustion processing is employed in RDF: large non-combustible items and ferrous metals are removed, and waste is shredded.

Post combustion processing frequently consists of ferrous and nonferrous metal removal and particle size control. In addition, stockpiling (aging) is done to improve the engineering performance of the residue. Because virtually all of the projects substitute incinerator residue for natural aggregate, efforts are made to supply the replacement material in a form as similar as possible to the natural material. Some companies have patented their aggregation processed and have applied trade name to their products (e.g., Ardellite, Boiler Aggregate, McKaynite, Permabase Plus, Rolite, etc.). A range of 5% to 90% substitution for natural aggregate in asphalt and concrete applications exists among the projects.

21.3 CURRENT REGULATORY FRAMEWORK

The regulatory framework for utilisation of incinerator residues is evolving due to the current debate. Therefore, the following descriptions of regulatory frameworks are intended only to provide a summary of different approaches. Only Denmark has a regulatory framework which is not under revision.

21.3.1 Denmark

The utilisation of granular incinerator ash for civil engineering purposes in Denmark has been regulated since 1983 by rules issued by the Danish Ministry of the Environment (Statutory order No, 568 of Dec.6, 1983). These rules apply to the use of small and moderate quantities of incinerator ash for specified purposes. Large scale applications of incinerator ash involving more than 30,000 tons of ash and ash applied in layers thicker than 5 m are regulated under the Disposal and Discharge Permit Act (Section 5 of the Environmental Protection Act). In 1989, these regulations were supplemented by a set of technical guidelines for the utilisation of bottom ash as a subbase material, issued by the Danish Highway Department (Phil et al., 1989).

The principles of the rules and guidelines regulating incinerator ash utilisation in Denmark are illustrated in the diagram shown in Figure 21.1. In principle, both bottom ash and fly ash or combined ash may be utilised. In practice, however, all fly ash and virtually all combined ash will fail to meet the conditions set on the heavy metal content of the ash. Therefore, the ability to collect the bottom ash separately from the fly ash at the incinerator is mandatory to ash utilisation.

There are chemical composition requirements for each use. Each portion of incinerator ash, with a maximum 5,000 tons, intended for utilisation must be sampled. The sample, which may be collected on-line (e.g., from a conveyor belt) or from a stockpile, must be a composite of at least 50 sub-samples of 2 kg each. If the ash has not been screened prior to sampling, the composite sample is passed through a 45 mm screen to remove large objects. In order to facilitate the subsequent crushing, ferromagnetic material, pieces of nonmagnetic metals, and pieces of unburnt material (paper, fabric, etc.) may be removed from the screened and air-dried ash sample, which is then reduced to 5 kg by means of a riffle sampler. After crushing to <2mm (e.g., using a jaw crusher), the amount of sample is further reduced to 100 g, which is subsequently ground (e.g. in a mortar grinder) to 95% (w/w) <90 mm and analysed for pH (in a 1% slurry in demineralised water after stirring for 0.5 hours under cover), acid neutralisation capacity (alkalinity above pH = 7), and lead, cadmium, and mercury (metals determined by partial digestion with half-concentrated nitric acid for 0.5 hours at 1 atm followed by atomic absorption spectrophotometry, AAS). The results are expressed as concentrations in the ground samples. Utilisation of the 5,000 tons portion of ash is permitted if the results of the chemical analysis comply with the criteria shown in Table 21.2.

The utilisation of ash that meets the quality requirements described above is further subject to quantitative and environmental protection/application related restrictions. The general conditions are the following:

If incinerator ash is to be used under paved roads/squares, the following additional requirements must be met:

Figure 21.1 Flow Diagram of Guidelines Regulating Ash Utilisation in Denmark

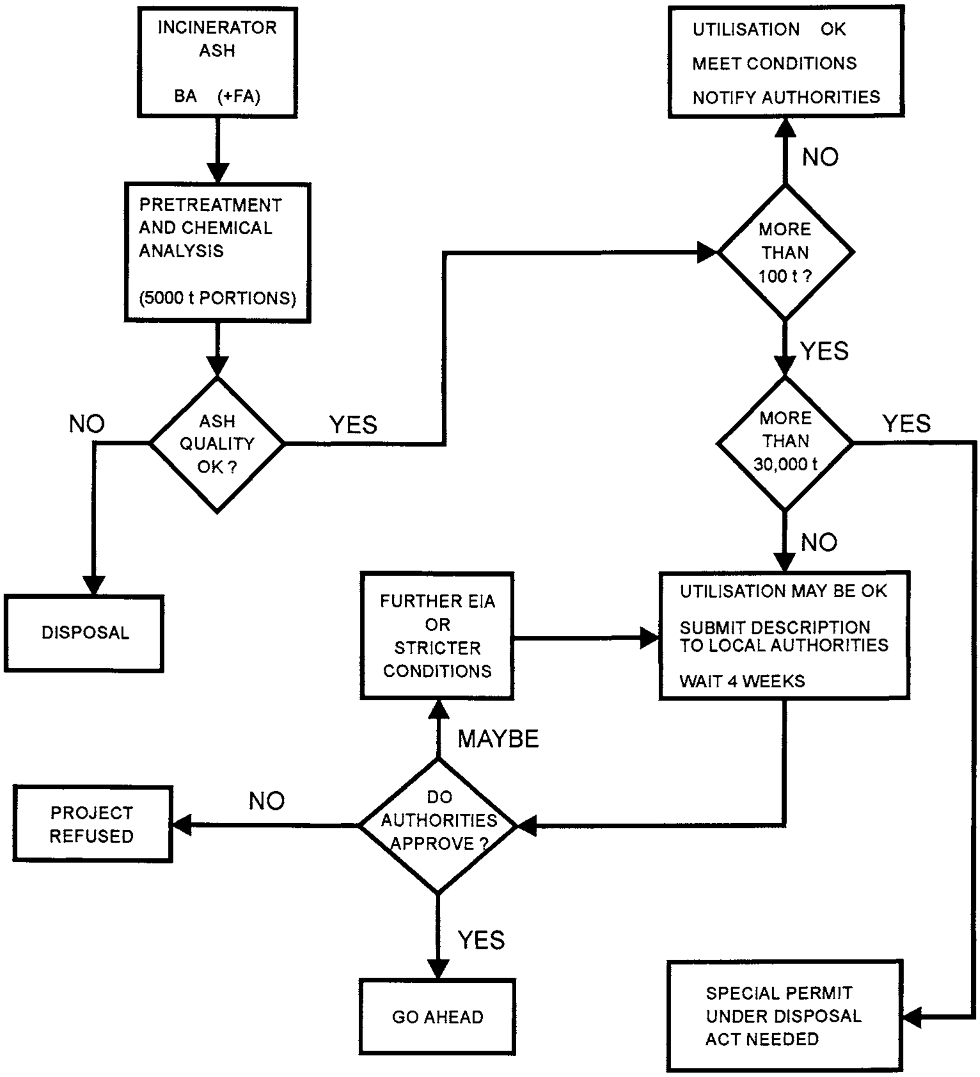


Table 21.2
Testing Requirements for Utilising Ash in Denmark

Parameter	Criteria
pH (1% Slurry)	> 9.0
Alkalinity	> 1.5 eqv/kg DW
Lead	< 3,000 mg/kg DW
Cadmium	< 10 mg/kg DW
Mercury	< 0.5 mg/kg DW

