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**THE POTENTIAL FOR USE OF
WASTE-TO-ENERGY FACILITY ASH
EXECUTIVE SUMMARY**

Final Report

Prepared for

**THE NEW YORK STATE
ENERGY RESEARCH AND DEVELOPMENT AUTHORITY**

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Town of Brookhaven
Town of East Hampton
Town of Huntington
Town of Islip
Town of Riverhead
Town of Shelter Island
Town of Smithtown
Town of Southampton
Town of Southold**

**EXECUTIVE SUMMARY
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Section 1

INTRODUCTION

This executive summary presents an overview of the investigations, findings, conclusions, and recommendations of the Long Island Regional Planning Board (LIRPB) study of the Potential for Beneficial Use of Waste-to-Energy Facility Ash.

This report is the product of more than six years of planning, investigation, report preparation, and peer review by an international group of experts. The full report consists of the following volumes:

Executive Summary

Volume 1: Long Island Ash Management Status

Volume 2: Sampling and Testing Procedures

Volume 3: Environmental Properties

Volume 4: Engineering Properties

Volume 5: Environmental Assessment

Volume 6: Engineering and Economic Evaluation

Volume 7: Legal and Institutional Issues

Volumes one through seven are briefly summarized in this executive summary with the exception of Volume 2 of the report, which serves as the documentation of the sampling conditions and testing methods used in measuring chemical and physical properties of the ash tested.

In 1983, out of concern for the sole source aquifer of Nassau and Suffolk counties, and anticipating widespread reliance on waste-to-energy technology as a substitute for landfilling, New York State enacted the Long Island Landfill Law. This law banned the burial of municipal solid waste (MSW) other than construction and demolition debris after December 1990. The law allowed burial of ash and down-time by-pass, but only within a limited area outside the deep recharge hydrogeologic zones.

However, by the mid-1980s, most of Long Island's 13 towns and two small cities were facing or about to face a municipal solid waste disposal crisis. With two small combustors on line and others under construction or in advanced planning, municipal inability to site and construct ashfills or to arrange for off-island residue disposal at reasonable cost became a major impediment to facility permitting and cost-effective waste management. When a New York State-sponsored effort to site and develop a single regional ashfill to serve the bi-county area failed, the Executive Director of the LIRPB was asked to obtain the participation and support of the two counties and the major municipalities in a New York State Energy Research and Development Authority (Energy Authority) sponsored and co-funded program to demonstrate the feasibility of the use of incinerator ash as a substitute for natural aggregate in construction applications.

The goal of the first phase of the program has been the identification and preliminary evaluation of beneficial uses or recycling opportunities that could reduce the quantity of ash requiring disposal and the associated costs; could help conserve Long Island's limited existing and potential ashfill capacity; and incidentally could decrease the need for "imported" natural aggregate.

The investigation was designed to provide the information needed to permit an assessment of the feasibility of ash recycling from environmental, engineering, economic, and institutional perspectives. This required the identification of the chemical and physical properties of the ash, an evaluation of the potential environmental, engineering, and economic issues associated with ash recycling, and an examination of the regulatory and legal issues.

A comprehensive ash sampling and testing program was implemented. This included testing of both the chemical and physical properties of ash collected from five waste-to-energy facilities. Chemical testing included examination of the inorganic elemental properties of each ash type collected, and examination of dioxins, furans, chlorobenzenes, and chlorophenols that might be contained in ash. In addition to the leaching tests used to classify the residues as hazardous or non-hazardous, samples of the ash were subjected to an additional series of leaching tests designed to simulate the expected field behavior of ash.

Physical testing included a series of analyses to compare and classify ash relative to natural aggregate and soil materials and typical engineering specifications.

To identify the significance and potential environmental and health risks associated with ash recycling activities, a comprehensive environmental assessment was prepared. This included an examination of the chemical and physical properties of combined ash, fly ash, and bottom ash; potential emissions or discharges resulting from ash recycling operations; and the impacts of these discharges on ambient air, soil, groundwater (or surface water), worker health, and indoor environment.

