Beneficial Use and Recycling of Municipal Waste Combustion Residues

a comprehensive resource document

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Beneficial Use and Recycling of Municipal Waste Combustion Residues — A Comprehensive Resource Document

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Preface

From about 1986 to October 1993, I managed the U.S. Environmental Protection Agency (EPA) Office of Research and Development's research on municipal waste combustion (MWC) residues. After completing a large project that evaluated the effectiveness of solidification/stabilization technologies for treating the residues, I began to focus on the development of technical criteria for the safe use of these residues with Dr. David Kosson at Rutgers the State University of New Jersey, and others from several countries. MWC ash was being safely used in other countries; this experience and the results of research and demonstrations in the United States showed that it could be safely used here, but most of the ash was being landfilled. I believed, as did many, that the development of criteria for safe use of MWC ash would help provide the basis for increased use and decreased reliance on landfilling of this resource.

Unfortunately, budget constraints and EPA's subsequent termination of research on MWC residues resulted in this work never being completed. One objective of that uncompleted work was to develop a document that compiled available information on the beneficial use of MWC residues. In October 1993, I left EPA to manage the U.S. Department of Energy's (DOE) Municipal Solid Waste Program at the National Renewable Energy Laboratory. Parts of this program involved support of ash utilization projects. Thanks to the support of Simon Freidrich of the DOE, the last task of the Program was to develop the document that I had been unable to do at EPA. This document, *Beneficial Use and Recycling of Municipal Waste Combustion Residues*, is the result of this work. Although less comprehensive than I had originally envisioned, it will, I hope, be a valuable addition to the literature and help increase the responsible use of MWC residues in the United States.

During the years I have been involved with this issue, I have had the opportunity to work with many interesting people from all over the world. I was also fortunate to participate in many international activities: the International Energy Agency, International Ash Working Group, international symposia, and similar activities dealing with ash. One experience I will always remember is participating in public hearings about ash. Quite often these hearings brought one thing into clear focus—that most people opposed to waste-to-energy (WTE) and the use of MWC ash did not have accurate information from credible resources. Although some did not care about the facts, I believe that many did. Emotion often ruled the meetings and dictated the final outcomes, resulting in ash use projects being delayed, moved to other locations, or canceled. Today people are more knowledgeable, or seem to be more willing to listen to credible sources. To be successful in implementing an ash utilization project, the developer must involve the public early in the process. I hope this document will help gain public support for responsible use of MWC ash.

The document summarizes data on the physical and chemical characteristics of MWC residues that are important for its successful use. A list and description of beneficial use projects in the United States are provided, as is a summary of ash use in several other countries. Also presented are data from leaching tests, analysis of leachates from ash landfills, analysis of TCLP testing of ash from several WTE facilities, and similar information. Results are presented of risk assessments conducted to evaluate human health risks associated with various ash uses. This and other information demonstrates, that the MWC ash can be safely used with no unacceptable risk to human health and the environment. Guidelines for its use are also discussed.

Although activities in several states appear to be encouraging for the increased use of MWC ash, there are still impediments to its widespread use. These include:

- Concerns about environmental liability. The document discusses the results of a recent analysis of this issue that shows how environmental liability can be managed and may no longer be a major impediment.

- Reluctance on the part of state and local permitting officials to address new issues. These permitting officials are routinely very cautious about approving permits for new projects using new and, to them, unknown materials. They are often understaffed. Therefore, the ash recycler's job is to help educate them about ash and its use and to provide the data and assistance needed to obtain an approved permit or beneficial use determination. Massachusetts, Florida, and Pennsylvania are leading the way in laying the foundations for beneficial ash use.

- Cost associated with obtaining permits. This is closely related to the previous item. Because permitting officials are not knowledgeable about ash and are very cautious, they may continue to request additional test data. This often results in long delays and can become very costly. Many are reluctant to accept data from other states, thus forcing the ash recycler to "reinvent the wheel." Hopefully this situation will improve as states are beginning to cooperate in accepting each others' data and as more information, such as this document, becomes available.

- Lack of markets for ash products and poor economics. Some consider this the main impediment to widespread use of ash. However, studies have demonstrated that ash performs well in several civil engineering applications. As more MWC residues are successfully used, the added experience will help open up markets for further use. Also, in areas where landfill costs are higher than the national average and natural aggregates are in short supply, the economics of using ash will improve. Additionally, as state permitting officials become more knowledgeable about ash products, permitting costs should decrease.

- Lingering concerns about the safety of using ash. Although the evidence demonstrates that the ash can be safely used, there are still concerns about beneficial use. These concerns must be addressed in a manner that is easily understood and credible. The proposed use must be legitimate, well planned, conducted according to appropriate scientific and engineering principles, and according to applicable regulations. Until ash use becomes a routine and accepted practice, the public must be involved from the beginning so they can learn that ash can be, and is being, used safely, and they can understand the details of the proposed project and other matters that are important to the project.

Although Phil Shepherd and I have attempted to accurately summarize all the information presented, errors will undoubtedly be found. I take responsibility for these errors. Also, many reviewers made excellent suggestions for additions to the document. Unfortunately, we had neither the time nor the resources to accommodate all these suggestions. We nevertheless believe this document will be useful to those interested in the beneficial use of MWC residues.

Carlton C. Wiles

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Preparing a document of this length and scope on a very focused topic requires high-quality assistance, including resource gathering through production. The authors were very fortunate to have had such assistance from many people. Professionals and practitioners alike gave valuable historical perspective and unpublished technical information. Many of these people are personally acknowledged on the following page. Our sincere apologies to anyone we missed. Authors of the cited literature provided insights into their reported studies. Many professionals, practitioners, and authors volunteered to serve as editorial reviewers of the final draft. The hours they expended made this a high-quality document that reflects the reviewers' broad perspective and pertinent knowledge and experience.

Three National Renewable Energy Laboratory employees contributed significantly to the writing and production of *Beneficial Use and Recycling of Municipal Waste Combustion Residues.* Lynda Wentworth quarterbacked the whole team. She kept everyone on their toes, on schedule, and on budget. We might still be writing and probably looking for more funds were it not for Lynda's skillful mastery of the process and polite reminders of what to do when. Stefanie Woodward was our editor. She had to take the sometimes hurried ramblings of two different authors and turn their language into the well-written prose you see within. Not an easy task! Stefanie deserves kudos for the final text. Irene Medina produced the final copy. She had to take countless pages created by three different typists of varying keyboard skills (two of us really have no skills in this department) and make the professional document seen here. People with Irene's talent are too infrequently acknowledged for what they bring to this kind of team effort.

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Acronyms

AAL	Allowable Ambient Levels
AAR	American Ash Recycling Corporation
AASHTO	American Association of State Highway and Transportation Officials
APC	air pollution control
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ASTSWMO	Association of State and Territorial Solid Waste Management Officials
BUD	Beneficial Use Determination
CB	chlorinated benzene
CBR	California Bearing Ratio
CEN	European Committee for Standardization
CERCLA	Comprehensive Response Compensation and Liability Act ("Superfund")
CDC	Centers for Disease Control
COE	Army Corps of Engineers
CORRE	Coalition on Resource Recovery and the Environment
CP	chlorinated phenol
DOE	U.S. Department of Energy
EAC	EAC Systems, Inc. (formerly Energy Answers Corp.)
EPA	U.S. Environmental Protection Agency
ESP	electrostatic precipitator
FBC	fluidized bed combustion
FHWA	Federal Highway Administration
FIT	Florida Institute of Technology
GAA	Government Advisory Associates
HRA	heat recovery ash
IAWG	International Ash Working Group
LEA	local enforcing agents
LIRPB	Long Island Regional Planning Board
LOI	Loss on ignition
L/S	Liquid to solid (ratio)
MB	mass burn
MSW	municipal solid waste
MSWI	municipal solid waste incineration
MWC	municipal waste combustion

NEPA	National Environmental Policy Act of 1969
NESWC	North East Solid Waste Committee
NREL	National Renewable Energy Laboratory
NYSDEC	New York State Department of Environmental Conservation
NYSERDA	New York State Energy Research and Development Authority
PADEP	Pennsylvania Department of Environmental Protection
PAH	polyaromatic hydrocarbon
PCB	polychlorinated biphenyls
PCDD	polychlorinated dibenzo-p-dioxins
PCDF	polychlorinated dibenzo-p-furans
PEL	permissible exposure limit
PM_{10}	respirable particulates less than 10 microns
RAP	recycled asphalt pavement
RCRA	U.S. Resource Conservation and Recovery Act
RDF	refuse derived fuel
RME	Reasonable Maximum Exposure
SPLP	Synthetic Precipitation Leaching Procedure
STLC	Soluble Threshold Limit Concentration
SUNYSB	State University of New York at Stony Brook
SWANA	Solid Waste Association of North America
TAA	Treated ash aggregate
TCDD	tetrachlorodibenzodioxin
TCDF	tetrachlordibenzofuran
TCLP	Toxicity Characteristics Leaching Procedure
TEQ	toxic equivalent
TSP	total suspended particulate
TTLC	Total Threshold Limit Concentration
UK	United Kingdom
USS	U.S. Standard
WTE	waste-to-energy

List of Elements

Symbol	**Element**
Ag	Silver
Al	Aluminium
As	Arsenic
Au	Gold
B	Boron
Ba	Barium
Be	Berylium
Bi	Bismuth
Br	Bromine
C	Carbon
Ca	Calcium
Cd	Cadmium
Ce	Cerium
Cl	Chlorine
Co	Cobalt
Cr	Chromium
Cs	Cesium
Cu	Copper
Dy	Dysprosium
Eu	Europium
Fe	Iron
Hf	Hafnium
Hg	Mercury
I	Iodine
In	Indium
K	Potassium
La	Lanthanum
Li	Lithium
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
Na	Sodium
Nd	Neodymium
Ni	Nickel
O	Oxygen
P	Phosphorus
Pb	Lead
Rb	Rubidium
S	Sulfur
Sb	Antimony
Sc	Scandium
Se	Selenium
Si	Silicon
Sm	Samarium
Sn	Tin
Sr	Strontium
Ta	Tantalum
Tb	Terbium
Th	Thorium
Ti	Thallium
U	Uranium
V	Vanadium
W	Tungsten
Y	Yttrium
Yb	Ytterbium
Zn	Zinc
Zr	Zirconium

Chapter 1
Background

Purpose

This document summarizes information from worldwide sources on the beneficial use of residues from the combustion of municipal solid waste (MSW). The information presented, including results of numerous research projects, field demonstrations, and actual full-scale projects, demonstrates that the ash can be safely used. This document will be useful to readers interested in ash use, those considering ash beneficial use projects, and persons needing a source of information about ash. Information important for planning and implementing ash use projects is presented. This includes data on ash characteristics, environmental considerations, guidance on selected ash use applications, and information on federal and state regulations and policies affecting ash use. Results of several studies evaluating the risks of using ash are presented. These are useful in providing an understanding of potential environmental and human health exposure pathways considered in evaluating ash use alternatives. Key points to consider in conducting leaching studies on ash are discussed and data are presented from laboratory and field leaching studies. Many ash research projects and ash use demonstrations are listed and provide sources for more detailed information on implementing beneficial use projects. Discussion of ash management practices in other countries shows that ash use in these countries is much more prevalent than in the United States. References are provided for readers who want more details on ash use.

In 1997, 103 waste-to-energy facilities in operation in the United States, serving the disposal needs of more than 31 million people. These facilities generated about 2800 MW of electricity from the disposal of 31 million tons of MSW. In the process, about 7 million tons of ash were produced. Most was used a landfill daily cover, as road bed, or was disposed of in landfills.[1]

Overseas practices and the large number of research and demonstration projects in the United States show that ash can be safely used. However, beneficial ash use has not progressed much in the United States. This could change because recent actions in several states have been encouraging and may help to increase beneficial use of ash.

Waste-to-Energy

This document concentrates on waste-to-energy (WTE) ash rather than on plant designs, incineration technology, and similar information. Readers interested in these details are encouraged to consult other sources such as the Integrated Waste Services Association, the American Society of Mechanical Engineers (ASME), and numerous publications. WTE plants burn the combustible fraction of the MSW stream to produce steam for electricity, industrial processes, or community heating. In 1995 the 112 operating WTE plants generated about 2775 MW of electricity each hour. This includes the equivalent of 100 MW of energy generated as steam at cogeneration facilities. This is equivalent to what is produced by about 30 million barrels of oil each year. In addition, these plants recovered 134,800 tons of recyclables before combustion and another 774,400 tons of ferrous metals from the ash stream.

There are three main types of WTE plant designs. These are mass burn, refuse derived fuel (RDF), and fluidized bed combustion (FBC). Mass burn plants burn the MSW as received at the plant, except to remove bulky items or other materials that cannot or should not be processed through the plant. Many of these plants process the ash to recover metals for recycling. RDF plants burn MSW processed to remove noncombustibles and shredded into a more uniform fuel. The RDF may be injected into the plant's boiler above the grate to burn in semisuspension or injected across the burning grate in a spreader stoker. Sometimes shredded RDF is densified into pellets or cubes and used as a partial substitute for coal. FBC burns RDF injected into a hot fluidized bed of noncombustible granular material. Some consider FBCs to be RDF plants. Mass burn systems are the most prevalent waste combustors in the United States, accounting for 69 of the 103 operating WTE facilities.

All these plants produce ash and residues. Characteristics of the ash may vary among the designs depending on process efficiency, waste preprocessing, the air pollution control (APC) system, waste composition, and other site-specific factors.

Residuals

The terms *ash* and *residues* are often used interchangeably. This, however, can be misleading. Ash refers to the matter that remains after complete combustion and is separate and different from APC residues. Residue includes unburned material, scrubber sludge, reaction products from the APC system, and other material that may end up in the final ash and residue stream. Therefore, from a technical viewpoint, residue includes the ash. However, many people use the word *ash* to refer to the total ash and residue stream leaving the plant.

Although technically there are more, three categories are routinely used to classify the residues as bottom ash, APC residues, and combined ash (the combination of bottom ash, APC residues, grate siftings, and heat recovery ash). Plants in the United States combine these streams for management in the plant. In most European countries and Canada the bottom ash and the APC residues are collected separately. Technically, ash and residues appear at several locations in the process. Table 1 shows the locations of ash and residues generation.[2,3]

Bottom ash comprises most of the residue generated. The quantity of bottom ash in the residue depends on the combustion facility design, operating conditions, and characteristics of the waste being combusted. Typically, about 80%–90% by weight of the residue produced is bottom ash (including grate siftings). Bottom ash is a heterogeneous mixture of slag, ferrous and nonferrous metals, ceramics, glass, other noncombustibles, and any unburned organics. After any large items are removed, it has the appearance of porous, grayish, silty sand and gravel. The APC residues consist of very fine particles collected by the APC equipment and the residues from chemicals used to treat emissions. It makes up about 10%–20% by weight of the ash produced. Combined ash looks very similar to bottom ash because the bottom ash is the major ingredient. The chemical composition of the fractions will vary. Most metals occur as oxides with significant amounts of metal chlorides, metal sulfates, and metal carbonates. The ash also contains trace amounts of environmentally important metals such as Pb and Cd and may contain very small quantities of dioxins and furans. The ultimate fate of these constituents in the environment caused some concern about the wisdom of using the ash.

Historical Perspectives

During the 1960s and through the mid-1970s, studies sponsored by the U.S. Bureau of Mines identified and quantified potentially recoverable and recyclable metals from the residues. Some showed that there were sufficient quantities of some marketable metals such as Cu and Ni.[4,5] However, little effort was made in the United States to recover these metals. The Federal Highway Administration (FHWA) conducted comprehensive investigations on the engineering and physical properties of the ash to determine its suitability as an aggregate substitute in portland cement and asphalt paving.[6] The FHWA conducted road paving demonstration projects using ash in six states. Investigators concluded that five of the six held up well. These projects evaluated the physical and engineering characteristics and did not address environmental aspects. Ash used in these investigations came from old batch-fed and traveling grate furnaces, which typically had very poor burnout, resulting in poor-quality ash. These and other studies also did not concentrate on the trace metals such as Pb and Cd. It was not until the late 1970s and 1980s that studies began to define and quantify the total and leachable quantities of potentially toxic constituents in the residues.[7] However, because investigators used different leaching and analytical procedures, results varied significantly and it was difficult to compare results.

Table 1.1: Categories of Ash Generated in WTE Plants

Ash/Residue Category	Location	Comments
Bottom	Material discharged from the bottom of the furnace, primarily the grate.	Normally the term *bottom ash* also includes grate siftings. May be called grate ash or clinker in Europe.
Grate Siftings or Riddlings	Material falling through the furnace grates.	Generally combined with bottom ash in the quench system.
Grate Ash	Bottom ash minus grate siftings	
Heat Recovery Ash (HRA)	Particulate matter collected from the heat recovery system.	May be further subdivided into boiler ash, economizer ash, superheater ash, etc., depending on the area of the heat recovery system from which it was collected. May be combined with either bottom ash or APC residue depending on facility design.
Fly Ash	Particulate matter carried over from the furnace and removed from the flue gas before sorbents are injected.	Includes volatiles condensed during flue gas cooling. Excludes ashes from the heat recovery system.
APC Residue	Combined material collected in the APC devices, including fly ash, injected sorbents, flue gas condensate, and reaction products.	
Combined Ash	Mixture of bottom ash, grate siftings, APC residues, and heat recovery ash.	WTE facilities in the United States routinely manage combined ash. Bottom ash and APC residues are collected and managed separately in Canada and Europe.

There was significant disagreement about the validity of any of these procedures to quantify and predict the amount that would leach under field disposal conditions. Additional concern surfaced when some municipal waste combustion (MWC) residue samples failed the regulatory electrostatic precipitator toxicity test used to classify waste as hazardous or nonhazardous. These samples failed because of Pb and Cd. This test was subsequently replaced by the Toxicity Characteristics Leaching Procedure (TCLP). Controversy about classifying ash as hazardous followed. This eventually resulted in litigation, conflicting rulings in two district courts, and a final ruling by the U.S. Supreme Court. The Court ruled the ash was not exempt from SubTitle C hazardous waste regulations.[8] The ruling required that the generator or owner of the ash determine whether the ash is hazardous. Testing now routinely uses sampling guidance from the U.S. Environmental Protection Agency (EPA) and delegated states, the regulatory TCLP, and any applicable requirements from the host state.[9,10]

Before the Supreme Court's ruling, the EPA several times changed positions on whether the ash was exempt. This and the lack of clear and definitive guidance from the federal level about ash management resulted in several states setting up their own rules. These rules varied from state to state, further complicating the issue. Before the mid-1980s, most ash was routinely co-disposed with MSW into landfills. This changed when states developed and began to carry out their own requirements based on toxicity concerns and the lack of clear EPA direction. This resulted in most of the ash being disposed into monofills, many requiring natural clay or synthetic liners or combinations of the two.

During the mid- to late 1980s, EPA's Office of Solid Waste studied MWC residues, leachates from the ash, ash management practices, and similar topics.[11,12] The purpose of much of this activity was to gather background data to support development of rules and guidance, should that become necessary. EPA's Office of Research and Development also conducted investigations of ash treatment and utilization alternatives.[13,14]

Based on a 1986 survey by the Government Advisory Associates (GAA), 80% of ash was landfilled without processing, 13% was landfilled after processing to recover metals, and 5% was processed in some manner before landfilling.[15] Less than 2% was used for some beneficial purpose. At that time, 19 states had regulations in place dealing with the ash. A 1996 survey conducted by the Solid Waste Association of North America (SWANA) showed that 25 of 28 states responding had some type of rule for managing MWC ash.[16] Of the states responding to the survey and telephone calls to additional states,[17] 32 allowed the ash to be disposed into monofills and 24 allowed co-disposal with MSW. This indicates that some states permit both. Landfill liner requirements varied among the states. In contrast, in 1993, 18 states allowed co-disposal in lined and unlined landfills and only four required ash monofills. In September 1996, the Association of State and Territorial Solid Waste Management Officials (ASTSWMO) released results of a survey of the 50 states.[18] This survey, States' Use of Waste and By-Product Materials, revealed that 25 states have formal requirements for a recycler to obtain approval for using or reusing a material such as foundry sand and MSW combustion ash. Many states have a Beneficial Use Determination (BUD) or similar permitting process in place; 17 states said they have such a formal process; four said the process was under development.

In 1995, only about 6% of the ash in the United States went to some beneficial use, much of this within landfills. This is in comparison with several European countries that use as much as 90% of the ash. Technical data and experience from U.S. studies and other countries show that ash can be beneficially used in ways that protect the environment and human health. At the Ash X Conference in November 1997, William Darcey suggested that ash recycling was now a reality.[19] From the perspective of a potential purchaser of ash recycling services, he discussed what he considered to be the five main arguments against beneficial ash use before 1995. These were:

- Ash may be hazardous.
- Ash recycling liability is uncontrollable.
- There are no proven ash recycling facilities.
- Ash recycling companies are not financially strong.
- Environmental regulators will not allow significant ash use.

He then provided arguments why these conditions no longer exist or can be managed and why beneficial use of ash is being accepted. These included:

- That testing of the ash since the U.S. Supreme Court decision has produced an extensive database that proves the ash is not hazardous and further processing by the ash recycling companies further improves its characteristics.
- He listed reasons why liability is controllable. (Also see discussion on liability in Chapter 7.) These included:
  a. Ash companies will accept contractual provisions transferring ownership of the ash to them.
  b. Reasonably priced insurance policies have become commercially available to cover ash product environmental liability.

   c. Conducting health risk assessments provides an additional measure of protection.

   d. When ash is incorporated into a commercially viable product (e.g., road base or block), there is judicial precedent that the owner or operator is no longer liable under the comprehensive Response Compensation and Liability Act (CERCLA).

- For many years, ash recycling companies in the United States and Europe have successfully used ash, with nine operating ash processing facilities in the Netherlands alone.

- Few startup and development companies have strong financial balance sheets, but innovative management and risk taking are overcoming this obstacle.

- Environmental regulators are slow in processing regulations, permits, and approvals, especially for new issues. However, since 1995 EPA has not been a significant impediment to ash recycling, and regulators in many states appear to be increasingly cooperative.

Darcey did not address the need for markets to be developed for beneficial ash use. Some believe this to be the most difficult impediment to its widespread use in the United States.

Chapter 2 of this document provides more details on the physical and chemical properties of the ash. Chapter 3 discusses uses for the ash and provides some guidance for various uses. Chapter 4 lists many research and demonstration projects. Chapter 5 discusses ash management in several other countries. Chapter 6 addresses environmental considerations of ash use. Chapter 7 deals with regulations and policies in place that affect ash use.

Chapter 2
The Nature of Ash

Introduction

This chapter provides information about the physical and chemical nature of WTE ash to give insight into the physical, chemical, and engineering properties of ash. Testing procedures and other factors that are important in designing and implementing beneficial use projects are also included. Data taken from many references and selected demonstration projects are presented. The data were combined in many cases because it is beyond the scope of this document to present all the available data that characterize ash.

Bottom ash and combined ash have the physical and mechanical properties required for successful use in several beneficial applications. These uses include concrete construction blocks, highway construction, shore erosion protection devices, asphalt paving, fill material, and landfill cover. Analyses for the inorganic constituents in the ash are more prevalent than for organics. However, the available data consistently indicate that dioxins, furans, and other organics in the ash from modern facilities will not deter beneficial use.

Ash should be fully characterized before beneficial use because each WTE facility differs in design, operating conditions, waste processed, location specifics, and other factors. However, once a facility's ash has been characterized for a specific use, another full evaluation should not be necessary. It should then only be important to conduct quality control and quality assurance programs to ensure the ash's characteristics do not change significantly. Successful beneficial use requires that one understand the physical properties and the chemical nature of the ash and their predicted behavior under expected use conditions. The information presented in this and other chapters will provide good insight for developing this understanding.

The various categories of ash (Table 1.1) differ in their physical and chemical properties. Ashes may also differ in response to seasonal and geographic variations in the makeup of solid waste. The nature of the combustion facility may also affect ash properties. RDF may yield ash differing from mass burn (MB) ash. This chapter concentrates on the bottom ash and combined ash because these are the two ashes most often considered for use. APC residues, bottom ash, and other fractions are combined for disposal in most U.S. facilities.

Ash Physical Properties

The physical properties of ash will strongly influence its selection as an aggregate in civil engineering applications. Bottom ash physical properties are very much like those of natural rock aggregate and gravel. Bottom ash consists of grate ash and grate siftings. Approximately 90% of bottom ash is grate ash, which remains on the grate or stoker during the combustion process. The grate ash is similar in appearance to a porous, grayish, silty sand with gravel material. Since the grate siftings (that material falling through the grates) make up only about 10% of the bottom ash, the bottom ash stream is very similar in appearance to the grate ash. Bottom ash consists primarily of glass, ceramics, ferrous and nonferrous metals, and minerals. Today, most WTE facilities recover the ferrous metals for recycling; some also process the ash to remove nonferrous metals for recycling.

Modern facilities have greatly improved ash characteristics compared to the older facilities. Therefore, Tables 2.1 and 2.2 present data on selected physical and mechanical properties from two recent studies. More detailed data are presented in the discussions of selected projects. The data in Tables 2.1 and 2.2 represent characteristics rated important by materials engineers when they select gravel or design concrete and asphalt structural mixtures containing aggregate. The physical and mechanical properties show that ash complies with

Table 2.1: Selected Physical Properties of MSW Combustor Ash[20]

Property	Bottom Ash	Combined Ash
Bulk Specific Gravity		
Fine (<No. 4 sieve)	1.70–1.81 [21] 1.50–2.22 [22]	1.86–2.03 [21]
Coarse (>No. 4 sieve)	2.11–2.23 [23] 1.93–2.44 [21]	1.96–2.24 [21]
Absorption (%)		
Fine (<No. 4 sieve)	12.0–17.0 [23]	4.8–14.8 [21]
Coarse (>No. 4 sieve)	4.1–4.7 [23]	3.6–10.0 [21]
Moisture Content (% Dry Wt)	29–66 [23] 22–62 [21]	17–76 [21]
Unit Weight, kg/m^3 (lb/ft^3)	960-1376 (60-86) [23]	992-1168 (62-73) [21]
Loss on Ignition (%)	6.4 [21] 3.7 [23] 1.5 [24]	2.5–13.5 [21]
Gradation (% Passing)		
Fine Fraction, <4.75 mm (No. 4 sieve)	50–70 [23] 42–62 [21]	50–70 [21]
Silt Fraction, <0.075 mm (<No. 200 sieve) Note: Higher 0.075 mm (No. 200) values were obtained in wash sieve tests.	60 [22] 9–16 [23] 2–6 [23] 2 [22]	15–20 [21]
Maximum Density, kg/m^3 (lb/ft^3)	1264–1568 (79-98) [23] 1712–1760 (107-110) [21]	1264–1728 (79-108) [21]
Proctor Compacted Permeability (cm/s)	Approx. 10^{-3}–10^{-4} [24,25]	Approx. 10^{-6}–10^{-9} [26]

many aggregate and gravel specifications. Further, ash can easily be graded in size to make products for many commercial applications.

Fly ash refers to fine particles carried over from the furnace. Fly ash becomes combined with APC chemicals and both are removed at the end of the process in a fabric filter or by an electrostatic precipitator (ESP). The collected residue is called APC residue. Some people incorrectly refer to APC residue as fly ash. The physical and chemical characteristics of the APC residues vary depending on the type of system used to control the air emissions from the WTE plant. Freshly collected fly ash usually appears as a fine, dusty material with little water content. The color may vary from white to gray to black, depending on its composition. Calcium chloride, a major constituent of dry and semi-dry process residues, imparts hygroscopic properties. Therefore, the residues will gradually absorb moisture from the ambient air, and the equilibrium moisture content will be strongly influenced by the CaCl content.[27] Residues from wet scrubber processes, not often used in the United States, have the appearance of a wastewater treatment sludge; usually dark in color. The water content will vary, depending on the degree of dewatering applied. Additional data are available on the chemical and physical properties of these ash streams.[27]

Table 2.2: Typical Mechanical Properties of MSW Combustor Ash[20]

Property	Bottom Ash	Combined Ash
Los Angeles Abrasion (%)		
Grading B	47.3 55–60	44–52
Grading C	43.4 41–47	36–45
Sodium Sulfate Soundness (%)		
Fines Fraction (<No. 4 sieve)	10.4–14.3 1.6–2.7	2.2–4
Coarse Fraction (>No. 4 sieve)	2.5–2.8 2.9	3.5
California Bearing Ratio (CBR) (%)		
0.1 in penetration	74–86 90–155	95–140
0.2 in penetration	104–116	
Angle of Internal Friction (deg.)	40–45	

Ash Inorganic Chemistry

Table 2.3 presents the concentrations of the major elements normally found in bottom ash and combined ash. *Major* is usually defined as concentrations greater than 10,000 mg/kg, or 1% by mass. These data were summarized from two recent studies in the United States.[20]

Table 2.3: Typical Chemical Composition (Percent) of Bottom and Combined Ashes

Constituent	Bottom Ash[28,29]	Combined Ash[27]
Silicon	16.8–20.6 18.3–27.4	13.8–20.5
Calcium	7.15–7.69 5.12–10.3	5.38–8.03
Iron	2.11–9.35 5.64–11.5	2.88–7.85
Magnesium	1.05–1.18 0.19–1.07	0.90–1.84
Potassium	0.84–1.02 0.72–1.16	0.84–1.15
Aluminum	4.77–5.55 3.44–6.48	3.26–5.44
Sodium	3.51–4.10 2.02–4.80	2.00–4.62

The ashes also contain several minor (1,000 mg/kg to 10,000 mg/kg) and trace (<1,000 mg/kg) elements as indicated in Tables 2.4 and 2.5. Table 2.4 shows analysis of ashes from several sources, primarily in the United States. The ranges of values presented are from many sources and may not be representative of the ash from modern WTE plants. Table 2.5 is from sampling and analysis of the ashes from facilities located in several countries, including the United States, as follows (the dates indicate the time the studies were conducted):

Table 2.4: Ranges of Concentrations of Inorganic Constituents in Fly Ash, Combined Ash, and Bottom Ash from Municipal Waste Incinerators

Parameter	**Fly Ash (μg/g)**	**Combined Bottom and Fly Ash (μg/g)**	**Bottom Ash (μg/g)**	**Combined Bottom and Fly Ash (μg/g)**	**Combined Bottom and Fly Ash (LIRPB) (μg/g)**
As	15–750	2.9–50	1.3–24.6	15–56	12–59
Ba	88–9,000	79–2,700	47–2,000	193–1,000	151–1,250
Cd	<5–2,210	0.18–100	1.1–46	18–152	5–116
Cr	21–1,900	12–1,500	13–520	45–665	51–1,270
Pb	200–26,600	31–36,600	110–5,000	1,070–22,400	689–13,300
Hg	0.9–35	0.05–17.5	ND–19	0.55–25.1	0.23–11.0
Se	0.48–15.6	0.10–50	ND–2.5	ND–5.7	0.01–6.3
Ag	ND–700	0.05–93.4	ND–38	4.1–13.0	ND–12.2
Al	5,300–176,000	5,000–60,000	5,400–53,400	5.93–13.0*	2,600–65,700
Sb	139–760	<120–<260	NR	NA	NA
Be	ND–<4	0.1–2.4	ND–<0.44	NA	NA
Bi	36–<100	NR	ND	NA	NA
B	35–5,654	24,174	85	NA	NA
Br	21–250	NR	NR	NA	NA
Ca	13,960–270,000	4,100–85,000	5,900–69,500	9.7–25.7*	4,670–99,100
Cs	2,100–12,000	NR	NR	NA	NA
Co	2.3–1,670	1.7–91	3–62	NA	NA
C_4	187–2,380	40–5,900	80–10,700	524–9,330	229–4,810
Fe	900–87,000	690–133,500	1,000–133,500	13,600–63,300	12,200–106,000
Li	7.9–34	6.9–37	7–19	NA	NA
Mg	2,150–21,000	700–16,000	880–10,100	1.02–2.2*	3,940–26,800
Mn	171–8,500	14–3,130	50–3,100	508–1,360	446–1,540
Mo	9.2–700	2.4–290	29	NA	NA
Ni	9.9–1,966	13–12,910	9–226	NA	19–219
P	2,900–9,300	290–5,000	3,400–17,800	NA	NA
K	11,000–65,800	290–12,000	920–13,000	0.79–1.4*	4,800–12,300
Si	1,783–266,000	NR	1,333–188,300	19.0–62.9*	2,170–231,000
Na	9,780–49,500	1,100–33,300	1,800–33,300	5,880–11,000	7,730–53,400
Sr	98–1,100	12–640	81–240	NA	NA
Sn	300–12,500	13–380	40–800	NA	NA
Ti	<50–42,000	1,000–28,000	3,067–11,400	NA	NA
V	22–166	13–150	53	NA	NA
Y	2–380	0.55–8.3	NR	NA	NA
Zn	2,800–152,000	92–46,000	200–12,400	2,120–15,800	1,660–21,300
A_4	0.16–100	NR	NR	NA	NA
Cl	1,160–11,200	NR	NR	766–44,200	500–249,000
Country	USA, Canada	USA	USA, Canada	USA	USA

*Results are for oxides and are expressed as percentages.
NA Not analyzed, as it was not part of the scope of work for this project.
ND Not detected.
NR Not reported in the literature
Source: The results in the first three columns are from "Characterization of MWC Ashes and Leachates from MSW Landfills, Monofills, and Co-Disposal Sites," EPA 530-SW-87-028A. The results in the fourth column are from "Characterization of Municipal Waste Combustion Ash, Ash Extracts, and Leachates," EPA 530-SW-90-029A, March 1990. The results in the last column are from the NYSERDA study and represents ashes sampled from 5 facilities from 1987 to 1989.[30]

Table 2.5: Composition Ranges of Bottom Ash from All Types of WTE Facilities, and Fly Ash, Dry/Semi-Dry, and Wet APC System Residues from Mass Burn WTE Facilities[27]

Element	Bottom Ash* (mg/kg)	Fly Ash (mg/kg)	Dry/Semi-Dry APC System Residues (mg/kg)	Wet APC System Residue w/o Fly Ash (mg/kg)	Wet APC System Residue/Fly Ash Mixture (mg/kg)
Ag	0.29–37	2.3–100	0.9–60	–	53
Al	22,000–73,000	49,000–90,000	12,000–83,000	21,000–39,000	71,000–81,000
As	0.12–189	37–320	18–530	41–210	130–190
B	38–510	–	–	–	–
Ba	400–3,000	330–3,100	51–14,000	55–1,600	330–1,300
Be	–	–	0.5–0.5	–	1.5–1.9
C	10,000–60,000	–	–	–	–
Ca	37,000–123,000	74,000–130,000	110,000–350,000	87,000–200,000	93,000–110,000
Cd	0.3–71	50–450	140–300	150–1,400	220–700
Cl	800–4,130	29,000–210,000	62,000–380,000	17,000–51,000	48,000–71,000
Co	6–350	13–87	4–300	0.5–20	14–22
Cr	23–3,170	140–1,100	73–570	80–560	390–660
Cu	190–8,240	600–3,200	16–1,700	440–2,400	1,000–1,400
Fe	4,120–15,000	12,000–44,000	2,600–71,000	20,000–97,000	15,000–18,000
Hg	0.02–7.8	0.7–30	0.1–51	2.2–2,300	38–390
K	750–16,000	22,000–62,000	5,900–40,000	810–8,600	35,000–58,000
Mg	400–26,000	11,000–19,000	5,100–14,000	19,000–170,000	18,000–23,000
Mn	83–2,400	900–1,900	200–900	5,000–12,000	1,400–2,400
Mo	2.5–280	15–150	9.3–29	1.8–44	20–38
N	110–900	–	–	1,600	–
Na	2,870–4,200	15,000–57,000	7,600–29,000	720–3,400	28,000–33,000
Ni	7–4,280	60–260	19–710	20–310	67–110
O	400,000–500,000	–	–	–	–
P	1,400–6,400	4,800–9,600	1,700–4,600	–	6,000–7,400
Pb	98–13,700	5,300–26,000	2,500–10,000	3,300–22,000	5,900–8,300
S	1,000–5,000	11,000–45,000	1,400–25,000	2,700–6,000	11,000–26,000
Sb	10–432	260–1,100	300–1,100	80–200	–
Se	0.05–10	0.4–31	0.7–29	–	12
Si	91,000–308,000	95,000–210,000	36,000–120,000	78,000	120,000
Sn	2–380	550–2,200	620–1,400	340–450	1,000
Sr	85–1,000	40–640	400–500	5–300	200
Ti	2,600–9,500	6,800–14,000	700–5,700	1,400–4,300	5,300–8,400
V	20–120	29–150	8–62	25–86	62
Zn	610–7,800	9,000–70,000	7,000–20,000	8,100–53,000	20,000–23,000

*See text for country and number of facilities.