- The distance to drinking water wells must be 20 m or more
- The ash must be placed above the highest groundwater table
- The maximum average thickness of the ash layer is 1 m, and the thickness of the ash layer must not exceed 2 m.

If the ash is to be used in unpaved single-lane roads and unpaved squares (maximum surface area of 2000 m^2), the following additional requirements must be met:

- The distance to drinking water wells must be 20 m or more
- The thickness of the ash layer must not exceed 0.30 m.

If a utilisation project of this nature involves less than 100 tons of ash of approved quality, it may proceed without any permit as long as the above conditions are met. If an ash utilisation project involves more than 100 tons but less than 30,000 tons of ash, a detailed description of the project must be submitted to the local authorities (county and municipality) in advance for approval. The applicant must then wait for 4 weeks. If he receives no (negative) reply within the 4 week period, the project is approved as submitted. Each county council may refuse the project if it is in conflict with environmental protection considerations or may ask the applicant to change the project or to provide an environmental impact assessment before resubmitting the project. Large scale applications of more than 30,000 tons of ash will usually covered by the legislation on disposal (Figure 21.1). When the ash is used a sub-base in road construction, it must comply with the following additional performance related conditions set by the Danish Highway Department:

- The bottom ash must not be mixed with fly ash (or any other materials);

- The bottom ash must be quenched immediately, and it must be stored for at least 1 month prior to utilisation; and,

- The bottom ash must be screened to maximum particle size of 50 mm, contain less than 9 percent (w/w) of fines below 0.075 mm, the loss on ignition (at 1000°C) must be less than 10 percent (w/w), and the content of water must be between 17 and 25 percent.

21.3.2 Germany

Guidelines for road construction have been developed (Hoesel, 1986), including options for the utilisation of bottom ash (grate ash only or grate ash combined with boiler ash) in the road surface (with or without binder), and use in road base and fill in areas such as parking lots, promenades, noise protection walls, etc. These guidelines serve as the basis for subsequent regulations.

The raw ash has to be stored a minimum of 3 months to reduce water content (initially about 30%) and allow swelling to occur. Sieving and ferrous removal prior to utilisation is also required. The following properties are specified for bottom ash: grain size < 32 mm; splintering during freeze-thaw testing between 0.5-8.5 wt.%; proctor density of 1.5-1.9 Mg/m^3 at 11-18% moisture content; LOI < 5%; and pH of 8 - 12 in water.

Bottom ash use should be at least 1 m above the groundwater table. In water quality protection areas, additional requirements recommended were: pure metals < 5%; unburnt material < 0.5%; LOI < 5%; particle size < 0.063 mm < 7%; soluble matter < 2%; leaching parameters based on DEV S4 test to include pH, conductivity, Cl, sulphate, EOX, TOC, Pb, Cr, Cd, Cu, Ni, Zn. Later guidelines prohibited the use of ash in water quality protection areas. Monthly monitoring of ash quality is also recommended.

Individual German states have issued regulations for ash utilisation. For example, in Hassia, bottom ash has to be pretreated according to the guidelines presented by Hoesel (1986) along with additional specifications (Hessisches, 1988). Ash must be aged for more than 2 months and have an LOI < 2%. Using the German standard leaching test (DEV S4), solubility measured as solid residue of evaporation must be < 1%, and limits for ions are (mg/l) NH_4 0.4, Cl 250, $S0_4$ 600, F 3, Pb 0.1, Cd 0.004, Cr 0.04, Cu 0.5, Ni 0.04, Zn 0.5, and Hg 0.001. The moisture content, pH and conductivity must be recorded. Every 2 years a PCDD/PCDF analysis is required but no limit is provided.

21.3.3 The Netherlands

The Netherlands currently has the most extensive framework proposed for utilisation of waste materials including incinerator residues. Management of these residues is regulated under the general framework established for solid wastes including dredge spoils, construction debris and other industrial and combustion residues (Eikelboom, 1992). The philosophical basis for the regulatory framework includes lifecycle management, (ii) marginal environmental burdening and (iii) user acceptance. The goal of lifecycle management is to maintain or modify the physical and environmental properties of residues to achieve the highest quality practical for recycling as granular construction materials, as many successive times as possible. The goal of marginal environmental burdening is to establish incremental increases in ambient soil and water contaminant concentrations below which environmental impacts are negligible or acceptable. The goal of user acceptance is to allow routine residue utilisation in environmentally acceptable applications with public and product user confidence. These goals have resulted in the development of a detailed set of regulations and supporting research. The key aspects of the regulatory framework are:

- Classification of waste substances and building materials,
- Establishment of target values for soils (including groundwater) and surface water,
- Establishment of standardised leaching tests, composition requirements and evaluation protocols for building materials, and
- Certification of residues for use

Classification of waste substances and building materials is based on whether the materials are granular or monolithic, the use of additional emission controls (e.g., covers, liners, etc.), and the degree of contact with water.

The target values for soils and groundwater are presented in Table 21.3. They were established based on a survey of soil and groundwater quality within the country. These target values then were used to determine acceptable marginal burdening levels for contaminants released from residues during use (Table 21.4). Marginal burdening is defined as "an increase of 1% in the level of pollution in relation to the target values in 1 meter of soil over 100 years." Soil composition was assumed to include 10% humus and 25% lutite. The assumed soil composition was used to estimate the distribution contaminants between assimilation by the soil and transport to groundwater. This approach indicated that marginal burdening of soil was also protective of groundwater.