An engineering and economic evaluation of ash recycling technologies was undertaken that included identification of the capital and operating requirements associated with ash recycling, as well as examination of the costs and potential cost savings associated with ash use.

Finally, regulatory and legal issues associated with ash recycling were identified and analyzed to identify institutional issues requiring additional attention.

The executive summary attempts to distill the vast amount of information contained in the separate volumes of the full report. The final section of the executive summary presents a brief discussion of major conclusions and recommendations.

Section 2

LONG ISLAND ASH MANAGEMENT STATUS

The combustion of MSW in modern waste-to-energy facilities is an integral part of a comprehensive waste management strategy on Long Island. On average, the process achieves a 70 to 75 percent reduction in weight and an approximately 90 percent reduction in volume, leaving a residue requiring use or disposal. However, it is and is expected to remain the best available option for ensuring proper management of the nonrecyclable fraction of the more than three million tons of solid waste generated each year by some 2.7 million residents and by business and industry. Volume 1 presents a more detailed description of solid waste, waste-to-energy, and ash management programs on Long Island.

Like much of the Northeast and the states of Florida and Minnesota, Long Island currently combusts a significant portion of its waste stream. The 1992 figures obtained from local officials and from the New York State Department of Environmental Conservation (NYSDEC) indicate that even with State-mandated municipal recycling and with increased composting of yard waste, some 1.6 million tons of MSW -- the equivalent of 54 percent of the locally generated solid waste stream -- was combusted at the five operating waste-to-energy facilities on Long Island at Hempstead, Long Beach, Babylon, Huntington and Islip.¹ As indicated in Figure 2-1, some 23 percent of the waste stream was collected for recycling, and another 23 percent was composted, landfilled, or shipped off the island.

The sense of crisis that characterized Long Island solid waste disposal and ash management planning at the inception of this program has lessened, at least temporarily. This is due primarily to a reduction in the quantity of MSW currently requiring local disposal. A deepening recession exacerbated by post-cold war cutbacks in defense spending led to a decrease in non-residential and total solid waste generation. At the same time, plummeting off-island tipping fees encouraged export, thus further reducing the tonnage of MSW requiring local disposal.

1. No MSW was combusted at Glen Cove in 1992 since the facility was temporarily shut down for retrofitting.

Figure 2-1: Long Island Municipal Solid Waste Stream (1992)

In addition, during the past few years, several municipalities -- confronted with siting controversies, the high capital cost of waste-to-energy facilities, and the hope that increased recycling and composting could obviate or drastically reduce the need for combustion -- decided to delay or completely abandon planned or proposed construction of waste-to-energy facilities. Since residue generation is directly related to facility operating capacity and percent use, the last minute cancellation of planned construction in North Hempstead and Oyster Bay and the decision not to proceed with planning for a facility in Brookhaven or a second facility in Islip have reduced the potential amount of residue that requires or could eventually require use or disposal.

Long Island's existing combustion capacity appears to be sufficient for its immediate needs. The relatively recent development of intermunicipal combustion and ash disposal agreements, together with the construction of two ashfills and the implementation of a multi-year demonstration of ash use in landfill capping have transformed an immediate solid waste and ash management crisis into a future problem.

Long Island now has six mass burn facilities with a total nameplate or design capacity of 4,787 tons per day (tpd). As indicated in Table 2-1, future expansions, if required, could add another 1,500 tpd, half of it at Hempstead and the remainder at Babylon and Huntington.

Since the quantity of ash produced can be expected to be between 25 and 30 percent, by wet weight, of the MSW processed, Long Island waste-to-energy facilities can be expected to generate between 463,000 and 566,000 tons of ash per year when all six facilities are operating at full capacity. The above estimate represents ash prior to ferrous removal, which can further reduce the quantity of ash requiring use or disposal by some 10 to 15 percent. Bottom ash constitutes approximately 85 percent of the residue, with fly ash accounting for the remainder. Long Island presently produces between five and six percent of the nine million tons of ash generated nationwide.