- Bottom ash–Canada (seven facilities, 1987–1992); Denmark (eight facilities, 1985–1991); Germany (three facilities, 1988); the Netherlands (five facilities, 1985–1989); Sweden (eight facilities, 1985); and the United States (Eight facilities, 1986–1992).

- Fly ash–Canada (one facility, 1986 and 1991); Denmark (four facilities, 1982–1992); Germany (three facilities, 1982–1987); Jersey, Channel Islands (one facility, 1988); the Netherlands (three facilities, 1985 and 1986); Sweden (three facilities, 1988); and the United States (two facilities, 1987 and 1989).

- Dry and semi-dry APC residues–Canada (three facilities, 1986–1991); Denmark (four facilities, 1989–1992); Germany (one facility, 1982), the Netherlands (one facility, reported in 1992); Sweden (four facilities, 1985–1988); and the United States (five facilities, 1988–1989).

Table 2.6 compares directly the elemental composition of dry scubber residue with bottom ash taken from one WTE facility.[31,32]

The preceding four tables list a profusion of data on elements present in ashes of different types from many sources. Two general conclusions come from these data. First, ash contains many cations, which is not surprising considering its source. Second, there is a similarity among ashes, which is surprising considering their sources. Analysis for cations only does not lead to insight into what ash really is, chemically, and how it might be predicted to perform based on its chemical composition. Most of the chemical analysis work on ash has been done using somewhat inexpensive techniques such as atomic absorption and inductively coupled plasma. Such methods do not identify chemical compounds present, nor do they measure the solubility of salts contained in the ash. They identify only the cations combined within the actual chemical compounds.

Some researchers reported on the petrology of grate ash.[33] In addition to minerals formed during combustion, researchers identified glass, metals, soil, ceramic ware, spark plugs, and more.[33,34] The mineral products that were in the ash included isotropic and amorphous compounds and crystalline minerals. The crystalline minerals included complex silicates of Ca, Al, Mg, and Fe. Melilite and akermanite were identified as being similar to some of the crystalline minerals identified. Common oxides such as lime (CaO) and magnetite (Fe_3O_4) were also present.[28] Ash is a lot like natural rocks. A fourth reference went into great detail and identified the composition of a typical ash particle as being 15% untransformed waste ingredients and 85% as being melt structure.[35] The ash was sampled in 1989 from a 2,000 tpd mass burn combustor. No information was provided on recycling recovery before combustion or metals recovery from the ash. The detailed analysis showed that the untransformed constituents in a typical ash particle included 10% glass, 2% soil minerals such as pyroxene, quartz, and feldspar, 2% metals, and 1% organics. The melt structure included 25% opaque glass, 20% isotropic glass, 10% schlieren, 10% spinel minerals, and 20% mellilite minerals.

Unlike natural rocks, however, ash as it is formed contains about 6% of soluble salts.[36] The range of solubility was 3%–14% for bottom ash.[27] APC residues contained much more soluble material composed of reaction products such as CaCl from the acid gas neutralization. One researcher reported water solubilities of 21%–23% for fly ash from ESPs and 27%–38% for APC residues.[27] But other researchers reported up to 65% water solubility for ESP and dry and semi-dry APC.[27] These high solubility reports applied to APC residue and residue combined with fly ash.

Leachates from ash monofills showed heavy metal concentrations near or below drinking water standards, but total dissolved salts tested several orders of magnitude above drinking water standards.[37,38] The salts consist predominantly of chlorides and sulfates of Na, P, and Ca.[38] Water quenching of ash at the end of the combustion process removes many of the soluble salts. Further, stockpiling and aging of ash is a common practice that further reduces soluble salts by natural leaching and chemical reactions.

Table 2.6: Elemental Composition of Dry Scrubber Residue and Bottom Ash from a Single WTE Facility, mg/kg

Element	**Concentration**			**Element**	**Concentration**	
	Scrubber Residue	**Bottom Ash**			**Scrubber Residue**	**Bottom Ash**
Ag	19.64	11.4		Mn	385.9	1,448
Al	29,600	57,800		Mo	29.23	33.1
As	45.98	25.6		Na	14,500	42,000
Au	0.25	0.60		Nd	5.55	10.2
Ba	449.24	994		Ni	49.57	633
Br	1,552	<27		O	300,000	~363,000
C	~70,000	~85,000		P	2,100	4,100
Ca	354,400	81,400		Pb	1,995	1,908
Cd	99.3	7.80		Rb	26.89	26.6
Ce	12.79	40.6		S	19,800	2,000
Cl	118,400	1,300		Sb	473.5	125
Co	9.43	27.0		Sc	1.88	3.40
Cr	131.83	1,335		Se	3.07	<0.80
Cs	1.42	0.90		Si	42,100	106,200
Cu	362.10	2,230		Sm	0.91	1.97
Dy	1.53	1.13		Sr	<538	446
Eu	0.25	0.40		Ta	0.36	0.99
Fe	6,572	132,200		Tb	<0.13	0.92
Hf	2.26	5.20		Th	1.93	3.96
Hg	31.44	<0.26		Ti	6,093	6,935
In	0.79	0.19		U	<1.80	1.62
I	25.66	<8.41		V	<12.37	37.5
K	<7,500	<5,000		W	5.78	6.97
La	6.83	13.9		Yb	<0.41	0.85
Mg	5,200	11,300		Zn	11,767	197
				Zr	125.5	125.5

Organic Chemicals in Ash

Information on organics in ash is limited compared to the available information on the physical properties and inorganic ingredients. Also, good information on the combustion conditions, sampling techniques, analytical procedures, etc. is lacking, which limits the usefulness for many of the data. Because of this, the International Ash Working Group (IAWG) presented data on bottom ash from sources where this information was available (see Tables 2.7a and 2.7b). Data compiled by the IAWG showed that the organic content tends to range from 2% to 4% in well burned out bottom ash. Results of scanning electron microscopy on the ash indicated that much of this carbon is unburned MSW.

Table 2.7a: Dioxins and Furans (ng/g) in Bottom Ash*

Country	Facility	Total Dioxins (PCDD)	Total Furans (PCDF)	1/TEQ	Ref.
Canada	GVRD	ND**	ND	–	39
	PEI	ND	ND	–	–
	LVH	ND	ND	–	40
	SWARU	0.4	<0.2	–	41
	QUC	ND	ND	–	42
Germany	A	0.036–0.039	0.096–0.102	0.0018	–
	B	0.041–0.048	0.091–0.094	0.0020	–
	C	0.025–0.029	0.054–0.068	0.0008	–
United States	Mid-Conn	0.04–0.31	0.10–0.50	–	43
	Dry Scrubber 1	–	–	–	44
	Dry Scrubber 2	–	–	–	–
	Dry Scrubber 2	–	–	–	–
	Dry Scrubber 3	–	–	–	–

* Table Adopted from the IAWG (see reference 26)
** ND indicates not detected.

Table 2.7b: Other Trace Organics (ng/g) in Bottom Ash*

Country	Facility	Total Chlorophenols (CP)	Total Chorobenzenes (CB)	Total Polyaromatic Hydrocarbons (PAH)	Total Polychlorinated Biphenyls (PCB)	Ref.
Canada	GVRD	9.0	ND	181	ND	39
	PEI	ND**	20	1,800	ND	–
	LVH	34.1	6.7	2,190	ND	40
	SWARU	164	4.0	19,000	8	41
	QUC	14–48	6.0–13.5	125–968	ND	42
Germany	A	–	–	–	–	–
	B	–	–	–	–	–
	C	–	–	–	–	–
United States	Mid-Conn	4-5	ND	13–29	ND	43
	Dry Scrubber 1	73	18	–	–	44
	Dry Scrubber 2	120	ND	–	–	–
	Dry Scrubber 2	36	ND	–	–	–
	Dry Scrubber 3	83	36	–	–	–

* Table adopted from the IAWG (see reference 26);
** ND indicates not detected.

The IAWG study reached the following conclusions.

- The concentrations of PCDD/ PCDF in the ashes is dependent on the particle size distribution (more in the smaller particles), combustion conditions, particulate carbon loading rates in the flue gas, and ash disposition rates in the back end as compared to the front end of the boiler.

- All types of modern WTE combustors generated much less PCDD/PCDF than older ones.

- The concentrations of PCDD and PCDF are several orders of magnitude higher in the APC residues than in the bottom ash residues.

- Most modern facilities achieve total PCDD and PCDF levels in bottom ash below 0.5 μg/g. This represents a total toxic equivalent (1/TEQ) of about 10 μg/g, which is the same order of magnitude found in many soils.

- Typical levels of chlorinated benzenes (CBs) and chlorinated phenols (CPs) in bottom ash were between 9 and 164 μg/g for CP and 4 and 34 for CB.

- Well-operated combustors can easily produce bottom ashes with total polyaromatic hydrocarbon (PAH) concentrations less than 100 μg/g. For polychlorinated biphenyls (PCBs), levels of less than 10 μg/g can be achieved, regardless of technology type. Typical ranges for PAH and PCB in bottom ash ranged from 13 to 2,190 μg/g (PAH) and below detection limits to 8 μg/g (PCB).

The IAWG report contains even more information on the characteristics of the various ash streams. In the United States, the ash streams are normally combined. Studies have indicated, however, that the physical properties of the combined streams are similar to those of bottom ash and the chemical properties of the combined ash can be determined through proportioning the contributions from each stream.[27]

A study by the New York State Energy Research and Development Authority (NYSERDA) concentrated on the PCDDs and the PCDFs because of their reported toxicity and carcinogenicity.[45] These compounds, particularly 2,3,7,8 TCDD and 2,3,7,8 TCDF had received the most attention with respect to the organic compounds present in combustion residues. Based on an extensive review of the literature available at that time, the Long Island Regional Planning Board (LIRPB) and NYSERDA concluded that, although other trace organic contaminants had been detected at higher concentrations than these compounds, it was highly unlikely that any of them would pose potential health hazards during beneficial use of the ash. The study did, however, pay special attention to CBs and CPs because their presence in the ash could result in the formation of dioxins and furans during any applications requiring heat. Although trace amounts of these compounds were detected (appreciably higher in the fly ash than in the bottom and combined fractions) the investigators concluded that it would be very unlikely that any PCDD/PCDF concentrations in the ash would be increased by the conversion of CBs and CPs to PCDF or PCDD. This is consistent with earlier studies, and with the observed low yields of PCDDs and PCDFs (usually less than 1%) from the combustion or pyrolysis of CBs and CPs.

The report concluded that it was very unlikely that dioxins and furans in the bottom ash will be a concern when assessing the environmental or health consequences of ash use. The report did, however, caution that a beneficial use application that resulted in exposing workers to high levels of fugitive dust could be of some concern, because the PCDDs and PCDFs are more likely concentrated in the finer particle size fractions.

Leaching studies were not conducted. They were judged not to be warranted based on the low levels of PCDDs and PCDFs found in the ashes compared to other leaching studies of ashes containing much higher initial levels of these compounds. Such studies had shown that leachates from the ashes had extremely low levels of these compounds. Additionally, PCDDs and PCDFs have extremely low aqueous solubilities, and partition to solid phases.

Physical Properties of Ash Used in Selected Projects

Following are summary results of physical characterization of the ash used in several beneficial use projects.

The Laconia, NH Bottom Ash Paving Project

This project consisted of two major parts. Part 1 involved a 2-year study to characterize the physical and chemical nature of bottom ash from the Concord, New Hampshire, WTE facility. Part 2 demonstrated and evaluated the use of grate ash from that facility as an aggregate substitute in asphalt used in the binder course of a section of road in Laconia, New Hampshire. The ash used in the paving demonstration was grate ash (bottom ash without the grate siftings) which had been size separated (trommel screen with 3/4-inch openings) and aged for 6 months.

The following information is provided from the final project report. The approximate 5-year project included comprehensive chemical and physical time-dependent investigations, including leaching studies, but the following focuses on the physical aspects of the study.

Table 2.8 is a listing of the physical testing conducted on the bottom ash (including the grate siftings) collected from the Concord WTE plant over a 7-month period. Table 2.9 indicates the frequency of testing and the American Society for Testing and Materials (ASTM) methods used. Table 2.10 presents results of the physical testing done on the bottom ash during the 2-year study. Means and ranges are provided.

Based on results from the Part 1 characterization study and the paving demonstration, the investigators provided suggested criteria to be applied in similar uses. These are presented in Table 2.11.

Ash in Concrete Blocks

In 1991, a boathouse was constructed at the State University of New York at Stony Brook (SUNYSB), using blocks fabricated from cement-stabilized ash.[46] The blocks were manufactured from bottom and combined ash collected from the Westchester WTE facility located in Peekskill, New York. The combined ash was a composite of approximately 15% fly ash and 85% bottom ash. Ash processing included magnetic separation of ferrous metals and screening to 3/8-inch or smaller particles. The ash was not aged before use.

The blocks contained 15% type II portland cement and 85% of an ash and sand mixture measured by dry weight. The bottom ash blocks contained 55% bottom ash and 30% sand; the combined ash blocks contained 64% combined ash and 21% sand.

Previous studies by the investigators at SUNYSB[47] had characterized the physical and chemical nature of the ash generated at the Westchester facility. Composite ash (combined fly ash and bottom ash) samples were collected at several different times: August 1985 and January 1986 for ongoing laboratory studies, September 1996 for fabrication of hollow masonry blocks by Barasso and Sons, Inc. (Islip, New York) and November 1986 for fabrication of hollow masonry blocks by Besser Company (Alpena, Michigan). The November 1986 sampling included bottom ash only samples for the particle size analysis. Also included in the analysis was the bottom ash remaining after sieving through a 3/8-inch screen, which was then crushed mechanically.

Table 2.8: Physical Testing Requirements[28]

Parameter	Purpose
1. Mass <3/4" (1.9 cm)	- Measure of Material Suitable for Base or Binder Course
2. Moisture Content	- Measure of Water Content for Handling, Drying
3. Bulk Specific Gravity, Fine	- Mix Design, Weight - Volume Conversions
4. Bulk Specific Gravity, Coarse	- Mix Design, Weight - Volume Conversions
5. Bulk Saturated Surface Dry Specific Gravity, Fine	- Mix Design, Weight - Volume Conversions
6. Bulk Saturated Surface Dry Specific Gravity, Coarse	- Mix Design, Weight - Volume Conversions
7. Apparent Specific Gravity, Fine	- Mix Design, Unit Weight
8. Apparent Specific Gravity, Coarse	- Mix Design, Unit Weight
9. Absorption, Fine	- Tendency to Absorb Asphalt
10. Absorption, Coarse	- Tendency to Absorb Asphalt
11. LOI	- Tendency to Absorb Asphalt
12. Ferrous Content	- Measure of Metallic Content, Corrodible Material
13. Passing #4 Sieve	- Grain Size Distribution
14. Passing #200 Sieve	- Grain Size Distribution
15. Uniformity Coefficient	- Cohesive Soil Property
16. Effective Size	- Cohesive Soil Property
17. Los Angeles Abrasion (Grading B)	- Material Strength, Friability
18. Los Angeles Abrasion (Grading C)	- Material Strength, Friability
19. Soundness, Fine	- Material Durability
20. Soundness, Coarse	- Material Durability
21. CBR @ 0.1"	- Material Strength
22. CBR @ 0.2"	- Material Strength
23. Optimum Proctor Moisture	- Material Compactibility
24. Maximum Proctor Density	- Material Compactibility
25. Unit Weight	- Compacted Volume-Density Relationships
26. Marshall Stability	- Asphalt Paving

Table 2.9: Physical Testing Methods and Frequencies[28]

Parameter	Method	Frequency[a]
1. Mass <3/4 inch	3/4 inch Wet Sieve	H
2. Moisture Content	ASTM D2216	H
3. Bulk SG, Fine	ASTM C128	H,D
4. Bulk SG, Coarse	ASTM C128	H,D
5. Bulk SSD, SG, Fine	ASTM C128	H,D
6. Bulk SSD, SG, Coarse	ASTM C127	H,D
7. Apparent SG, Fine	ASTM C128	H,D
8. Apparent SG, Coarse	ASTM C127	H,D
9. Absorption, Coarse	ASTM C128	H,D
10. Absorption, Coarse	ASTM C127	H,D
11. LOI	ASTM C114	H,D
12. Ferrous Content	Hand Magnet	H,D
13. Passing #4 Sieve	ASTM C136	H,D
14. Passing #200 Sieve	ASTM C136	H,D
15. Uniformity Coefficient	ASTM C136	H,D
16. Effective Size	ASTM C136	H,D
17. Los Angeles Abrasion Grading B	ASTM C131	S
18. Los Angeles Abrasion Grading C	ASTM C131	S
19. Soundness, Fine	ASTM C88	S
20. Soundness, Coarse	ASTM C88	S
21. CBR @ 0.1 inch	ASTM D1883	D
22. CBR @ 0.2 inch	ASTM D1883	D
23. Optimum Proctor Moisture	ASTM D1557	D
24. Maximum Proctor Density	ASTM D1557	D
25. Unit Weight	ASTM C29	D
26. Marshall Stability	ASTM D1559	D

[a] H - hourly composite, D - daily composite, S - selected daily composites

Table 2.10: Upper and Lower Limits of Physical Properties of Bottom Ash

Property	Mean	Range
Mass Rejects, %	32.9	20.8–50.1
Mass <3/4 inch, %	67.01	49.8–79.1
Water Content, %	37.8	22.3–60.5
Uniform Coefficient	21.7	8.3–34.0
Effective Size	0.29	0.11–0.52
BSG, Fine	1.86	1.55–2.22
BSG, Coarse	2.19	1.92–2.43
BSG SSD, Fine	2.13	1.893–2.40
BSG SSD, Coarse	2.32	2.11–2.58
Apparent Specific Gravity, Fine	2.56	2.20–2.98
Apparent Specific Gravity, Coarse	2.51	2.31–2.76
Absorption, Fine	14.7	6.81–24.7
Absorption, Coarse	5.69	1.79–12.2
LOI, %	6.36	3.16–9.99
Iron Content, %	25.8	11.8–39.6

Source: Laconia Paving Project

Table 2.11: Suggested Criteria for Analogous Applications[28]

Category	Criteria
Combustor/Ash Type	
Combustor Type	Modern Mass Burn with Good Combustion Practices
Grate Type	Reciprocating, Rocking, Rolling, Traveling
Ash Type	Bottom, Grate
Ash Treatment	Physical
Ash Aging	To Be Determined by User
Moisture Control	Yes
Ash Characteristics	
Total Metals	
-Si	Distribution and Central Tendency Similar to Concord Grate or Bottom Ashes
-Cl	
-Pb	
LOI	$\bar{x} < 10\%$
Mix Design	
Binder Course Type	State or User Specified
Ash Substitution	< 50%
Mix Design	State or User Specified
Mix Design Performance	State or User Specified
Environmental Performance	
Monolith Leaching Test or Other Suitable Test*	
Monolith Total Availability (If Monolith Leach Test is Used)*	
-Cl	< 2,000 mg/kg
-Pb	< 150 mg/kg

* See Chapter 6.

Particle Size and Moisture Content

The ash samples were sieved (ASTM D422-63) dry using a series of U.S. Standard (USS) sieves: 3 inch, 1.5 inch, 0.75 inch, Numbers 4, 10, 18, 40, 60, 100, and 200.[47] Results of grain size analysis showed that the grain size distribution for the six ash samples fall predominantly in the sand size range (<4.75 mm, > 0.075 mm), with lesser amounts in the gravel (>4.75 mm) and silt or clay size (<0.075 mm). However, the percentage in each size range varied among the samples as indicated in the following:

August 1985 composite sample	4.5%	in gravel size range
	89.2%	in sand size range
	6.3%	in silt or clay size range
January 1986 composite sample	28.9%	in gravel size range
	67.3%	in sand size range
	3.8%	in silt or clay size range

The mean grain size ranges also varied with the September 1986 composite sample and the January 1986 composite sample having mean grain sizes of 1.02 mm and 2.03 mm, respectively.

Moisture contents for the ash samples were reported as:[47]

August 1985 composite ash	2.25%
January 1986 composite ash	14.1%
September 1986 composite ash	9.98%
November 1986 bottom ash	9.92%
November 1986 composite ash	15.3%

Loss on Ignition and pH

Loss on ignition (LOI) for the ash samples are provided in Table 2.12. The LOI determinations were made at 500ºC and 900ºC. The investigators stated that this was done because at 900ºC to 1,000ºC, where LOIs are routinely done, results may also reflect loss of water of crystallization, loss of volatile organic matter before combustion, and decomposition of mineral salts during combustion. The LOIs were done at 500ºC because biogenic organics are burned off at this temperature and this was of interest in this study. Results of the LOIs on all the samples were well below the ASTM C618 (ASTM 1974) requirements of maximum allowable LOI of 12% for coal fly ash used in portland cement concrete. Table 2.12 also presents the pH for these samples.

Ash in Shore Protection Devices[48]

In other research conducted at the Waste Management Institute, Marine Sciences Research Center, SUNYSB, ash from the Baltimore RESCO resource recovery facility was evaluated for use in the fabrication of shore protection devices. The objective of the studies was to produce a mix of ash and cement that would meet or exceed Army Corps of Engineer (COE) requirements for marine construction applications. Combined bottom and fly ash were collected in 1988. The ferrous metals had been magnetically removed. For this work, the combined ashes were screened to less than 9.5 mm ("screened ash"). Ash remaining on the screen (>9.5 mm) was crushed and the "crushed ash" was screened to <9.5 mm. About 5% of the ash remained on the screen after crushing and appeared to be mostly ferrous metals. The additional processing (crushing and screening) produced a 3:1 (vol/vol) ratio of "screened ash" and "crushed ash." These were blended in a ratio of 3:1 to produce samples for testing.

Table 2.12: LOI and pH for the Westchester Ash Samples[47]

Ash Type	at 500°C % LOI ± (S.D.)	at 900°C % LOI ± (S.D.)	pH*
August 1985 Composite Ash	1.83 ± (0.19)	3.89 ± (0.25)	12.7
January 1986 Composite Ash	5.04 ± (0.57)	6.44 ± (0.63)	11.5
September 1986 Composite Ash	5.60 ± (1.54)	6.57 ± (1.81)	10.4
November 1986 Bottom Ash	5.92 ± (0.97)	6.96 ± (1.24)	8.8
November 1986 Composite Ash	5.23 ± (0.34)	6.51 ± (0.33)	10.5

*Ash - distilled-deionized water mixtures (1:1 W/V) at 10 minutes.

Results of Physical Testing Conducted on the Ash

The following physical characterizations were conducted on the ash collected:

- Particle-size analysis—the distribution of particle sizes was determined by sieving nine randomly collected samples that were blended as described earlier. They were sieved dry and mechanically shaken in a RO-TAP sieve shaker. The analysis followed ASTM D422-63 (ASTM 1980) protocol using a series of standard sieves. For the “screened ash,” the predominant size fraction fell within the sand size range (<4.75 mm to >0.15 mm), with lesser amounts in the gravel (>4.75 mm) and silt or clay sizes (<0.15 mm). The “crushed ash” was almost evenly distributed between gravel-sized particles (51%) and sand-sized particles (44%). The combined ash exhibited a grain size distribution falling between the “screened ash” and the “crushed ash” data. All three ash types have a silt or clay fraction of approximately 5%.

- Friable particles—Conducted in accordance with ASTM method C-142, “Clay Lumps and Friable Particles in Aggregate” (ASTM 1980). This test provides information on the suitability of the residue as aggregate in concrete. It determines the extent to which the residue aggregate will crumble under pressure. As indicated in Table 2.13, the percentage of friable particles ranged from less than 1% for the crushed ash to 10.7% for the screened fine ash. The investigators reported, however, that when all fractions were combined, the friable particles were less than the 5% limit as recommended by ASTM C-33 for concrete used in piers, retaining walls, girders, and abutments exposed to severe weather conditions.

- Specific gravity and absorption—Both ash types (screened and crushed) were screened to segregate the fine particles (<2.36 mm) from the coarse particles (>4.75 mm). Standard test methods for specific gravity and absorption of coarse aggregate (ASTM C-127) using a pycnometer were employed for the coarse ash samples. The specific gravity and absorption of the fine particles in both screened and crushed ash were determined using ASTM method C-128 (ASTM 1983). See Tables 2.13 and 2.14 for results of this testing. The investigators reported that specific gravity values for natural aggregates typically range from 2.2 to 2.9; percent water adsorption for these materials is typically about 3.3%, although values as high as 7% are acceptable. This information is useful in determining how much water should be added to a mix to ensure proper hydration of the cement.

- Moisture content—Samples were dried to constant weight in an oven at 110°C for 24 hours in accordance with ASTM. See Table 2.15 for these results.

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Table 2.13: Absorption and Friable Particles in MSW Combustion Residue[48]

Ash Type	Absorption of Coarse Aggregates	Absorption of Fine Aggregates	Friable Coarse	Particles Fine
Screened	3.65%	14.8%	2.35%	10.7%
Crushed	2.35%	8.28%	0.86%	2.29%

Table 2.14: Moisture Content and Specific Gravity of MSW Combustion Residue[48]

Ash Type	Moisture Content	Specific Gravity	Dry Basis Specific Gravity	Saturated Surface Surface-Dry Specific Gravity
Screened	1.40%	2.42	1.80	2.22
Crushed	0.31%	2.60	2.06	2.42

Studies at the Florida Institute of Technology[49,50,53,72,73]

In a series of studies conducted at the Florida Institute of Technology (FIT), investigators evaluated the use of bottom ash for several beneficial uses such as in highway construction, artificial reefs in the marine environment, in precast concrete, and similar uses.[72,73] These studies included the characterization of the physical and chemical properties of the ash. The following information on the physical characterizations is abstracted from several of the project reports and papers.

Development of Criteria for Evaluating Bottom Ash for Construction Applications

In 1991, FIT investigators evaluated the properties of bottom ash to develop criteria and recommendations for using MWC bottom ash in additional studies concerned with construction.[72] In this work, bulk density, fineness modulus, moisture content, LOI, and grain size distribution were determined. See Table 2.15 through Table 2.20 for results of this testing on ashes from three facilities, which included mass burn and RDF.

These studies also evaluated the effects of particle size distribution of the ashes on their subsequent stabilization with cement. In Table 2.17, the ash noted as “treated” was produced by manually blending the ash to generate a mixture with a particle size distribution fitting within the limits of lightweight aggregate. Table 2.18 shows the specifications for a lightweight aggregate; Table 2.19 shows the “as received” grain size distribution; and Table 2.20 shows the final treated product.

Table 2.15: Percentage of Glass and Metals and Size Distribution in WTE Bottom Ashes Used in FIT Study

Component	Pinellas County Facility Ash	West Palm Beach Facility Ash	Key West FacilityAsh
Metal	0.2	17.8	0.6
Glass	0.1	2.1	2.5
> 1/2 inch	9.8	19.5	15.2
1/4 inch–1/2 inch	30.7	16.9	31.3
< 1/4 inch	55.2	43.7	50.4

Table 2.16: Physical Properties of WTE Ashes Used in FIT Study

Property	PC Ash	WPB Ash	KW Ash
Bulk Density (lb/ft^3)	84	66	70
Moisture Content (%)	13.4	26.3	18.9
Diameter at 50% finer (D_{50}, mm)	3.3	2.5	3.5
Fineness modulus	5.61	5.29	5.75
LOI (%)	5.35	7.63	7.17

Table 2.17: Particle Size Fraction (Percent) of WTE Ashes Used in the Study

Size Fraction	WTE Ashes		
	Pinellas County	West Palm Beach	Key West
Ash as Received			
P<1/4"	67	71	60
1/4" < P < 1/2"	33	29	40
Ash Treated			
P<1/4"	70	70	80
1/4" < P < 1/2"	30	30	20

Table 2.18: Limit of Grain Size Distribution for Lightweight Aggregate

Sieve Size (mm)	High Limit (% finer)	Low Limit (%finer)
19.05	100	100
12.50	100	95
4.75	80	50
0.30	20	5
0.15	15	2

Table 2.19: Grain Size Distribution of WTE Bottom Ashes as Received (Particles < ½"), Percent passing

Sieve Size	Pinellas County Ash	Key West Ash	West Palm Beach Ash
19.05	100	100	100
9.525	95	91.2	93.91
4.75	62	60.2	70.06
2.36	38	35.2	48.18
1.18	23	20.4	30.85
0.60	12	9.2	16.65
0.30	6	4.8	7.97
0.15	2	2.6	3.13
0.08	1	1.6	1.71

Table 2.20: Grain Size Distribution of WTE Bottom Ash Treated to Fall in the Limit of Lightweight Aggregate, Percent passing

Sieve Size (mm)	Pinellas County Ash	Key West Ash	West Palm Beach Ash
19.05	100	100	100
9.525	97	95	94
4.75	73	76	69
2.36	44	44	48
1.18	28	25	30
0.6	14	11	16
0.3	7	6	8
0.15	2	3	3
0.075	1	2	1

Bottom Ash for Highway Construction

Sources of the Ash and Physical Testing Conducted. The objective of this 1991 FIT study was to evaluate the shear strength and deformation characteristics of MWC ash for use in highway construction. Bottom ash from the North County Regional Resource Recovery Facility (Palm Beach County, Florida) and the Pinellas County Resource Recovery Facility (Pinellas County, Florida) were collected over a 2-year period and compared. The Palm Beach facility is an RDF process and the Pinellas County facility is an MB process. Both processes separate out metals; the RDF before combustion and the MB from the ash. The following physical testing was conducted on these ashes:

- Moisture content (ASTM C-566-89)
- Physical composition (visual sorting of fractions passing a No. 4 sieve but remaining on the No. 8 sieve)
- Grain size distribution (ASTM D-422-63)
- Specific gravity (ASTM D-854-92)
- Moisture-density relationship (ASTM D-698-91 and ASTM D-1557-91)
- Unconfined compressive strength (ASTM D-2166-91)
- Consolidated-drained triaxial shear (Bishop and Henkel)
- Elastic modulus (tangent method)
- CBR (ASTM D-1883-92)

Results and Conclusions from Physical Testing. Tables 2.21, 2.22, and 2.23 provide the results of this physical testing of the bottom ashes. Based on these results, the investigators concluded that the strength and deformation characteristics of the MWC bottom ash are similar to other soils. The engineering parameters indicated that either MB or RDF ashes will perform adequately in many highway applications, provided that proper quality control is maintained. Specific conclusions follow:

- The moisture-density relationships for the bottom ash are very similar to conventional soils. MB ash exhibited slightly higher maximum dry densities and lower optimum moisture contents than RDF ash. A decrease in the ash grain size resulted in a decrease in the maximum dry density and an increase in optimum moisture content.

- The unconfined compressive strength of the compacted bottom ash is similar to strengths exhibited by compacted fine grained soils. Compaction moisture content and energy are controlling factors for unconfined compressive strength of freshly compacted ash. Allowing compacted bottom ash to age increases the compressive strength.

- The stress-strain curves for both ash types increased as dry unit weight and confining pressures increased. Both ashes exhibit elastic moduli similar to loose sands.

- CBR values of both ash types are very sensitive to the compaction moisture content of the sample. MB bottom ash exhibits unsoaked CBR values twice as large as the RDF ash. Both ashes exhibit CBR values greater than 10 and can be classified as very good subgrade materials. CBR values for the MB bottom ash exceed 100, indicating that it can be used as road base. RDF ash, however, is not recommended as road base because its CBR value was less than 100. A loss of strength and little to no swell occur for both ash types after soaking.

- The specific gravity of the bottom ash was found to be a function of metals content. MB bottom ash exhibited higher specific gravities than the RDF ash. A decrease in grain size resulted in a decrease in specific gravity for both ashes.

Table 2.21: Summary of Physical Properties for MWC Bottom Ash[49]

Property	**MB**	**RDF**
Moisture Content Range as delivered %	11-19	16-26
Grain Diameter at 10% passing (mm)	0.33	0.17
Grain Diameter at 60% passing (mm)	4.1	1.8
Grain Diameter at 30% passing (mm)	1.5	0.55
Uniformity Coefficient, Cu	12.4	10.6
Coefficient of Curvature, Cc	1.66	0.99
Specific Gravity (passing #4 sieve)	2.79	2.55
Specific Gravity (passing #8 sieve)	2.72	2.45
AASHTO Classification	A-1-a	A-1-a
USCS Classification	SW	SW
ASTM Aggregate Classification	#89	#89

Table 2.22: Moisture-Density Results for MWC Bottom Ash[49]

Bottom Ash Source	**Compactive Energy ASTM**	**Optimum Moisture Content (%)**	**Maximum Dry Density (kN/m^3)**
		Passing #4 sieve	
MB	D-698	15.5	18.1
	D-1557	12.6	19.1
RDF	D-698	18.3	15.4
	D-1557	17.6	16.3
		Passing #8 sieve	
MB	D-698	17.8	16.5
	D-1557	16.4	17.8
RDF	D-698	20.8	12.9
	D-1557	19.3	15.4

1 kN/m^3 = 6.36 pcf

Table 2.23: CD Triaxial Shear Results for MWC Bottom Ash[49]

Ash Type	Relative Compaction (%)	Dry Unit Weight as tested (kN/m³)[a]	Compactive Energy ASTM	Friction Angle (°)	Cohesion (KPa)[b]
MB < #4	100	18.1	D-698	50	27.6
	95	17	D-698	48	27.6
	90	16.5	D-698	44	27.6
MB < #4	100	NA[c]	D-1557	NA	NA
	95	NA	D-1557	NA	NA
	90	17.1	D-1557	47	13.8
RDF < #4	100	15.4	D-698	45	27.6
	95	14.8	D-698	42	27.6
	90	13.8	D-698	38	13.8
RDF < #4	100	16.1	D-1557	47	34.5
	95	15.3	D-1557	45	20.7
	90	14.6	D-1557	41	20.7
MB < #8	100	16.7	D-698	42	13.8
	95	15.9	D-698	39	13.8
	90	14.6	D-698	30	13.8
MB < #8	100	17.7	D-1557	47	20.7
	95	16.9	D-1557	43	20.7
	90	16.1	D-1557	40	13.8
RDF < #8	100	13	D-698	41	13.8
	95	12.3	D-698	35	13.8
	90	11.7	D-698	24	13.8
RDF < #8	100	15.6	D-1557	46	20.7
	95	14.7	D-1557	42	20.7
	90	14	D-1557	39	13.8

[a]1 kN/m³ = 6.36 pcf
[b] kPa = 0.15 psi
[c] NA - Not Attainable

The Effects of Aging on Physical Properties of Bottom and Combined Ash[50]

FIT also evaluated the effects of aging on properties of bottom and combined ash from an MB facility. The metals had been removed from the ash before the investigations. In the experiment, the ashes were aged at 10°, 25°, and 40°C with water content of 7%, 15%, and 22% (saturation) for periods of 5, 30, 60, 90, and 180 days. After aging the ashes were dried and ground, when necessary, to determine grain size distribution, bulk density, specific gravity, pozzolanic activity, and mineral formation. Cylinders of the ash-concrete mixes were fabricated for compression testing to determine any effects on strength from aging. This information was also used to select preliminary mix designs for follow-up studies. Review of the test results will provide additional insight into the physical properties of the ash and ash-concrete properties, as well as the effects of aging the ash.