Contaminant release limits for building materials incorporating wastes are based on standardised column leach test for granular materials (NEN 7343) and a monolith leach test (NEN 7345) for molded construction materials (Aalbers, 1992). Detailed structured assumptions and extrapolations based on the physical structure of the material, application and leaching mechanisms have been developed to permit development of limits for laboratory tests. Utilisation of monolithic and granular wastes is classified based on contact with water and whether or not additional barriers (e.g., liners and covers) are employed:

Type A -	Submerged or always in contact with water
Type B -	Primary contact with water is from precipitation (estimated contact with water 14% of time)

Table 21.3
Target Values for Soil and Groundwater Quality in The Netherlands

Substance	Ground mg/kg	Groundwater µg/l	Surface Water µg/l
Cr	100	1	5
Co	20	20	NA
Ni	35	15	9
Cu	36	15	3
Zn	140	65	9
As	29	10	5
Mo	10	5	NA
Cd	0,8	0,4	0,05
Sb	(2.6)	NA	NA
Se	(1)	NA	(10)
Sn	20	10	NA
Ba	200	50	(200)
Hg	0,3	0,05	0,02
Pb	85	15	4
V	(68)	NA	NA
F	500	500	1500
CN-complex	5	10	NA
CN-free	1	5	(50)
SO_4	(500)	150,000	100,000
Br	20	300	8,000
Cl	(200)	100,000	200,000

- values from “Beleidstandpunt Over De Notitie Milbowa” (0.5-0.2-1992 with the exception of the values, which are in brackets).
- the values of chloride, fluoride, bromide and sulphate in surface water are limit values.
- NA = not available
- Sb, Se, and V from [13]

Aalbers, 1992

Table 21.4
Maximum Acceptable Marginal Burdening Levels for Contaminants Released from Residues During Use in The Netherlands

Substance	Ground	Groundwater
	max. accept. immersions mg/m^2 per 100 year	max. accept. immersion mg/m^2 per 1 year
As	400	
Ba	3000	
Cd	10	
Co	300	
Cr-tot	1500	
Cu	500	
Hg	4	
Mo	150	
Ni	500	
Pb	1000	
Sb	35	
Se	15	
Sn	300	
V	950	
Zn	2000	
Br	300	
Cl		30000
F	7000	
SO_4		45000
CN-tot	70	
CN-free	15	

V1 building materials - application without additional emission controls

V2 building materials - application with additional emission controls (e.g., covers, liners, etc.)

The relationship between the maximum allowable release and the release observed during the standardised monolith leaching test is described by:

$$I_{max}(J\ yr) = E_{max}(64d)*f_{ext}*f_{bev}*f_{tem}*f_{iso}$$

where:

$I_{max}(J\ yr)$=maximum acceptable emission into the ground in a period of J year (mg/m^2);

$E_{max}(64d)$=maximum acceptable emission out of a material determined with the tank leaching test in 64 days (mg/m^2);

f_{ext}=extrapolation factor for the extrapolation from $E_{max}(64d)$ to $E_{max}(J\ yr)$;

f_{bev}=correction factor for wetting period;

f_{tem}=correction factor for the difference between the laboratory temperature and the temperature in the field;

f_{iso}=isolation factor for V2 building materials (this factor is 1 for V1 materials).

The criteria for determining if diffusion is the controlling release mechanism is based on the slope of the cumulative release curve from the monolith leach test:

Slope > 0.6-Emission is not diffusion controlled (more rapid) and the column leach test should be applied

0.35 < Slope < 0.6-Emission is diffusion controlled;

Slope <0.35-Emission is not diffusion controlled (slower) and the 64 day emission can be used as an estimate or be based on the column test.

Diffusion based emission is classified based on pD_e as:

$pD_e > 12$-low mobility
$10.5 < pD_e < 12$-intermediate mobility
$pD_e < 10.5$-high mobility

If the pD_e is less than 10 for a species, depletion of that species can be anticipated to occur during the 100 yr assumed use interval. The release is estimated based on one dimensional diffusion from a flat plate. The quantity available for release is estimated based on the availability leach test (NEN 7340).

The effects of weathering on the rate of diffusion are assumed to decrease the release rate. This implies physical durability and the occurrence of weathering mechanisms, such as carbonate uptake, which occur over the 100 year assumed use interval. The correction to account for this effect was to assume an increase in the pD_e of 0.01/yr. The cumulative effects of the above derivation are summed in an overall extrapolation factor or multiplier to translate release from 64 day tank leaching results to a 100 yr release interval (Tables 21.5 and 21.6).

Table 21.5
Extrapolation Factors for Determining Release in the Field from Laboratory Leaching Results for Cases where Depletion is Anticipated (The Netherlands)

Layer thickness (m):	0.3	0.5	0.7	1.0	2.0	10
pD_e	f_{uit}	f_{uit}	f_{uit}	f_{uit}	f_{uit}	f_{uit}
8	2	2	3	5	10	24
9	5	8	11	16	23	24
10	15	21	23	24	24	24

f_{uit} = E(100yr)/E(64d)

Table 21.6
Extrapolation Factors for Determining Release in the Field from Laboratory Leaching Results with Geometric Considerations, Depletion and Assumed Effects due to Weathering Included (The Netherlands)

Layer thickness (m):	0.3	0.5	0.7	1.0	2.0	10
pD_e	f_{ext}	f_{ext}	f_{ext}	f_{ext}	f_{ext}	f_{ext}
8	2	2	3	5	10	15
9	5	8	11	15	15	15
>10	15	15	15	15	15	15

f_{ext} = E(100yr)/E(64d)

Chloride and sulphate are considered exceptions to the above extrapolation factors because the maximum acceptable emission is defined to be that which would be released over a period of one year. This recognises the limited natural attenuation which occurs for these species and the potential direct impact on groundwater resources. The extrapolation factor, f_{ext}, for chloride and sulphate is 2.4. The other factors for translating release from tank leaching results to field conditions are to correct for differences in the frequency of wetting, temperature and isolation (e.g., barriers such as liners and covers). The correction factor, f_{bev}, for always immersed conditions is 1.0 while for non-immersed applications it is 0.14. The factor of 0.14 is based on an average precipitation occurrence, and hence surface wetting, of 14% of the time in The Netherlands. While this is used as a multiplier to emission, a more appropriate approach would be to modify the release time interval using $(0.14)^{0.5}$. The correction factor for temperature, f_{tem}, was based on an Arrhenius approach to diffusion kinetics and a mean laboratory and field temperatures of 20 C and 10 C, respectively. This resulted in f_{tem} equal to 0.7. The correction factor for isolation, f_{iso}, was assumed to be 0.14 when addition barriers were employed and 1.0 when the material was directly exposed.