Although existing waste-to-energy capacity now appears sufficient for bi-county needs, it is likely that in the long run improved economic conditions, enforceable flow control, limitations

<p align="center">Table 2-1</p> <p align="center">LONG ISLAND WASTE-TO-ENERGY FACILITIES, 1993</p> <p align="center">RATED CAPACITY AND FUTURE EXPANSION POTENTIAL</p> <p align="center">(tons per day)</p>						
Municipality	Rated Capacity 1993	Expansion Potential	Maximum Possible Capacity	Air Pollution Control Equipment		
				ESP	Scrubber	Baghouse
Glen Cove ¹	250	--	250	♦		
Hempstead	2,319	750	3,069		♦	♦
Long Beach	200	--	200	♦		
Babylon	750	375	1,125		♦	♦
Huntington/Smithtown	750	375	1,125		♦	♦
Islip	518	--	518		♦	♦
Total	4,787	1,500	6,287			
<p>1. Temporarily undergoing renovation; expected to resume operations in 1993.</p>						

on the import of out-of-state waste, or glutted markets for some of the materials collected for recycling may necessitate the expansion of one or more of the existing facilities. Any expansion will result in a proportionate increase in the amount of residue necessitating use or disposal.

The LIRPB has developed estimates of current and future ash production predicated on the assumption that, on an average daily or annual basis, the tonnage of solid waste combusted will equal the permitted operating capacity of the nameplate or rated capacity of the facility, whichever is greater; and that whatever capacity is not used by the host community will be used to combust MSW or by-pass from other localities, or commercial and industrial waste collected by private carters throughout the bi-county (Nassau and Suffolk) area.

Two scenarios were considered. The first or current ash generation scenario assumed continuation of current commercial/industrial waste generation levels and opportunities for inexpensive off-island waste disposal. The second or future ash production scenario assumed increased waste generation and/or loss of off-island disposal options, followed by projected expansion of bi-county waste-to-energy capacity.

Today, the region has sufficient existing or potential ashfill space to accommodate residue from all its waste-to-energy facilities. With the four larger plants sending ash to the Babylon and Brookhaven landfills and the smaller ones exporting their residue, ash disposal appears to be a manageable problem, at least for the next few years. Near term -- that is, within the next five to seven years -- the bi-county area is not likely to encounter an ash disposal crisis, assuming that the permitting and construction of planned disposal capacity proceed in a timely fashion.

Calculations of the estimated time to exhaustion of Long Island ashfill capacity are presented in Table 2-2 for the current ash generation scenario and for different levels of diversion for beneficial use. Similar calculations for the second or future ash production scenarios are presented in Volume 1.

Long term, there is likely to be a significant imbalance between ash generation and local ashfill capacity. The exhaustion of the bi-county area's finite disposal capacity or the establishment of legal or economic barriers to export, or both, can be expected to make beneficial use not only desirable but essential.

Table 2-2 APPROXIMATE TIME TO EXHAUSTION OF ASHFILL CAPACITY (years)		
Percent of Ash Diverted for Beneficial Use ¹	Babylon ²	Brookhaven ³
0	6.8	17.9
10	7.2	19.6
25	7.9	22.9
50	9.6	33.7
¹ . Assumes diversion begins by the end of 1997. ² . Assumes Babylon receives ash from Huntington, Islip, and Babylon facilities. ³ . Assumes Brookhaven receives ash from Hempstead facility only.		

There are numerous potential markets for ash as a substitute for natural aggregate. Ash can be used either alone or as a component of fill material, bituminous concrete, or Portland cement concrete. It can also be used as landfill cover, and in construction applications, in artificial reefs, shore protection, and dune restoration. Although the mandated cessation of landfilling in Nassau and Suffolk counties has reduced the local market for ash as daily cover, recent changes in 6 NYCRR Part 360 are expected to facilitate the use of ash in capping or final closure of as-yet uncapped landfills.

Section 3

MUNICIPAL WASTE COMBUSTOR ASH AND ASH RECYCLING

Municipal waste combustors at modern mass burn waste-to-energy facilities in the United States generate nearly nine million tons of ash annually, the residue from burning 35 million tons of trash. The ash generated at modern waste-to-energy facilities is a composite of different residues collected at several locations within the facility. Figure 3-1, which depicts a cross section of a typical waste-to-energy facility, identifies five separate collection points and their corresponding ash streams. These ash streams include

- Grate ash (GA);
- Siftings (S);
- Boiler ash (BLA);
- Scrubber ash (SA); and
- Precipitator ash (PA) or baghouse ash (BHA).