Bottom Ash Results

- There were no significant changes in the specific gravity under any conditions tested beyond the 180-day aging period (Table 2.24). Generally, the grain size distributions were in the range of sand size (0.075 mm–4.75 mm) and gravel size (>4.74 mm). This is very similar to results from other studies and were either within the range or near the low limit for light weight aggregate.

- The specific gravity was within the normal range for aggregate (reported to be 75 to 110 lb/ft^3) and increased slightly with aging of the ash (Table 2.25). An approximate 10% increase in bulk density was observed for the ash aged longer than 60 days with a water content of 22%. This indicates that the engineering properties of the ash may be improved by aging.

- The pozzolanic activity indexes (ASTM C311-90) of all bottom ash samples were higher than 100, indicating that the MWC bottom ash possesses pozzolanic properties (Table 2.26). These indexes are either similar to or greater than those reported for high-grade coal fly ash and were much higher than those reported for oil shale ash and MWC fly ash from MB facilities and RDF facilities.

The following tables illustrate the comments in the previous bullets.

Combined Ash Results

- Similar to bottom ash, there were no significant changes in specific gravity over a period of 90 days aging (Table 2.27). When compared to the bottom ash, combined ash has more sand size particles (0.75 mm–4.75 mm) because of the fly ash in the matrix. However, the distribution curves for the combined ash particles were still within the range of the grain size distribution curves for lightweight aggregate.

- Specific gravity was slightly lower for the combined ash, but still within the range of a normal aggregate (75–110 lb/ft^3) (See Table 2.28). The bulk density increased slightly over aging time with an approximate 18% increase observed for combined ash aged 30 days with 22% moisture.

- The pozzolanic activity index of the unaged combined ash was only 65. However, as aging time increased, the pozzolanic index value increased to more than 100 after 60 days of aging (Table 2.29).

Chemical Properties of Ash Used in Selected Projects

The Laconia, New Hampshire Bottom Ash Paving Project

This field demonstration project is briefly described in Chapter 4.

Comparison of the Elemental Concentrations in Bottom Ash with Those in Soils. Table 2.30 summarizes the mean value for all the elemental total concentrations in the bottom ash samples analyzed during the earlier 2-year characterization study (see section on physical properties). Also shown are the concentrations of these elements typically found in soils. These data show that the concentrations of all the major constituents (Si, Fe, Al, Ca, etc.) found in the bottom ash are similar to those found in soils. Trace elements such as Cr, Cu, Zn, Pb, Cd, and Hg, however, are enriched.

Table 2.24: Specific Gravity (gr/cc) of Aged MWC Bottom Ash[50]

Water Content (%)	Temperature (ºC)	Aging Time (day)					
		0	5	30	60	90	180
7	10		2.80	2.79	2.73	2.78	2.74
	25		2.90	2.04	2.67	2.73	2.82
	40		2.70	2.81	2.73	2.81	2.75
15	10		2.84	2.77	2.88	2.84	2.74
	25	2.79	2.85	2.82	2.85	2.73	2.83
	40		2.87	2.87	2.80	2.88	2.80
22	10		2.88	2.67	2.89	2.81	2.79
	25		2.92	2.01	2.77	2.83	2.76
	40		2.75	2.62	2.82	2.83	2.80

Table 2.25: Bulk Density (lb/ft^3) of Aged MWC Bottom Ash[50]

Water Content (%)	Temperature (ºC)	Aging Time (day)					
		0	5	30	60	90	180
7	10		79	78	82	90	87
	25		85	80	83	86	85
	40		83	81	85	87	83
15	10		82	82	92	87	87
	15	82	84	79	87	87	84
	40		85	76	92	88	83
22	10		80	77	88	91	86
	25		81	80	85	94	85
	40		82	79	87	90	86

Table 2.26: Pozzolanic Activity Index of Aged MWC Bottom Ash[50]

Water Content (%)	Temperature (ºC)	Aging Time (day)					
		0	5	30	60	90	180
7	10		201	159	164	118	113
	25		149	158	139	144	111
	40		187	143	143	107	91
15	10		113	167	127	106	120
	25	126	134	158	107	135	111
	40		143	149	110	139	106
22	10		133	144	157	121	140
	25		133	149	148	138	118
	40		133	143	136	140	114

Table 2.27: Specific Gravity (gr/cc) of Aged MWC Combined Ash[50]

Water Content (%)	Temperature (ºC)	Aging time (day)					
		0	5	30	60	90	180
10	10		2.80	2.75	2.80	2.80	2.76
	25		2.70	2.74	2.81	2.82	2.83
	40		2.73	2.76	2.76	2.75	2.80
15	10		2.72	2.70	2.84	2.80	2.76
	25	2.77	2.71	2.71	2.81	2.75	2.77
	40		2.74	2.76	2.76	2.72	2.82
22	10		2.77	2.72	2.77	2.82	2.79
	25		2.74	2.73	2.73	2.83	2.79
	40		2.75	2.78	2.83	2.80	2.76

Table 2.28: Bulk Density (lb/ft^3) of Aged MWC Combined Ash[50]

Water Content (%)	Temperature (ºC)	Aging Time (day)					
		0	5	30	60	90	180
10	10		86	88	86	89	88
	25		84	91	88	86	91
	40		91	89	89	86	91
15	10		85	83	91	89	86
	25	74	83	87	90	82	90
	40		89	87	89	85	90
22	10		84	89	90	90	92
	25		87	88	87	94	88
	40		84	83	86	87	89

Table 2.29: Pozzolanic Activity Index of Aged MWC Ash[50]

Water Content (%)	Temperature (ºC)	Aging Time (day)					
		0	5	30	60	90	180
10	10		89	92	105	105	106
	25		83	87	150	133	99
	40		84	93	110	136	124
15	10		87	91	105	105	105
	25	65	86	90	127	124	125
	40		87	96	119	113	115
22	10		92	90	136	131	107
	25		95	98	120	126	102
	40		97	93	133	125	113

Table 2.30: Upper and Lower Limits for Bottom Ash and Soil Elemental Composition (mg/kg)[28]

	Bottom Ash[a]		Soils[b]	
	Range	Average	Range	Average
Al	34,400–64,800	52,530	10,000–300,000	71,000
Ca	51,200–102,900	78,275	7,000–500,000	13,700
Fe	56,400–114,950	82,940	7,000–550,000	38,000
Si	182,500–274,000	233,000	230,000–350,000	320,000
Na	20,200–48,000	37,200	750–7,500	6,300
K	7,200–11,600	9,330	400–30,000	8,300
Ba	785–1,480	978	100–3,000	430
Mg	1,900–10,700	7,555	600–6,000	5,000
Cl	1,105–4,190	2,289	20–900	100
Br	16.65–126	45.5	1–10	5
Mn	605–1,560	1,033	20–3,000	600
Ti	3,490–9,500	7,085	1,000–10,000	4,000
Sr	0.0–1,000	581	50–1,000	200
As	17.9-189	42.0	1–50	5
Sb	60–283	118.0	-	-
V	31.6–123	57.5	20–500	100
Mo	20–161	45.4	0.2–5	2
Co	21–43	29	1–40	8
Cr	867–2,005	1,419	2–100	100
Cu	1,140–6,980	2,414	2–100	30
Ni	249–855	610	5–500	40
Zn	2,198–7,640	3,500	10–300	50
Pb	1,200–6,600	2,855	2–200	10
Cd	2.62–70.6	18	0.01–0.70	0.06
Hg	0.0–2.25	0.95	0.01–0.30	0.03

[a] Data based on 18 daily composites collected.
[b] Data based on compilation by Lindsay (1979) for a wide variety of soils.

Elemental Concentrations in Bottom Ash, Fresh Grate Ash, and Aged Grate Ash

This study also analyzed the concentrations of these elements in fresh and aged grate ash. Table 2.31 provides these data. Note differences in the concentrations of some elements, particularly the higher amount of Pb, in the bottom ash, which contains grate siftings, compared to that in the grate ash.

Table 2.31: Total Elemental Composition for Bottom Ash, Fresh Grate Ash, and Aged Grate Ash[28]

Element	Bottom Ash Total Composition, mg/kg		Fresh Grate Ash Total Composition, mg/kg		Aged Grate Ash Total Composition, mg/kg	
	Range	Average	Range	Average	Range	Average
Al	34,400–64,800	52,530	44,900–52,700	47,912	47,900–54,400	50,907
As	18–189	42	13.13–28.28	20.93	17.56–25.04	21.04
Ba	785–1,480	978	460–1,275	845	530–1,900	1,112
Br	17–126	46	19.85–51.54	31.97	15.27–38.95	24.40
Ca	51,200–102,900	78,275	50,800–65,300	58,600	54,200–67,400	62,236
Cd	3–70	18	3.44–8.60	6.93	3.85–10.19	6.86
Cl	1,105–4,190	2,289	700–2,340	1,713	470–2,590	1,338
Co	21–43	29	18.69–79.49	39.84	19.77–77.20	38.60
Cr	867–2,005	1,419	701–1,129	855	622–1,079	787
Cu	1,140–6,980	2,414	1,185–2,105	1,598	1,161–2,242	1,516
Fe	56,400–114,950	82,940	80,700–99,700	89,562	84,600–112,000	99,007
Hg	0.0–2.3	0.95	BDL	BDL	BDL	BDL
K	7,200–11,600	9,330	5,400–11,400	7,771	4,800–10,100	7,831
Mn	605–1,560	1,033	760–1,230	937	940–1,450	1,052
Mo	20–161	45	19.34–41.58	29.80	18.69–61.87	34.45
Na	20,200–48,000	37,200	30,800–43,000	37,825	34,600–46,000	38,914
Ni	249–855	610	440–585	501	347–591	464
Pb	1,200–6,600	2,855	903–2,885	1,400	895–1,710	1,278
Sb	60–283	118	60.48–98.28	75.62	57.30–94.59	80.94
Se	No Data	No Data	24.19–25.08	24.63	23.48–24.56	24.02
Si	182,500–274,000	233,000	215,570–259,040	240,767	215,460–257,900	236,422
Sn	No Data	No Data	141–605	276	147–309	229
Sr	1–1,000	581	310–530	386	270–670	462
Ti	3,490–9,500	7,085	5,000–6,800	5,937	5,100–7,100	6,100
V	32–123	57	31.88–43.08	38.69	33.28–58.45	45.00
Zn	2,198–7,640	3,500	2,852–4,140	3,394	2,707–4,070	3,304

Ash in Concrete Blocks

Table 2.32 presents the concentration of several elements found in the bottom ash and combined ash used to fabricate the ash-concrete blocks used in the construction of the boathouse.

Ash in Shore Protection Devices

The elemental composition of the combined ash collected from the Baltimore RESCO facility for this project is presented in Table 2.33.

Table 2.32: Mean and Standard Deviation of Concentration of Metals Measured in MSW Combustor Ash[51]

Analyte	Bottom Ash (μg/g)	Combined Ash (μg/g)
Fe	89,100 (15400)	80,200 (1900)
Ca	64,700 (7250)	7,200 (3340)
Al	51,700 (3200)	5,200 (3700)
Na	47,800 (1850)	37,500 (750)
Mg	10,500 (400)	11,800 (310)
K	7,500 (60)	11,100 (400)
Zn	6,080 (220)	5,370 (120)
Pb	3,260 (750)	4,070 (120)
Cu	2,200 (340)	1,600 (330)
Ba	730 (65)	870 (45)
Cr	250 (10)	220 (40)
Mn	130 (10)	930 (30)
Ni	130 (20)	140 (20)
As	20.4 (3.2)	<25
Cd	26.5 (3.1)	59.4 (10)
Ag	<5	<5
Se	<19	<25

Table 2.33: Elemental Composition of the Baltimore RESCO[a] Ash Samples[52]

Metal	3:1[b] Screened: Crushed	Crushed[c] Ash	Screened[d] Ash
Al (%)	3.59	3.12	4.43
Si (%)	22.5	22.8	19.5
Fe (%)	7.85	7.47	8.37
Ca (%)	8.67	8.32	9.38
Mg (%)	1.10	0.89	1.16
Na (%)	5.44	6.46	5.16
K (%)	0.69	0.61	0.84
Zn (µg/g)	3610	2030	5620
Pb (µg/g)	3240	3150	3730
Cu (µg/g)	1820	1160	2100
Mn (µg/g)	1120	815	1370
Ba (µg/g)	1090	1090	1230
Cr (µg/g)	320	276	300
Cd (µg/g)	16.1	7.9	33.0
As (µg/g)	16.9	21.9	22.6
Se (µg/g)	BDL[e]	BDL	BDL
Hg (µg/g)	BDL[f]	BDL	BDL

[a] Baltimore RESCO combined ash sampled during August 1988.
[b] 3:1 is the mix ratio of screened combined ash to crushed combined ash used for block manufacture.
[c] Crushed ash is the fraction of the combined ash sample that was retained on a 3/8-inch screen, and then ground using a jaw crusher to a particle size <3/8-inch.
[d] Screened ash is the fraction of the combined ash sample which passed through a 3/8-inch screen.
[e] Selenium detection limits = 12 μg/g
[f] Mercury detection limits - 2 μg/g

Studies at the Florida Institute of Technology

The 1991 FIT studies generated information about the concentrations of Pb and Cd in the combined residues from six WTE facilities in Florida. Data are presented on the total concentrations and the concentrations in the coarse and fine fractions for samples collected approximately 6 months apart. These data are presented in Tables 2.34, 2.35, and 2.36. Table 2.37 provides a brief description of the facilities. There were differences among the plants and between the two sampling events.

Table 2.34: Concentration (μg/g) of Pb and Cd in Florida's MWC Ash[53]

WTE Plant	Pb		Cd	
	Sample I	Sample II	Sample I	Sample II
A	2,180 ± 990	1,890 ± 200	46.1 ± 8.3	19.6 ± 1.0
B	3,140 ± 290	1,880 ± 290	41.5 ± 16.5	5.93 ± 0.2
C	4,140 ± 1,430	2,480 ± 320	40.2 ± 8.6	46.5 ± 4.5
D	2,960 ± 280	1,000 ± 130	47.1 ± 27.7	14.9 ± 0.6
E	5,240 ± 210	1,810 ± 260	28.6 ± 2.0	35.1 ± 1.4
F	3,960 ± 660	963 ± 75	58.3 ± 17.8	31.6 ± 1.1

Table 2.35: Concentration (μg/g) of Pb and Cd in Different Particle Sizes of Florida's MWC Ash (Sample I)[53]

WTE Plant	Pb		Cd	
	Coarse	Fine	Coarse	Fine
A	2,530 ± 290	1,320 ± 500	34.3 ± 0.9	33.7 ± 6.9
B	2,490 ± 280	3,080 ± 190	25.4 ± 6.2	48.7 ± 10.9
C	3,060 ± 600	1,530 ± 390	27.6 ± 4.2	37.7 ± 3.1
D	4,300 ± 680	2,780 ± 220	12.1 ± 0.3	51.1 ± 5.5
E	3,980 ± 370	4,490 ± 260	19.4 ± 0.6	41.1 ± 0.9
F	2,830 ± 630	2,610 ± 130	23.8 ± 2.7	82.0 ± 7.3

Coarse Fraction: particle size larger than 1 mm but smaller than 4 mm
Fine Fraction: particle size smaller than 0.25 mm

Table 2.36: Concentration (μg/g) of Pb and Cd on Different Particle Sizes of Florida's MWC Ash (Sample II)[53]

WTE Plant	Pb		Cd	
	Coarse	Fine	Coarse	Fine
A	3,130 ± 350	2,090 ± 130	58.2 ± 0.9	111 ± 6
B	2,500 ± 350	2,900 ± 50	7.73 ± 0.4	34.5 ± 3.0
C	3,220 ± 260	2,770 ± 100	80.7 ± 10.5	111 ± 3
D	1,520 ± 160	2,750 ± 370	12.2 ± 0.6	54.7 ± 2.0
E	2,460 ± 260	2,960 ± 160	22.2 ± 1.4	96.5 ± 3.1
F	4,170 ± 230	2,740 ± 130	36.2 ± 3.6	123 ± 5

Coarse Fraction: particle size larger than 1mm but small than 4 mm
Fine Fraction: particle size smaller than 0.25 mm

Table 2.37: WTE Facilities Participating[53]

WTE Plant	Design Capacity (TPD)	Startup Year	Technology Type	Air Pollution Control*	Ash Treatment
A	1,200	1995	Mass Burn	DSCR/FF/NOX/A	NA
B	2,000	1989	RDF	DSCR/ESP	Yes
C	1,000	1991	Mass Burn	DSCR/FF	NA
D	3,000	1985	Mass Burn	ESP	Yes
E	3,000	1989	RDF	ESP	NA
F	1,200	1987	Mass Burn	ESP	NA

*DSCR: dry acid gas scrubber; ESP: electrostatic precipitator; FF: fabric filter; NOX: thermal denox;
A: carbon absorption

Chapter 3
Productive Use of Ash

The physical and chemical nature of ash described in Chapter 2 suggests many potential uses as an ingredient in products and as a processed replacement for rock products. Ash is, after all, very much like crushed rock with some residual metal, glass, and soluble salts. More than 80% of WTE plants stabilize ash before use or disposal.[54] Treatments used to stabilize ash include lime (45%), phosphoric acid (32%), undisclosed acid (6%), and some by-product dusts from kilns.[54] Three locations reported using portland cement to stabilize ash.[54] Treated ash is available for beneficial use. Facilities that control acid gas emissions with alkaline chemicals in a dry scrubber or by reagent injection into the combustion unit are also adding chemicals to the ash. Calcium and Na are the common cations in these chemicals. The chemicals may include lime, hydrated lime, $NaHCO_3$, and other carbonates of Na such as, for example, the mineral trona. The chemical by-products from the process may include NaCl, CaCl, $CaSO_4 \cdot 2H_2O$, Na_2SO_4, and a host of other possibilities. For example, there are at least 16 possible reaction products of SO_2 with Na emission-control chemicals. The amounts of treating chemicals and their reaction products in ash have not been reported. Obviously ash from every facility will be different and there is likely to be a seasonal variation within some facilities.

Potential Uses

Ash use has been pursued for many years. European countries use ash extensively as a substitute for natural rock aggregate in civil engineering applications such as roadways and fill. Field tests in the United States followed similar paths by adding low-strength portland cement applications such as concrete blocks. Chapter 5 describes applications for ash use in foreign countries.

Raw Ash

Ash and products processed from ash can substitute for or supplement gravel and crushed rock in many civil engineering applications. Ash was successfully used in demonstration projects of these applications in the United States, and processed ash is commercially used in Tennessee, Pennsylvania, and Europe. Raw ash without added asphalt or portland cement binder works as a gravel and aggregate substitute in road base. It is also used as daily cover in landfill operations. Daily cover, usually soil, is required to cover waste deposited each day in all landfills. The cover discourages pests and prevents the trash from being wind-blown.

Chapter 4 describes more than 40 ash demonstration and research projects. Several researchers intent on maintaining records of ash applications compiled the list. Unfortunately for those in the ash business, commercial successes may go unreported. SWANA surveyed waste combustors in 1996 with the goal of learning who was using ash successfully.[54] Eighty-one waste combustors responded. The respondents' total waste processing capacity equaled about half the ash generated in the United States. Only 20% of respondents disclosed beneficial use of ash.[54] All these used ash free of asphalt or portland cement in the following applications.[54]

Daily landfill cover, ten locations
Intermediate landfill cover, three locations
Final landfill cover, one location
On-site landfill roads, eight locations
Landfill berms, two locations
Undisclosed other uses, five locations

The reference did not reveal the nature of eight landfill roads. They may be dry “gravel” roads, bituminous pavement, concrete, or crushed concrete as used at Puente Hills in Los Angeles.

Asphalt Pavement

Substituting ash for rock aggregate in bituminous pavement, also called asphalt concrete, has proven to be a straightforward procedure in 14 field demonstrations. In many cases screened-to-size ash has substituted for rock aggregate, frequently in a size range smaller than 3/4-inch. In recent trials it was necessary to slightly increase the asphalt content on a weight basis. However, the actual relative volumes of ingredients may have changed very little because ash has lower bulk and true densities than the replaced rock. The final topic in this chapter reports on guidelines for formulating long-lasting asphalt pavements made from ash. One thing is clear from the many field tests: Asphalt pavement made from ash lasts as long as conventional pavement and no environmental or health effects were reported. Ash pavements are safe and long lasting.

Portland Cement

Ash has been used in portland cement and portland cement concrete. There is an important distinction here. Many people use the two terms interchangeably, but portland cement is the binder that holds inert sand and rocks together to make portland cement concrete. Ash has occasionally been reported to have pozzolanic (cement)-like qualities and thus acts as a supplement to portland cement. This may be true in cases where the ash was treated with lime or contains residual reactive Ca compounds from APC treatment. Other possibilities include the presence of hydratable gypsum from APC reactions and binder-forming oxychloride reactions between APC reaction products and unreacted reagent. FIT reported that bottom ash used in its studies had pozzolanic properties absent Ca compounds from pollution control chemicals.[50]

Ash from the WTE facility in Charleston, South Carolina, was once used to manufacture portland cement using a now obsolete wet process. Charleston showed that ash is not suitable for cement manufacture by the modern, dry kiln process.

Portland Cement Concrete

Ash was substituted for rock aggregate in several portland cement field tests. The most frequent application was in concrete blocks. Blocks made with ash can be found in buildings in Columbus, Ohio; Albany, New York; Rochester, Massachusetts; and Stony Brook Long Island, New York. Artificial reefs made from ash blocks performed well in the ocean off the coast of Long Island. These tests, like the asphalt road tests, are described in Chapter 4.

Commercial Experience

Processes used to prepare ash for use fall in two broad categories—chemical and physical. Chemical processes react with, or immobilize, certain ash ingredients that might contribute to problematic performance of the final product. Physical processes separate unwanted ingredients such as ferrous metal and sort the ash into a narrow range of particle sizes suitable for the intended use. Some processes combine chemical treatment and physical sorting of the ash. The chemical treatments include adding lime or acid, commonly phosphoric acid. The physical processes include magnetic separators to remove ferrous metals and screening devises to separate the various desired particle sizes of ash. Eddy current devices occasionally separate metals such as Al and Cu. Screening will also remove very large incombustible items. Trommel screens, large rotating drums with holes in the periphery, are used occasionally as are inclined flat screens, common to quarrying operations.

Aging is not a commonly used ash treatment. It was used, however, on at least two demonstration projects. Aging was an effective stabilization treatment for ash used in roadway paving projects in Laconia, New Hampshire,[55] and Elizabeth, New Jersey.[56] (France, Germany, and other countries may require that ash be aged before use. See Chapter 5.)

Four firms actively sell treatments for ash or for processing ash for beneficial use in new products. Three of the companies manufacture and sell a product made from ash. These firms are American Ash Recycling, Energy Answers, and Rolite. The fourth company, Wheelabrator Environmental Systems, Inc., sells two ash treatments designed to render ash environmentally benign. A synopsis of these firms' activities appears here.

American Ash Recycling

American Ash Recycling Corp. (AAR) is headquartered in Jacksonville, Florida. It is a wholly owned subsidiary of Environmental Capitol Holdings Group of Affiliated Companies, Inc. AAR offers complete design, permitting, financing, construction, and operation of facilities to produce a processed ash for beneficial use and recycling. AAR patent-pending technology recovers ferrous and nonferrous metals as well as unburned combustibles from the raw ash. The remainder is processed and chemically treated into an environmentally safe aggregate for use as road base, structural fill, landfill cover, in asphalt paving, and in portland cement concrete.

AAR's first facility started operating in Nashville, Tennessee, during 1993. The Tennessee Department of Environmental Conservation issued a Permit by Rule on October 9, 1992 for AAR to process ash from the Nashville Thermal Transfer Corporation's WTE facility to recover ferrous and nonferrous metals. Then on January 26, 1993, the Tennessee Department of Environmental Conservation issued a Permit by Rule for the beneficial use of the processed ash aggregate. Ash processed at the 65 t/h Nashville facility comes from the Nashville Thermal Transfer Corporation's WTE plant. Additional ash is mined from the ash monofill where the AAR recycling facility is located. Thus, the AAR facility provides a dual benefit of converting fresh ash to a usable product and reclaiming landfill volume by also processing the mined ash.

AAR's second facility, rated at 150 t/h started operating in April 1998 in York, Pennsylvania. The Pennsylvania Department of Environmental Protection issued a General Permit for Processing/Beneficial Use of Municipal Waste on December 23, 1997. The permit allows an ash processing capacity of 240,000 t/yr. The primary ash source is York County Solid Waste Authority's WTE facility. Secondary capacity accommodates other WTE units.

AAR also licensed its patent-pending ash recycling technology through a Technology License Agreement for the territory of Japan to Kurita Water Industries, Ltd. Kurita purchased a mobile ash recycling unit from AAR in August 1997. The unit is rated at 1 t/h and is used for demonstrations.

AAR's process takes the residue from metal recovery, removes unburned material, and adds WES-PHix®, a chemical treatment, to stabilize heavy metals in the ash.[57] A physical fractionation step then sorts the ash into size gradations needed for its use as an aggregate and gravel substitute. The product was about 30%–35% gravel size and 60%–65% sand size by ASTM nomenclature.[58] Fine particles passing a USS No. 200 sieve were in the range of 4%–6%. Permeability and density were similar to conventional rock aggregates.

EAC Systems, Inc.

EAC Systems, Inc. developed an ash aggregate product at its resource recovery facility in Rochester, Massachusetts. Called SEMASS Boiler Aggregate™, the product grew from extensive development and field demonstrations in Albany, New York, and Rochester, Massachusetts. Field demonstrations took place over a period of about 12–13 years. A subsidiary corporation, Engineered Materials Company, was formed to manufacture and sell SEMASS Boiler Aggregate™. On December 24, 1996, the Massachusetts Department of Environmental Protection issued a final beneficial use determination to Engineered Materials Company for use of SEMASS Boiler Aggregate™ in Massachusetts paving projects. The aggregate product is manufactured from waste combustion ash by removing ferrous metals from the ash and screening it to the desired particle size range. Grain size is 95%–100% passing a 1/2-inch screen and 95%–100% retained on a 200-mesh sieve. It is called Well-Graded Sand with Gravel under ASTM nomenclature and as Stone Fragments, Gravel and Sand under Association of State Highway and Transportation Officials (AASHTO) nomenclature.[59]

A representative average particle size distribution over the period January 1994 through June 1996 was:[59]

	cumulative percent passing
1/2-inch screen	99.4
USS No. 4 sieve	65.5
USS No. 10 sieve	37.9
USS No. 20 sieve	18.1
USS No. 40 sieve	8.2
USS No. 60 sieve	4.5
USS No. 100 sieve	2.7
USS No. 200 sieve	1.3

SEMASS Boiler Aggregate™ behaved like conventional aggregate in tests for compaction, permeability, abrasion, CBR, and specific gravity. Representative values for these test results were:[59]

permeability	ASTM D2434-68	5.1×10^{-2} cm/sec
compaction	ASTM D1557, C	97.31 @ 4.81% water
abrasion	ASTM C313, D	39%
CBR	ASTM D1883-93	34 @ 90%
specific gravity	ASTM D854	2.53

EAC Systems, Inc. sold the SEMASS facility but Engineered Materials Co. continued to manufacture and market Boiler Aggregate™ as a subsidiary of EAC Systems, Inc. Engineered Materials has offices in Rochester, Massachusetts, and Albany, New York. The company developed a second source of Boiler Aggregate™ at EAC Systems, Inc.'s waste combustion facility in Pittsfield, Massachusetts.

Rolite, Inc.

Rolite, Inc., located in Wayne, Pennsylvania, began operating in 1988. The patented Rolite® Process uses portland cement, water, special mixing equipment, and controls to physically and chemically change ash into a manufactured aggregate. Process conditions can be adjusted to meet the requirements of various ash sources. The process significantly reduces leachability of metals and salts in the ash.

Rolite® is a round, uniformly graded material that may be used in a variety of construction applications. It has been used as daily landfill cover and final cover, landfill gas venting layer, structural fill, drainage fill, and road subbase. Rolite® was approved for landfill use in Delaware, New York, and Pennsylvania. The firm processed more than 400,000 tons of ash from 11 WTE plants in four states from 1989 to 1997. It operates an ash treatment and recycling facility in New Castle, Delaware, where, since 1995, the principal source of ash has been the Camden Resource Recovery Facility.[60]

Wheelabrator Environmental Systems, Inc.

Wheelabrator has two patented processes for treating ash to significantly reduce the leachability of metals. One process is called WES-PHix®. It is based on a phosphate and lime treatment and is used at many WTE facilities in the United States and Japan. The WES-PHix® process is available for license from Wheelabrator. Licensees operate the process in their own plants to treat ash for regulatory compliance measured by the TCLP specified by EPA. Treated ash may be landfilled following local and EPA regulations and has been approved for beneficial use in some states. For example, WES-PHix® is used by American Ash Recycling Inc. at its Nashville, Tennessee, and York, Pennsylvania, ash processing plants.

The WES-PHix® process immobilizes heavy metals. It was reported to be especially effective in immobilizing Pb and Cd.[61] Chemicals used in the WES-PHix® process include soluble phosphate and lime. Mixed with water to treat ash, these chemicals promote the formation of insoluble metal phosphates. The process may be supplemented with metals recovery and particle size classification to manufacture commercial products.

Wheelabrator offers a second, patented process for treating ash called McKaynite. McKaynite targets converting ash into a usable aggregate product. McKaynite aggregate can be used to replace natural rock aggregate in asphalt concrete, as road base material, and as landfill cover.

The process starts with combined ash (fly ash, scrubber residue, and bottom ash). Really large materials are removed and ferrous metals are recovered. Then the ash is crushed before treating with undisclosed chemicals. The treatment immobilizes heavy metals, stabilizes the ash, and forms weak agglomerates. After a short curing period, the treated ash is again crushed and sorted by size to meet customer specifications. In April 1993 the State of Florida approved McKaynite process aggregate for road construction and as a substitute for soil cover at sanitary landfills. Florida law allows the beneficial use of ash to count against State-mandated recycling goals.

Lysee Shell/Caloosa Shell

Lysee Shell had a product called PermaBase Plus that used ash in a soil-cement type of product. The State of Florida approved the use of PermaBase Plus in 1993 following successful demonstration tests. The developer of PermaBase Plus purchased Lysee Shell and changed the name to Caloosa Shell. No sales of PermaBase Plus occurred despite State approval. Caloosa Shell withdrew PermaBase Plus from the market.

Other companies may be engaged in the beneficial use of ash. However, their activities have not been publicized.

Guidelines for Use

Waste combustion ash use has successfully displayed good performance in several applications for more than 20 years. Detailed descriptions of U.S. demonstrations appear in Chapter 4. Ash performed successfully as an aggregate substitute in asphalt paving with only one, less-than-satisfactory experience in Harrisburg, Pennsylvania, in 1975. Ash also substituted successfully for rock aggregate in concrete blocks in several large demonstrations in four states. Ash in portland cement concrete also showed some promise at times, but glass, metal, and soluble salts need to be removed for applications in which strength and appearance are important. Ash also showed promise as a pozzolan in portland cement applications when Ca compounds from pollution control or ash stabilization remained in the ash. The largest use for ash is as daily landfill cover and intermediate cover. The second largest use is on-site landfill roads.[54] Several references contain guidelines for using ash in asphalt paving, in portland cement compositions, and as bank and fill aggregate. Not all the referenced guidelines agree, although there are no substantive contradictions. The following section reviews some experiences and guidelines offered. Readers can decide what best suits their circumstances. They can then draft specifications and practices applicable to their desired use, ash source, and market circumstances.

Asphalt Pavement

Mix Design Considerations

Asphalt paving is the most successfully researched and demonstrated use for ash. Several reports contain guidelines for using ash in asphalt paving based on one demonstration or laboratory study. A comprehensive set of guidelines appears in *User Guidelines for Waste and By-Product Materials in Pavement Construction*, section 10, from FHWA printed in April 1998. This document revealed that European countries used MSW grate ash, fly ash excluded, in road construction as fill material and as an embankment material for nearly 20 years. The FHWA confirmed the findings in Chapter 4, that ash passing a 3/4-inch screen and with metal removed can be substituted for 10%–25% of natural aggregate in bituminous surface courses and up to 50% in base and binder courses. The preferred maximum amounts were stated as 25% by weight in binder and base courses and 15% in surface courses. Paving test results suggested adding hydrated lime at 2% by weight of the aggregate to prevent stripping of asphalt binder from the ash.

Early FHWA field tests showed that MWC ash could be mixed, placed, and compacted with conventional asphalt paving machinery. FHWA Guidelines are summarized here.

Material Processing

Segregation of Ash. Coarse ash particles in bottom ash should be kept separated from fine ash particles in fly ash, pollution control residue, and grate ash. Keeping the coarse and fine particles separated will reduce the load on the screening operation that follows.

Screening. Screen the ash through a 3/4-inch sieve. Material passing this size is suitable for use as an aggregate substitute. Screening to an even smaller size, for example 1/2-inch, could produce a better aggregate substitute because some weak and unstable clinker particles would be eliminated. Screening to the smaller maximum size might slow down the process because wet ash might clog the smaller pores in the screening equipment.

Ferrous and Nonferrous Metal Removal. Ferrous metal must be removed from the ash. Nearly all ash sources do this routinely. Some remove metal before screening and some after screening. Some screen only the bottom ash when it is collected separately from the fly ash. Magnetic separators are used. Nonferrous metals may be removed to make a higher-quality, metal-free product. Processors frequently select eddy current separators where nonferrous separation is practiced.

Blending. The guideline states that ash must be blended with natural rock aggregate to meet the requirements of AASHTO T27-84. Guideline ratios appeared elsewhere in the document as 25% maximum ash for base and binder courses and 15% maximum ash for wearing courses.