Inversion of the above derivation permits estimation of acceptable laboratory results based on defined field conditions as

$$E_{max}(64d) = I_{max}(100yr)/(f_{ext}*f_{tem}*f_{bev}*f_{iso})$$

A similar laboratory to field extrapolation approach was applied for granular materials. In this case, the principal mechanism of contaminant release is assumed to be by percolation through the granular material. This is in contrast to when a granular material compacted in place results in a low permeability layer which may be treated as a monolith or diffusion controlled leaching. Examples of typical limit values for leaching test results on monolithic and granular materials are presented in Table 21.7. Since 1995, the limit value on composition S1 has been withdrawn following discussions between regulators and industry.

21.3.4 Sweden

In Sweden, both the utilisation and disposal of residues are treated in the same manner under The Environmental Protection Act (Hartlén, 1989 and 1991; Fällman, 1992). Thus, individual regulatory reviews including local and regional authorities are required for each specific application (Figure 21.2). The general philosophy in evaluating utilisation applications is that the specific utilisation scenario should result in (i) improvement of general environmental conditions, and (ii) have less environmental impact than disposal. Examples of uses that may satisfy these criteria are use as cover in a municipal waste landfill, in road paving applications where the residue is covered with an asphalt layer, or where natural aggregate is in limited supply. To date, very little utilisation has occurred, and utilisation regulations are under review.

21.3.5 United States

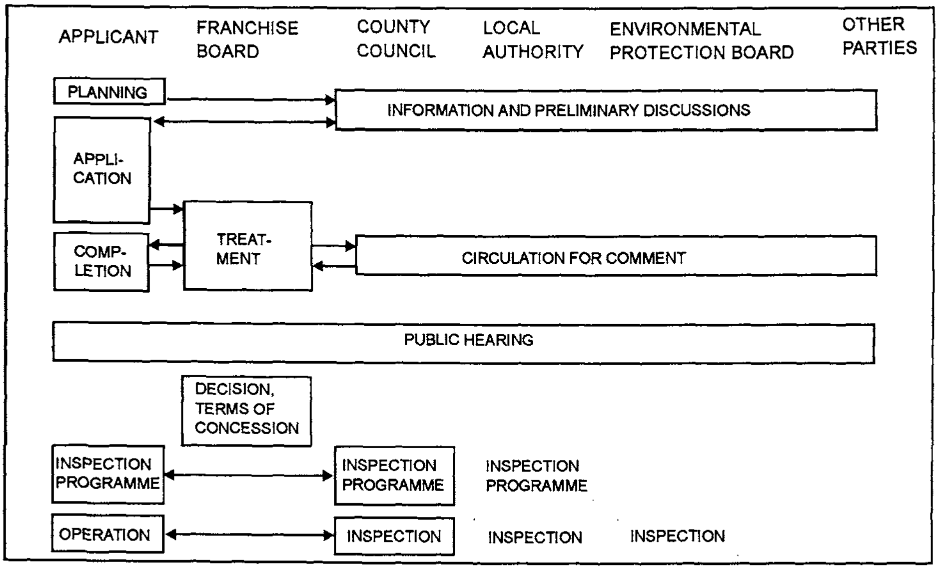
The United States currently does not have national standards for the utilisation of residues. Requirements for the U.S. Environmental Protection Agency to develop criteria for ash utilisation are being considered in pending legislation. In the absence of national guidelines, several states have developed applicable regulatory requirements. Florida and New York are the two states that have the most extensive requirements.

Table 21.7
Maximum Acceptable Limits for Leaching Test Results on Granular (mg/kg) and Monolithic (mg/m2) Materials (proposed, The Netherlands)

Leaching	standard values oBB granular materials in mg/kg			standard values oBB products in mg/m^2		
Substance	U1	U2	S1	U1	U2	S1
As	0.30	3.0	375	25	125	750
Ba	4.0	40	7500	350	1750	15000
Cd	0.010	0.10	10	0.70	3.5	20
Co	0.20	2.0	250	15	75	500
Cr	1.0	10	1250	90	450	2500
Cu	0.35	4.0	375	30	150	750
Hg	0.010	0.050	5	0.30	1.5	10
Mo	0.050	0.50	125	4.0	20	250
Ni	0.35	4.0	250	30	150	500
Pb	0.80	8.0	1250	75	375	2500
Sb	0.030	0.30	50	2.5	13	100
Se	0.020	0.20	50	1.8	9.0	100
Sn	0.20	2.0	250	20	100	500
V	0.70	7.0	1250	60	300	2500
Zn	1.4	14	1250	125	625	2500
Br	0.20	2.0	500	20	100	1000
Cl	600	5000	5000	2250	11250	1000000
CN- complex	0.050	0.50	125	4.5	23	250
CN-free	0.010	0.10	25	0.90	4.5	50
F	5.0	50	4500	440	2200	9000
SO_4	750	10000	25000	15000	45000	40000

A = A-type application; B = B-type application

Figure 21.2 Regulatory Reviews Required for Specific Applications of Ash Utilisation in Sweden



Florida requires an ash management plan as part of the operating permit for an incinerator facility. These plans must be updated and reviewed at least once every five years (Florida reg. 17-702.400), and must address the methods, equipment and structures needed to control dispersion of ash during handling, processing, storage, loading, transportation, unloading and disposal. The plan must consider potential pathways for human and environmental exposure including inhalation and direct contact (human exposure) and migration to soil, groundwater and surface water (environmental exposure). Recycling of ash (utilisation) is explicitly discussed in the regulations (Florida reg. 17-702.600). The generator of ash, at least monthly must describe the chemical and physical properties of the ash which is to be recycled. Prior to the recycling of ash, the process and use of the ash must be shown not to cause discharges of pollutants to the environment. In addition, in order to utilise ash, the following steps must be completed:

- describe chemical and physical properties of the finished product line;
- identify the quantity of ash used in the product;
- identify the quantity of product to be marketed or used;
- demonstrate the process will physically or chemically change the ash residue so that any leachates produced after processing will not cause a violation of surface or ground water standards;

- demonstrate ash or products will not endanger human health or the environment;
- performance standards need to be established as well as operational criteria.

New York also requires the development of an ash management plan for each incinerator facility (New York reg. section 360-3.5). Ash generation, handling, storage, testing, transportation, treatment, and disposal or beneficial use plan must be included. Ash utilisation is regulated by a beneficial use petition. The party who desires to beneficially use ash must petition to utilise the ash. There is no permit involved directly with ash utilisation. As a result of no permit being required, there are no public hearings required. The party petitioning for ash to be used as an ingredient or as a substitute for a raw material must:

- demonstrate that the resulting material is not a waste requiring disposal;
- have a known market or disposition;
- not accumulate the material speculatively;
- have contractual arrangements with a second person for use as an ingredient and this person has to have the equipment to do so;
- chemically and physically characterise the ash;
- identify the quantity and quality to be marketed;
- describe the proposed method of application or use, available markets and marketing agreements;
- demonstrate that the intended use will not adversely affect the public health, safety, welfare and environment;
- provide a description of each product mixture, if the use of the ash includes the mixing with different types of materials.