Typically, where residue disposal rather than use is contemplated, all of the separate ash streams are collected and combined prior to discharge from the facility. The combination of all of these ash streams is referred to as combined ash (CA). The term bottom ash (BA) is commonly used to refer to the grate ash, siftings and boiler ash streams. The term fly ash (FA) is used to refer to ash discharged from the air pollution control system such as scrubber ash and precipitator or baghouse ash streams.

Grate ash is the ash fraction that remains on the stoker or grate at the completion of the combustion cycle. It is similar in appearance to a grayish, silty sand with gravel, with small amounts of unburnt organic material and chunks of metal. The grate ash stream consists primarily of glass, ceramics, ferrous and non-ferrous metals, and minerals. It comprises approximately 85 percent of the total ash stream.

Figure 3-1
Mass Burn Waste-to-Energy Facility
Typical Cross Section and Ash Streams

The siftings component is the ash fraction that falls through the grate during the combustion process and is subsequently recombined with the bottom ash. It is similar to grate ash; however, it is limited in top size by the openings in the grate. It constitutes less than 10 percent of the total combined ash stream.

Boiler ash, scrubber ash, and precipitator or baghouse ash consist of particulates originating in the primary combustion zone area that are subsequently entrained in the combustion gas stream and carried into the boiler and air pollution control system. As the combustion gas passes through the boiler, scrubber, and precipitator or baghouse, the entrained particulates are extracted. Extraction mechanisms in the boiler and scrubber are gravitational (i.e., settling, agglomeration, particle impingement on heat transfer surfaces); electrical (i.e., charged particle attraction by means of an electrostatic precipitator), and filtering (i.e., collection on baghouse fabric) mechanisms. The ash extracted from the combustion gas consists of very fine particles, with a significant fraction measuring less than 100 microns in diameter.

The boiler ash stream has a grayish, powdery appearance. The gray color is believed to be due to the presence of organic matter in the fine particles. In certain facilities, boiler ash can be further segregated into ash fractions that are collected in different zones in the boiler (e.g., superheater ash, economizer ash, and convection zone ash). Generally, the boiler ash comprises approximately two to three percent of the total combined ash stream.

The scrubber and baghouse streams have a white, powdery appearance. The scrubber ash usually comprises less than one percent of the total combined ash stream. The white color results from the addition of lime in the scrubber. The baghouse or precipitator ash comprises approximately 15 percent of the total combined ash stream.

Each waste-to-energy facility has individual design and operating features that may modify the characteristics of the ash streams to some degree. However, in well-operated modern mass burn facilities with similar air pollution control and ash handling equipment, such differences are not expected to have a significant effect on the environmental and engineering properties of the ash or its potential for beneficial use.

There are significant differences, however, between ash generated at modern waste-to-energy facilities and that generated at older facilities. Newer facilities, with improved furnace designs, generally achieve better burnout and have reduced organic content in the ash product. In newer facilities, the introduction of lime or a lime-based reagent into the pollution control system for the purpose of reacting with and scrubbing out acid gases from the combustion gas stream produces a fly ash that contains both reacted and unreacted lime. Older facilities without acid gas scrubbing do not have lime in their fly ash. Finally, newer facilities with improved air pollution control equipment more efficiently capture the finer particulate materials and trace contaminants, which many of the older facilities release into the air. In the future, it also is likely that more stringent air pollution control requirements (e.g., mercury and NO_x control) may alter both the physical and chemical properties of fly ash streams.

The residues produced at refuse-derived fuel (RDF) facilities, where the incoming municipal solid waste stream is shredded and presorted to remove ferrous metal and in certain cases non-ferrous metal prior to combustion, also can be expected to have differing physical and chemical properties from residues generated at mass burn facilities.