The material processing requirements referred to vitrified ash without guidance. Chapter 4 of the Guidelines revealed that vitrified ash was used in only one field demonstration. One test probably did not give sufficient information to establish a guideline.

Engineering Properties

Gradation. The FHWA Guidelines referred to MWC ash passing a 3/4-inch screen as a well-graded material. About 60% of bottom ash and combined ash can be classified as a fine aggregate. The dust fraction of ash, referred to as silt content, is that portion of ash passing a No. 200 USS sieve. Many tests reported in the literature cited in this chapter and in Chapter 2 showed that the dust content of ashes will range from 5%–15%. The particle size distribution in ash makes it well suited for paving use and easy to blend with conventional aggregate in high ratios. FHWA cautions that ash must meet the same gradations as conventional aggregate and comply with the specification in AASHTO T 27-84.[62]

Unit Weight. Ash is lighter than most rock aggregate. Many sources referred to ash as a light weight aggregate. Ash bulk densities were in the range of 90–150 lb/ft^3. Lower unit weight increases asphalt demand on a weight basis because the volume of aggregate is greater than that of heavier aggregates. Lower density increases the yield, or paved area, per ton of paving mix.

Durability. Durability of aggregate refers to the ability of the aggregate to resist crumbling or fracture during paving manufacture. Durability is measured as the increase in fine particle content during controlled tumbling, abrasion, or impact. A test called the California Abrasion Test is frequently referenced. Ash meets criteria for durability by this test, but it sometimes rates as less durable than rock aggregate.

Moisture Content. Ash is water quenched at most combustion facilities. This results in high moisture contents of 30%–60% at the paving plant. Aggregate drying is part of the paving mix preparation process and water in the ash is evaporated. The high and variable water content, however, may influence operation of the dryer.

Absorption. Many ashes are very absorptive. This is especially true of fine bottom ash material passing a No. 4 USS sieve with an opening of 0.187 inch. The coarse material retained on a No. 4 sieve may have only one-third to one-fourth the absorptivity of the fine fraction.[63] Combined ash had a broader range of absorptivity than bottom ash.[64] The data sources used in this comparison were disparate. But both illustrate ash's rather high absorptivity, in the range of 3%–12% by ASTM Testing Methods C127 and C128 for the size range to be used in asphalt paving. High absorptivity does not rule against using ash as a paving aggregate as attested by the many successful field demonstrations. High absorptivity combined with lower density can increase the amount of asphalt on a weight basis needed to formulate an acceptable mixture.

Stripping. Hydrated lime was added to the early FHWA test pavements. No stripping was noted in reports on the condition of these pavements. More recent test pavements placed in the late 1980s and 1990s used no hydrated lime or other anti-stripping agent. No references were found to stripping tests conducted on specimens from pavements placed in the 1990s. No signs of stripping have been reported from the field tests. Local experience and judgment should guide the selection of anti-stripping agents. The FHWA guidelines stated that stripping should not be a concern with ash contents up to 15% as a fine aggregate replacement.[65]

Mix Design. The variability among ashes, especially in density and absorptivity, illustrates the importance of developing a mix design for each ash. Three approaches to mix design have been used. The Hveem test is little used today. It may have adherents in places such as California and Maine, but few others. The Marshall Stability Test is the most frequently referenced mix design tool. It, too, may be losing favor because of some reported discrepancies in its results and championing of the Gyratory method by some research in the late 1980s to early 1990s Strategic Highway Research Program.

The FHWA guidelines observed Marshall stability test results to be comparable to those obtained with natural aggregates. A comprehensive research and field test in New Hampshire noted that the Gyratory Test Method provided an excellent mix design compared to the Marshall method.[55] The Gyratory Test Method can be found in ASTM D3387.

Ash's lower density and higher absorptivity can lead to the need for a slight increase in asphalt content compared to many natural aggregates. FHWA guidelines stated that requirements for additional asphalt cement should be low if the ash content is held below 20%.[66] On the other hand, the detailed New Hampshire program concluded that, based on the physical properties and testing of the field pavements, the use of grate ash for an aggregate substitute up to 50% by weight is viable and recommended.[55] The Gyratory test can be a viable mix design tool that predicts asphalt content requirements for mixes that contain ash.

Pavement Construction

Ash Storage. Ash contains salts that may hydrate and expand. Storing the ash for a period of time will stabilize the salts and hydrogen-forming metals such as aluminum before mixing the ash into asphalt paving. Some European countries store ash for 1–6 months before using it as a granular base material.[67] Ash used in two mid-1990s pavements in the United States was also aged before use.[55,56] The FHWA guidelines noted that storing ash at least 30 days is sufficient for ash contents under 20%.

Mixing. No changes in mixing are indicated when ash substitutes for up to 50% of the natural aggregate. Possibly high moisture content suggests care in observing process temperature control. Carryover of fines to the baghouse should also be observed to avoid an unanticipated dust problems in the baghouse.

Placement and Compaction. Conventional machinery and methods are applicable to paving mixes containing ash.

Granular Base for Roadways

Ash has long been used as a granular base and fill in Europe. More than 50% of available ash is used this way in Germany, Denmark, and the Netherlands.[67] Only a few tests have been conducted in the United States.[68] Ash has very high stability and low density, making it desirable for base and fill applications. Ash's low durability may bear consideration in some applications. Ashes vary and durability should be checked for each source before use.

Material Requirements

FHWA guidelines recommend that ash used in base and fill applications should be limited to bottom and grate ash to minimize dust and ensure a product similar to natural minerals used in these applications. Metals should be removed from the ash to ensure a granular product. Metal removal is common practice in waste and ash processing operations. Europeans found thorough burnout of the ash to be important with a maximum 5% loss on ignition desirable. And, as with asphalt paving applications, aging of the ash before use is recommended. The previously referenced FHWA guidelines suggest a 1–3 month aging period.

Engineering Properties

Five aggregate characteristics relate to its performance in granular base and fill use. These qualities are particle size, density, stability, durability, and drainage.

Particle Size. FHWA guidelines recommend that ash be screened to pass a 3/4-inch opening. Material passing a 1/2-inch sieve is also acceptable. Particles larger than 3/4-inch are less granular and may include unwanted metals and glass. The screened ash should meet the particle size distribution limits specified in AASHTO M147.[69]

Density. The compacted density of processed ash reported in Table 2.2 is 80–110 lb/ft^3. Maximum density occurred at moisture contents of 12%–16% by weight. This is a little lower than the density of many mineral aggregates. The lower unit weight means that ash will yield a slightly higher coverage per ton than conventional base material.

Stability. The CBR test is used to measure the stability of aggregates. Table 2.2 reports typical results for processed ash. The high friction angle of 40–45 combined with angular particles creates a good bearing capacity similar to crushed stone.

Durability. Abrasion test results in the 40%–60% range characterize material that is not highly durable. Freeze-thaw resistance, on the other hand, was excellent. These data appear in Table 2.2. Graded bottom ash performed well in base and fill applications despite its rather low abrasion resistance.

Drainage. The Proctor permeability test reveals bottom ash to be a free-draining material (see Table 2.1). However, combined ash, especially with retained lime from APC residue, was reported to be rather impermeable.[70]

Design and Construction

Design for granular base with ash is the same as for natural aggregates. If combined ash with retained lime is used, performance like a stabilized base material should be anticipated. Additional testing following ASTM 593 must be done in such a case. Machinery and methods for storing, handling, laying, and compacting ash are the same as for natural aggregate.

Storing. Ash should be aged in storage for 1–3 months. Aging will help stabilize potentially reactive ingredients and allow the ash to dry before use.

Laying and Compacting. FHWA guidelines reference using a 10-ton vibratory roller for compaction after laying the ash in place with conventional machinery. Aged and well-drained ash will help achieve the desired maximum density.

Environmental Considerations

No references were found to groundwater and dust measurements to assess the environmental implications of using ash as or in granular base or fill. Field experience in Europe covers many years with no adverse environmental incidents reported. The few installations in the United States were apparently not monitored for leaching and emissions. One outdoor ash storage pile was extensively monitored and the results showed that no problems would be expected if the material were to be screened and used as granular base.[56]

Concrete Products Formulation Considerations

The FHWA guidelines that provided many of the asphalt paving criteria did not address issues for MWC ash use in portland cement mixtures. Reports from several field studies provide guidance in selecting criteria and methods for using ash in portland cement.

Guidelines for using ash in portland cement concrete include the following general admonitions.

- Remove iron particles to avoid staining and pitting (verbal from John Norton based on the first of two concrete block buildings at the Columbus Ohio landfill).

- Remove glass particles to avoid glass solution in the alkali formed as cement cures. This can reduce strength and cause surface pitting (common knowledge).

- Remove metal particles, especially Al, to avoid hydrogen gas-forming reactions with alkali (several unpublished field reports). Aging the ash will help stabilize metals like Al.

- Ash aged for at least 60 days at 22% water content will yield improved engineering characteristics.[71]

A FIT study concluded that ash worked similar to lightweight aggregate and could be mixed with portland cement to make products such as patio stone, solid and hollow blocks, and brick pavers.[72] Specific guidelines developed in this study included the following.

- Maximum particle size should be less than 1/2 inch.

- Water content of the ash should be less than 20%. The water content should not be counted as part of the mix design water.

- High bulk density is preferred but this was not quantified.

- Loss on ignition should be low but this was not quantified.

Some data from laboratory tests at the FIT are shown in Tables 3.1 and 3.2.

The ash/cement mixtures used in the above testing are described in Table 3.2.

A second FIT development program addressed use of ash in blocks intended for use in ocean reefs.[73] This research concluded that bottom ash passing a 3/4-inch screen could be used as a substitute for conventional aggregate with portland cement and additives to make concrete blocks having weight and compressive strength comparable to moderate strength lightweight concrete. The blocks had excellent seawater resistance. Mixtures of bottom ash with fly ash and scrubber residue were also tested but in ratios that would have no commercial significance. Ash use guidelines developed in this study included the following.

- Water/cement ratio should be 1 for optimum strength and workability.

- A combined factor of safety against tensile failure of five and four against compressive failure should be used.

Other university researchers found bottom ash to be a suitable aggregate for use in load bearing and non-load bearing concrete blocks.[74] They developed a rationale for why blocks are a better portland cement bound product for ash than would be poured-in-place concrete. Lower strength requirements and absence of steel reinforcements that would be subject to chloride attack led the list. The authors developed a list of guidelines for using ash in concrete blocks.

- Mix design is sensitive to aggregate size gradation.

- Sand or other natural aggregates are required to be used with the bottom ash.

- Type I and II cements give the best results.

- ASTM C90 strengths can be met with 12% or lower cement content depending on the amount of pozzolans added.

Table 3.1: Physical and Engineering Properties of Stabilized WTE Ash-Concrete

Mixes*	Compressive Strength (psi)		Unit Weight (lb/ft^3)		Impact Resistance (deci ft lb/in^2)	
	7 days	28 days	7 days	28 days	Crack	Fracture
PC-1	967 ± 106	1130 ± 360	108	110	ND	ND
PC-2	636 ± 59	572 ± 84	102	105	250	416
PC-3	715 ± 157	818 ± 238	104	104	400	450
PC-4	665 ± 61	773 ± 83	102	101	300	433
PC-5	825 ± 136	971 ± 169	105	107	450	600
PC-6	619 ± 172	899 ± 336	103	106	ND	ND
PC-7	584 ± 165	524 ± 49	110	107	ND	ND
PC-8	385 ± 69	485 ± 115	100	102	400	466
WPB-1	192 ± 6	284 ± 9	72	85	ND	ND
WPB-2	571 ± 64	706 ± 27	85	84	366	433
WPB-3	329 ± 17	430 ± 51	88	88	491	550
WPB-4	291 ± 50	367 ± 76	78	80	383	466
KW-1	664 ± 76	982 ± 61	97	95	ND	ND
KW-2	356 ± 30	647 ± 85	82	84	350	450
KW-3	434 ± 36	786 ± 132	88	92	383	550
KW-4	443 ± 114	581 ± 57	93	96	225	541

*KW-Key West; PC- Pinellas County; WPB - West Palm Beach.

- Plasticizer can improve strength by 10%.
- Non-load bearing block specifications can be met with 100% bottom ash mixes.

Field research involving a large concrete block building in Ohio concluded that ash aggregate can not be used alone. It must be blended with other materials for strength and durability.[75]

Money to Be Saved

Ash disposal costs. Ash generators paid $39.72/ton to have their ash landfilled, according to SWANA.[54] That disposal price could cost a modest-size WTE plant about $8,000/day. SWANA reported that only 20% of waste combustors use *some* of their ash.[54] Ash content of waste burned is about 25% by weight.[76] The amount of waste burned was about 34 million tons in 1996.[77] A little conservative arithmetic reveals the annual price paid for landfilling ash in the United States to be around $290,000,000. Seven and one-quarter

Table 3.2: Mix Designs of Stabilized WTE Ash-Concrete

Mixes[a]	Ash Ratio[b]	Water/Cement	Mixer	Workability Slump, inch)
PC-1	67/33	1.44	Drum	.05–1.5
PC-2	67/33	1.44	Blade	2
PC-3	80/20	1.44	Blade	0.75
PC-4	80/20	1.44	Drum	1.5
PC-5	67/33	1.11	Drum	0.5
PC-6	67/33	1.11	Blade	0.375
PC-7	80/20	1.11	Drum	0.375
PC-8	80/20	1.11	Blade	0
WPB-1	71/29	1.62	Drum	2.25
WPB-2	71/29	1.44	Drum	1.5
WPB-3	71/29	1.44	Blade	0.5
WPB-4	71/29	1.56	Drum	1.5
KW-1	60/40	1.44	Drum	0.75
KW-2	60/40	1.44	Blade	3.75
KW-3	80/20	1.44	Blade	1.5
KW-4	80/20	1.44	Drum	0.25

[a] KW-Key West facility; PC-Pinellas County facility; WPB-West Palm Beach facility.
[b] Ash ratio represents the ratio of particles less than 1/4 inch to particles greater than 1/4 inch but less than ½ inch.

million tons of ash could replace 350,000 truckloads of gravel and aggregate. Responsible stewardship of our natural assets suggests that it would be worthwhile to use ash instead of landfilling it.

What would an ash aggregate product cost? Assuming that the ash will be stabilized and ferrous metal recovered whether the ash is landfilled or converted into a product, the added cost will only be for screening, storing, loading, and shipping. This would probably be around \$2–\$5/t. The ash generator could give the product away for a cost reduction of about \$32–\$38/t. Selling the product for one-half the average price of gravel (\$4.61)[78] would give the generator an increased cash flow of about \$40–\$43/t of ash sold.

Lessons Learned

Demonstration tests and laboratory research teach many valuable lessons. Ash from different sources may differ. Each ash should be tested and qualified for its intended use. Ash is a good substitute for gravel and aggregate in asphalt concrete. It also works well as an aggregate in concrete blocks, and as a gravel substitute on unpaved roads. Manufacturing an aggregate product from ash generally involves three steps. One step stabilizes the ash with a chemical treatment such as WES-PHix® or, perhaps, lime. Stabilization is followed, or sometimes preceded, by magnetic removal of ferrous iron contaminants that were not previously withdrawn as part of a recycling program. Finally, the ash is classified into the desired particle size range by passing it over one or more selected screens.

Ash products generally have lower true and bulk density than comparably sized natural rock aggregates. Typical data appear in Chapter 2. Ash has also been described as more porous than rock aggregate. This difference will require more binder in asphalt compositions on a weight basis. No references were found on volumetric formulation of pavings. There may be little or no increased binder demand on a volume basis.

FIT published an ash use protocol in 1996.[79] However, this protocol addressed only maintaining repeatability of ash using an unspecified leaching test. The protocol did not talk about how ash might be used or the physical qualities that influence its performance.

Risk assessments, groundwater, soil, and air testing at demonstration sites showed that there are no health or environmental risks associated with ash use. No precautions or special procedures are required when substituting manufactured ash products for natural aggregate. Many details on environmental considerations appear in Chapter 6.

Chapter 4
Research and Demonstration Projects

Compiling an all-encompassing list of ash product demonstration and research projects is a never ending task. Just when the list seems to be complete, someone comes along and asks, “But what about ------?” The EPA sponsored a project at Rutgers, the State University of New Jersey, in 1991 to list and summarize all field research and demonstration projects. The National Renewable Energy Laboratory (NREL) funded a similar project with a private firm in 1993. Both projects were completed but sponsors did not publish the results. This chapter contains the results of both lists, supplemented with anecdotal information and updates from principals involved in a few of the field tests. Ash uses included asphalt paving aggregate, portland cement concrete and block aggregate, landfill cover, road base as a gravel substitute, and a few other applications.

Demonstrations and Field Research

Field tests and demonstrations over a nearly 25-year period clearly showed that there are no technical, environmental, or health barriers to the productive use of ash or its ingredients.

A synopsis of each demonstration is shown in Table 4.1

Table 4.1: Ash Demonstration Projects and Field Tests

Application	**Location**	**Date**	**Contact**	**Comment**
Asphalt Paving	Houston, TX	1974	FHWA	excellent
	Philadelphia, PA	1975	FHWA	OK
	Delaware County, PA	1975	FHWA	OK
	Harrisburg, PA	1975	FHWA	poor
	Harrisburg, PA	1976	FHWA	vitrified ash, excellent
	Washington, D.C.	1977	FHWA	good
	Lynn, MA	1980	FHWA, Wheelabrator	excellent
	Albany, NY (parking lot subbase)	1983	Patrick Mahoney Energy Answers	OK
	Tampa, FL Acline St.	1987	Wheelabrator	OK up to 10% substitution
	Ruskin, FL, test cells	1990	Wheelabrator	environmental testing OK
	Hennepin County, MN	1992	Minnesota Pollution Control Agency	project abandoned
	Hillsborough County, FL	1992	County Solid Waste Dept.	project abandoned

Application	Location	Date	Contact	Comment
	Shelton, CT	1992	Connecticut Resource Recovery Authority	landfill access road
	Rochester, MA	1992	Patrick Mahoney, Energy Answers	entrance roadway, OK
	Laconia, NH	1993	Jim Presher, Concord Regional Solid Waste	OK
	NY/NJ	1996	Tom Fiesinger, NYSERDA	entrance to the Elizabeth Industrial Park on Center Drive in Port Elizabeth, New Jersey
	Baltimore, MD	unknown	Baltimore RESCO	roadway subbase
	Honolulu, HI	1998	Colin Jones, city govt.	up ramp at H-Power WTE
Concrete	Albany, NY block foundation	1983	Patrick Mahoney Energy Answers	OK
	Rochester, MA block building	1987	Patrick Mahoney Energy Answers	OK
	L.I. Sound Reef	1987	Frank Roethel, SUNY	OK
	L.I. SUNY block building	1990	Frank Roethel, SUNY	OK
	Montgomery County, OH block building	1991	Montgomery County	OK
	Montgomery County, OH block building	1992	Montgomery County	OK
	Los Angeles Puente Hills L.F. aggregate	1992 (continuing)	L. A. Sanitation	synthetic aggregate used as road surface
	Ruskin, FL	1993	Perma-Base, Inc.	Soil cement additive
	Islip, NY special aggregate for landfill closure	1993 (continuing)	Rolite, Inc.	commercial process
	Pinellas County, FL Reef		county waste management	not approved
	Palm Beach County, FL, reef and guard rails from Tirelog™	1991	John Ryberg Palm Beach County Solid Waste Authority	tests successful, no commercial use

Application	Location	Date	Contact	Comment
	Richmond, VA vault for train barrier	1997	Phil Robinson Environmental Solutions, Inc	no funds for completion
	Hampton, VA revetment wall	1997–1998	Phil Robinson Environmental Solutions, Inc	phosphate cement, testing in 1997–1998
Portland Cement	Tacoma, WA shale substitute	1991	Tacoma Public Utilities	presumed ongoing
	Charleston, SC	before 1980	Charleston WTE plant	worked only in wet process for cement, an obsolete technology
Landfill Cover	Honolulu, HI	1996	Colin Jones, city govt.	worked very well
	Long Beach, CA	ongoing		daily cover
	Blydenburgh, NY	ongoing		gas venting layer
Vitrification	Albany, OR	1993	Herb Hollander ASME	report published, available from ASME[80]
	UCLA	may be on going	Prof. J.D. MacKensie	microwave to make ceramic tile
	Harrisburg, PA	1989	John Lukens, Harrisburg WTE	made some material
	Boston, MA	1995-6	Shawn Worster NESWC	made some material

Asphalt Paving

Houston, Texas

The FHWA placed 300 feet of demonstration pavement somewhere in Houston, Texas, during 1974. A 6-inch base course contained 100% ash aggregate, 9% binder, and 2% lime. The test section was reported in excellent condition in 1978[81] and again in 1993.

Philadelphia, Pennsylvania

Another FHWA demonstration was placed somewhere in Philadelphia in 1975. Ash replaced 50% of rock aggregate in a 90-foot test section of 1 1/2-inch surface course. Binder content was 7.4% and 2.5% lime was added.[82] The condition was reported as acceptable in 1993.

Delaware County, Pennsylvania

This FHWA test road was identical in design to the Philadelphia demonstration except for 7% binder. A demonstration section was 60 feet long and was placed in 1975, but the exact location is unknown.[82] Its condition was also reported as acceptable in 1993.

Harrisburg, Pennsylvania

This is the first of two FHWA demonstrations somewhere near Harrisburg. The road was placed in 1975. Its design was identical to the Delaware County test and the length was about 220 feet.[82] Condition was reported to be poor in 1993.

Harrisburg, Pennsylvania

This second FHWA demonstration near Harrisburg was placed on Route 22 in Dauphin County 1 year after the first.[83] It used vitrified ash as 100% of the aggregate. Asphalt binder content was 6.7% with no lime added. The 1 1/2- inch surface course was reported to be in excellent condition in 1993.

Chambersburg, Pennsylvania

Vitrified ash, probably from the same batch used in the Harrisburg test, was also used in a test pavement placed near Chambersburg in 1976.[84]

Washington, D.C.

FHWA's 1977 ash demonstration was in Washington, D.C. Ash replaced 70% of natural rock aggregate in one mixture and comprised all the aggregate in a second.[85] Four hundred feet of 4 1/2-inch base course contained 9% binder and 2% lime. The condition was good in 1993.

Lynn, Massachusetts

References to ash paving in Lynn, Massachusetts, suggest that there may have been three paving demonstrations: an FHWA job in 1979; a Wheelabrator-sponsored job on Route 128; and a Wheelabrator-sponsored job on Route 129 in 1980. Only one ash paving demonstration was found in Lynn. It is on Route 129 and consists of five test sections placed during November 1980 on 1.5 miles between Goodwin Circle and the beginning of St. Ann's Cemetery. The Commonwealth of Massachusetts Department of Public Works reported in July 1991 that "...the incinerator residue section is comparable to our type I sections of roadway." Another source reported in 1993 that the test section was in good condition. Obtain further information by referring to the following documents:

Mass. D. P. W. Contract #21342
F. A. Project Number: M-3510(001)
Mass. D. P. W. Report R-37-0, May 1986
Mass. D. P. W. Ten Year Follow-up Report to R-37-0, July 26, 1991

Albany, New York

Bottom ash from the OGS Boiler Facility in Albany, New York, replaced gravel as the subbase for a parking lot constructed in 1983 at a waste shredding plant near the Rapp Road landfill. Twelve inches of bottom ash were placed on a geotextile filter membrane. The ash was covered with a 2 1/2-inch wearing course of asphalt concrete. Ferrous metal was recovered from the ash before use. Environmental testing in 1987 sampled groundwater and found no hazardous conditions. Analysis detected no heavy metals in the water. The parking lot was in good physical condition in June 1997.

Tampa, Florida

McKaynite, a proprietary aggregate processed from ash, was used as aggregate in asphalt paving.[86] A 1-inch wearing surface was placed on 2,000 feet of Acline Street between 45th and 50th streets during February 1987. McKaynite replaced 5%, 10%, and 15% of the sand component in three 500-foot test sections. Up to 10% substitution acted the same as standard design mixes placed for comparison. Monitoring stopped after 1 year. The McKaynite used in this project was made by crushing, screening, and chemically stabilizing combined ash from the Tampa WTE facility. The road was still in place in April 1997 and was described as showing some wear. Florida allows beneficial use of ash to be counted against state-mandated recycling goals.[87]

Ruskin, Florida

This test also used McKaynite processed from four WTE plants in Florida.[86] Planners designed the test to thoroughly study the environmental implications of ash use in paving. Bituminous paving and unmixed McKaynite were placed in defined sections over a 5-acre area at the Tampa WTE site. Testing included 12 controlled monofills with monitoring wells installed to study water quality. The test materials did not adversely affect the environment. Testing stopped after 2 years.

Shelton, Connecticut

The Connecticut Resource Recovery Authority relocated and paved 1,800 feet of access road leading to the top of the Shelton landfill in 1992.[88] Bottom ash was used alone and mixed with gravel as structural fill 3 meters deep. The various paving test sections placed on the structural fill used bottom ash passing a 3/4-inch screen at a 50% content in the mix. Bottom ash acted well as a structural fill and as aggregate in bituminous paving.

Rochester, Massachusetts

The SEMASS WTE facility developed an aggregate product called Boiler Aggregate™ from its bottom ash. It replaced 30% of conventional rock aggregate in a new asphalt concrete access road to the facility. The binder course was placed in January 1992 and the surface course followed in April of that year. A comprehensive risk assessment concluded that the asphalt paving composition will not pose a significant risk to the environment or human health.[89]

Hennepin County, Minnesota

Hennepin County, Minnesota, planned a demonstration using treated ash pellets from its waste combustor as aggregate in asphalt paving. The treated ash pellets were reported to be the product of Municipal Services Corporation in Kennesaw, Georgia. No listing for this company or its principal was found in March 1997. Discussion of the project started in January 1989. A permit application for the site in Dayton, Minnesota, was submitted in December 1989. Public opposition forced a change to rural Corcoran, Minnesota, before Spring 1992. A health risk assessment using EPA models showed no significant human health risk from the demonstration. Public hearings were held in April 1992, following which the Hennepin County Board of Commissioners decided that the project would no longer be considered. They also formed an advisory committee to contract further study of municipal waste ash use and management. The Hennepin County Department of Environmental Management reported on March 17, 1997, that no demonstration project was approved and none is being considered.

Hillsborough County, Florida

Hillsborough County, Florida, planned a small (100 feet by 100 feet) test section of asphalt paving on County Road and Street Department property. Combined ash would replace approximately 10% of rock aggregate in the mixture. A permit was granted, but expired before the project started. The project was not done because contaminated soil at the site would have biased the planned testing.

Laconia, New Hampshire

Bottom ash from the Concord, New Hampshire, waste combustor replaced half of the natural aggregate in an asphalt paving binder course that was used to repave a section of U.S. Route 3 in Laconia, New Hampshire, during May 1993. Two years of intensive sampling and testing found no environmental or health risks. Sponsorship of the project included Concord Regional Solid Waste Cooperative; Wheelabrator Environmental Systems, Inc., U.S. Department of Energy (DOE) through NREL, and EPA through Rutgers University. The project and its results are described in detail in a three-volume report (NREL/TP-430-20959, 20960, and 20961) published by NREL.

New York and New Jersey

A 750-foot road section on Port Authority property at the entrance to the Elizabeth Industrial Park on Center Drive in Port Elizabeth, New Jersey, contained an asphalt mixture with bottom ash from the Warren County, New Jersey, facility. Paving was done in 1996. Before paving, an extensive environmental test was done on a large pile of ash used for the test. Ash pile tests included dust generation, rain water runoff, and air and soil sampling. The ash pile tests showed no environmental or health risks over a 1-year period starting in 1994. Project sponsors and participants included Long Island Regional Planning Board, NYSERDA, Port Authority of New York and New Jersey, New Jersey Department of Transportation, New Jersey Department of Environmental Protection, and DOE through NREL. NREL published a two-volume report (NREL/SR-430-22847) on the ash pile tests.

Baltimore, Maryland

Ash replaced gravel as roadbase in 400 feet of road construction. Untreated ash and ash treated with a proprietary phosphate, WES-PHix®, were used according to a private report prepared in 1993. Follow-up environmental and physical monitoring was reportly conducted by Wheelabrator Environmental Systems, Inc., but this could not be confirmed.

Honolulu, Hawaii

The City and County of Honolulu conducted a major ash use research program sponsored by DOE through NREL. Research results led to planning two field demonstrations of ash use. One demonstration as aggregate in a roadway was placed on an up ramp at the H-Power WTE facility. The ash was initially judged as too wet for bituminous hot mix, but a reduction in the planned ash content produced a manageable mixture. NREL published a report (NTIS ID DE9500012) on the research.

There may be other asphalt paving ash demonstrations, but none were found in the available documents. For example, the National Cooperative Highway Research Program contemplated ash use demonstrations under solicitation, NCHRP Project 20-5 topic 22-10. The Strategic Highway Research Program solicited proposals under a 1991 Program Announcement for Enhancing Waste Material Utilization in Highway Construction under the SHRP IDEA Program.

Concrete

Albany, New York

Portland cement concrete blocks in which ash replaced all of the natural aggregate and a little of the sand formed the foundation of a house. Processing removed ferrous metal before the bottom ash was sized smaller than 3/8 inch. Placed in 1983, the project was tested for environmental effects and was observed several times during the first 6 years. No ground, water, or air hazards were detected. The foundation was in excellent condition in 1997.

Rochester, Massachusetts

Several ash/concrete applications were installed at the SEMASS WTE facility in 1987 and 1988. Two reports paint different pictures of what occurred. The ash aggregate, called Boiler Aggregate™, was made by removing ferrous materials from ash and screening to the desired size. One report says that the aggregate was used in concrete blocks for the building facade and concrete curbing. A second report refers to the Boiler Aggregate™ being made only from bottom ash. The second report references the blocks forming interior walls in offices, lockers, and shower rooms. Other, non-concrete applications for the aggregate at this location included parking lot, roadway, and receiving area base material or aggregate in bituminous concrete, depending on the reference used. Environmental testing revealed no risks from any of the ash applications.

State University of New York at Stony Brook

Bottom ash and combined ash from the Westchester County WTE facility served as aggregate in masonry blocks used in constructing an artificial reef in Conscience Bay, Long Island. The blocks contained 85% ash and 15% type II portland cement. The reef was 10 feet long by 4 feet high, two blocks deep. It consisted of an initial test of 10 blocks placed in 1987 and 20 blocks with ash from a different facility placed in 1988. The blocks retained their original strength and no adverse environmental effects were found as recently as 1992.

State University of New York at Stony Brook

Bottom ash and combined ash from the Westchester County WTE facility were used as aggregate in 14,000 masonry blocks used in constructing a boathouse in 1990. The ash was processed to remove metals and screened to size. It replaced two-thirds to three-fourths of the natural aggregates. A total of 350 tons of cinder blocks were used to build the structure. Interior walls contained only stabilized bottom ash. Two exterior walls were the same and two used blocks made with combined ash. Blocks made with ash were stronger than the conventional blocks. Interior air quality was equal to or better than outside. Water and soil samples showed no health or environmental hazards.

Montgomery County, Ohio

Bottom ash was used as aggregate in portland cement concrete blocks forming the outer, non-load bearing walls at the fly ash management building of the local WTE facility. Construction was completed in 1991. A second concrete block building was built at the WTE site in 1992. This, too, used ash as aggregate in the portland cement concrete blocks. A retaining wall also used blocks containing ash aggregate. All structures were in good condition in 1997. There was a small amount of spalling from the surface of blocks used in the first building. This occurred early; was traced to ferrous metal in the ash; and was eliminated in the second building by more efficient ferrous metal separation before block manufacture.

Los Angeles, California, Puente Hills Landfill

Approximately 15 acres of landfill roads and tipping areas were surfaced with an aggregate made from screened ash smaller than 1 inch. The 90% ash was mixed with 10% type II portland cement and formed into 6-foot by 20-foot by 1 1/2-foot blocks. Landfill vehicles crushed the cured blocks into gravel-sized pieces to form the aggregate. The test succeeded and the practice continued in 1997 using all the ash from the WTE facility in Commerce. Ash from the Long Beach WTE facility is also used, but this ash is mixed with a lesser amount of portland cement. The mixture does not set up as does the treated Commerce ash mixture.

Ruskin, Florida

Ash from the Hillsborough County WTE facility was used as a substitute for part of the rock aggregate in a portland cement mix, soil cement base. The mixture carried the trade name Perma-Base Plus. The State of Florida approved this application in 1993.[87] Florida allows beneficial use of ash to be counted against State-mandated recycling goals.[87]

Islip, New York

Rolite, Inc., has a process for treating ash with portland cement in a patented process to make “Rolite,” a lightweight aggregate. Several hundred thousand tons of combined ash from several WTE facilities have been converted to aggregate since 1989 at the Blydenburgh Landfill in Happauge, New York. The aggregate is used at the landfill to form a gas venting layer and as lightweight fill in areas being closed.

Pinellas County, Florida

The COE failed to approve a demonstration reef proposed for Madeira Beach in 1991.

Palm Beach, Florida

The State of Florida funded the Palm Beach County Solid Waste Authority’s 1991 development of a product called Tirelog™, a waste tire-clad, concrete log containing ash aggregate. Tests using these logs as reef barriers and highway guard rails showed the applications to be viable. Palm Beach County reported in 1997 that there had been no commercial use of Tirelog™.

Virginia

Two ash-in-cement applications have been referenced in Virginia, but no demonstration or research applications had been installed as of February 1998. The first application researched using ash as aggregate in portland cement concrete for a unique product. The concrete was to have formed a deployment vault for a traffic protection barrier at high-speed railway crossings. The concrete formulation research was done by Environmental Solutions, Inc., of Richmond, Virginia. Consolidated Launchers Technology developed the retractable, protective traffic barrier. The processed bottom ash used in the research could be used at a loading of 9.8 wt % in the high-strength concrete required for this application. Insufficient funding was available to complete field testing of the entire system.

A second Virginia application planned to deploy ash-containing revetment blocks in a beach restoration project at Rudee Inlet in Virginia Beach. Failure to obtain approval moved the plan to an area near Hampton, Virginia. Environmental Solutions, Inc., of Richmond researched block formulations for this project. The approach used a phosphate cement binder. Preliminary laboratory tests completed in August 1997 showed that processed bottom ash was an outstanding aggregate for the phosphate binder. Reinforcement seemed to go beyond mechanical effects and outstanding composite strengths were achieved. The first full-sized revetment block was cast in January 1998 using ash from the Southeastern Public Service Authority WTE facility.

Formulation research for these two Virginia projects was sponsored by the NREL. A report on the portland cement deployment vault is available through the National Technical Information Service. An order number was not available when this document was written, but the title is “Use of Ash from Municipal Waste Combustion.”

Portland Cement

Tacoma, Washington

An undefined fine fraction separated from combined ash replaces shale in the manufacture of portland cement. No records are kept of locations where the cement has been used. This has been an ongoing operation since May 1991. The combustion facility burns an indiscriminate mixture of RDF, wood, and coal. Limestone is added to the combustion process, which may influence the acceptable ash performance in cement manufacture.