21.4 TECHNICAL REQUIREMENTS

The three major categories of applications include use as a lightweight aggregate either for road base construction, as a fill for embankments, or as an amendment for Portland cement concrete or bituminous asphalt. Most physical utilisation criteria are based on standard engineering tests. Specific physical requirements will vary based on the type of application (e.g., asphalt pavement, cement concrete, structural fill, etc.) and local construction regulations. Table 21.8 provides a summary of the physical testing requirements that may be required and typical acceptable values. Many of the tests traditionally specified for construction may not be directly applicable to bottom ash testing. However, they may be necessary for market acceptance. Most frequently, bottom ash can be blended with other aggregates to achieve specific design criteria.

Table 21.8
Physical Criteria and Property Ranges for Utilisation of Bottom Ash

Requirement	Asphalt Pavement	Concrete	Structural Fill
Particle Size Distribution	• Specific to location & application design • Uniformity coefficient (d60/d10) can be specified • total content of fines (<60μm) ≤ 10% (including all materials*)	• Specific to location & application design • Uniformity coefficient (d60/d10) can be specified • ≤ 10% fines (< 60μm)	• Specific to location & application design • Uniformity coefficient (d60/d10) can be specified • ≤ 10% fines (< 60μm)
Loss on Ignition	≤ 3%; lower values are preferred	≤ 3%; lower values are preferred	≤ 5%; lower values are preferred
Moisture Content	≤ 15% (geotechnical); as dry as practical is preferred	≤ 15% (geochemical)	approx. 16-17% (proctor optimum for mod. compaction)
Durability	• Specific to location & application design • LA Abrasion • California Bearing Ratio • Sodium sulphate soundness	• Specific to location & application design; applicable to final product • Unconfined compressive strength	• Specific to location & application design • Shear strength • California bearing ratio for base course material
Expansion	Aging for ≥ 3 months at ≥ 16% moisture	Aging for ≥ 3 months at ≥ 16% moisture	Aging for ≥ 3 months at ≥ 16% moisture
H_2 Evolution	Metal recovery for ferrous and nonferrous metals recommended	Metal recovery for ferrous and nonferrous metals required	Metal recovery for ferrous and nonferrous metals recommended
Water retention and transmission			• Hydraulic conductivity • capillary suction

* This means that the fines content of the ash must be less than 10% to account for contributions from other materials

Some additional limitations have been applied to bottom ash materials being considered for utilisation. Organic matter in bottom ash may create problems with respect to subsidence in the specific construction application and the evolution of gases as the organic matter degrades. In some European countries bottom ash samples found to contain >3% LOI are deemed unacceptable for use and must be deposited in a landfill. The ash must be processed to generate material with the proper grain size distribution (max. grain size 45-50 mm, <10% of the total weight <0.06 mm grain size). This may preclude a large portion of the bottom ash from RDF combustion systems which tends to consist of smaller grain sizes due to the preprocessing of waste feed. Pre-processing, such as screening and removal of oversize material and ferrous and nonferrous metals, is essential because metallic forms of these elements are detrimental to the utilisation of bottom ash as an aggregate. Separated metal can be directly recycled.

21.5 UTILISATION LIFE CYCLE AND ENVIRONMENTAL CONSIDERATIONS

Development of a comprehensive program for utilisation of incinerator residues requires consideration of ash handling requirements and potential environmental impacts throughout the life cycle of residue utilisation, beginning with ash generation and ending with either permanent use or ultimate disposal. A utilisation program also must consider local climate, geography and sociology. The following sections are intended to provide an overview of relevant considerations and suggestions for regulatory approaches.

The typical projected life cycle of incinerator residues during utilisation includes the following stages:

1. Ash generation (production at the facility)
2. Physical processing
3. Stockpiling
4. Manufacture
5. Use in designated application, and
6. Post-utilisation management and disposal

Potential ash impacts and considerations are essentially common independent of utilisation application from the time of ash generation to the point of manufacturing. Subsequent stages in the life cycle are significantly more application dependent because of the nature of the material in which the ash will be used and exposure scenario during use. For example, utilisation in Portland cement applications will have different effects on contaminant release than utilisation in bituminous pavement.

21.5.1 Ash Type Selection and Elements of Concern

Currently, bottom ash without grate siftings or boiler ash is considered to have the greatest potential for utilisation because it typically has the lowest content of leachable metals of concern (e.g., lead, cadmium, mercury, etc.) and soluble salts. In addition, this ash fraction has physical properties similar to lightweight natural aggregates and represents approximately 80 volume percent (70 wt %) of the total residues generated.

Grate siftings are excluded because of the content of fine particulates and relatively high contents of elemental lead and aluminum. Boiler ash is excluded because of the potential for relatively high content of more volatile metals such as cadmium and zinc. APC residues are excluded because of high soluble salt content (40-60 wt %) and relatively high contents of metals of concern such as cadmium, lead, zinc and mercury. The use of APC residues is also limited because of its high content of fine-grained particles which gives it high moisture holding capacity and therefore susceptible to frost expansion, and is difficult to compact.

The chemical elements and species which are of potential environmental concern in the residues are Pb, Cu, Cd, Cr, Mo, Hg, Zn, total soluble salts (e.g., Na, K, Cl^-, SO_4^{-2}) and total soluble organic carbon. These elements and species were selected based on either current regulatory guidelines for drinking water or solid waste management, leachability, potential aquatic life toxicity or potential engineering effects.

21.5.2 Ash Generation

Ash generation is defined as the production of the residues to be utilised at the incinerator facility. This stage is the most critical for quality control. The intent at this stage should be to produce as uniform a product (ash) as possible that will permit utilisation after subsequent processing. This will minimise the amount of processed ash that would be rejected as unacceptable at later stages or require disposal. Development of an overall quality control plan that would minimise testing requirements while maintaining ash quality is needed. Critical testing parameters during this stage would be loss on ignition (LOI), alkalinity, total leachable salts, leaching potential or availability of key elements, and moisture. LOI serves as an indicator of combustion efficiency and residual organic matter. Alkalinity or acid neutralisation capacity provides a measure of the material behaviour in the environment because of leaching of potentially toxic metals is strongly a function of pH. Development of a pH titration curve also would permit estimation of the contributions of hydroxide, bicarbonate and carbonate buffer systems.