Regardless of the type of waste-to-energy facility, once the ferrous metal is removed from either combined or bottom ash and the ash is screened and/or crushed to size fractions of approximately 1/2-inch or less, the ash fraction displays characteristics that are similar in many ways to sand and stone products commonly used in construction applications.

Municipal waste combustor ash recycling involves activities in which the ash generated from municipal waste combustors is used as a substitute aggregate material in construction applications. At the present time in the United States, almost all of the nine million tons of ash produced annually is landfilled, in sharp contrast to European practice. In some European nations (e.g., The Netherlands and Denmark) more than one-half of the bottom ash generated by municipal waste combustors is used in construction applications. Lesser percentages are used in West Germany and France. Applications in which ash use has been proposed are presented in Figure 3-2. In Europe the most common application is the use of ash as a road base material.

Figure 3-2
Potential Ash Recycling Applications

The recent interest in municipal waste combustor ash use in this country is comparable to earlier interest in the use of residues from coal combustion facilities as a construction material. Coal ash is now included in many construction material specifications. In the United States, of the approximately 80-90 million tons of ash produced by coal-fired power plants each year, approximately 20 to 25 million tons are being used.

Section 4

CHEMICAL AND ENVIRONMENTAL PROPERTIES OF MSW COMBUSTOR ASH

From an environmental perspective, the relevant chemical properties of MSW combustor ash are those that have the potential to produce an adverse impact on air, water, or land environments. Chemical properties of interest are the inorganic and organic components of the various ash streams, their leaching characteristics, and potentially volatile constituents. Table 4-1 presents a listing of the tests that were used to characterize the ash in this program.

In general, major constituents in MSW combustor ash, i.e., elements found in concentrations greater than one percent (10,000 micrograms per gram [$\mu\text{g/g}$]) on a dry weight basis (dwb), include aluminum (Al), calcium (Ca), iron (Fe), silicon (Si), potassium (K), sodium (Na), and magnesium (Mg). From an environmental perspective, characteristics of the major constituents that are of greatest interest are their solubilities in water, the hydration reactions in which they become involved, and the complexes they may form with other constituents.

Inorganic minor elements, found in concentrations of less than one percent dwb, include arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), manganese (Mn), nickel (Ni), selenium (Se), silver (Ag), and zinc (Zn). From an environmental perspective, characteristics of these constituents that are of greatest interest are their toxicity or potential carcinogenicity, and the potential for release of these inorganic components into the environment at concentrations that could result in adverse environmental or human health impacts.

A comparison was made of the reported concentrations of major and minor constituents in samples collected at each of the five waste-to-energy facilities and from data reported in recent studies undertaken by the U.S. Environmental Protection Agency (U.S. EPA), Environment Canada, New York State, and the University of New Hampshire, as reported in Volume 5.

With the exception of calcium concentrations in fly ash and combined ash, data for most of the major and minor elements were in reasonable agreement for the five facilities and the studies cited. Facilities using dry scrubber air pollution technology have

Table 4-1 CHEMICAL TESTING PROGRAM	
Test Category	Test
Elemental Characterization	Group 1: Metals - Al, As, Ba, Cd, Cr, Cu, Fe, Pb, Hg, Mn, Ni, Se, Ag, Zn
	Group 2: Metals and anions - Ca, K, Mg, Na, Si, Cl, SO ₄ ⁻
Organic Characterization	Polychlorinated-p-dibenzodioxins
	Polychlorinated dibenzofurans
	Chlorophenols
	Chlorobenzenes
Leaching Behavior	Acetic Acid pH 5 Leaching Procedure
	Acetic Acid pH 2.8 Leaching Procedure
	Deionized Distilled Water (DIDW)
	Synthetic Acid Rain (SAR)
	Cascade DIDW
	Cascade SAR
	Sequential Chemical Extraction

higher concentrations of calcium in their fly ash and, as a result, in their combined ash. Table 4-2 presents the expected concentrations of both major and minor constituents associated with MSW combustor ash. The data suggest that for many elements (i.e., As, Cd, Hg, Pb, antimony [Sb], boron [B], cobalt [Co], Zn), concentrations are enriched in the fly ash fraction.