Charleston, South Carolina

During some period before 1980, ash from the Charleston WTE facility was used in the manufacture of portland cement. The nearby factory used an old, wet process to make cement. The process using ash was successful and continued for several years until the modern, dry process replaced the wet process. Ash use stopped at that point. There are no records, and memories seem uncertain. It is unclear whether ash use stopped because ash was incompatible with the chemistry of the dry process or because of a possible disagreement over pricing of the ash.

Landfill Cover

Honolulu, Hawaii

The City and County of Honolulu conducted a major ash use research program sponsored partly by DOE through NREL. Research results led to planning two field demonstrations of ash use. One demonstration was as landfill cover at the landfill. A formal risk assessment was prepared in December 1996 and a permit modification was requested early in 1997. The Hawaii Department of Health approved a 1-week demonstration of ash based on the risk assessment. NREL published a report (NTIS ID DE95000212) on the research.

Blydenburgh and Happauge, New York

Refer to Islip under the concrete heading. Portland cement treated ash is used as the landfill cover here. Rolite is the name of the product.

Several landfills regularly use ash as daily cover. Information on this appears in Chapter 3.

Laboratory Research

The projects described above were called either “development” or “research.” The terminology is of little consequence. Most of the projects were installed under field-use conditions. A few, like the Ruskin, Florida, test, did not involve commercial-use conditions and were therefore more like conventional research. Many projects followed laboratory and simulation research. Examples of these include Honolulu, Laconia, and New York/New Jersey.

The technical literature on ash includes more than 450 citations plus about 80–90 papers from 10 sessions of the annual International Conference on Municipal Solid Waste Combustion Ash Utilization. Most of the citations can be found in the following three sources.

- National Renewable Energy Laboratory/U.S. Department of Energy Report, *Data Summary of MSW Management Alternatives Volume XI, Alphabetically Indexed Bibliography*, available from the National Technical Information Service as Product DE 93008306

- Resource Recovery Incinerator Ash: An Annotated Bibliography 1966–1986 published by The Environmental Institute of the University of Massachusetts as Publication No. 87-2

- Annotated Bibliography of Municipal Waste Combustor Ash Research prepared for the EPA by Science Applications International under EPA Contract No. 68-WO-0025 in 1993.

The proceedings of the international conferences may be purchased from The Coordinate Group, Inc., Box 3356, Warrenton, VA 20188-1956. The telephone numbers are 800/627-8913 and 540/347-4500. FAX is 540/349-4549 and email is ash@coordgrp.com.

Most of the citations relating to laboratory work deal with ash properties, ash chemistry, landfill leachate, general studies, testing, and reviews. Very little ash use laboratory research appears in the technical literature.

The EPA supported several ash-related research projects during the early 1990s. The topics of these research projects were as follows.

- The U.S. EPA MWC Ash Solidification/Stabilization (S/S) Evaluation Program[90,91,92,93]

  Researchers compared four commercial ash treatments to portland cement treated ash. Extensive physical and chemical testing produced several important conclusions. These conclusions involved the various treatments, the TCLP and other leach tests, and release rates for metals and salts in the residues. The potential for release of metals was very low for all the residues. These low metal release rates applied to compacted, granular, untreated bottom ash, and combined ash. A phosphate process was the most effective in reducing the potential for lead leaching from the residues.

- Effect of Municipal Waste Combustion Ash Monofill Leachate on Selected Containment Barrier Components[94]

The study concluded that performance of the four barrier membranes tested would be unaffected by leachate from ash monofills.

- The Nature of Lead, Cadmium, and Other Elements in Incinerator Residues and Their Stabilized Products.[95]

  Several papers were based on this research.[96,97] The results gave insight into the mineral composition of ashes and found that Pb was bound tightly in complex polycrystalline silicate material.

- Mobility of Dioxins and Furans from Stabilized Incinerator Residues in Seawater.[98,99]

  A 2-year test period found no leaching of dioxins and furans into a marine environment.

A few publications describe laboratory research on designing paving mixtures. Some of this research provided the basis for planning demonstration projects. Two examples are referenced here.[100,101]

The Florida Institute of Technology conducted an extensive ash research program from the early to mid-1990s.[102] It tested the properties of bottom ashes and researched their applications in asphalt and concrete products. This research is further referenced in Chapters 2 and 3.

Vitrification Research

Perhaps the largest ash research project was a joint effort of ASME and the Bureau of Mines. This research was also supported by NREL for DOE. The project had 22 corporate and 11 governmental sponsors. The research was conducted at the Bureau of Mines facility in Albany, Oregon. The goal was to vitrify ash using an electric melting furnace. Many tests were conducted and the entire project is described in great detail in ASME Report CRTD-24 titled "Investigative Program on Vitrification of Residue from Municipal Waste Combustion Systems." Ash from several sources was vitrified, but there was no subsequent commercial use of the process.[103]

An earlier vitrification research project involved Rutgers University and Corning Glass with support from EPA. The bench-scale process was reportedly successful.[104]

During 1995 and 1996, three vitrification trials on a blend of coal ash and combined MWC fly and bottom ash occurred in a cooperative venture between New England Power and the North East Solid Waste Committee (NESWC). They used a proprietary electric melting technology. The products intended for production during these trials were poured curb cuts, spun mineral wool, and a quenched frit material. Various technical obstacles included an elevated level of ferrous metal in the NESWC ash that interfered with smooth pouring of melted material during early trials. Generally, good melting occurred in all runs. However, none of the trials resulted in sufficient quantities of satisfactory target products to test and develop markets. Identifying optimal blend ratios of the ash types and other technical challenges were among the reasons. As a result, cooperative participants abandoned the effort. NESWC continued to landfill its ash in Peabody Massachusetts during 1997. This work was not published and information in this paragraph was provided by those involved with the research.

Professor J.D. MacKensie of the University of California at Los Angeles investigated using microwave technology to make stabilized ceramic building tile from ash. Results of this work were not found.

DOE and Westinghouse Electric Corporation sponsored five vitrification tests using an electric melting furnace during the late 1980s.[105] Three samples of combined ash and two of fly ash were tested. Researchers concluded that additional tests were needed to verify the results that included

- Formation of metals on the furnace bottom
- Buildup of carbon
- Buildup of volatiles in the cold top
- Particulate emissions.

The glassy product contained very little of the Pb and Cd originally present in the ash samples. The source did not report whether Pb and Cd reported to the fume or to the non-glassy slag or to both.

John Lukens of the Harrisburg WTE facility ran several ash vitrification tests using electric arc, oil, and gas-fired melters. The quenched particulate product was tested in road base, concrete, and bricks. One or more of these products may have been used as aggregate in the bituminous pavement placed during 1976 and reported to be in good condition in 1993.

Corporate research on ash led to the introduction of proprietary commercial products like Boiler Aggregate™, WES-PHix®, Rolite®, and McKaynite. The references provide some description of the products and their uses, but, like much corporate research, the details are held as proprietary information.

Chapter 5
Management of Municipal Waste Combustion Ash in Other Countries

This chapter discusses MWC ash management in several countries: Bermuda, Japan, The Netherlands, Denmark, Germany, France, Sweden, and the United Kingdom. Strategies for ash management vary among the countries, but all have a more systematic ash management approach than does the United States. Beneficial use of the ash is significantly more prevalent in several countries than it is in the United States.

Ash Management in Bermuda[106,107,108]

Bermuda generated about 80,000 tonnes of waste in 1995. This is projected to increase to about 120,000 tonnes by 2009. Bermuda's WTE facility opened in 1994 and is known as the Tynes Bay Waste Treatment Facility. It is a mass burn incinerator with energy recovery from two separate processing lines, each with a capacity of 6 tonnes/h for a total of 288 tonnes/d. Only about half of this capacity is expected to be used until nearly 2008. This will generate about 43 tonnes of combined bottom and fly ash daily (16,000 tonnes/yr).

After an extensive testing and evaluation program, Bermuda selected an ash management program designed to reclaim land and provide shore protection for the Airport Waste Management Facility located at Castle Harbor. The studies included:

- Laboratory leaching tests on untreated bottom ash (granular), untreated fly ash, and combined ash (granular and solidified) with ocean water and rainwater using column, batch, and tank leaching procedures
- Acute and chronic toxicological effects of ash leachates on several marine organisms
- Emissions modeling of contaminants from different disposal options
- Modeling of the dilution of emitted contaminants in the surrounding sea
- Chemical, biological, and hydraulic baseline studies at Tynes Bay and Castle Harbor, the two candidate sites for ash disposition
- An environmental impact assessment.

Results of these and other evaluations showed that the environmental impact of placing stabilized ash blocks into the sea would be acceptable.

At the Tynes Bay Waste Treatment Facility, the ash is graded and ferrous materials removed by magnetic separation. The ash is then mixed with 16% cement by weight. The resulting ash-cement mixture is transported in ready-mix trucks and poured into molds located at the Castle Bay facility. About 25, 1-m cubed blocks, each weighing about 2 tonnes, are produced daily. When cured, the ash blocks are placed into the sea and used to construct walls for cells in the 40 foot deep Castle Harbor. The ash concrete cells are being filled with other waste materials as part of the foreshore reclamation project.

Ash Management in Japan[109,110]

The management of MWC ash in Japan is governed by the Waste Management Law as amended, which is the result of amending the Law for Promoting Utilization of Recyclable Resources and the Waste Disposal and Public Cleansing Law in 1991. As a result of this law, MWC fly ash is designated as a domestic waste requiring special management because it possesses special properties (trace amounts of hazardous materials) that may harm the environment. Direct landfilling of the fly ash is not permitted and it must be treated before final disposal. Treated waste must meet criteria specified by the Environmental Agency (Notification 42

[1992]). Treatment techniques are specified by the Minister of Health and Welfare. These methods include melting followed by solidification of the remaining residues, solidification by cement, chemical stabilization, and acid/solvent extraction. No full-scale plants actually melted the fly ash in 1998. It is being tested only in demonstration and experimental projects.

In 1991, 83% of the combustion facilities disposed of fly ash with bottom ash and 13% of these facilities treated the ash using solidification techniques. Currently 15 plants melt (vitrify) their combined ash. The number of plants using melting is expected to increase to 21 by the year 2001. In July 1996, Kurita Water Industries, Ltd., licensed the use of Duos Engineering (USA), Inc., patent-pending MWC ash recycling technology, which is the same as the American Ash Recycling technology in the United States. Kurita has installed Ash-Nite® (WES-PHix® in the U.S.) at about 100 facilities.

Slag produced by melting is the main fraction of municipal solid waste incineration (MSWI) ash that is used. In 1995, 134,000 tons of slag were produced by the plants that use melting technologies. This represents only about 3% of the ash produced in Japan. Of this amount, about 17% or 22,800 tons were used in civil engineering projects such as fill material, roadbeds, interlocking blocks, and asphalt aggregate. By the year 2001, the production of slag is expected to increase to 205,103 tons annually and beneficial use is expected to increase.

Ash Management in the Netherlands[110,111]

The Netherlands National Implementation Plan, issued by the Dutch Ministry of Housing, Physical Planning and Environment provides the strategy for using secondary materials. This plan covers all aspects for the use, treatment, and disposal of MSWI residue streams. The plan provides for research into new and improved options for treatment; implementation of management systems to maintain or increase use of bottom ash in construction; and finding appropriate methods to use or dispose of fly ash and flue gas cleaning residues.

The Netherlands decided that the beneficial use of waste residues as secondary materials takes precedence over disposal. Ash management is governed by the Regulation for Construction Materials (November 1995). This regulation permits a marginal impact (release) to the environment over a 100-year period. However, it requires a critical evaluation of soil quality criteria and covers utilization on land and in water. It also distinguishes between granular products, shaped products, and monolithic materials and soils.

Bottom ash fell into a special category of this regulation until 1998. The government's intention is to promote the beneficial use of this material, although it recognizes that the ash may not meet the strict requirements of the regulation. Bottom ash is used as fill in road embankments and as road base, but the design must minimize rainwater infiltration. More than 90% of the bottom ash is used.

Approval for using the ash is based on the quantity of the constituents of concern that are released for 100 years. Release is determined from controlling mechanisms measured by leaching procedures. For granular materials, the release is controlled by percolation and is determined using a column test (NEN 7343). For a monolithic form, diffusion controls the release of the constituent of concern and a tank leach test (NEN 7345) is used.

In 1995, 620 kilotons of bottom ash were produced and 690 kilotons were used. In several different years, the Netherlands has used more bottom ash than produced, indicating some stockpiling until used. Less than 20 kilotons were disposed during 1995. From 1997 to 2000, bottom ash production is expected to increase to 980 kilotons or more. Fly ash production from ESPs amounted to about 55 kilotons in 1995. Of this, about 16 tons were used and 37 kilotons were treated. Projected production of ESP fly ash is expected to be 85 kilotons by the year 2000 with 22 kilotons used and 63 kilotons treated. APC residue production in 1995 was about 20 kilotons excluding ESP fly ash. This is expected to increase to about 28 kilotons from 1997 to

2000. The projected increase in the production of these residues indicates an increased reliance on the use of incineration with energy recovery as a method for managing MSW.

Some fly ash has been used as an admixture in preparation of asphalt fillers, but most has been disposed into nonhazardous landfills. As of January 1998, fly ash is not allowed in landfills unless treated. Currently the flue gas cleaning wastes are stored in special bags while studies are being conducted on potential uses and better treatment and disposal methods.

Ash Management in Denmark[110,111,112]

In Denmark, waste that cannot be recycled must be incinerated. In 1993, 58% (1,334,000 tonnes) of domestic or household wastes were processed by WTE facilities. Danish policy is that the residues produced from incineration should be used provided no unacceptable environmental impacts are created. Thirty-one MSWIs processed 2,040,000 tonnes of waste including the 1,334,000 tonnes of MSW. The WTE plants are either mass burn or cogeneration plants. In 1993, these facilities produced 400,000 to 500,000 tonnes of bottom ash and 40,000 to 70,000 tonnes of fly ash and APC residues.

In principle, combined ash and fly ash may be used. However, in practice, they fail established chemical composition criteria, including a pH in a 1% slurry greater than 9.0; an alkalinity greater than 1.5 eqv/kg; metals concentrations after partial nitric acid digestion as follows: Pb less than 3000 mg/kg, Cd less than 10 mg/kg, and Hg less than 0.5 mg/kg. Because of these requirements, bottom ash is collected separately for beneficial use.

Collected bottom ash is processed to remove metals for recycling amounting to about 10% of the bottom ash. Ten percent is disposed into landfills; the remaining 80% is available for use in civil engineering projects. Bottom ash has been used for parking lots, paths, roads, and as fill material since 1983. Ash use is regulated by the Danish Ministry of Environment. If more than 30,000 tonnes are used in one project or in layers higher than 5 m, it is regulated under the Disposal and Discharge Permit Act (Environmental Protection Act). Any ash used must be 20 m or more from drinking water wells. For use under pavements, the thickness of the ash cannot exceed 1 to 2 m or have a surface area exceeding 2000 m^2. For use in unpaved areas, the thickness of the ash can not exceed 0.3 m. New rules that were scheduled to be implemented in 1997 included additional leaching requirements for constituents other than just Pb, Cd, and Hg.

Bottom ash is considered a good substitute for gravel, which is in limited supply in Denmark. This need, and the fact that the landfill disposal tax is avoided if ash is used, provide good incentive for beneficial use. Use is sensitive to activity of the construction industry, which has used 60% to 90% of the bottom ash produced in recent years.

APC residues (fly ash and acid gas cleaning residues) are classified as special hazardous wastes and are not used. These wastes are being temporarily landfilled while efforts are under way to develop treatment technologies. Soluble salts in these residues cause problems in treatment. All APC residues will be disposed, perhaps after treatment, at two or three special landfills to be located near the sea.

Ash Management in Germany[110,112,113]

Germany has a mandate to recover and use all residues or ingredients in residues, if economically feasible. This strategy requires that all municipal waste incineration residues be separated into the various fractions, including the grate siftings. About 60% of the bottom ash (1.8 million Mg/yr) is used in road paving and similar projects. Before use, this material is stored for “aging” for 3 months. This utilization is regulated by the various states in Germany and the requirements differ somewhat from state to state. Requirements that provide for the backfilling of mined cavities to prevent subsidence have resulted in the use of salts or dry scrubbing residues as a backfill for this purpose. Germany continues to support research and development efforts into better methods for treatment, separation, and beneficial use.

Several factors in Germany are producing an increased use of incineration with energy recovery for managing solid waste. Table 5.1 summarizes parameters set by the Technical Directive for Residential Waste that residues must meet before they can be landfilled. The table also includes limits for bottom ash use in road construction. These were established in a memorandum by a board of German states ministers (the LAGA).

Table 5.1: Parameters Set by the Technical Directive Residential Waste and the LAGA*

Parameter	LF Class 1	LF Class 2	LAGA*
Loss on Ignition wt. %	3	5	
Total Organic Carbon, wt. %	1	3	1
Cl (mg/L)			250
Cu (mg/L)	1	5	0.3
Zn (mg/L)	2	5	0.3
Cd (mg/L)	0.05	0.1	0.005

*LAGA - Board of German States of Ministers set these limits for bottom ash use in road construction.

The requirements for LOI and total organic carbon content will require, in most cases, that waste be incinerated before land disposal. Composting and similar biological treatments cannot meet these specifications. In addition, 1996 regulations and resulting strategies place material recovery and energy recovery on an equal basis, after waste prevention, in the waste management hierarchy. As a result of these and other actions, four additional incineration plants were under construction and 19 are in the planning phase as of 1998. These are in addition to the 52 incineration plants and one pyrolysis plant that processed approximately 11 million Mg of waste in 1995. As indicated by these activities, WTE will significantly increase in Germany with an expected concurrent increase in the use of bottom ash.

Ash Management in France[114,115]

In 1994, France incinerated about 18 million tonnes of waste, which produced about 2.16 million tonnes of bottom ash. Numbers were not provided for the APC residues. Of the 2.16 million tonnes of bottom ash, approximately 45% (about 1 million tonnes) were used in civil engineering applications. Only bottom ash is used. Fly ash must be treated by solidification before disposal into a landfill.

In May 1994, regulations were established by the Ministry of the Environment concerning the use of the bottom ash in road construction and other applications. These regulations and subsequent requirements specify the chemical and physical properties of the residues before they are acceptable for use.

Using the results of subjecting the ash to the French leaching test (NFX31-210), bottom ash is divided into three potential categories as follows:

Category

V	Bottom ash with low leaching characteristics. Can be immediately used as road base.
M	Bottom ash can be stored (maturation) as long as 12 months; characteristics after storage determine whether material can be used.
L	Bottom ash must be landfilled.

Table 5.2: The Category that Bottom Ash Falls into Is Based on Results of Leaching Tests

	V	M	L
% Unburnt Material	<5%	<5%	>5%
Hg*	<0.2	in between	>0.4
Cd*	<1	in between	>2
Pb*	<10	in between	>50
As*	<2	in between	>4
CrVI*	<1.5	in between	>3
Sulfates*	<10,000	in between	>15,000
T.O.C.*	<1500	in between	>2000

*mg/kg of dry matter

Before establishing final requirements, France sampled and analyzed ash from 10 facilities to determine, among several objectives, how the bottom ash compared to the requirements of Table 5.2. Bottom ash from only one plant met the requirements for Category V, bottom ash from four plants fell into Category M, and from five plants fell into Category L. The report, however, noted that the plants were not being efficiently operated during the sampling. After 9 months maturation, seven of the bottom ashes met the requirements of Category V, one fell into Category M, and two in Category L. Three leaching tests and several geotechnical tests were used to evaluate the ash with the conclusion that, when bottom ash is produced under good combustion conditions and maturation, it is a satisfactory replacement for gravel.

As a result, France conducted studies to evaluate three maturation techniques in full-scale tests. The objective was to optimize bottom ash treatment so that it will meet the criteria for beneficial use. France also constructed several experimental road sections using bottom ash as subbase to further evaluate the environmental aspects of bottom ash use. Using the results of these studies, requirements were established for the maturation process and for procedures that must be followed in releasing bottom ash for beneficial use. Aged bottom ash must meet the minimum requirements of Category V. At time of receipt, the client receiving the ash must be provided a data sheet containing information about the environmental and physical characteristics of the aged ash. It also must include information such as lot number, truck volume, and similar data that permit the quality and quantity of the ash used to be tracked. The client is also provided documentation that wastewater (leachate) from the aged residue meets applicable requirements and limits the French government places on the use of the ash.

Results of the road tests showed good physical and engineering properties. Water that percolated through the road material was tested at least once per month. The French concluded that the residue product used in the roads did not adversely affect the natural waters. The concentrations of measured constituents were less than the maximum acceptable for drinking water.

Ash Management in Sweden[110,112]

Fly ash and bottom ash must be collected separately in Sweden. Fly ash may require treatment before disposal or be disposed into special lined landfills, or into special lined cells within a landfill. Under the Environmental Protection Law, approval for beneficial use of ash must be given by the local city council. Each case, for disposal or use, is judged separately and requirements may vary. A few ash use projects were moving ahead slowly in Sweden during 1998.

Ash Management in the United Kingdom[116,117]

In 1996, 41.8 million tonnes of waste were collected in the United Kingdom (UK). About 90% of this went to landfills; 5% was recycled; and 5% burned in WTE plants. This situation, however, is changing with the development of strategies and regulations that promote sustainable waste management (Making Waste Work, the Department of the Environment, 1995). This strategy places energy recovery in the same category as composting and recycling, following the categories of reduction and reuse. National targets were established for recovery (40%) of MSW by the year 2005, along with reductions in landfilling and increases in recycling or composting (25% by 2000). Coupled with directives concerned with packaging wastes, the UK expects to collect large amounts of wastes that are not suitable for recycling; that energy recovery will be the most likely way to recover value from these wastes; and that landfilling will be avoided. In addition, a landfill tax was established (October 1996), which taxes each tonne of waste being landfilled.

Based on these and other factors, the UK expects to combust around 2.7 million tonnes of waste by the year 2005. It estimates that this will generate about 800,000 tonnes of bottom ash and 10,000 tonnes of mixed fly ash and air pollution residues. Under current Special Waste Regulations (September 1996), bottom ash is not listed as a special waste; the mixed fly ash and APC residues are listed as such. Special wastes require more stringent management. Under the UK landfill tax system, bottom ash has been placed in an “inactive” category. This resulted in two positive effects to the energy from waste industry: (1) ash is taxed at £2/ tonne rather than the £7/tonne for “active” waste; and (2) the “inactive” category is expected to help encourage consideration of beneficial use of the ash as an aggregate.

Currently all residues from WTE plants in the UK are landfilled, but the industry and the government are working toward developing beneficial uses for the bottom ash. Several factors are driving this:

- The potential for cost savings compared with landfilling (tax avoidance plus potential revenues from use)
- WTE plant operators desire to maximize use of the materials from their plants
- The need to counter arguments and perceptions that energy from waste is not compatible with recycling
- The potential contribution to landfill reductions and aggregate recycling targets.

In 1996, UK researchers recommended that bottom ash be weathered and aged to promote carbonation, pH reduction, and other stabilization reactions as an appropriate method to treat the ash before beneficial use. They concluded that there were no commercially available methods to adequately treat the APC residues. Two potential barriers to beneficial use of the ash were identified:

- The leaching test that would eventually be selected to evaluate the acceptability of the material for use. (A method being proposed by the European Committee for Standardization (CEN) uses 100 g of the material crushed so that 95% passes a 4-mm screen. This fraction is subjected to a two-stage extraction using unbuffered distilled water: the first stage in 200 mL of water for 8 hours and the second stage in 800 mL of water for 16 hours.)

- Regulatory Uncertainty—Three separate UK agencies believe they should regulate ash use and be involved in developing guidelines for beneficial use applications.

Several industrial projects have been implemented in attempts to promote ash use and to further evaluate potential environmental performance. These include:

- SELCHP Ltd has been active in developing ash processing technology to use the ash in road construction applications.

- SELCHP Ltd and Bardon Roadstone, an aggregate company, paved a car park using bottom ash in the concrete subbase. Environmental monitoring is being conducted on this project.

- A road in Greenwich was resurfaced using bottom ash in the bitumen-coated base layer. Additional car parks were scheduled for repaving using bottom ash.

- In July 1997, SELCHP began operations of what is believed to be the first ash recycling plant in the UK. The plant separates ferrous and nonferrous metals from the ash and is expected to process 60 to 100 tonnes of ash each year.

Summary

Based on information in this chapter, the countries discussed, except perhaps Sweden, increasingly rely on the use of combustion with energy recovery as a major component of their waste management strategies. This is the result of policies similar to Germany's landfill requirements and a more realistic view of what can be economically recycled. These countries also require separation of the residues for utilization, and generally use only the bottom ash, except for the Netherlands, which uses some fly ash to produce asphalt fillers.

Also, most of these countries view the ash as a resource to be recycled, rather than as a waste to be disposed into a landfill, provided the recycling protects the environment. Several also established criteria and procedures for determining acceptable use and disposal options, and all continue to support research and development efforts for improved treatment and use technologies.

Chapter 6
Environmental Considerations

Overview

From an environmental perspective, MWC ash has been considered both toxic and benign. Depending on the advocate's view and the agenda, the ash can and should be used or it should be considered and managed as a hazardous waste. Reasons most often cited for not permitting beneficial use are the Pb and Cd contents of the ash and the potential for their leaching into the environment. Dioxins in the ash have also been cited as a reason for not permitting use. Liability issues have also deterred ash use. The validity of these concerns, however, has not been supported by the results of the many studies. On the contrary, a great deal of research and numerous demonstrations in a number of countries and the actual beneficial use history and practices in a number of European countries have documented that the ash can be used in a manner protective of human health and the environment. Rather than viewing this material as a waste, these countries consider it a resource that must be used rather than disposed into landfills.

Ash contains Pb, Cd, and other trace constituents that must be considered in any beneficial utilization project. It also contains high levels of soluble salts that could harm groundwater.[118,119] Fugitive dust from ash processing, transport, storage, and construction operations could cause concern to worker safety and health.[120] However, studies, including comprehensive risk assessments, have demonstrated that these concerns can be managed or are not at a high enough level to prevent safe use. These studies have consistently demonstrated that Pb and Cd or other trace metals that may leach from the ash under field conditions (including in marine environments) are well within allowable standards.[121] The minute quantities of dioxins in the ash do not leach.[121] Fugitive dust can be controlled and under most conditions and does not pose any health threats. Some studies indicate that the physical and chemical nature of the ash helps improve its environmental performance.[122] See Chapter 2 for information on the concentrations of constituents in the ash that may be of concern to human health and the environment.

Laboratory leaching tests have routinely been used to estimate the potential for heavy metals to leach from the ash. Many laboratory tests have been used with little if any consistency among them. Many of the tests are regulatory, such as the EPA's TCLP, and were designed more for classifying a material rather than for providing a valid assessment of its leaching potential under a given field condition. This and other factors resulted in disagreement among many regulators (and opponents of ash use) and those favoring ash use as to the validity of using a single laboratory test such as the TCLP to predict leaching performance when placed in field conditions. In the past several years, the Netherlands and others have proposed and are using a combination of laboratory leaching tests and other techniques to evaluate and predict the release rate of constituents over extended time periods.[123,124] Such approaches provide a much more systematic and scientific method to evaluate a selected residue's acceptability for beneficial use. In fact, analysis of leachate from ash monofills and from a number of ash beneficial use projects have demonstrated that the TCLP and similar laboratory leach tests do, in fact, over estimate the cumulative release of a number of constituents contained in the ash compared to the concentrations found in field leachates.[121,125,126] However, comparisons of laboratory and field data over a given pH range for selected constituents do show similarities.[124]

In many cases the combined ashes in monofills generate leachate with extremely low levels of heavy metals, quite often near or below drinking water standards.[121,125] The ash from modern WTE plants consistently passes the TCLP test and therefore is not hazardous by definition. It can be managed as a nonhazardous material, depending on specific state requirements. The Synthetic Precipitation Leaching Procedure (SPLP), EPA Method 1312, is considered by some a more predictive leachability method and was used by several states during 1998. The procedural method is very similar to the TCLP, but uses a 60/40 ratio by weight of sulfuric/nitric acid instead of the acetic acid specified in TCLP. SPLP is designed to duplicate acid rain leachability and, therefore, may be more predictive of actual field performance.

This chapter discusses environmental factors that should be considered when evaluating, designing, and implementing an ash beneficial use project. Results of selected laboratory and field leaching studies are presented along with information on fugitive dust and potential pathways for release of emissions during the processing and use of the ash. Where applicable, information is presented on strategies for controlling emissions. Summaries of risk assessments conducted for selected ash use projects are also presented.

Potential Pathways for Release of Emissions

There are a number of potential pathways by which emissions may be released during ash processing, use, and ultimate disposition. The major potential adverse environmental impacts are with the generation and release of leachates and fugitive dust.[120,124] Figures 6.1 through 6.4 show examples of potential release pathways under several scenarios.[120] The discussions on risk assessments later in this chapter also provide information on the potential pathways for release of constituents of concern when evaluating various beneficial use options.

Fugitive Dust

Fugitive dust can occur at several points along the path of ash generation, ash processing, ash use, reuse of products containing ash, storage, and construction activities. Techniques are available for controlling any fugitive dust problems. Simple and inexpensive methods such as maintaining an adequate moisture level in the ash, processing inside of a building, using dust suppressants, and covering the ash during transport and storage, have effectively prevented or controlled fugitive dust. When storing ash outside, in addition to controlling fugitive dust, one should place the ash on an impermeable base (e.g., high-density polyethylene) as a safety factor against transfer of trace constituents to the soil.

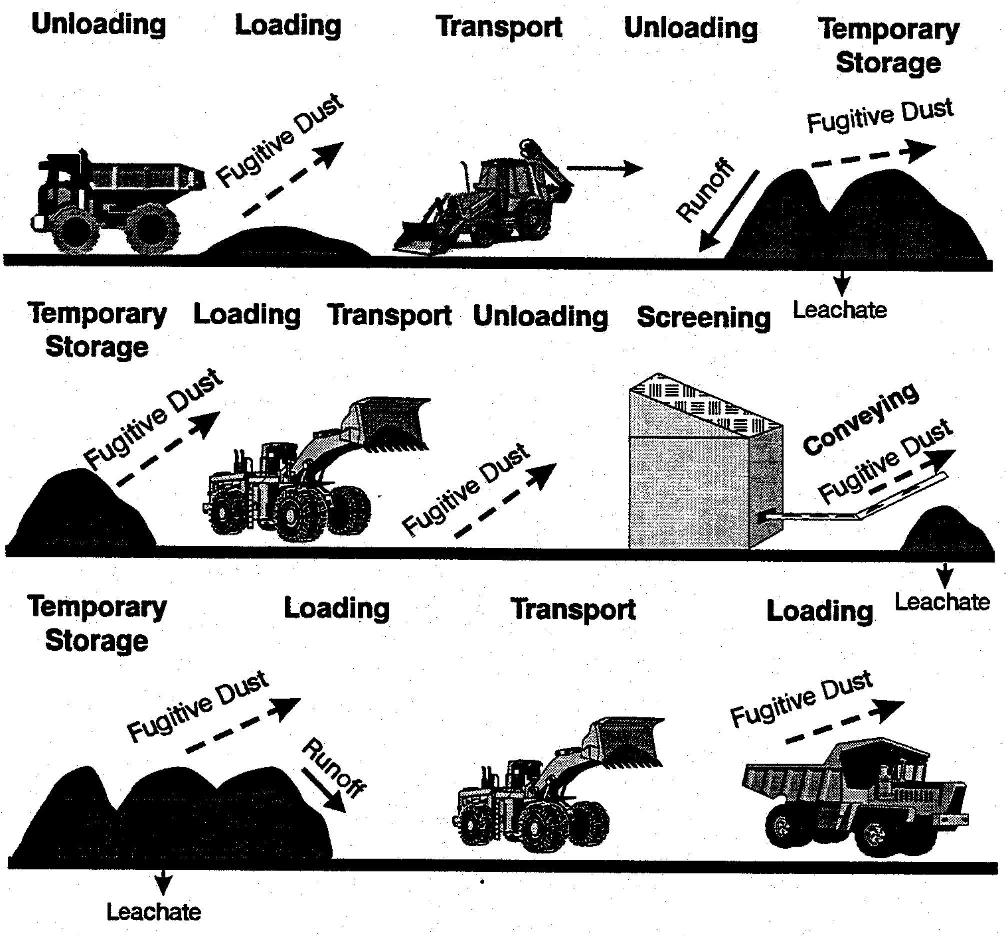
Results of investigations designed to determine potential worker health risks associated with processing dry ash in the laboratory led the investigators to conclude:[127]

- *“---that handling dry MSW combustor ash in a laboratory is not significantly different than handling conventional aggregates and poses no unacceptable environmental or health hazards to workers.”*

- *“The data indicates that the particulate loading measured in this investigation was substantially lower than the OSHA nuisance criteria of 5 mg/M^3* (reference reported 5 when it should have read 15). *In addition, the separable fraction (<10μm) was substantially below the OSHA criteria of 0.2 mg/M^3* (reference reported 0.2 when it should have read 5).*”*

- Results of this investigation also indicated that the maximum concentrations of PCDDs and PCDFs associated with the dust resulted in a 2,3,7,8-TCDD toxicity equivalent of <0.7 pg/M^3. When compared to the New York State Department of Health guidelines for worker exposure, the ash would not pose any adverse human health risks from PCDDs and PCDFs. Trace metals found in the dust were all below OSHA criteria.

In 1990, Mullen reported the results of a study that characterized the dust generated from uncontrolled stockpiles of processed bottom ash, and from road construction activities where the processed bottom ash was used as a road subbase and base course aggregate.[128] Results of modeling and simulations demonstrated that dust generated from the construction activities using this bottom ash did not represent a significant source of exposure to heavy metals in the ash. Air quality dispersion models were performed to predict the potential for fugitive particulate emissions from storage and construction uses of Boiler Aggregate™ and their effects on ambient air quality. Results were compared with Massachusetts Allowable Ambient Levels (AALs).



Potential Source	Release Mechanism	Primary Transfer Media	Mitigating Measures
Unloading	Fugitive Dust	Air	Cover or Dust Suppressant
Loading	Fugitive Dust	Air	Cover or Dust Suppressant
Transport	Fugitive Dust	Air	Cover or Dust Suppressant
Temporary Storage	Fugitive Dust Leachate Runoff	Air Groundwater Surface Water	Cover or Dust Suppressant Cover Piles Cover Piles
Screening	Fugitive Dust	Air	Cover or Dust Suppressant
Conveying	Fugitive Dust	Air	Cover or Dust Suppressant

Figure 6-1. Storage and processing facility: operations, sources, transfer mechanisms, receptors, and mitigating measures.