Total leachable salts is an important parameter because total salt loadings can adversely affect soil and potable water resources. Total salt content can also adversely affect the durability of Portland cement-based products. The leaching potential, or availability, of key elements is important as threshold values for acceptance based on projected impact at the utilisation scenario. Availability is recommended rather than total concentration because fractions of each element of concern may be bound in mineral forms that would make it non-leachable or biologically unavailable under the normal extremes of environmental conditions. An example of this would be lead or chromium bound in a silicate matrix. Moisture content is important to insure that while excessive interstitial pore water does not exist (e.g., geotechnical moisture content should be less than 20%), enough moisture is present to prevent fugitive dust problems and allow proper aging of residues to proceed (>16%; see "stockpiling").

The frequency of testing to be carried out needs to be developed based on a statistical evaluation of the acceptable range and variation of critical parameters. Acceptance criteria should establish both the mean and the acceptable variance of analytical results that limit the quantity of material beyond the threshold limits that would render an entire lot of material unacceptable. Thus, testing at this stage would be for screening and quality control purposes and would be based on prior knowledge and detailed characterisation of the class of residue to be evaluated. Specific thresholds should be based on projected impacts for each utilisation scenario, since different utilisation scenarios may have different acceptance thresholds. For more broad scale requirements, grouping of utilisation scenarios by type of use with general site restrictions may be practical.

21.5.3 Physical Processing

Physical processing of ash is defined as mechanical processing such as ferrous and nonferrous metal removal, and crushing and screening to control the particle size gradation of the material to be utilised. Removal of oversized material is necessary to facilitate subsequent processing into appropriate products (e.g., asphalt paving material or concrete forms) and would be based on the specific utilisation scenario. The principal environmental and occupational health impact concerns during this stage would be a consequence of fugitive dust. Removal of fines may be necessary to minimise fugitive dust, and attendant controls, during subsequent stages. These operations may occur either at the facility or at the stockpiling location. Physical processing operations should be carried out with practices intended to minimise fugitive dust and avoid potential occupational health hazards.

21.5.4 Stockpiling

Stockpiling of ash is carried out for several reasons. First, during stockpiling, aging reactions occur within the ash which further stabilise the material. These reactions include oxidation, hydration and carbonation (fixation or uptake of atmospheric carbon dioxide) reactions. Oxidation of reduced metals typically results in less leachable forms. Carbon dioxide uptake results in a pH shift of the material from typically greater than eleven to more neutral pH, e.g., less than 9. This process also results in respeciation of some elements from hydroxides to carbonates. The net result of this process is a shift in the pH domain and speciation of the material to a less leachable regime for metals such as lead and zinc. Hydration reactions typically result in swelling of the material. These swelling reactions must be allowed to progress prior to utilisation to avoid detrimental effects on the structural durability of the final products. In the Netherlands, bottom ash is required to be aged a minimum of 6 weeks prior to utilisation (Born, 1994). Exact intervals required for sufficient ash aging have yet to be defined, but preliminary findings indicate a period between one and three months is sufficient.

A second reason for ash stockpiling is to allow for storage of the material because of seasonal demand. For example, most paving applications will be able to utilise the material only six to eight months out of the year depending on local climate.

Potential environmental or health impacts from stockpiling can be a consequence of fugitive dust, precipitation runoff, leachate or site access. Fugitive dust can be controlled by limiting the fraction of fine material (less than 100 µm) permitted in the stockpile and maintaining a minimum water content (greater than approximately 16 percent). Minimum moisture content also will facilitate ash aging processes. All runoff and leachate from the stockpile should be collected and treated if necessary. Applicable storm water and local regulations may be sufficient to address these concerns. Site access should be controlled to avoid unwanted human exposure.

Minimum ash stockpiling intervals should be established based on ash aging requirements. Maximum storage intervals should be based on the local annual climatic cycle. Consideration must be given if the aging process period and the seasonal demand period are mismatched. For example, in the northeast U.S. ash generated in July may have to be stockpiled until the following April for paving applications. Maximum ash stockpile quantities can be based on either annual use or demonstrated prior agreements for use with the entity receiving the ash after stockpiling.

21.5.5 Manufacturing

Manufacturing is defined as the processing of the ash into the final product form. This stage for paving applications would include ash drying and blending with asphalt at the asphalt plant, and placement of the pavement. This stage for Portland cement applications would include mixing with Portland cement, water and natural aggregate and forming into final structures such as blocks. Ash handling requirements during this and subsequent stages, should conform with standard handling procedures for materials which the ash is replacing.

Potential environmental or health impacts during the manufacturing stage could result either from fugitive dust or drying process emissions. Asphalt production will require drying of the ash prior to blending with other aggregates and asphalt. Aggregate drying typically is carried out at approximately 200°F. This temperature is not high enough to volatilise metals of concern, but may cause some entrainment of fine particles in the drying air stream, thus potentially increasing air emissions. Fugitive dust and air emissions impacts most likely can be minimised by limiting the fraction of fines in the ash stream.

21.5.6 Use Applications

A general approach for selection of acceptable utilisation applications and overall control of utilisation can be classified by the following steps:

i. Detailed ash characterisation

ii. Detailed evaluation of environmental impacts from proposed application

iii. Ash screening and quality control

iv. Verification of Ash characterisation, and

v. Categorically approved utilisation for certain applications with limited restrictions (previously defined)

Detailed ash characterisation would require determination of the statistical variation of the ash to be utilised, including chemical, physical and leaching characteristics. Acceptance limits for key parameters and statistical evaluation methods need to be established to provide an indication of the material's performance during use. After the variability of key characteristics has been determined, only a reduced set of analyses for quality control would be required at the time of ash generation. Ash characteristics and behaviour would be verified prior to use. This approach is often referred to as ash "certification." Certification would be granted to a specific incinerator facility after the initial statistical verification confirmed that the facility consistently meets quality control criteria. An initial set of potential quality control parameters has been presented in the section entitled "Ash Generation". This approach is possible because it has been demonstrated that residues from similar types of facilities exhibit common characteristics. Thus, only quality control and screening for non-characteristic properties are required.

Evaluation of impacts from proposed applications and potential approaches to criteria are presented in the sections that follow. For utilisation to be practical, extensive permitting should not be required for categorically approved applications which meet predefined restrictions. Predefined restrictions may include restrictions on location of ash utilisation and maximum quantities allowable. Record keeping should be required with regard to the location, quantity and nature of each utilisation application.