MSW combustor ash from modern waste-to-energy facilities contains a relatively small organic fraction (i.e., approximately five percent dwb). This fraction is typically reported as loss on ignition and is commonly used to indicate the combustion efficiency within a waste-to-energy plant. Of the various organic compounds that have been identified as trace components of MSW combustor ash, the polychlorinated-p-dibenzodioxins (PCDDs) and the polychlorinated dibenzofurans (PCDFs) have received the most attention. This is because of the toxicity and carcinogenicity of certain isomers of these two series of chlorinated hydrocarbons reported in animal studies. Results of this study as well as those of other investigations undertaken by U.S. EPA and Environment Canada, reported in Volume 5, have shown PCDDs and PCDFs in modern waste-to-energy facilities to be primarily associated with the fly ash fraction.

Table 4-2
EXPECTED ELEMENTAL CONCENTRATIONS
IN MSW COMBUSTOR ASH FRACTIONS

(mg/kg, dwb)

Element	FA ¹	CA/BA ²
Al	52,000	48,000
Ca	110,000 ³	61,000
Fe	21,000	51,000
K	15,000	8,500
Mg	11,000	11,000
Na	21,000	31,000
Si	84,000	160,000
Ag	3.2	12
As	100	29
Ba	500	880
Cd	260	48 ⁴
Cr	140	320
Cu	1,100	1,800
Hg	22	2
Mn	750	910
Ni	71	90
Pb	4,000	2,500 ⁵
Se	2.2	3.4
Sb	350	120
B	230	85
Co	120	29
Zn	12,000	4,700

1. FA represents the fly ash stream.
2. CA / BA represents the combined ash and the bottom ash stream.
3. Concentration represents Ca levels from facilities with dry scrubber technology for acid gas control. Ca concentrations from facilities with only electrostatic precipitator air pollution control technology can be expected to be approximately 20% lower.
4. Concentration is associated with combined ash. The bottom ash concentration can be expected to be approximately 33% of this value.
5. Pb concentration in bottom ash can be expected to be approximately 20% lower than this value.

Comparative data on these compounds are usually reported in terms of the total concentration of all dioxins and furans with four or more chlorine atoms per molecule and the concentration of "toxic equivalents." Toxic equivalents are calculated by using weighting factors based on the relative toxicity of each of the many dioxin and furan isomers as compared to the most toxic, 2,3,7,8-tetrachloro-p-dibenzodioxin (TCDD).

The Centers for Disease Control (CDC) regards a one part per billion (ppb) toxic equivalent concentration as the threshold level in assessing the hazardous or non-hazardous nature of residential soils. In this study, all bottom ash samples were below detection limits, combined ash samples ranged from below detection limit to 0.9 ppb, and fly ash samples ranged from below detection limits to 18.0 ppb. Examination of finer fly ash fractions suggests the possibility of PCDD and PCDF enrichment in these finer particles.

The data obtained in this study indicate that the primary concern associated with leaching from MSW combustor ash is that associated with the inorganic constituents. Major elemental leaching manifests itself in the form of a high total dissolved solids (TDS) content in the extraction fluid. The results of minor elemental leaching tests reveal that a significant fraction of most trace metals is unavailable for leaching under simulated field conditions. However, under acidic conditions, lead and cadmium are more readily available, and lead is also more readily available under extreme alkaline conditions.

The leaching evaluation also demonstrated that while particle size distribution and metal speciation are important factors in determining trace metal availability for leaching, the pH of the final liquid medium is, in most cases, the controlling variable in determining the extent of metal release. In general, the data show that trace metals are more soluble under acidic conditions and less soluble under neutral or alkaline conditions.

Results of the regulatory leaching tests, Extraction Procedure (EP) Toxicity and Toxic Characteristic Leaching Procedure (TCLP), reveal that fly ash releases trace metals to a greater extent than bottom ash and, on occasion, metal concentrations will exceed the regulatory threshold for both lead and cadmium. Bottom ash leachate concentrations for lead and cadmium are significantly lower and rarely reach regulatory limits. For the most part,

concentrations of lead and cadmium found in regulatory test extracts are primarily a function of the alkalinity of the ash and the final pH of the extractant, and only secondarily dependent on the lead and cadmium content of the ash.