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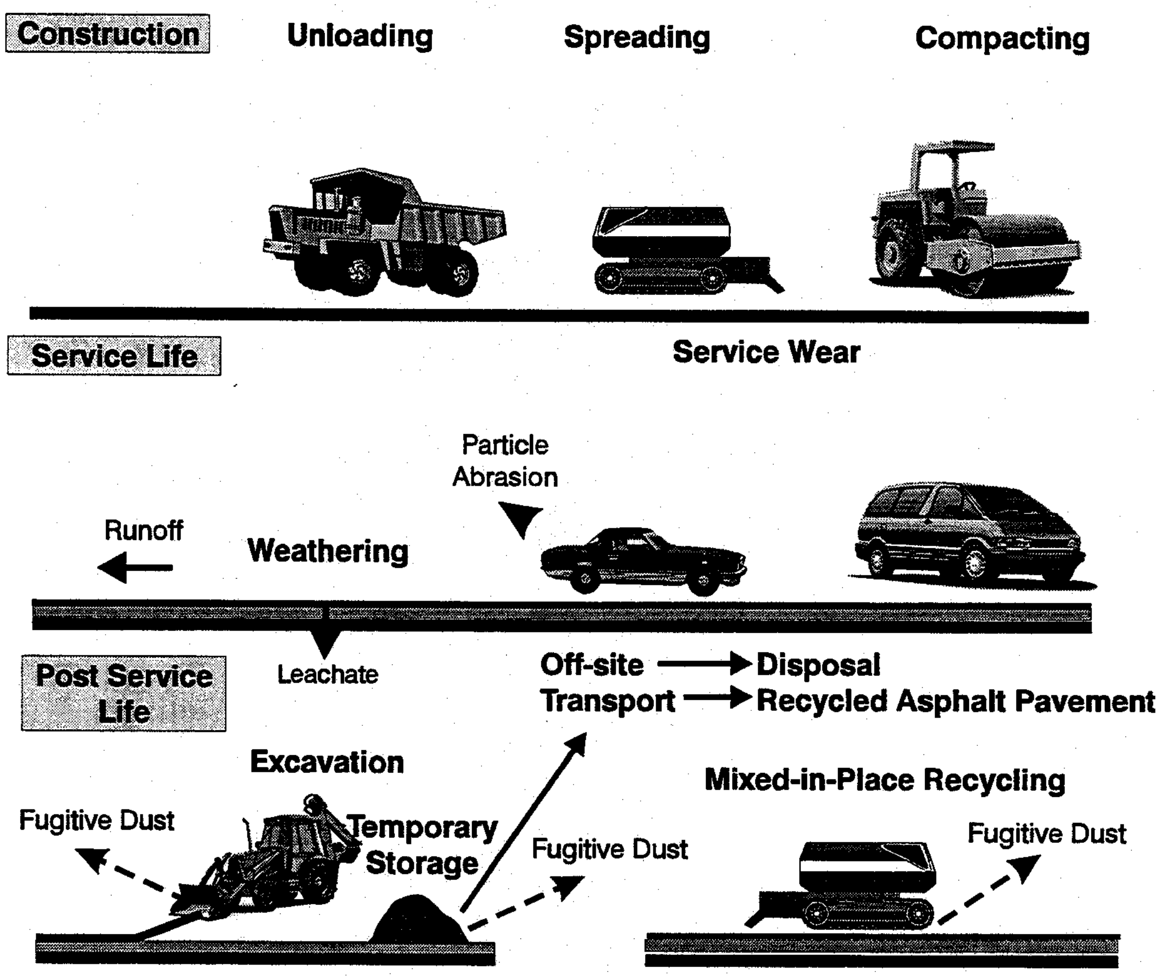
Chemical Technologies



Potential Source	Release Mechanism	Primary Transfer Media	Mitigating Measures
Weathering	Leachate	Groundwater	Pavement Encapsulation
	Runoff	Surface Water	Pavement Encapsulation
Service Wear	Particle Abrasion	Air	Pavement Encapsulation
Excavating	Particle Abrasion	Air	Dust Suppressants and Cleanup
	Fugitive Dust		Dust Suppressants
Temporary Storage	Fugitive Dust	Air	Dust Suppressants
	Leachate	Groundwater	Pavement Encapsulation
	Runoff	Surface Water	Pavement Encapsulation
Mixed-in-Place Recylcling	Fugitive Dust	Air	Dust Suppressants

Figure 6-2. Hot mix asphalt: construction, service life, and postservice life operations, sources, transfer mechanisms, receptors, and mitigating measures.

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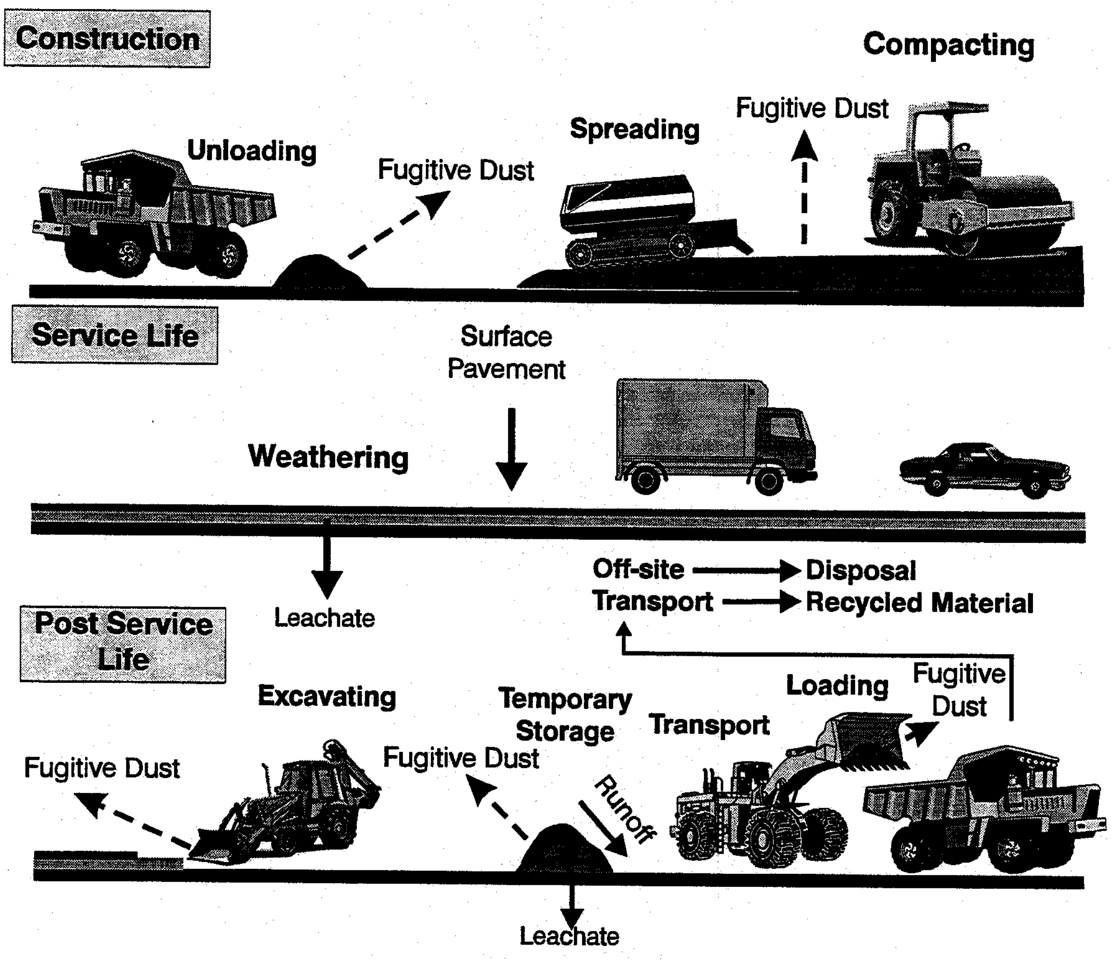

Potential Source	Release Mechanism	Primary Transfer Media	Mitigating Measures
Transport	Fugitive Dust	Air	Dust Suppressants
Unloading	Fugitive Dust	Air	Dust Suppressants
Loading	Fugitive Dust	Air	Dust Suppressants
Temporary Storage	Fugitive Dust Leachate Runoff	Air Goundwater Surface Water	Dust Suppressants Cover Piles Cover Piles
Spreading	Fugitive Dust	Air	Dust Suppressants
Compacting	Fugitive Dust	Air	Dust Suppressants
Weathering	Leachate	Groundwater	Pavement Encapsulation
Excavating	Fugitive Dust	Air	Dust Suppressants

Figure 6-3. Granular base: construction, service life and postservice life operations, sources, transfer mechanisms, receptors, and mitigating measures.

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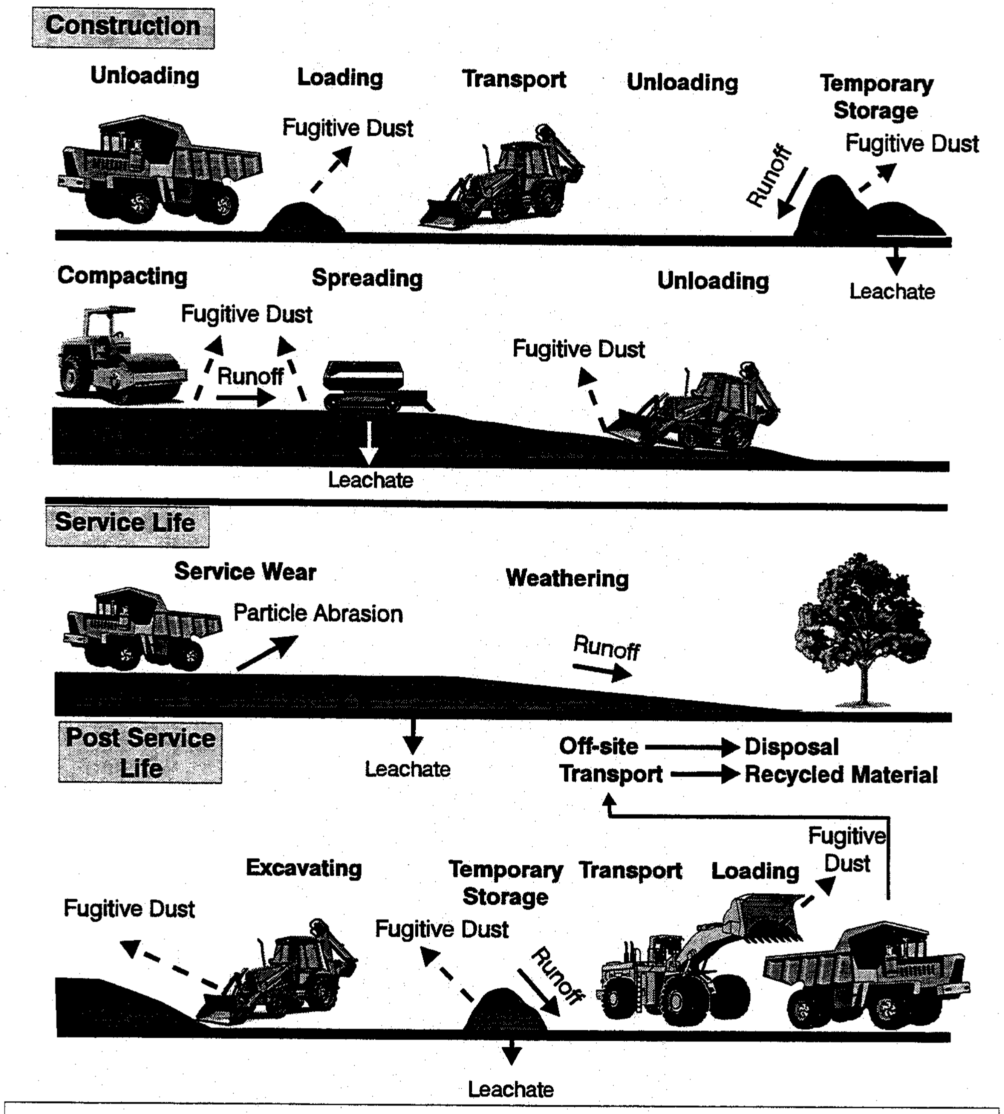

Potential Source	Release Mechanism	Primary Transfer Media	Mitigating Measures
Transport	Fugitive Dust	Air	Dust Suppressants
Unloading	Fugitive Dust	Air	Dust Suppressants
Loading	Fugitive Dust	Air	Dust Suppressants
Temporary Storage	Fugitive Dust	Air	Dust Suppressants
	Leachate	Goundwater	Cover Piles
	Runoff	Surface Water	Cover Piles
Spreading	Fugitive Dust	Air	Dust Suppressants
Compacting	Fugitive Dust	Air	Dust Suppressants
Service Wear	Particle Abrassion	Air	Pavement Encapsulation
	Fugitive Dust	Air	Pavement Encapsulation
Weathering	Fugitive Dust	Air	Pavement Encapsulation
	Leachate	Groundwater	Pavement Encapsulation
Excavating	Fugitive Dust	Air	Dust Suppressants

Figure 6-4. Embankment or fill: construction, service life and postservice life operation, sources, transfer mechanisms, receptors, and mitigating measures.

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Chemical Technologies

EPA-approved models were used to calculate the predicted ambient concentrations of particulates at perimeter receptors based on established emission rates from weathering and industrial activities and hourly meteorological data. Concentrations of Pb, Cd, Cu, and Cr at the receptor showing highest particulate loadings were calculated based on laboratory analyses of Boiler Aggregate™ as a function of particle size. Comparison of the worst-case metals concentrations with the AALs showed that in no instance did the metals concentrations exceed the AALs.

In a recent NREL-sponsored study, the air was monitored to measure fugitive emissions associated with processing bottom ash that involved conveying, screening, and ferrous metals removal.[129] The processed ash was stockpiled before use in a paving demonstration, and monitored for fugitive dust emissions during static conditions (no human activity) and during repeated turning by a front end loader to simulate repeated retrieval and replacement. Upwind and downwind emissions were monitored by high volume air samplers and personnel samplers were used to measure total suspended particulates (TSPs) and respirable particulates (PM_{10}) during processing periods.

Results of this study showed that:

- There were no measurable differences between the ambient air TSPs and trace metal concentrations upwind and downwind of the stockpile during static monitoring.
- The TSP concentrations measured in the ambient air near the stockpile were similar to the TSP concentrations reported at the other air monitoring stations in New Jersey and were below New Jersey's annual TSP criteria of 75 $\mu g/m^3$. The TSP concentration downwind of the bottom ash stockpile was 62 $\mu g/m^3$.
- During ash processing, PM_{10} concentrations, and TSP trace metal concentrations in the emissions were significantly below OSHA permissible exposure limits (PELs).
- During the stockpile turning events, PM_{10} concentrations were one to two orders of magnitude, TSP concentrations at least two orders of magnitude, and TSP trace metal concentrations several orders of magnitude below OSHA PELs, respectively. This was the case even though there was visible dust observed and a measurable increase in the ambient PM_{10}, TSP, and TSP trace metal concentrations. Scanning electron microscope analyses of TSP and PM_{10} samples collected during stockpile turning indicated that the major fraction of TSP particulate matter was in the PM_{10} size ranges (<10 microns, with 55% to 95% evenly distributed throughout the PM_{10} range).
- Soil quality near the stockpile was not adversely affected. Soil samples collected had elemental concentrations comparable to other soils typically found in New Jersey.

Leaching of MWC Ash

There is a relatively large body of information about the leaching behavior of MWC ashes. A number of laboratory tests are available and have been used to investigate the potential for the ashes to leach constituents of concern. Also available are numerous documents that present detailed discussions on leaching theory, factors that affect the leaching behavior of materials in various situations, differences among the various regulatory leaching tests, and similar information. The IAWG and others have reviewed and reported on leaching of ashes.[124,130,131] It is not the intent of this document to present these details. For further details on this subject refer to the references provided for this chapter and other sources. Readers considering conducting leaching studies on ash and relying on the results to design, permit, and implement ash use projects should become knowledgeable about this information or hire a consultant who is experienced in the field.

The following information is provided as general guidance in the area of leaching:

- Many consider that the release of toxic constituents through leaching represents the greatest potential environmental and human health threat from the disposal and use of MWC ashes. This has resulted in significant controversy over the years.
- No single leaching test is adequate to fully and accurately predict the potential for an ash or an ash product to release constituents of concern under field disposal and beneficial use conditions.
- A number of regulatory leaching procedures have been developed and used by various countries and states to characterize whether a material is hazardous. A number of research tests have also been used. These tests may or may not provide information useful in determining the potential for an ash to leach selected constituents in the field or to predict long-term leaching behavior. Table 6.1 is a partial listing of available leaching tests. Refer to other sources for details of these and other leaching tests.[124,132,133,134]

Table 6.1: A Partial List of Leaching Tests

Leaching Test	Country	Reference
EP Toxicity Test	USA	USEPA Method 1310
TCLP	USA	USEPA Method 1311
SPLP	USA	USEPA Method 1312
Total Availability	Netherlands	NVN 7341
Serial Batch Test	Netherlands	NVN 7349
Tank Leaching Test	Netherlands	NVN 7345 (NVN 5432)
Column Leaching Test	Netherlands	NVN 7343
French Leaching Test	France	NF X 31-210
Single Batch Extraction	Germany	DIN 38-414 S4
Single Batch Extraction	USA	ASTM
ANSI/ASN 16.1	USA	American Nuclear Society
Multiple Extraction Procedure	USA	USEPA Method 1320
Long-Term Testing of Solidified Radioactive Waste	International Standards Organization	ISO 6961/82
Acid Neutralization Capacity	Canada & others	Canada Method 7
Japan Leaching Test	Japan	JLT-13
California Waste Extraction	USA	State of California
Modified Sequential Chemical Extraction	Waste Water Technology Centre, Canada	WTC Laboratory Manual of Methods(1990)

- In the United States, the TCLP is the federal regulatory leaching test used to determine whether a waste is hazardous based on the toxicity characteristic. As with many such tests, it determines the quantity of selected constituents that leach from the tested material over a relatively short period of time under the specific conditions of the test. Although this information is used to classify the material as hazardous or nonhazardous, it usually has very limited value in predicting the concentration versus time or cumulative leaching over time.

- Two main mechanisms control the release of contaminants from residues. These may occur together and are greatly simplified in the following descriptions:

  - Solubility-controlled release, in which partial dissolution of mineral phases reach chemical equilibrium with the leachant. This is usually the mechanism that dominates with granular residues where the leachant percolates through the residues. Solubility-controlled leaching usually occurs at liquid to solid (L/S) ratios less than 20.

  - Diffusion-controlled release, which results in extremely slow release of elemental compounds into the leachant by diffusion. This is usually the controlling mechanism in cases where the leachant flows around, rather than through the residue. This occurs when residues have either been treated to produce a monolithic form or have permeabilities lower than the surrounding soils.

- There are a number of factors that influence leaching behavior of a material (including MWC residues). These include:

  - Liquid to solid ratio, the volume of leachant applied to the solid, usually expressed as L/kg. Laboratory batch leach tests typically have L/S ratios between 6 and 100:1; cumulative batch tests usually have L/S ratios in increments of 10 to 20:1; or column and lysimeter tests with L/S ratios as high as 5:1. The latter tests most closely approximate conditions observed in disposal sites.

  - Time the residue is exposed to the leachant

  - Solution pH, redox (Eh), ionic strength, and ligand concentrations affect reactions that occur at the pore water/solid interface that influences leaching. Such reactions include precipitation, dissolution, ion exchange, and specific adsorption. Some metals (e.g., Pb) become more soluble at high- and low-solution pH ranges than at neutral pH. This amphoteric property should be considered when evaluating the leaching behavior of these metals.

  - Reaction kinetics, temperature, and mass transfer affect reaction velocities.

  - Availability of the constituent (how much of the contaminant is available for leaching)

  - Chemical speciation of the contaminant

  - The permeability of the residue (granular or monolith form).

- Analyses of leachates from monofills containing combined residues have indicated that laboratory leaching tests generally overestimate the metal concentrations observed in the field leachates. However, when the IAWG researchers compared data from a number of laboratory tests with field data, they observed that the release of specific elements over a given range of pH were similar to those for field and lysimeter leachates. They concluded that the solubility-controlling phases in the field are not significantly different from those in the laboratory when pH and redox effects are taken into account. The significance of this is that if the pH of the field environment is known, the concentration of elements that are solubility controlled can be estimated for field leachates based on laboratory-generated pH/solubility curves. However, pH is only one factor among many that influence the leaching process. Concentrations observed for the metals in field leachates have typically been near or below drinking water standards.

- Although leachates from combined ashes in monofills have low concentrations of heavy metals, the total dissolved salts concentrations may be several orders of magnitude above drinking water standards. This must be carefully considered when planning a beneficial use project. Soluble salts can adversely affect the performance of cement-based and other types of ash products as well as the quality of groundwater.[121,135,136]

Estimating Cumulative Release of Contaminants from Leaching Ash

Kosson et al. reported on an approach using laboratory leach tests and modeling to help predict the rate at which constituents in MWC residues will leach during beneficial use and disposal[137]. In this work, the authors applied the technique to several ash utilization and disposal scenarios using bottom ash, combined ash, and APC residues. The approach uses laboratory tests to measure fundamental leaching parameters that include determining the maximum quantity of the constituent available for leaching, the solubility- and diffusion-controlled leaching behavior, and the physical and chemical retardation factors.

Using this approach the authors estimated the cumulative release of Cl and Pb for several different utilization and disposal scenarios. As an example, the cumulative release of Pb over a 100-year period from an asphalt matrix (where MWC ash was used as an aggregate) was estimated to be 0.07 mg/kg for bottom ash, 6 mg/kg for APC residues, and 0.1 mg/kg for the combined ash. The values are based on the amount of ash used. The validity of the approach was tested using data from actual field projects. In one case, core samples were extracted after 10 years from a road where compacted bottom ash was used as a base course. Based on the analysis of the core samples, the release of the Pb and the subsequent accumulation in the underlying soil indicated a cumulative release of 0.1–0.4 g Pb/m^2 of soil area over the 10 years. This compared favorably with the 0.38 g Pb/m^2 cumulative release estimated using the authors approach for diffusion-controlled release.

Results of Selected Ash Leaching Studies

Leachates from an Ash Stockpile

The ash stockpile study described earlier included testing of leachates collected during 35 storms over a period of about 1 year.[129] Analysis of the metals in the runoff showed that Pb was the only trace metal that exceeded drinking water standards. However, this result was based on the assumption that all analyses for Pb that were below analytical detection limits leached at the detection limit (which were above drinking water limits). A number of Pb analyses were below detection limits, so this probably resulted in an overestimate of the concentrations of Pb that actually leached. Soluble constituents that leached at levels above drinking water standards were Na, Mn, sulfates, and chlorides. Concentrations of organics in the runoff were below New Jersey Groundwater Criteria.

H-Power Ash

For nearly 9 years, staff at the H-Power WTE plant monitored the results of TCLP testing on the combined ash generated at the plant.[138] Figures 6.5 through 6.13 depict the results of this testing on As, Ba, Cd, Cr, Pb, Hg, Se, and Ag. As the graphs show, the ash met the requirements of the TCLP. However, this may not be the