Two primary routes for environmental impact require consideration for most applications. The first route is through particle transport followed by either incorporation into soil or sediment, or food chain uptake. Food chain uptake is a much greater concern for marine applications. The principal controls over particle transport are through limiting direct abrasion on surfaces containing ash and through requiring specific product durability.

The second exposure route is through leaching, followed by impact on either groundwater, surface water or soil resources. Contaminant release through leaching can be viewed as consisting of two components, contaminant release potential and contaminant release rate. Establishing limits on cumulative contaminant release over a fixed time interval (e.g., 100 yr) is a potential approach for providing a uniform basis for comparison of potential impacts from both utilisation and disposal. The cumulative contaminant release could be projected based on integration of release rate and release potential data for defined geometries. This projection could include application specific information such as mean temperatures and precipitation to provide translation of laboratory data to field scenarios. Details of this approach have been provided in the Leaching of Products Chapter.

Cumulative contaminant release would be the most important parameter for elements or species of concern that accumulation in the surrounding environment. Release rate or flux would be the most important parameter for non-accumulating elements or species (e.g., sodium, chloride). Release potential would be the limiting parameter when the utilisation scenario is a permanent placement of the ash. This would be the case for marine applications.

Results from estimating long term constituent release can be compared to natural materials performance or evaluated based on an environmental impact assessment. Alternative approaches that can be considered include the approaches of site specific risk assessments, marginal burdening or defining an acceptable release limit. Site specific risk assessments most likely would be overly burdensome for implementation without affording additional environmental protection, except for very large scale utilisation projects. The marginal burdening approach is limited by the need to define background levels for application locations or regions. Alternatively, it is recommended that the acceptable release limit should be defined as resulting in an impact which is a fraction (e.g., 10%) of the applicable soil or groundwater standard. In order to facilitate this assessment, the following assumptions are recommended:

- The impacted area used as the assessment basis for accumulating constituents (e.g., trace metals) should be 10 cm depth of soil below the application;
- The impacted area used as the assessment basis for mobile constituents (e.g., TDS) should be based on the annual flux of groundwater in the uppermost 1 m of the aquifer below the application. Thus, a dilution volume per m^2 of application surface can be estimated; and,
- The time frame for impact should use either the design life of the application or a default interval of 100 yr.

For example, if the soil quality standard for Pb was 100 mg/kg, a cumulative release that resulted in less than a 20 mg/kg increase in the 10 cm of soil below the application over 100 years would be considered acceptable. This approach provides for environmental protection while permitting regional flexibility with respect to climate and environmental standards.

In addition, locations for utilisation should consider natural conditions, such as distance to sensitive natural resources and depths to groundwater. Life-cycle analysis for the material also should be carried out to evaluate the fate of the material after the designated use period and to assure compatibility with standard product recycling or disposal practices.

The result of the above estimation should be approval of routine application for utilisation projects with limited impact potential (e.g., structural fill less than a nominal thickness, aggregate in asphalt and landfill cover) while large scale applications (e.g., wind barriers, sound barriers, structural fill greater than a nominal thickness) would require site specific review and permit.

Paving Applications. The primary paving applications considered for use of residues is in the wearing course (roadway surface), binder course, base and embankments. Options for use of ash which has been physically processed and aged are (i) as a compacted granular material (ii) directly incorporated in asphalt, (iii) further solidified or chemically stabilised and used as a compacted granular material, or, (iv) further solidified or chemically stabilised and incorporated in asphalt.

Examples

In Sweden, use of compacted bottom ash as roadbase underlying asphalt pavement and as embankment was evaluated in a test road segment located in Mälmo (Hartlén, 1994). Use of fresh bottom ash, bottom ash which had been aged for one year and natural aggregate was compared (Figure 21.3). All ash was screened to less than 20 mm and had ferrous metal magnetically removed prior to use. It was found that aged ash (moisture content 16%) was readily compacted while compaction of fresh ash (moisture content 23%) resulted in failure of bearing capacity during compaction. Both ash types had an optimum moisture content of about 14% for proctor compaction. Maximum compacted dry density for ash was between 1.79 and 1.82 tonne/m^3. Test results on the road indicated that the ash layers physically performed similarly to the natural aggregate. Environmental evaluation indicated that release of trace elements from bottom ash was similar to or less than that observed for natural materials (Table 21.9; Hartlén and Lundgren, 1991).

In the Netherlands, fly ash (ESP ash without scrubber residue) has been used as a fine aggregate filler in asphalt for approximately 10 years (Hudales, 1994). Approximately 40% of the 60,000 tonnes of fly ash produced annually is used in this application. A maximum substitution of 35% for natural materials may be achieved. Tank leaching tests (NVN 5432) of asphalt containing fly ash found that leaching met applicable contaminant release standards by greater than a factor of 3.

Steketee and Urlings (1994) reported that substantial reductions in trace element and COD leaching was achieved by aging bottom ash in stockpiles for 12 months under moist, aerobic conditions. Leachate pH had decreased from 11.4 to 9.9 during this interval.

Figure 21.3 Test Road Built Up in Six Different Sections

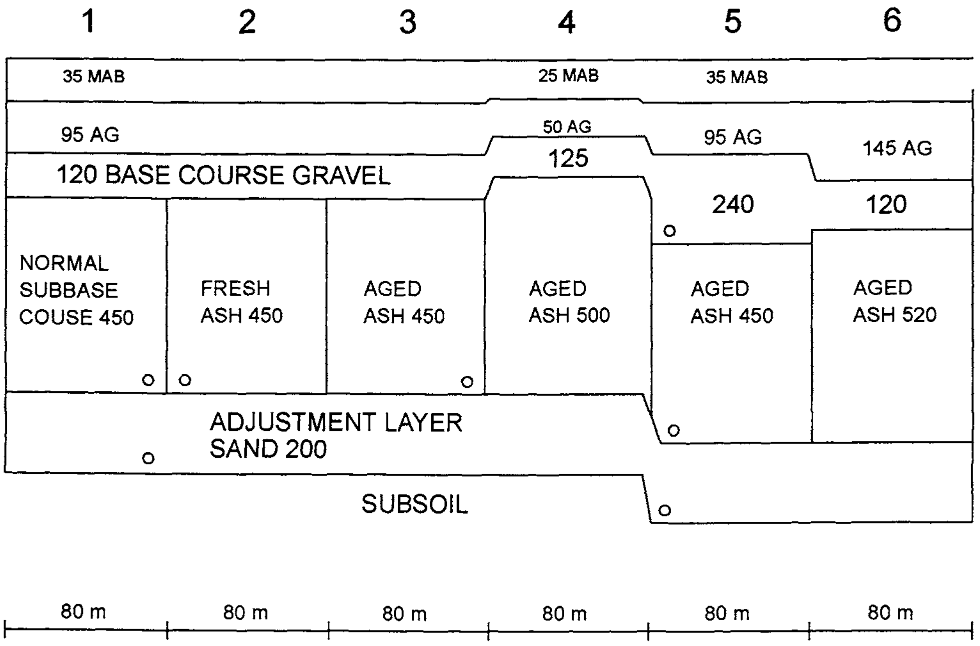


Table 21.9
Observed Release of Trace Elements from Bottom Ash During Utilisation in a Paving Application (Sweden)