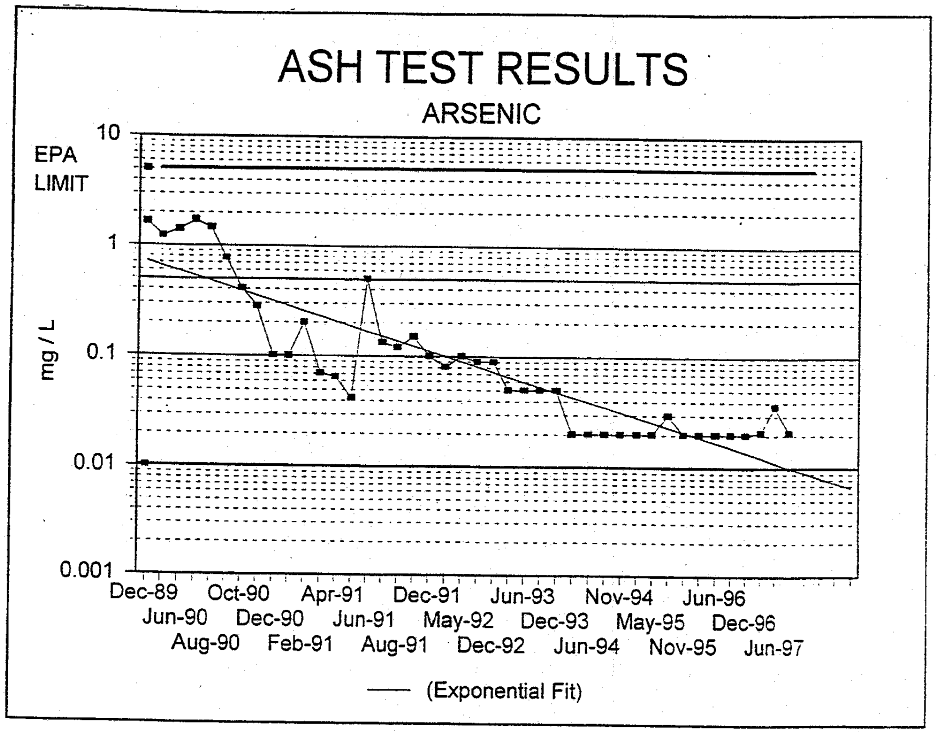

Figure 6.5. Arsenic

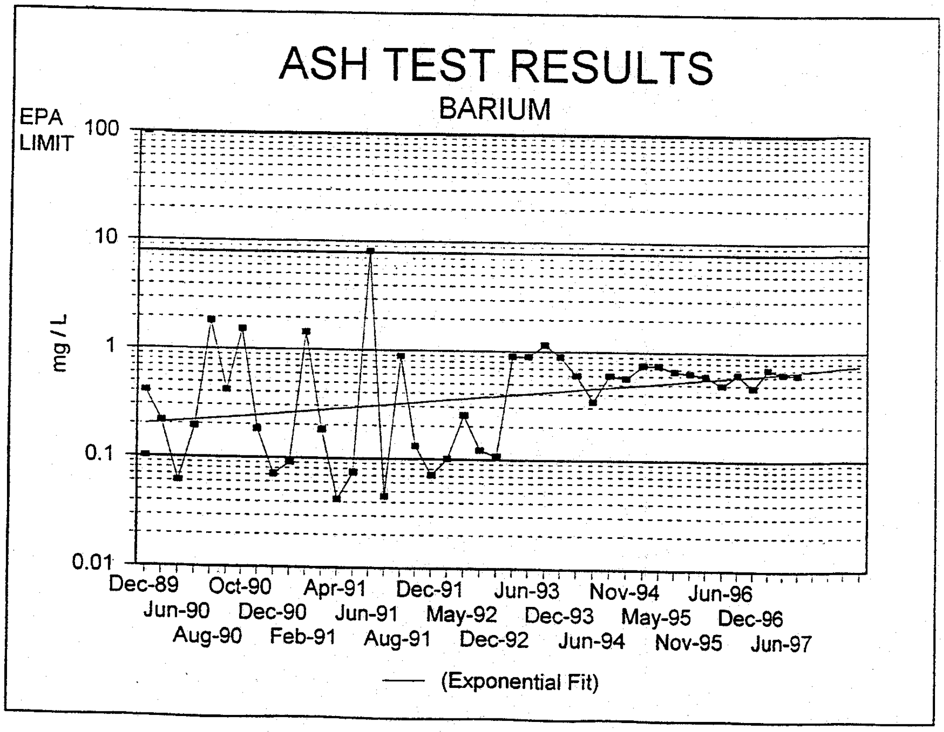

Figure 6.6. Barium

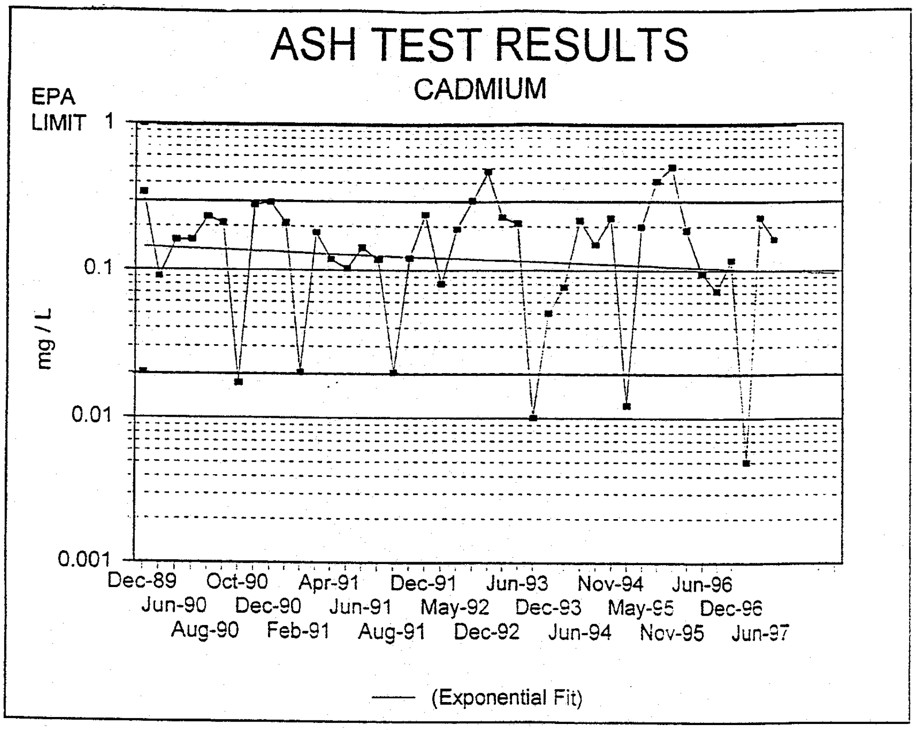

Figure 6.7. Cadmium

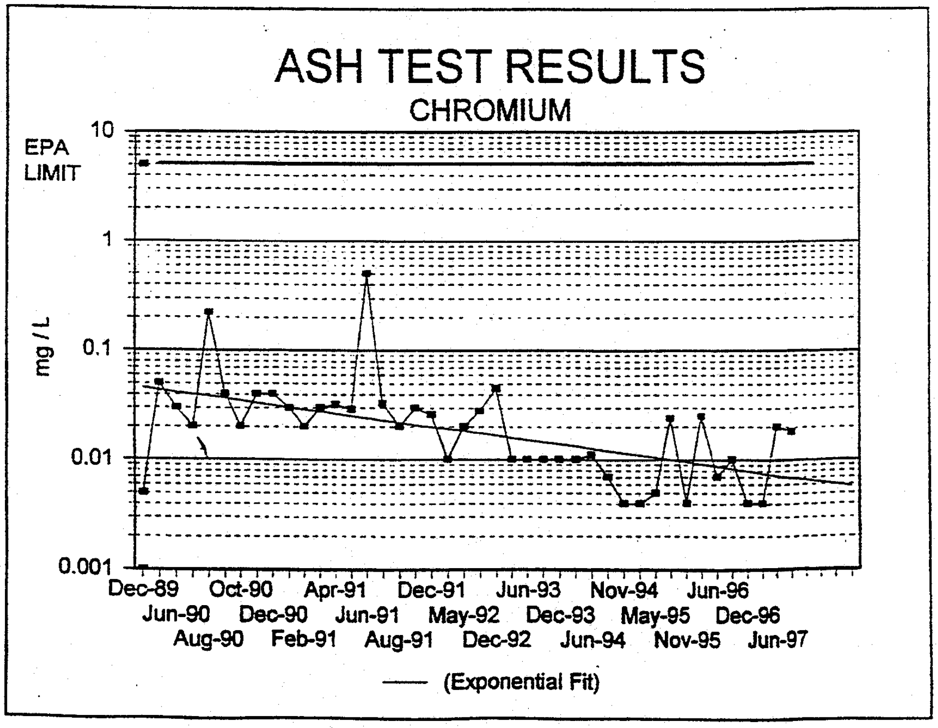

Figure 6.8. Chromium

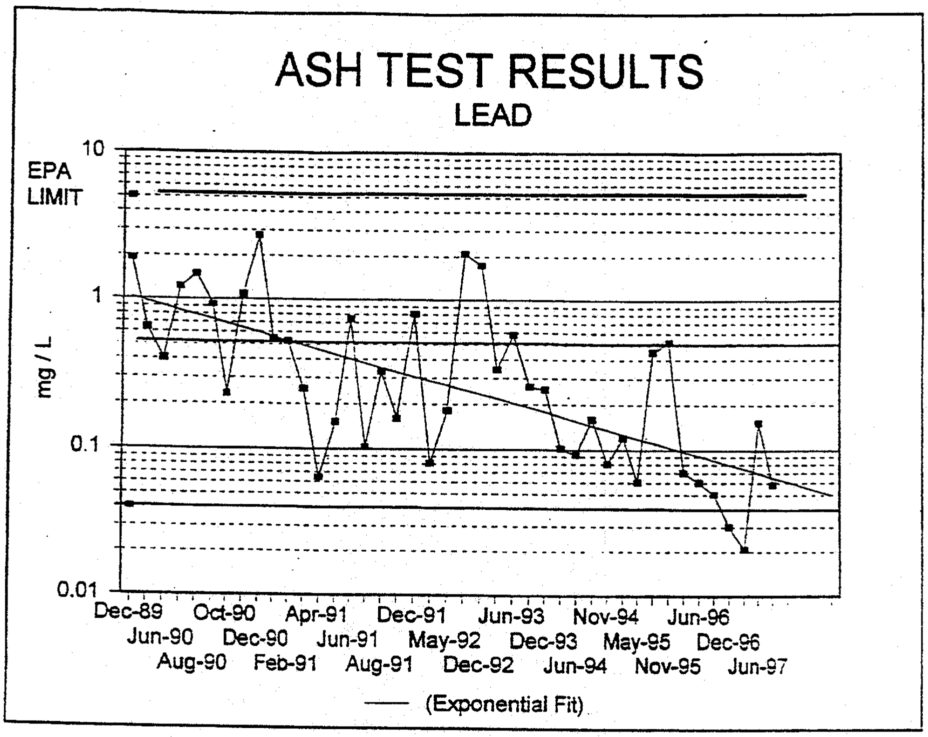

Figure 6.9. Lead

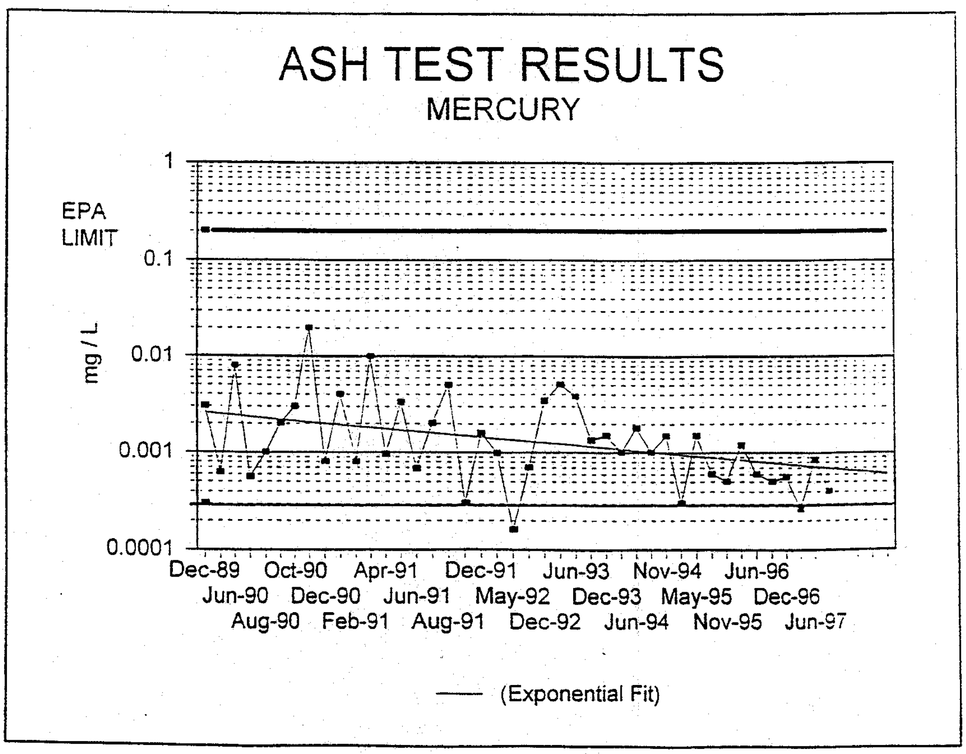

Figure 6.10. Mercury

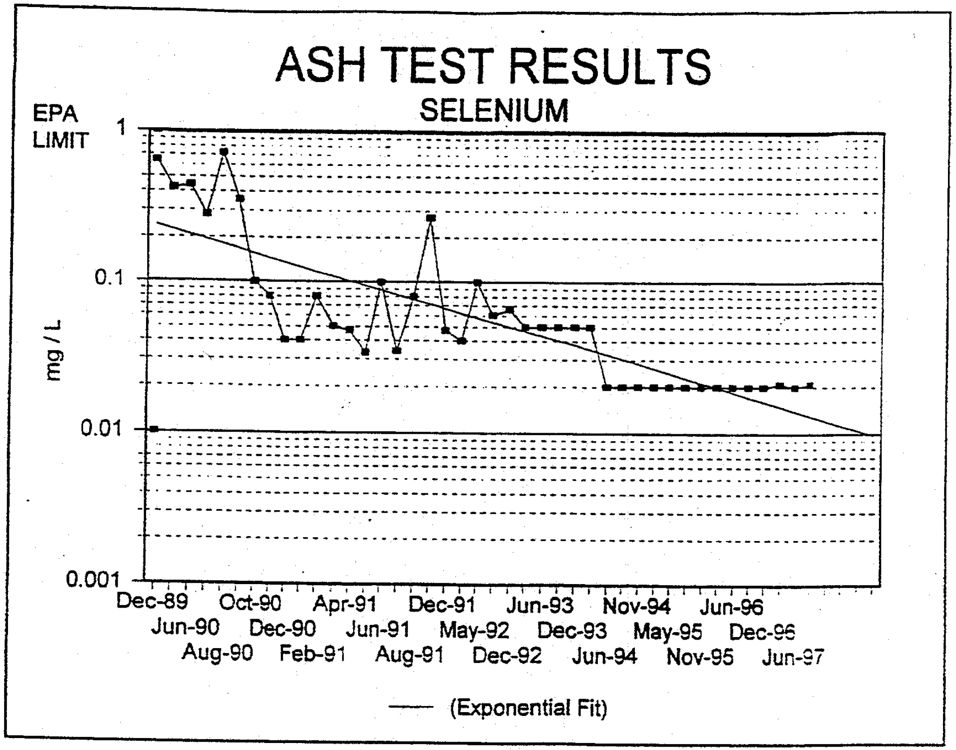

Figure 6.11. Selenium

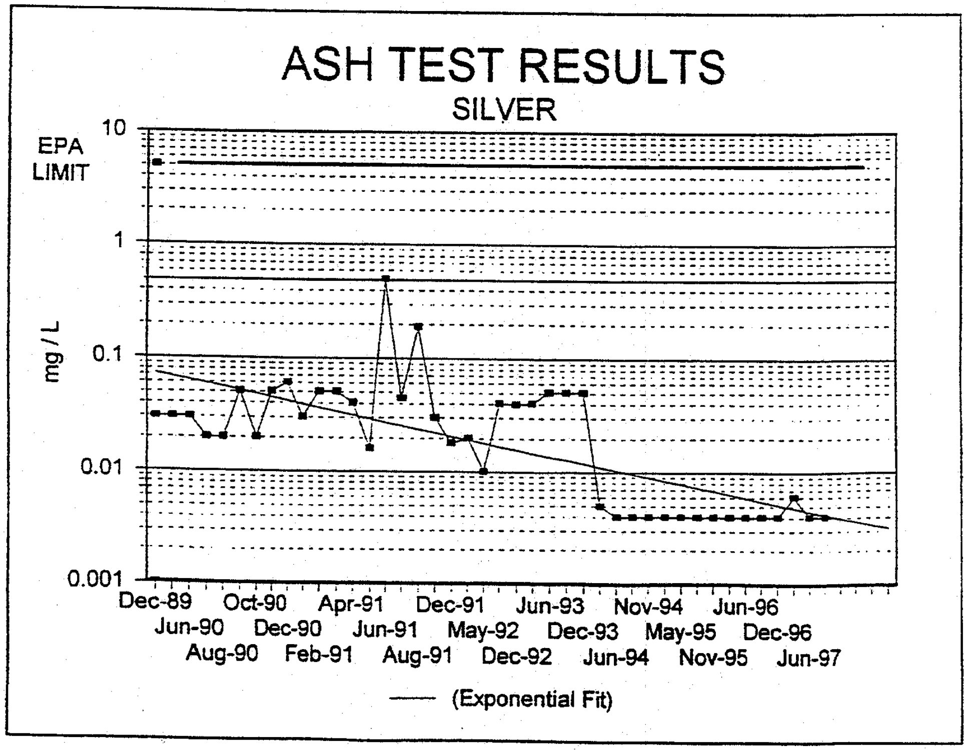

Figure 6.12. Silver

significant result. In all cases, except for Ba, there has been a downward trend in the concentrations of these constituents in the ash as determined by the TCLP. During the 9 years, there were no additional recycling initiatives that could have affected these results. Therefore, a conclusion is that efforts to reduce Pb in paint, Hg in batteries and fluorescent bulbs, and similar efforts have reduced the amounts of these constituents in consumer products, thus reducing the amounts that end up in the waste going to the WTE plant. Thus, the quality of the ash has improved over time.

TCLP Test Data from Wheelabrator Environmental Systems, Inc.

Table 6.2 summarizes 7 years of TCLP testing results on combined ash from a WTE facility. The data were provided by Wheelabrator Environmental Systems, Inc., for use in this document and the table represents a condensation of these data. All the ash tested was treated with the WES-PHix® process. Testing was started in 1990 and conducted monthly afterward. The 1997 data were omitted because only 2 months testing results were available.

Table 6.2: TCLP Test Results on Combined Ash—all units are mg/L

Year	As	Ba	Cd	Cr	Hg	Pb	Se	Ag
1990	0.0100	1.0830	0.1530	0.0713	0.0063	0.3976	0.0066	0.0432
1991	0.0100	0.8917	0.1288	0.0719	0.0091	0.4083	0.0050	0.0400
1992	0.00858	1.4590	0.1395	0.0730	0.0093	0.4457	0.0055	0.0398
1993	0.0096	1.2150	0.3575	0.1717	0.0074	0.4317	0.0036	0.0533
1994	0.0231	0.6371	0.4463	0.1019	0.0248	0.3033	0.0042	0.0367
1995	0.0070	2.4866	0.3060	0.1000	0.0163	0.4828	0.0058	0.0336
1996	0.0106	2.3741	0.2782	0.1065	0.0089	0.5987	0.0029	0.0585

Wheelabrator also provided TCLP testing results from a second mass burn facility (Table 6.3). This testing, conducted in June 1998, included only two metals. The WES-PHix® treatment was applied to the ash before testing. Since plants apply the WES-PHix® treatment process at different levels to meet their specific needs, TCLP test results may vary from plant to plant.

In 1995, Wheelabrator Environmental Systems, Inc., reported the results of TCLP testing of ash from 15 facilities.[139] The ash was sampled and analyzed following guidance developed by the EPA.[99] Table 6.4 presents a summary of these data.

Table 6.5 presents TCLP test data on combined ash from several facilities.

Leachates from Ash Landfills

Several studies characterized the leachates generated from landfills containing MWC residues. Probably the longest such study in the United States is the evaluation of the leachate generated at the Woodburn Municipal Waste Combustion Ash Monofill, located in Marion County, Oregon. In 1986, the EPA selected this site to evaluate the long-term characteristics of leachate from an ash monofill. Several organizations sponsored this investigation over its 9-year life. The evaluation included characterizing the leachates generated in the monofill, ashes aging in the monofill, and the surrounding soils. Details of the monofill design, ash placement,

Table 6.3: TCLP Test Results on Combined Ash in June 1998

Date	Final pH Results	Cadmium, mg/l	Lead, mg/l
6/8/98	9.75	0.0027	<0.025,BDL*
6/8/98	7.91	0.208	0.072
6/9/98	10.79	<0.0022,BDL	BDL
6/9/98	10.64	BDL	BDL
6/10/98	10.08	0.0024	BDL
6/10/98	10.67	0.0023	0.026
6/11/98	10.28	BDL	BDL
6/11/98	9.93	BDL	BDL
6/12/98	11.09	BDL	BDL
6/12/98	11.12	BDL	0.052

BDL=below detection limit

site characteristics, and similar information are available in the project reports.[140] Tables 6.6 and 6.7 present summary results of the concentrations of selected metals found in the leachates from Cell 1 and Cell 2.[141] Cell 1 was used as an interim ash fill and was only partially closed in 1990 when Cell 2 was put into operation. Cell 1 was closed in 1997. No leachate was generated from Cell 1 in 1994 and 1995, but small amounts were collected in 1996 and 1997 because of unusually heavy rains and some flooding.

Some of the major findings from the Woodburn ash monofill study follow:

- The major constituents in the leachates are dissolved salts, primarily of chloride, sulfate, Ca, Na, and K.

- Concentrations of metals in the leachates were all below EP-toxicity and TCLP maximum allowable levels.

- The 2,3,7,8-TCDD toxicity equivalency for ash samples analyzed were less than the 1 ppb limit that the Centers for Disease Control (CDC) recommends for residential soils. Dioxin levels in all soil samples were below the 1 ppb CDC recommended level for residential soils.

- Concentrations of metals in the soils near the monofills did not exceed those found in the background samples. Note that the ash monofill is not covered daily. The metal contents of the soils are within regional and national levels. Some soil samples collected near roads subject to frequent vehicular traffic did contain higher levels of lead.

Table 6.4: Results from TCLP Testing of Ash from 15 WTE Plants (mg/L)

	Baltimore	Bridgeport	Claremont[a]	Concord[a]	Falls[b]	Gloucester[a]	McKay	Millbury
PB	0.32–1.4	<0.5–0.66	<0.5	<0.5	<0.1–0.5	0.078–0.6	<0.42–0.49	<0.18
Cd	0.045–0.85	<0.1–1.25	<0.05–0.4	<0.05–0.29	0.06–0.69	0.07–0.89	<0.006–0.035	<0.016-0.67
	N. Andover	N. Broward	Pinellas	Saugus	Spokane	S. Broward	Westchester	
Pb	<0.18	<0.14–0.19	0.021–0.21	0.18–4.7	<0.1–0.75	<0.2–1.0	0.049–0.95	
Cd	0.016–0.53	<0.01–0.05	0.048–0.859	0.007–0.77	<0.05–0.3	<0.01	0.016–1.3	

[a] Results are from the analysis of 14 consecutive monthly samples.
[b] Results are from the analysis of 13 consecutive weekly samples.

Table 6.5: TCLP Leaching Test Results for Four WTE Facilities[a]

All Tests Performed on Combined Ash

Facility	**Ash Treatment**	**Month/Year**	**Result Is Average of No. of Tests**	**Metals in Leachate, mg/L**							
				As	**Ba**	**Cd**	**Cr**	**Pb**	**Hg**	**Se**	**Ag**
A	H_3PO_4	1/97	4	ND*	0.64	3-ND 0.019	0.054	ND	ND	3-ND 0.41	ND
		2/97	4	ND	0.54	0.138	ND	ND	0.0137	3-ND 0.50	ND
		3/97	4	ND	0.49	0.102	ND	ND	0.0228	ND	ND
		4/97	4	ND	0.63	0.142	ND	ND	0.0075	ND	ND

Facility	Ash Treatment	Month/Year	Result Is Average of No. of Tests	Metals in Leachate, mg/L							
				As	Ba	Cd	Cr	Pb	Hg	Se	Ag
		5/97	4	ND	0.63	0.162	ND	ND	2-ND 0.0032	ND	ND
		6/97	4	ND	0.62	0.078	2-ND 0.064	ND	2-ND 0.0030	ND	ND
		7/97	4	ND	0.63	3-ND 0.029	ND	ND	3-ND 0.0038	ND	ND
		8/97	4	ND	0.54	ND	3-ND	ND	ND	ND	ND
		9/97	4	ND	0.49	ND	0.047	ND	ND	ND	ND
		10/97	4	ND	0.46	0.070	3-ND 0.047	ND	1-ND 0.0047	ND	ND
		11/97	4	ND	1.35	ND	ND	1.52	ND	ND	ND
		12/97	4	ND	1.35	ND	2-ND 0.183	0.43	ND	3-ND 0.49	3-ND 0.046
A	None	1/98	4	ND	1.75	ND	3-ND 0.082	0.92	ND	ND	ND
		2/98	4	ND	1.71	ND	2-ND 0.050	ND	ND	ND	ND
		3/98	4	ND	1.75	ND	3-ND 0.042	1.00	ND	ND	ND
B	None	1/96	14	ND	0.87	4-ND 0.475	ND	10-ND 0.25	9-ND 0.0026	ND	ND
		8/96	10	-	-	6-ND 0.398	-	9-ND 0.22	-	-	-

Facility	Ash Treatment	Month/Year	Result Is Average of No. of Tests	Metals in Leachate, mg/L							
				As	Ba	Cd	Cr	Pb	Hg	Se	Ag
		2/97	10	-	-	1-ND 0.54	-	6-ND 0.66	-	-	-
		9/97	10	-	-	8-ND 0.02	-	ND	-	-	-
		4/98	10	-	-	9-ND 0.12	-	ND	-	-	-
C	None	9/97	3	ND	0.73	0.011	2-ND 0.013	0.248	ND	ND	ND
		10/97	3	ND	0.54	0.017	ND	1.15	ND	1-ND 0.18	ND
		1/98	3	2-ND 0.354	0.520	2-ND 0.012	2-ND 0.021	ND	1-ND 0.0026	2-ND 0.129	ND
		4/98	3	2-ND 0.16	0.541	1-ND 0.055	1-ND 0.016	ND	2-ND 0.0035	1-ND 0.136	ND
D	None	4/95	14	ND	0.68	ND	0.062	2-ND 0.08	12-ND 0.0006	0.015	ND
D	None	7/95	14	ND	0.49	ND	0.047	0.04	12-ND 0.0012	ND	13-ND 0.16
		11/95	14	ND	0.51	10-ND 0.174	ND	0.10	13-ND 0.0003	12-ND 0.030	ND
		3/97	10	-	-	2-ND 0.170	-	3-ND 0.029	-	-	-
		8/97	10	-	-	ND	-	0.06	-	-	-

[a] Data courtesy of American Ref-Fuel

*ND = below detection limit

Table 6.6: Concentration of Metals (μg/L) in Leachate from Cell 1

Analyte	1988 (5)[a]	1989 (2)	1990 (5)	1991 (4)	1992 (1)	1993 (2)	1996 (4)	1997 (1)
Al	NA	810	ND	225	100	ND	ND	ND
As	218	53	ND	1	ND	ND	ND	ND
Ba	NA	ND	1044	797	630	570	450	360
Cd	0.6	1.4	ND	1.8	2.5	8.6	16.5	ND
Cr	19	ND	ND	2.5	6	2.5	ND	ND
Cu	ND	ND	ND	18	70	20	48	ND
Pb	31	13	ND	ND	79	ND	6	ND
Hg	ND	ND	ND	ND	ND	ND	0.3	ND
Zn	200	250	2	20	510	30	215	ND

[a] Numbers in ( ) indicate number of sampling events during the year. The value shown is the numerical average of samples for the year and assumed that non-detects were zero. The analytical detection limits may have changed over the period of the project and some were not available for inclusion in this document.
NA: Not Analyzed
ND: Not Detected

Table 6.7: Concentration of Metals (μg/L) in Leachate from Cell 2

Analyte	1992 (1)[a]	1993 (3)	1994 (5)	1995 (1)	1996 (4)	1997 (1)
Al	200	ND	680	350	ND	ND
As	ND	8	ND	ND	ND	ND
Ba	2300	3010	991	1800	1075	5620
Cd	92	475	215	261	73	30
Cr	60	0.7	ND	ND	ND	ND
Cu	140	410	99	140	42	ND
Pb	41	63	20	100	5	ND
Hg	ND	1	0.6	ND	0.2	ND
Zn	420	833	219	300	330	1900

[a] Numbers in ( ) indicate number of sampling events during the year. The value shown is the numerical average of samples for the year and assumed that non-detects were zero. The analytical detection limits may have changed over the period of the project and were not available for inclusion in this document.
ND: Not Detected

In 1993, Roffman reported the results of evaluating data from analyses of leachates from nine ash disposal facilities.[142] She made the following observations:

- The leachates are rich in salts.
- Metal concentrations in the leachates were below the maximum allowable by RCRA (TCLP) limits. Often the leachates met the primary drinking water standards for the metals.
- Metal concentrations, particularly Pb and Cd, were often lower in the field leachates than in the corresponding laboratory extracts.

Table 6.8 presents results from analysis of leachate collected from a Danish ash monofill each year for 20 years.[143] The monofill contains approximately 10,000 tonnes of bottom ash and fly ash (without scrubber residues); the amount of fly ash is estimated at 15%. By 1992, 6150 m^3 of leachate had been removed from the landfill. As indicated by the data, the concentrations of trace metals have remained low over the 20-year period. The concentrations of soluble salts were high initially, but have decreased significantly over time. The one exception, sulfate, increased, most likely because of the decreasing concentration of Ca. Collection and analysis of this landfill leachate continues in 1998.[144]

Leaching of Bottom Ash and Bottom Ash-Asphalt Blend

Bottom ash and an asphalt hot mix containing 9% asphalt and a blend of 75% aggregate and 25% bottom ash have been subjected to leaching in field lysimeters for almost 9 years. Details of the study are available.[145] Materials were placed in field lysimeters October 1990. Leachates were then collected from the lysimeters each succeeding spring, summer, and fall through 1998. They were analyzed for a number of constituents. Based on the total concentrations of each constituent in the ash determined before use, the maximum quantity of each available to leach, and other factors, the investigators determined the cumulative amount that each measured constituent leached from the bottom ash and the asphalt mix over the period. A comparison was then made between the untreated bottom ash and the asphalt mix to determine the effects of the asphalt on the release rates of the measured constituents. Table 6.9 presents the cumulative amounts leached for selected constituents from both the untreated bottom ash and the asphalt mix. The percentage reduction in the quantities released is also presented. There were many non-detects for several of the constituents as indicated in the table. During the course of the almost 9 years, analysis technology changed resulting in changes in detection limits. Because of this, the investigators assumed that all samples that were below detection limits leached at the detection limit. This results in the most conservative estimate of the release rate and the values shown overstate the actual release rates for these constituents. This also affected the capability of the investigators to calculate the actual percentage reduction in release rates. Note, however, that even with the conservative approach, the cumulative release over the 9 years for Pb, Cd, Zn and other constituents is low.

Leaching of Treated Ash Aggregate

The AAR provided data on the analysis and leaching of its treated ash aggregate (TAA) ash product. Table 6.10 presents the total Pb and Cd concentrations in the TAA and the concentrations in the leachates from the TCLP and SPLP leaching tests. AAR reported that concentrations of organic constituents had never been observed above the laboratory detection limits.

Table 6.8: Leachate Quality over 20 Years from a Danish MWC Ash Monofill

Parameter	Unit	Variation 1973-1992 (22 observations)	Average Values	
			1973–1974	1991–1992
pH		8.7–10.5	8.8–10.1	8.9–10.2
Alkalinity	meqv/1	1.4–9.3	2.5	7.4
Redox potential, E_h	mV	-10 – -290	-66	–
Conductivity	mS/m	1400–3900	3100	1900
BOD5 (from 1981)	mg/L	<2–26	–	2
Sulfate	mg/L	2000–7200	3100	6100
Chloride	mg/L	2400–11400	9300	3300
Ammonia-N	mg/L	2.6–87	39	3.9
Na	mg/L	2800–7300	5600	3600
K	mg/L	600–4300	3900	800
Ca	mg/L	32–1000	670	58
As	mg/L	0.005–0.025	0.014	0.010
Cd	mg/L	<0.0001–0.001	<0.003	<0.0002
Cr	mg/L	<0.001–0.08	0.03	<0.002
Cu	mg/L	<0.0005–0.21	0.013	0.018
Fe	mg/L	<0.01–0.76	0.21	0.055
Hg	mg/L	<0.00005–0.003	0.00008	0.0004
Pb	mg/L	<0.0005–0.04	0.0013	0.007
Zn	mg/L	<0.01–0.59	0.05	0.09
Ionic strength	gmol/1	0.18-0.48	0.41	0.23
Accumulated L/S	1/kg	0.017-0.615	0.027	0.602

Note: Bottom ash and fly ash. Fly ash estimated at 15%.

Table 6.9: Leaching of Bottom Ash and Bottom Ash/Asphalt

Element	Bottom Ash (mg/Kg Bottom Ash)	Bottom Ash/Asphalt (mg/Kg Bottom Ash)	Percentage Reduction
Cl	879.6200	62.0588	92.94
Br	15.0626	4.6458	69.16*
NH_3	4.8277	0.5745	88.10
SO_4	5180.3500	295.2735	94.30
Si	9.2002	9.1374	0.68
Ca	1704.0800	119.7294	92.97
Fe	4.5332	0.3199	92.94
K	201.2000	15.6479	92.22
Na	675.2597	39.2604	94.19
B	6.8186	1.4508	78.72*
Cd	0.0132	0.0152	-15.15*
Cu	0.1575	0.0725	53.97*
Pb	231.6776	11.5215	15.61
Mg	231.6776	11.5215	95.03
Mn	2.9390	0.8766	70.17
Sr	6.5530	0.5132	92.17
Zn	0.0798	0.0895	-12.16*

* Indicates that a large number of the data were below detection limits, which gives the most conservative value possible for the percentage reduction. See text.

Table 6.10: Cadmium and Lead Concentrations in Leachates from TAA (mg/L)

Facility	Analysis	Year	No. of Samples	Cd		Pb	
				Mean (mg/L)	95% UCL[a]	Mean (mg/L)	95% UCL
AARTN[b]	TCLP	1993-98	282	0.28	0.30	0.33	0.37
	Total Metals	1993-98	26	32.4	38.0	1.316	1.524
AARPA[c]	SPLP[d]	1998	108	0.005	0.006	0.034	0.046
	Total Metals	1998	4	36.9	47.8	959	1,059

a. UCL-Upper Confidence limit
b. AARTN-AAR facility in Tennesee
c. AARPA-AAR facility in Pennsylvania
d. Pennsylvania requires the use of the SPLP.

6.11: Concentrations of Metals in Leachates from TAA (mg/L)

Facility	Statistics	As	Ba	Cd	Cr	Pb	Hg	Se	Ag
AARTN[a] (TCLP)	N[b]	42	42	41	42	42	42	42	42
	Mean	0.11	0.47	0.18	0.11	0.23	0.010	0.10	0.03
	95% UCL	0.16	0.56	0.21	0.15	0.27	0.015	0.153	0.03
AARPA[c] (SPLP)	N	12	12	12	12	12	12	12	12
	Mean	0.0065	0.303	0.004	0.003	0.025	0.001	0.009	NA
	95% UCL	0.011	0.493	0.007	0.004	0.039	0.002	0.014	NA
	Regulatory Limit	5.0	100	1.0	5.0	5.0	0.2	1.0	5.0

a. AARTN-AAR facility in Tennessee
b. N-number of samples
c. AARPA-AAR facility in Pennsylvania

AAR also provided data on the concentrations in the leachates of additional metals in the TAA. These data are summarized in Table 6.11

Results of Risk Assessments

Honolulu Combined Ash

A human health risk assessment was conducted for the proposed use of H-Power (Honolulu) combined ash as daily cover for the Waimanalo Gulch Landfill in Ewa, Oahu, Hawaii.[146] The risk assessment used data from measured concentrations of dust, metals, and crystalline silica generated during a 6-day demonstration of using combined ash as daily cover at the landfill in July 1996. The risk assessment evaluated the noncarcinogenic and carcinogenic effects of As, Ba, Cd, Cr, Pb, Hg, Ni, Se, Ag, and dioxin and furan cogeners. Key receptors who could be exposed to the combined ash, ash-derived dust, and ash leachate were identified as landfill workers, adults and children who may visit the site, and adults and children who live in nearby neighborhoods south of the site. Metal concentrations in the dust were assumed to be 100% ash-derived. Direct and indirect exposure pathways were evaluated and included inhalation of fugitive dust on- and off-site, and incidental ingestion of, and dermal contact with, ash while on site. Risk assessments were conducted for a number of ash handling scenarios that might conceivably occur during the use of the ash as daily cover.

The following results of the risk assessment were excerpted directly from the executive summary of the final report:

> *Results of the final risk assessment indicate that the estimated 99th percentile blood level would be 6.7 micrograms lead per deciliter (μg Pb/dL) blood for on-site workers associated with daily operations, and 7.3 μg Pb/dL blood for on-site workers associated with ash mining,* ***if*** *the workers failed to adhere to Federal and State regulations requiring personal protective equipment and personal hygiene protection under the applicable OSHA standards for arsenic, cadmium, and zinc. Both are well below the acceptable benchmark level of 25 μg Pb/dL blood for adult males. Non-carcinogenic risk assessment for other chemicals of concern resulted in Hazard Indices of 0.4 and 0.6 for workers associated with daily operations and ash mining, respectively. Both Hazard Indices are below the regulatory concern level of 1.0. Estimated carcinogenic risks were 3 x 10^{-5} and 5 x 10^{-5} for workers associated with daily operations and ash mining, respectively. Both are within the U.S.*

> *EPA's target risk range of 1x10^{-4} to 1x10^{-6} and OSHA's criteria for setting occupational standards (1 x 10^{-3}).*
>
> *The estimated 99th percentile blood lead level for on-site children who visit the landfill and who were assumed to be exposed to the H-Power ash by various exposure pathways was 3.4 μg Pb/dL blood. This value, which included exposures to numerous media via multiple pathways, is well below the acceptable benchmark level of 10 μg Pb/dL blood for children. Non-carcinogenic risk assessment for other chemicals of concern resulted in a Hazard Index of 0.2, which is below the regulatory concern level of 1.0. Estimated carcinogenic risk was 4 x 10^{-6}, which is well within the U.S. EPA's target risk range of 1 x 10^{-4} to 1 x 10^{-6}.*
>
> *The estimated 99th percentile blood level for offsite children who were assumed to be exposed to the H-Power ash by various exposure pathways, such as ash tracking and inhalation of wind blown dust, was 1.9 μg Pb/dL blood. Each exposure scenario included the summation of numerous exposure media and exposure pathways. These values are well below the acceptable benchmark level of 10 μg Pb/dL blood for children. Non-carcinogenic risk assessment for other chemicals of concern resulted in a Hazard Index of 0.001, which is below the regulatory concern level of 1.0. Estimated carcinogenic risk was 2x10^{-8}, which is less than the U.S. EPA's target risk range of 1 x 10^{-4} to 1 x 10^{-6}.*
>
> *The estimated 99th percentile blood lead level for on-site adults who were assumed (to) visit the landfill and to be exposed to the H-Power ash by various exposure pathways was 1.8 μg Pb/dL blood. This value is well below the acceptable benchmark level of 10 μg Pb/dL blood for pregnant female adults. Non-carcinogenic risk assessment for the other chemicals of concern resulted in a Hazard Index of 0.05, which is below the regulatory concern level of 1.0. Estimated carcinogenic risk was 4 x 10^{-6}, which is well within the U.S. EPA's target risk range of 1 x 10^{-4} to 1 x 10^{-6}.*

The results of this risk assessment clearly show that the use of the H-Power combined ash as daily cover at this site is an acceptable practice that will not pose human health problems.

Similarly, results from a comprehensive risk assessment demonstrated that there would be no adverse health effects from using H-Power combined ash as the bottom layer of the final cover for the Waipahu landfill.[147] This risk assessment considered additional exposure pathways including incidental ingestion and dermal contact with surface water and sediment while swimming in West Loch of Pearl Harbor, incidental ingestion and dermal contact with leachate while on-site, and consumption of fish caught in West Loch.

AAR's Treated Ash Aggregate

In 1996, results were reported on the health and environmental risk assessment conducted to evaluate the potential long-term environmental effects from production and beneficial use of AAR's TAA.[148] TAA is the result of processing combined MWC ash to remove ferrous and nonferrous metals and unburned materials. The processed ash is then treated using the WES-PHix® process. Chemicals of concern considered in the risk assessment were As, Ba, Ca, Cr, Cu, Pb, Hg, Se, Ag, Zn, and dioxins.

The following potential release pathways were evaluated:

- Loading and unloading of TAA
- TAA storage in stockpiles

- Production of asphalt paving material containing TAA
- Transporting TAA
- Use of TAA as a protected subbase in a roadway
- Use of TAA as a commercial protected structural fill
- Use of TAA as daily cover and final cover for landfills
- Use of TAA as an aggregate substitute in asphalt or concrete paving materials, and
- Reuse or final disposal of paving material containing TAA.

Potential health risks to workers and potentially affected residential (adult and child) receptors were evaluated for the following exposure pathways:

- Worker exposure to TAA by accidental ingestion and inhalation
- Worker exposure to TAA constituents dissolved in rainwater runoff
- Nearby residents inhaling airborne particulates emitted from TAA processing facilities
- Residential exposure to soils potentially contaminated by disposition of particulates of TAA emitted from storage piles, from processing plants, and by erosion of roadways containing TAA
- Residential exposure to soils potentially contaminated by overland transport of TAA via runoff from storage piles containing 100% TAA and 40% TAA encapsulated with asphalt or cement
- Residential exposure to TAA constituents which could have potentially leached from storage piles, road base subbase, and landfills using TAA as daily and final cover. This scenario assumed that the constituents entered a groundwater system that is used for residential purposes, including drinking and bathing
- Exposure to TAA constituents in a surface water body potentially affected by overland transport from stockpiles containing 100% and 40% TAA
- Exposure from ingestion of food grown in soils potentially contaminated by releases from TAA processing facilities, storage piles, and from roadway deterioration.

The risk assessment and carcinogenic and non-carcinogenic risks were conducted using EPA procedures and guidelines. Conservative assumptions were used so that EPA’s concept of a “Reasonable Maximum Exposure (RME)” was maintained. RME is defined as “the highest exposure that is reasonably expected to occur” for a given exposure pathway.

Results of this comprehensive risk assessment demonstrated that noncarcinogenic and carcinogenic risks are well within EPA recommended goals for all exposure situations evaluated. Review of the specific risks revealed that much of the estimated risk arises from direct worker contact with 100% TAA. These risks, while below regulatory goals, are further reduced by administrative and engineering controls in place.

Risks to residents resulting from air emissions, rainwater runoff, and leaching from piles, roadways, and landfills are well below EPA acceptable criteria.

Boiler Aggregate™ in Asphalt

A comprehensive risk assessment evaluated the potential health and environmental effects throughout the expected life cycle of using Boiler Aggregate™ in asphalt.[149] (Boiler Aggregate™, produced by Engineered Materials Corporation, is an aggregate produced from bottom ash from which ferrous and nonferrous metals have been removed.) This included manufacturing the Boiler Aggregate™ asphalt product, transportation of and stockpiling of Boiler Aggregate™, Boiler Aggregate™ asphalt product transport, placement of Boiler Aggregate™ asphalt roadways, milling and excavation for reuse of the Boiler Aggregate™ asphalt, reuse of the Boiler Aggregate™ asphalt, and use of Boiler Aggregate™ asphalt as unregulated fill. Potential receptors for the risk assessment included residents down gradient of multiple sources of Boiler Aggregate™ for 30 years, a child also down-gradient of multiple sources but who also trespasses onto the property where Boiler Aggregate™ is stockpiled, a plant worker who handles Boiler Aggregate™ during asphalt plant operations, and a road construction worker who scarifies roads containing Boiler Aggregate™ in binder and base courses.

Pathways considered for potential human exposure included:

- Ingestion of drinking water containing leachates from Boiler Aggregate™ stockpiles, a roadbed, and a recycled asphalt product pile
- Inadvertent ingestion of and dermal contact with Boiler Aggregate™
- Inhalation of fugitive dust at the asphalt plant where Boiler Aggregate™ is stored, handled and blended
- Inhalation of fugitive dust generated during road scarification.

In addition, potential ecological impacts were evaluated for:

- Surface waters affected by uncontrolled runoff from Boiler Aggregate™ stockpiles;
- Surface water affected by leachate from roadbeds containing Boiler Aggregate™; and
- Surface waters affected by leachate from sites where recycled asphalt pavement (RAP) containing Boiler Aggregate™ is stored or disposed.

Aquatic species were included as potential receptors in cases where the leachates and runoff containing Boiler Aggregate™ might affect their habitats.

The results of this risk assessment found that all human health risks were below Massachusetts DEP and EPA’s target levels for acceptable risks when proper management techniques are used. Although lead constituted the highest potential hazard from exposure to Boiler Aggregate™, this hazard was below all applicable health criteria. Ecological exposure levels were also acceptable. The risk assessment demonstrated that the beneficial use of Boiler Aggregate™ asphalt will not pose unacceptable risk to human health and the environment.

In 1996, the Massachusetts Department of Environmental Protection, after several years of comprehensive evaluations, issued a BUD permit for the use of Boiler Aggregate™ in asphalt paving applications.

Minnesota Combined Ash[150]

A health risk assessment was conducted for a proposed MWC ash utilization demonstration project that would substitute treated combined ash for 30% of the natural aggregate in bituminous pavement in Corcoran, Minnesota. The ash aggregate was produced using combined ash and some proprietary ingredients not reported. Using acceptable EPA computer models, conservative assumptions, and acceptable procedures for conducting health risk assessments, results were as follows:

- No significant human health risk arose from the use of the ash aggregate as a replacement for 30% of natural aggregate. The assessment showed that the local air quality and the health of local residents would be improved by paving the road and that the benefits would be similar using either the ash aggregate or all natural aggregate.

- Data clearly demonstrated that none of the noncarcinogenic hazard quotations exceeded EPA goals for any of the scenarios considered. The potential carcinogenic risks were below the EPA acceptable range of 10^{-4} to 10^{-7} excess cancer risks. Total carcinogenic and noncarcinogenic health risks were evaluated for infants, children, and adults for inhalation, ingestion, dermal contact, and consumption of food grown in soil near the site.

Mercury Vapor from a MWC Ash Landfill[151]

In June 1992, Roffman reported on results of an assessment of air quality and health risks associated with potential Hg vaporization from a MWC ash landfill. Results of the assessment showed that the air emissions of Hg vapor from the ash landfill under consideration were very small, even using conservative assumptions that enhance Hg vapor emissions. The calculated highest short-term and maximum annual ground level concentrations of Hg vapors were below applicable state standards and guidelines and the inhalation reference air concentration.