Substance	Leachate from sorted BA	Background surface water	Local water course	Contamination factor	Unit
Cl	120	4	5.1	1.3	mg/l
SO_4	300	15	17.8	1.2	mg/l
Al	50	30	30.2	1.01	µg/l
Cd	0	0.02	0.025	1.2	µg/l
Cr	4	0.3	0.34	1.1	µg/l
Cu	20	0.7	0.89	1.3	µg/l
Ni	25	0.5	0.74	1.5	µg/l
Pb	10	0.2	0.30	1.5	µg/l
Zn	100	2.0	3.0	1.5	µg/l

In 1993, a 350 m length of a secondary roadway in Leconia, New Hampshire with daily traffic from 5,000 to 20,000 vehicles per day was reconstructed using aged grate ash as an aggregate substitute in the binder course (Musselman et al., 1994). The binder course was 5 cm thick and employed 50% substitution of grate ash for natural aggregate. 7% asphalt cement was determined to be the optimum asphalt content for this substitution rate. A 300 m control section included only natural aggregate in the binder course for comparative purposes. Road physical performance to date has been considered the same as the control section. Detailed environmental monitoring is part of the testing program, but has not yet been reported.

Applications using ash without further treatment as an aggregate replacement in asphalt used for binder or base courses should be given the highest priority. Significant reductions in potential contaminant release would be realised as a consequence of ash incorporation into asphalt. Further emphasis is given to these applications because both would have at least an impermeable asphalt layer above the utilised material, if not both above and below. Lower priority is given to use of ash in the wearing course because of potential abrasion and direct environmental exposure. Concern also exists about dust generated during milling of the wearing course during maintenance and repaving operations. Use of granular material directly as the wearing course is considered unacceptable. Use of granular material in embankments should be limited except in locations where salt release would not constitute a problem or if other precautions to limit salt release are established. Use of ash incorporated into asphalt for embankments is not considered a practical option because asphalt based materials are not typically used in that application. Use of treated ash (e.g., ash which had been further solidified or chemically treated) generally is ranked lower, except for use as compacted granular base, than use of untreated ash because additional processing requirements and economic concerns.

Terrestrial Cement Concrete Applications. Terrestrial cement concrete based applications can be classified based on whether the structures are environmentally exposed or further isolated. Use of ash in concrete blocks, decorative paving blocks, or precast forms are typical applications. Isolation from exposure may be based on the application of sealants or use inside a building. The potential impact of salts (e.g., chloride) on concrete reinforcement must also be considered.

Landfill Cover. Use of ash in municipal waste landfill applications present a unique environmental scenario because of the typical existence of environmental protection measures such as liners and leachate collection. Therefore, the principal exposure route of concern would be through fugitive dust.

Marine Applications. The marine environment can be considered more environmentally sensitive than the paving applications because of direct contact of marine biota with the application structure and the sediment and water column in the immediate vicinity of the application. The principal mechanisms for environmental impact in the marine environment would be through leaching and particle transport.

Particle transport is much more important in the marine environment than in the paving applications because it may be manifested through (i) erosion and biota uptake from the water column, (ii) erosion and biota uptake in local sediments or (iii) direct particle uptake by surface-attached biota. In all cases, food chain magnification of specific contaminants must be considered. Emphasis on particle transport also increases requirements for structural durability of ash containing materials.

Definition of priority utilisation scenarios for the marine environment is complex because of the variety of marine environments and ecologically sensitive areas that exist. Primary variables are the salinity, intensity of wave energy, and the degree of water circulation or flushing. Lowest potential impact areas would be areas of high salinity and a high degree of water circulation. Sensitive areas such as coral reefs or highly productive estuaries should be avoided.

Application Restrictions. This type of potential restriction would limit the type of ash to be utilised and the specific utilisation application. An example would be restriction of grate ash use to binder and base course layers in paving applications. For marine applications, an analogous limitation would be for use in defined structures either for shoreline protection or artificial reefs. The goal of this type of restriction is to facilitate development of highest priority applications first and to allow for revisions to criteria as more performance data becomes available.

Location Restrictions. This type of potential restriction excludes ash utilisation in environmentally sensitive areas. It also could be used to control site accessibility or provide for safety margins based on projected impacts. Examples for protection of sensitive areas include prohibiting ash utilisation in wetland areas or near coral reefs. Examples for control of site access or providing for additional safety margins are limiting use to applications on landfills or in industrially zoned areas, or, requiring a minimum distance from paving applications to groundwater supplies.

Quantity Restrictions. This type of potential restriction is used to limit the maximum quantity of ash to be used in a single location before more extensive review or permitting would be required.

Record Keeping and Monitoring Requirements. Records should be required to be maintained detailing each utilisation application. Information required should include ash characteristics, type of use and location of application. This would allow for future investigation of application performance. Routine environmental monitoring should be required only during pilot-scale evaluations of potential applications or for applications which exceed certain quantity restrictions. Extensive monitoring of every point of use is unwarranted and would be impractical and prohibitive.

21.5.7 Reuse and Disposal

Paving Applications. Roads, parking lots and other paving applications are considered to have a finite application period. This period may be defined in terms of years or decades depending on the specific scenario. Asphalt pavement is frequently recycled into new paving material. Controls should be established that limit use of recycled ash containing materials to applications approved for initial utilisation. Disposal of ash containing materials should be in conformance with applicable guideline for similar materials not containing ash.

Marine Applications. Shoreline protection installations and artificial reefs are considered permanent structures. Therefore, criteria for environmental acceptability should consider the utilisation scenario as the ultimate disposition of the material.

21.5.8 Economic Considerations

Estimates of costs associated with utilisation of incinerator residues are considered very site-specific because of varied requirements for permitting, testing, transportation and cost offsets achieved through reduction in disposal and natural material costs. Generally, cost estimates have not been published. An additional consideration which has limited utilisation in some areas has the absence of clear definition of potential product liability. Especially in the United States, parties that may participate in ash utilisation are extremely reluctant until the extent of their potential product liability is defined and perhaps limited.

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