Other Actions

The Massachusetts permit for Boiler Aggregate™ use limits the use of the ash product to a 10% substitution. However, this and other actions indicate positive steps toward increasing the beneficial use of ash in the United States and the belief that beneficial use can be protective of human health and the environment. Some other actions are :

- In December 1997, the Pennsylvania Department of Environmental Protection (PADEP) issued General Permit WM GMOO3 for the processing of MWC ash and beneficial use of TAA as a base and subbase under roads and other paved surfaces, aggregate for asphalt manufacturing, structural fill materials, and substitute aggregate in concrete. This followed the evaluation of ash management alternatives and actions by the York County Resource Recovery Authority, which had determined that beneficial use of its ash was environmentally and economically preferable to landfill disposal. The PADEP therefore focused its strategy on implementing beneficial use of the ash and in December 1997, granted AAR a general permit to use its processed ash in the Commonwealth of Pennsylvania.[152]

- In May 1998, the governor of Florida signed legislation that authorizes the Florida Department of Environmental Protection to develop rules and regulations for the beneficial use of MWC ash.[153] In September, the Florida Department of Environmental Protection was in the process of drafting guidance for preparing beneficial use determinations for using MWC ash.[168]

- In 1996, the Department of Environmental Protection in Connecticut issued a report, *Resource Recovery Ash Residue Management*, which concluded that "The Department supports ash utilization as the best long-term technique for managing ash residue." The report further stated that research showed that processed ash could be used in bituminous roads for road subbase, in concrete, and in soil cement.[154]

Summary Comments

MWC ash can be safely used. Laboratory investigations and field projects demonstrate that metals in the ash do not leach at levels harmful to human health and the environment. Results of analyzing leachates from ash monofills show that the concentrations of metals are often near or below drinking water standards. Furthermore, results of health risk assessments confirm that MWC ash and MWC ash products can be used without risk to human health and the environment. Therefore, if properly managed, there are technical justifications for increasing the beneficial use of MWC ash in the United States.

Chapter 7
Regulations and Policies

Introduction

Many studies have been conducted on ash management, including beneficial use. These studies documented that MWC ash has physical characteristics allowing its use in many applications. Studies also show that beneficial use can be done in ways protective of the environment and human health. Lack of clear federal guidelines and inconsistent state rules and regulations have contributed to the poor acceptance of ash use in the United States. This chapter provides information on the federal and state regulations applicable to ash use.

Some information was reproduced from a report published by EAC Systems, Inc.[155] This chapter also summarizes results from two recently conducted surveys. State regulations on ash management vary significantly, and several states are either revising their rules or are just beginning to develop them. Several have also recently taken actions that may help implementation of ash beneficial use. These include Pennsylvania, Florida, and Connecticut.[156,167] Therefore, information in this chapter should be used as guidance only. It is critical that developers of beneficial use projects become knowledgeable about the host state's requirements early in the process.

Federal Regulations

Three federal laws affect or could affect beneficial use of ash. Many state environmental regulatory agencies have used these as a framework for developing their regulations on ash management.

The National Environmental Policy Act of 1969 (NEPA) requires that environmental impact assessments be prepared for all federal actions that could have adverse environmental effects.[158] The assessment must result either in a negative determination or detail the effects that the action will have on the environment. It is unlikely that NEPA will be a factor in most ash utilization projects.

Ash generated at WTE facilities is regulated under the U.S. Resource Conservation and Recovery Act (RCRA).[159] After several years of uncertainty about whether the ash was exempted from Subtitle C of RCRA, the issue was clarified by the Supreme Court in 1994.[160] Because of the Court's decision, operators of WTE facilities must determine whether the ash is hazardous based on the toxicity characteristic provision of Subtitle C. If determined to be hazardous, the ash must be managed according to RCRA, Subtitle C requirements. In the case of ash, this would normally mean disposal into a hazardous waste landfill. If determined not hazardous, the ash can be disposed into a municipal waste Subtitle D landfill or beneficially used. Usually, the determination uses the EPA's TCLP in addition to an alternative leaching procedure, as specified by a state (e.g., California requires the California Waste Extraction Test).[161] Some states may also require total metal and organics analysis and fish bio assays. After the 1994 Supreme Court's ruling, the EPA issued guidance to help in the sampling and analysis of the ash when using the TCLP.[162] This is only guidance, not a regulatory requirement in all states.

The 1980 CERCLA, commonly known as "Superfund," has caused some concern regarding the beneficial use of ash.[163] CERCLA provides the legal framework for assigning joint and several liability for persons found responsible for disposing or arranging for disposal of a waste later found to be the source of harmful contamination. This concern of potential liability was a significant impediment to owners or operators of WTE facilities setting up ash beneficial use projects. Several occurrences have led some to believe that this potential liability threat is no longer significant. Darcey reported several reasons why this is the case.[164,165] These include the fact that health risk assessments conducted for ash use projects have shown that ash can be used without harm to human health and the environment. Ash from WTE facilities has consistently tested nonhazardous since the Supreme Court decision. The quality of the ash has improved since states banned selected materials such as batteries going to WTE facilities. Further processing of the ash to remove ferrous and nonferrous metals, along with stabilization and other processing that prepares the ash for use, also helped. In addition, insurance policies are commercially available at reasonable cost to cover ash product environmental liability. Further, Darcey also reported that there is federal judicial precedent that a facility owner or operator is not liable under CERCLA if an ash recycler incorporates the processed ash into a commercially valuable product such as road base or blocks.

In 1998, the Municipal Waste Management Association published the results of an analysis of liability issues associated with the beneficial use of ash.[166] Results of this analysis demonstrated that local governments that generate MWC ash, which when tested does not exhibit hazardous characteristics, have several levels of protection against environmental liability. This is the case if they (1) provide the ash to a bona fide recycling operation; (2) the recycler or the local government treats the ash, if necessary, to satisfy state and federal laws; (3) the recycler has obtained all necessary state and local approvals; and (4) the MWC ash is used in products that are introduced into the economic mainstream in a manner that limits the potential for human exposure. The document provides details to explain each of these and presents results of court cases that provide legal precedent.

No specific regulations address beneficial use of the ash. However, provisions in RCRA and other federal policies encourage the recycling and use of waste products.

State Rules and Regulations

In July 1995, EAC Systems, Inc. published a document “Municipal Waste Combustor Ash Beneficial Use: Summary of Rules, Regulations and Demonstration Projects.” Section 3 of this document, State Rules and Regulations, is reproduced here as it provides an excellent summary of the status at that time.[167] EAC’s footnote numbers may have changed for consistency within this document but the narrative is as written by EAC. In reviewing this section, please note that several states have developed rules for ash use and others are in the process of developing or changing rules. One example is the State of Florida which, in 1998, was preparing guidance for WTE ash beneficial use determinations.[168] Therefore, some of the information presented in the EAC document is outdated and those interested in implementing ash use projects should become knowledgeable of the host state’s requirements.

3.0 STATE RULES AND REGULATIONS

Sixteen of the seventeen states profiled have existing, planned or proposed beneficial use supportive language in their rules and regulations. The language and terminology used in the rules varies across each state. States such as Florida, New York and Washington have entire chapters or sections devoted to MWC ash management and beneficial use, while other states broadly address the beneficial use of solid wastes. The different language used to define, interpret and permit beneficial use can be summarized as follows:

- *Beneficial use;*
- *Use constituting disposal;*
- *Risk analysis, comparative risk analysis, degree of hazard analysis;*
- *Solid and special waste classification and declassification;*
- *Exemptions from solid waste regulations; and*
- *Direct reuse and alternate use;*

The scope of regulatory control also differs from state to state. Some states are very specific in their regulations, listing certain eligible wastes and uses, while others broadly define beneficial use permit *application criteria and limitations. While many of the states profiled here have already adopted beneficial use regulations, states such as Connecticut, Maine, Minnesota and New Jersey are currently developing their rules. A summary of the variety of beneficial use language is provided in Table 2.*

Table 2: Summary of Beneficial Use Language by State

STATE	*BENEFICIAL USE LANGUAGE IN RULES AND REGULATIONS*
Alabama	*Ash regulated as solid waste; provisions to allow for alternate use; approval is granted on a case-by-case basis.*
California	*Regional authorities approve ash use in landfill footprints*[*]*; WET test required.*
Connecticut	*Updated State Solid Waste Management Plan supportive of beneficial use; regulations for MWC ash beneficial use being developed.*
Florida	*Chapter devoted to MWC ash management and recycling; permits issued on a site-by-site basis for MWC ash reuse; also issues research and demonstration permits.*
Hawaii	*No existing or planned/proposed rules.*
Illinois	*Ash is classified as a special solid waste; if reclassify to non-hazardous solid waste can recycle; some recycling applications remove solid waste classification, unless used in a manner constituting disposal.*
Maine	*Rules to be finalized summer 1995; risk analysis, risk-based decision making process to be included in rules.*
Massachusetts	*Beneficial use of solid waste; ash is regulated as solid waste; approval for beneficial use granted on a case-by-case basis.*
Minnesota	*Currently writing rules for beneficial use of coal ash.*
New Hampshire	*Calls beneficial use "direct reuse"; for solid waste facilities, direct reuse is built into operating permits; also have permits for research and demonstration projects.*
New Jersey	*Developing rules similar to those of New York State.*
New York	*Section devoted to ash management and beneficial use; land applications are beneficial use at a landfill; also beneficial use as a product ingredient or substitute for raw material.*
Ohio	*Solid waste regulation exemptions based on beneficial use.*
Pennsylvania	*General permitting for beneficial use.*
Tennessee	*Beneficial use in recycling definition; developing new rules to establish clear agency authority in making beneficial use determination and to establish application procedure; allow reuse except in manner constituting disposal.*
Virginia	*Exclusions and exemptions from solid waste regulations based on beneficial use.*
Washington	*Demonstration and "class-use" permitting for use constituting disposal; use as an ingredient in product, or substitute for product need not be permitted.*

**A landfill's "footprint" can be defined as the area within the perimeter of the lined landfill cells, over the leachate collection system. In contrast, the perimeter of the landfill is inclusive of all areas up to a landfill's property line, including the scale house, etc.*

Much controversy currently revolves around the methods used to properly estimate the contaminant release that would result from MWC ash field use. Technical arguments have stated that laboratory tests overestimate the releases that occur in the field and are not indicative of actual field conditions and release rates.[169] *States such as Florida, New York and Washington have attempted, through the promulgation of their ash management rules, to provide guidance on environmental monitoring and standards for MWC ash use that better reflects field conditions.*

3.1 Alabama

The Alabama state regulations allow for the alternate use of solid wastes; municipal waste combustor ash is categorized as a solid waste. One paragraph in the Alabama regulations addresses the alternate use of MWC ash. This paragraph states that the alternate use of MWC ash must receive approval from the Alabama Department of Environmental Management prior to implementation (335-13-4-.26(4)). Alternate use approval is granted on a case-by-case basis.[170]

3.2 California

California regulations require toxicity testing of the MWC ash for characterization prior to disposal. The state requires the use of the Waste Extraction Test (WET) for toxicity testing of any substance which may potentially fall under RCRA. This test is more stringent than the Federal Toxicity Characteristic Leaching Procedure (TCLP), and measures both soluble thresholds and total thresholds. Appendix B provides a list of the Soluble Threshold Limit Concentration (STLC) and the Total Threshold Limit Concentration (TTLC) for inorganic substances.

In California, regional, rather than state, authorities have primary jurisdiction regarding water or land discharges, and beneficial use applications fall under their approval processes.[171] *These regional boards, or local enforcing agents (LEAs), are autonomous, and they inspect and permit solid waste disposal facilities. The LEAs also act as the liaison between the facilities and the state Integrated Waste Management Board. For the demonstration projects described in section 4.2, the permitting authorities are the Regional Water Quality Control Boards, who regulate the landfills. Information regarding the structure of California solid waste regulations and its guidance on MWC ash beneficial use continues to be investigated.*

APPENDIX B

California WET Test Threshold Limit Concentrations for Inorganic Substances

Substance	STLC[a]	TTLC[a] Wet-Weight mg/kg
Antimony and/or antimony compounds	15	500
Arsenic and/or arsenic compounds	5.0	500
Asbestos	-	1.0 (as percent)
Barium and/or barium compounds (excluding barite)	100	10,000[b]
Beryllium and/or beryllium compounds	0.75	75
Cadmium and/or cadmium compounds	1.0	100

Substance	*STLC*[a]	*TTLC*[a] *Wet-Weight mg/kg*
Chromium (VI) compounds	*5*	*500*
Chromium and/or chromium III compounds	*560*	*2500*
Cobalt and/or cobalt compounds	*80*	*8000*
Copper and/or copper compounds	*25*	*2500*
Fluoride salts	*180*	*18,000*
Lead and/or lead compounds	*5.0*	*1000*
Mercury and/or mercury compounds	*0.2*	*20*
Molybdenum and/or molybdenum compounds	*350*	*3500*
Nickel and/or nickel compounds	*20*	*2000*
Selenium and/or selenium compounds	*1.0*	*100*
Silver and/or silver compounds	*5*	*500*
Thallium and/or thallium compounds	*7.0*	*700*
Vanadium and/or vanadium compounds	*24*	*2400*
Zinc and/or zinc compounds	*250*	*5000*

[a] *This is a list of Inorganic Persistent and Bioaccumulative Toxic Substances and their Soluble Threshold Limit Concentrations (STLC) and Total Threshold Limit Concentration (TTLC) Values. STLC and TTLC values are calculated on the concentrations of the elements, not the compounds.*

[b] *Excluding barium sulfate.*

[c] *In the case of asbestos and elemental metals, applies only if they are in a friable, powdered, or finely divided state. Asbestos includes chrysotile, amosite, crocidolite, tremolite, anthophyllite, and actinolite*

3.3 Connecticut

At this time, Connecticut regulations do not address beneficial use. However, the state is currently updating its 1991 Solid Waste Management plan, which will include beneficial use support.[172] *A draft of the updated plan will be available for public notice and comment during the summer of 1995.*

While the 1991 plan briefly endorses beneficial use, it does not describe the Connecticut Department of Environmental Protection's (DEP) specific intentions regarding its permitting. The updated plan will set a direction for the development of beneficial use rules and regulations, and it will specifically encourage the reuse of MWC ash. Adoption of this plan will provide the DEP with specific goals and criteria towards developing regulations. Currently, the agency is reviewing other states' beneficial use regulations, including those of New York and Pennsylvania, to provide guidance. The DEP is open to addressing uses of MWC ash outside of a landfill's footprint.[172]

3.4 Florida

The Florida Administrative Code contains a chapter detailing the requirements for solid waste combustor ash management (Chapter 17-702), including provisions for beneficial use. Under

17-702.400, solid waste combustors are require to submit an MWC ash management plan, which must include the anticipated quantities of fly and bottom ash and the identification of MWC ash components that can be recycled. This plan must also address the beneficial use of MWC ash (17-702.400(1) and (4)).

Section 17-702.66 addresses the recycling of MWC ash. To reuse the ash, a facility must comply with the following criteria (17-702.66(1)-(2)(c)).

- *Monthly descriptions of the chemical and physical properties of the MWC ash; and*
- *Prior to beginning reuse, the ash processor must demonstrate that the processing and use of the ash will not cause discharges of pollutants to the environment by:*
    - *Describing the chemical and physical properties of the finished product line, identifying the quantity of MWC ash used in a product and identifying the quantity and quality of the end product;*
    - *Demonstrating that the process will physically or chemically change the MWC ash so that any leachate produced after processing will not cause a violation of surface or ground water quality standards;*
    - *Demonstrating that processed MWC ash or the resulting products will not endanger human health or the environment. Exposure risks that should be considered include inhalation, ingestion, skin contact and migration to soil, surface and groundwater.*

Florida also issues research and demonstration permits for beneficial use demonstration projects. Permitting for the use of ash and ash products is done on a site-by-site basis. Natural aggregate is scarce and costly in Florida, and this fact provides incentive for the state to remain supportive of using ash as an aggregate substitute, particularly for uses outside of a landfill's footprint.[173]

3.5 Hawaii

Hawaii regulations do not contain beneficial use supportive language. At this time, there are no plans to update or change the regulations to include provisions for beneficial use, although regulators understand it is an area which requires attention.[174]

3.6 Illinois

The Illinois Administrative Codes address beneficial use through the classification and declassification of solid and special wastes. Both solid and special wastes are regulated by 35 IAC Subtitle G: Waste Disposal. Under Illinois regulations, MWC ash is classified as a special waste. The Illinois definition of special waste includes non-RCRA Industrial Process Waste and Pollution Control Waste. Bottom ash is an Industrial process Waste, while fly ash is a Pollution Control Waste.[175]

Illinois regulations include provisions to apply for a declassification of a special waste (35 IAC, Part 808 Special Waste Classifications). Once a special waste is declassified, it is regulated as a solid waste and may be recycled as specified in Part 721. The classification or declassification of a special waste is based upon a degree of hazard analysis, determined by a "toxic score" as defined in 808.Appendix B (808.245).

Part 721 defines the recycling of solid waste. If a material is recycled by using it in a manner constituting disposal, it continues to be regulated as a solid waste under 721.102(c)(1). If a material is recycled by using it as an industrial process ingredient to make a product, or as an effective substitute for a commercial product, then it is no longer classified as a solid waste (721,102(e)(1)).

3.7 Maine

Maine will be finalizing its rules and regulations regarding solid waste beneficial use during the summer of 1995.[176] *Few details on the regulatory language are available at this time, and this report will be updated once the final rules are released. Although MWC ash beneficial use will not be directly addressed, the rules will provide a means by which MWC ash is eligible for requesting beneficial use approval.*

The rules will not restrict any materials from applying for beneficial use approval. Risk analysis and risk-based decision making will be incorporated into the rules, as well as risk management, in which a method of managing a product's use to reduce risk may allow the product to qualify for beneficial use. The regulations will also include provisions for "reduced procedure licensing" that will simplify the approval process for specific wastes and their specific uses and locations of use.

3.8 Massachusetts

The beneficial use of solid wastes is addressed by the Massachusetts regulations, 310 CMR, Section 19.060. Once a beneficial use determination has been made, the subject material is no longer classified as a solid waste (19.060(5)). The regulations do not outline specific wastes or uses eligible for beneficial use determination. Massachusetts regulations also contain provisions for permitting demonstration projects (19.062).

Sections 19.060(2)(a)-(f) outline the application requirements for beneficial use determination, which include:

- *Chemical and physical characterization of the discarded material;*
- *Identification of the quantity, quality and source of the material;*
- *The proposed method of handling and utilization of the material;*
- *A description of how the proposed utilization will result in a viable and beneficial substitution of a discarded material for a commercial product or commodity;*
- *A demonstration that the proposed methods of handling and storing the discarded material will not adversely affect the public health, safety or the environment; and*
- *A demonstration that the proposed utilization or end-products will not adversely effect the public health, safety or the environment.*

3.9 Minnesota

Minnesota is currently writing rules for coal ash beneficial use, due for public notice and comment during the summer of 1995. The use of comparative risk analysis will be an integral part of these rules.[177] *This report will be updated once the draft rules are publicly available and reviewed.*

3.10 New Hampshire

New Hampshire regulations address solid waste beneficial use as "direct reuse." As long as a material is utilized as specified in the direct reuse permit, it is no longer classified as a solid waste.[178] There are three levels of permitting relevant to direct reuse (Part ENV-WM318):

- *Certificate for direct reuse;*
- *Operating permits which allow direct reuse; and*
- *Research and demonstration project permits.*

The certificate for direct reuse is applicable only to facilities that are not solid waste facilities, such as a bioenergy plant which burns wood for energy.

The operating permits which allow direct reuse are applicable to solid waste facilities. If an existing facility would like to change its ash management methods and begin reuse, it must apply for an operating permit modification. The facility must be able to demonstrate that the proposed use is proven and safe for the climatic conditions of New Hampshire. As of the date of this report, no facilities have obtained a permit modification for MWC ash reuse.

For a research and demonstration permit, the organization or corporation sponsoring the project must partner with a college or university. The demonstration project findings are key to obtaining the direct reuse operating permit modification. New Hampshire regulators believe that the results of a demonstration project that occurred in another geographic area cannot necessarily be extrapolated to their state due to differences in climate, road salting conditions, acid rain, etc. They require that the intended direct reuse be proven safe for conditions specific to New Hampshire. This permit allows the interested parties to obtain the required information to label a technology or beneficial use proven and safe.[178]

New Hampshire has not yet adopted TCLP testing into their regulations; the regulations still specify EPTox, but the regulators verbally recommend facilities execute TCLP testing.[179] For a new facility, testing is required of each "batch" of ash produced or leaving the facility, and when that facility demonstrates a consistent ash quality across many batches, the frequency of sampling is reduced.[178]

3.11 New Jersey

New Jersey is developing beneficial use regulations which will be available for public notice and comment summer 1995. The proposed beneficial use rules are very similar to those of New York State.[180]

Once the rules are promulgated, beneficial use application and approval will be a two-tiered process. If a beneficial use proposal has not been previously demonstrated or proven, then a demonstration project will be required. A Certificate to Operate, which requires an environmental impact statement, ash characterization using TCLP, and proof that no long term adverse effects will result from the demonstration project, will be issued. For roadway projects, the New Jersey Department of Transportation also evaluates the engineering specifications.

New Jersey is also implementing a Universal Waste Program which it believes goes hand-in-hand with successful beneficial use. MWC ash's total metal numbers, and the resultant perceived risk and liability, can influence the economics of beneficial use.[180] The cost of ash utilization may be artificially escalated due to the asphalt plants' perceived risks and liabilities. The Universal Waste Stream *program works towards reducing any real or perceived risks and liabilities and toward providing a better comfort level by removing specific wastes from the solid waste stream.*

The state has identified six discarded products that contribute most of the lead, cadmium and mercury that results in MWC ash. Source separation and collection programs are being established for the following wastes:

- *Consumer electronics;*
- *CRT tubes;*
- *Lead acid batteries;*
- *Nickel cadmium batteries;*
- *Mercury switches; and*
- *Fluorescent light bulbs.*

3.12 New York

New York solid waste regulations, Section 360-3.5, contain comprehensive provisions addressing MWC ash management and beneficial use. This section includes guidance on the following aspects of ash management:

- *Testing requirements and procedures;*
- *Contents of an ash management plan;*
- *Disposal;*
- *Landfill applications; and*
- *Other beneficial use applications.*

3.12.1 Landfill Applications

Subdivision 360-3.5(h) addresses the use of MWC bottom or combined ash, either alone or blended with other aggregate materials or reagents, on solid waste landfills. Valid applications include, but are not limited to:

- *Landfill cover;*
- *Temporary or permanent roads;*
- *Part of the final cover or cap;*
- *Final site grading; and*
- *Use as a building or construction material within the boundaries of the landfill.*

Samples of the ash must be tested using two different leaching procedures, TCLP and the leaching procedure described in Technical Resource Document SW-924.[181] *The SW-924 procedure is executed using distilled, deionized water as the leaching fluid. For the following metals, the TCLP and the SW-924 extractions are required to yield less than 100 times the New York State Ground Water Quality Standards:*

- *Arsenic;*
- *Barium;*
- *Cadmium;*
- *Chromium;*
- *Lead;*
- *Mercury;*
- *Selenium; and*
- *Silver.*

Prior to using the MWC ash in landfill applications, results of the TCLP and SW-924 tests for at least six representative samples must be submitted to the New York State Department of Environmental Conservation (NYSDEC). Test results must be submitted quarterly after commencement of the utilization, and it must be demonstrate statistically, with 90% confidence, that the leaching requirements are not exceeded (360-3.5(h)(l)(iii) and (iv)).

Additional requirements which must be met to utilize MWC ash in landfill applications include:

- *Demonstration that the MWC ash, or blend of ash with other aggregates or reagents, meets the specifications of and exhibits the performance characteristics required for the intended application (360-3.5(h)(1)(ii));*

- *Submittal of an operation plan which ensures that potential fugitive dust emissions and run-off are controlled during on-site loading, transport, unloading and processing (360-3.5(h)(1)(v)); and*

- *Proper disposal, according to 360-3.5(g), of any part of the ash stream which is not utilized (360-3.5(h)(1)(vi)).*

3.12.2 Other Beneficial Use Applications

Subdivision 360-3.5(I) addresses the beneficial use of bottom ash, fly ash and combined ash as an ingredient or as a substitute for a raw material. Prior to beneficial use approval, the applicant must demonstrate to the NYSDEC that (360-3.5(i)(1)):

- *The resultant material is not a waste, has a known market or disposition, and is not accumulated on speculation; and*

- *Contractual arrangements have been made with a second party for use as an ingredient in a production process and that the second party has the necessary equipment to do so.*

Additional information which must be submitted by the applicant includes (360-3.5(i)(2)(i)-(iv)):

- *A chemical and physical characterization of the MWC ash and the finished product, and identification of the quantity and quality to be marketed;*

- *A description of the proposed method of application or use, potential markets and potential marketing agreements;*

- *A demonstration that the intended use will not adversely affect public health, safety, welfare or the environment; and*

- *A description of each mixture used if the MWC ash utilization includes mixing with different types of materials.*

3.13 Ohio

The Ohio Administrative Codes specify exemptions from the solid waste regulations based on approved beneficial uses (3745.27.03). Once these materials are exempt, they are subject to Ohio's air, land and water pollution laws, Chapter 6111 of the Ohio Revised Code. MWC ash is classified as a solid waste, but is not specified in the list of exemptions for beneficial use. Coal combustion *bottom and fly ash and spent foundry sands are exempt from hazardous or residual solid waste regulations when they are beneficially used.*[182] *To facilitate the interpretation of this rule, the Ohio EPA, Surface Water Division, has developed a policy, Beneficial Use of Nontoxic Bottom Ash, Fly Ash and Spent Foundry Sand, and Other Exempt Uses.*[183] *This policy describes notification and permit requirements, siting criteria and design standards for uses outside of a landfill's footprint.*

3.14 Pennsylvania

Pennsylvania regulations address the beneficial use of residual wastes in Chapter 287, Subchapter H, sections 287.611-287.652. A residual waste that is beneficially used is no longer considered to be a solid waste (287.7). Municipal waste combustor ash is a special handling waste under the definition provided in Subchapter A; the beneficial use rules of this chapter also apply to special handling wastes.[184]

General permits can be issued for a particular residual waste category that is beneficially used (287.611), including use as a construction material (287.611(d)(2)), as long as the use of a residual waste does not pose a greater harm than the use of the product which the residual waste is replacing (287.611(3)). Once a general permit is issued, other parties who use the same waste for the same purpose need not apply to the Department to operate under the existing permit. They are, however, required to file a registration with the Department prior to operating under the general permit, and to comply with the general permit requirements (287.612).

Sections 287.661-287.666 address the beneficial use of coal ash in applications including:

- *Structural fill;*
- *Soil substitutes or soil additives;*
- *Manufacture of concrete;*
- *Antiskid material or road surface material (bottom ash only); and*
- *Drainage material or pipe bedding.*

3.15 Tennessee

Tennessee regulations allow solid waste reuse, except in a manner that constitutes disposal. The regulations define "reclaim," "recover," or "recycle" as any method, technique or process used to separate, process, modify, treat or otherwise prepare a solid waste so that component materials or substances may be beneficially used or re-used as products or raw materials (1200-1-7-.01(2)). This definition also excludes uses in a manner constituting disposal from being valid beneficial uses or re-uses.

Tennessee is currently developing rules that will establish a clear authority for the Tennessee Department of Environmental Protection to make a beneficial use determination. These new rules will also establish procedures to follow when applying for a beneficial use permit.[185]

3.16 Virginia

The Virginia Solid Waste Management Regulations, Part III: Identification of Solid Wastes, contain exclusions and exemptions for beneficially used solid wastes. Section 3.2(E) specifies the following exclusions:

- *Materials used or reused as ingredients in an industrial process to make a product;*
- *Materials used or reused as effective substitutes for commercial products; and*
- *Materials that are beneficially used.*

Coal combustion by-products are the only specific material and beneficial use listed (3,2(E)(2)Note). When used in the manufacture of another product, such as concrete, concrete products, or lightweight aggregate, or as a substitute for a product or material resource, such as roofing granules or pipe bedding, coal combustion by-products are not considered solid wastes.

Section 3.3 lists conditional exemptions from the solid wastes regulations. The exemptions defined for coal-combustion by-products include (3.3(A)(4), (5), 3.3(b)(1),(2)):

- *Use as a soil nutrient additive, stabilization agent, structural improvement or other agricultural purposes under the authority of the Virginia Department of Agriculture and Consumer Services;*

- *Use as a traction control material or road surface material if the use is consistent with Virginia Department of Transportation specifications;*

- *Use as a base, sub-base or fill material under a paved road, the footprint of a structure, a paved parking lot, sidewalk, walkway or similar structure; and*

- *Processing with a cementitious binder to produce a stabilized structural fill product.*

Municipal waste combustor ash exemptions occur on a case-by-case basis.[186] *Virginia regulations have no requirements for TCLP or EPTox testing.*[187]

3.17 Washington

The Washington Administrative Codes (WAC) contain municipal waste combustor ash utilization standards (173-306-490). These standards are comprehensive, and include the following aspects:

- *Standards for accumulation prior to utilization (173-306-490(2)(a));*
- *Use constituting disposal (173-306-490(b));*
- *Demonstration and class-use permitting (173-306-320);*
- *Use in an industrial product, or as a substitution for a product (173-306-290(2)(c)); and*
- *Additional factors (173-306-490(2)(b)(iii).*

The Washington Department of Ecology examines many factors in the approval of MWC ash use. In addition to the information described in sections 3.17.1 and 3.17.2 below, the following information is reviewed by the Department (173-306-490(2)(b)(iii)):

- *The effectiveness of the utilized ash or ash product for the claimed use;*

- *The degree to which the used ash is similar to an analogous product;*

- *The extent to which the used ash or ash product minimizes loss or escape to the environment;*

- *The extent to which the used ash or ash product impacts public and employee health and the environment given a reasonable worst case exposure, risk assessment analyses, and* *compliance with the performance standards for groundwater, soil, air quality and surface waters as defined in 173-306-440(2) (see below);*

- *The extent to which an end market for the re-used ash and ash product is guaranteed;*
- *The time period between generating the ash and its reuse or utilization;*
- *The degree to which the end uses and end users can be tracked and recorded (only applicable to uses constituting disposal); and*
- *Other factors as appropriate.*

Section 173-306-440(2) provides the performance standards for groundwater, soil, air quality and surface waters referenced above. Those standards are:

- *Primary drinking water standards as specified in the WAC Chapter 248-54;*
- *Based on annual soil samples, the cadmium loading in the upper six inches of soil cannot exceed the following:*
    - *If the pH of the soil is greater than or equal to 6.5, cadmium loading cannot exceed 0.5 kg per hectare annually or a total accumulation of 20 kg per hectare;*
    - *If the pH of the soil is less than 6.5, cadmium loading cannot exceed total accumulation of 5.0 kg per hectare.*
- *Air quality based on emission standards of particulates, dusts or gases and other ambient are quality standards, including that of lead. The level of lead will not exceed the latest national ambient air quality standards, or shall not exceed 1.5 micrograms per cubic meter; and*
- *Receiving water quality standards for surface waters.*

3.17.1 Use Constituting Disposal Permitting

Ash utilization in a manner constituting disposal can be permitted, and it includes, in addition to placement on the land, placement in the water, as in ocean reef construction. Two levels of permitting is available for ash utilization in a manner constituting disposal, demonstration and class-use permits. Prior to obtaining a class-use permit, a demonstration permit is issued. The demonstration permit specifies a limited time period and quantity of ash used in the project (173-306-320(1)(c)), and requires the submittal of a report containing the results of all field tests and laboratory analyses, and any other data.

The Department of Ecology uses this information in its determination of whether or not to issue a class-use permit. Class-use permits are required for MWC ash utilized in a manner constituting disposal, and are issued to the sellers or distributors of the ash products to a class of users (173-306-320(2)). Limitations on the class of users of the utilized ash or ash products may be incorporated into this permit to protect human health and the environment, as necessary.

3.17.2 Approval of Other Uses

Use of MWC ash as an industrial product ingredient or as an effective commercial product substitute are also valid ash utilizations (173-306-290(2)(c)). These uses do not require demonstration or class-use permits. Since the ash is being used in normal production processes and the MWC ash products are used in a similar manner to commercial products (for example, ash used as an aggregate substitute in cement construction blocks), this utilization is not considered to be waste management. To use ash in these applications, it must be shown that the ash or ash products closely resemble products or raw materials rather than waste.

The Department also considers the following factors prior to granting a request for use in a product or as a substitute for a product (173-306-40592)(c)(ii)):

- *Relative interests of the applicant, other property owners likely to be affected by the activity, and the general public; and*
- *Whether the ash handling practices or facility location protect public health, worker health, safety and the environment at least as well as the standard disposal.*

The results from two recent surveys conducted by ASTSWMO and SWANA provide additional information on the status of ash use and applicable regulations among the states.[188,189]

Information from the 1996 ASTSWMO survey revealed the following:

- Twenty-five states responded that they have formal requirements for recycling residues (including MWC ash)
- Eighteen states indicated they had no formal requirements, but responded that requests would be handled as follows:
  - Three states refer requests to the State Department of Transportation
  - Nine process approvals on a case-by-case basis
  - One state requires that approval first be obtained from the highway department
  - Two require evidence that the waste be not hazardous
  - Two require justification that the use is for beneficial purposes
  - One requires a case-by-case review by the jurisdictional health department
  - With respect to BUD, 21 states said they had no formal process, 17 do have one, and four states were in the process of developing BUD procedures.

The SWANA survey, also conducted in 1996, dealt specifically with MWC ash utilization and management.[189] Twenty-eight useful surveys were returned in which regulators identified 81 operating MWCs. These facilities generate slightly more than 4 million tons of ash each year. Following is a summary of the survey results:

- Twenty-six states (where all 81 facilities are located) require ash testing and recommend the TCLP in their regulations. However, nine states said that alternative testing methods were allowed as a substitute for the TCLP.

- Fourteen states require a combination of ash testing frequencies or periods; quarterly (14 states); as an operation permit requirement (13); annually (8); and at the disposal site to confirm that other materials have not been mixed with the ash (1).

- Twenty-one states require each MWC facility to develop an ash management plan.

- Twenty states allow ash utilization; seven states do not use the ash. Regulatory requirements varied, but included conducting a pilot program, conducting a research and development project, peer review of pilot study results, etc. Ash as daily cover at a landfill was the most prevalent use, although use as asphalt aggregate and concrete were also indicated.

- Many states had requirements for transporting the ash. These varied among the states but included covering the ash during transporting, wetting the ash, requiring leak tight trucks, washing the trucks after hauling the ash, etc.

- The predominant ash disposal method was in an ash monofill. The liner requirements varied among the states but most use composite or double composite liner systems. Although many states allow codisposal, the trend is toward requiring disposal into ash monofills.

The survey also included information provided by each facility responding on their ash management practices, including treatment, use, testing and other factors. Readers are referred to the survey for this additional information.

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13. ABSTRACT *(Maximum 200 words)* This document summarizes information from worldwide sources on the beneficial use of residues from the combustion of municipal solid waste. The information presented, including results of numerous research projects, field demonstrations, and actual full-scale projects, demonstrates that the ash can be safely used. It includes data on ash characteristics, environmental considerations, guidance on selected ash use applications, and information on federal and state regulations and policies affecting ash use.

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