Section 5

PHYSICAL AND ENGINEERING PROPERTIES

Properly processed municipal combustor ash has physical and engineering properties that are comparable to a lightweight, silty and gravelly sand with traces of organic matter.

The physical properties testing program comprised a series of tests designed to permit a comparison of the engineering characteristics of ash and of natural aggregate. Table 5-1 lists the physical tests undertaken in this program.

Details on the physical testing of the ash are presented in Volume 4. On the basis of this testing, the characteristics of screened, ferrous-free ash can be described in geotechnical terms as follows:

Ash is a grayish, lightweight silty sand and gravelly mixture with traces of organic matter; in the minus 2-inch fraction approximately 40 percent consists of angular particles that are greater than the No. 4 sieve (4.76 mm), and approximately 16 percent is greater than 1/2-inch; about 10 to 15 percent of the mixture consists of non-plastic fines; it is a cohesionless material but exhibits apparent cohesion when wet; the fines exhibit weak pozzolanic properties and hydration reactions with salts contained in the material can be expected to cause some swelling or expansion; the combined ash fraction contains approximately 3 to 5 percent lime.

Additional processing, such as ash melting, sometimes referred to as vitrification, can further enhance potential engineering properties of the material. Quenched vitrified ash is a lightweight slag, ceramic, or frit-type product. This material is more like a sandy, gravelly mixture with low absorption characteristics.

Based on examination of the engineering property test data generated in this study, ferrous-free, minus 1/2-inch incinerator ash can be classified as an artificial aggregate material, and could be used as a substitute for natural aggregate in construction applications. Ash, however,

Table 5-1
PHYSICAL TESTING PROGRAM

Test Category	Test	Method
Composition Characterization	Moisture Content	ASTM D2216-80
	Organic Content	ASTM D2974-87
	Visual Classification	-
Gradation Characterization	Sieve analysis for fine and coarse aggregates	ASTM C117-87 & ASTM C136-84A
Durability Characterization	Magnesium sulfate soundness of aggregates	ASTM C88-76
	Los Angeles Abrasion Test	ASTM C131-81
	Breakdown in sizes of graded aggregates	NJDOT Method A 8
	Clay lumps and friable particles	ASTM C142-78
Field Gravimetric Characterization	Moisture-Density Test	ASTM D1557-78
	Specific gravity & absorption of coarse aggregates	ASTM C127-81
	Specific gravity & absorption of fine aggregates	ASTM C128-79
	Unit weight and voids	ASTM C29-87
	Bulk density	-
Variable Properties	Swelling properties	-
	Strength development	-
	Water soluble fraction	-
Soil Classification	Liquid limit, plastic limit and plasticity index of soils	ASTM D4318-84
	Classification of soils for engineering purposes	ASTM D2487-85

has certain properties that could negatively affect its behavior in engineering applications. These properties include:

- High fines content;
- High moisture content;
- High organic content;
- High glass content;

- Marginal durability;
- High absorption rates;
- Swelling properties;
- Weak cementitious properties of scrubber ash; and
- High salt content.

Table 5-2 contains a summary of the problems from an engineering perspective associated with each of the properties listed and measures that could be used to offset these deficiencies.

Two basic engineering applications in which ash could be used are: 1) as an unbound aggregate material (i.e., fill or road base), or 2) in bound applications such as bituminous concrete (i.e., road paving) or Portland cement (i.e., ready mix, block, or paving stone). For almost all of these applications, ash will have to be blended with other materials to achieve characteristics that will ensure its compliance with existing specifications. The exact mix design will depend on the particular application. Ash may be used as an unbound material alone or blended with other aggregate materials in amounts ranging from 50 to nearly 100 percent. For use in bituminous or Portland cement, blending rates generally range from 15 to 50 percent.¹

From an engineering perspective, the grate or bottom ash fraction is a more suitable aggregate material than combined ash. It has a lower fines content; lower percent absorption; is less susceptible to swelling;² will not produce cementitious reactions, since it does not contain fly ash and lime; and contains less water-soluble material.

-
1. Blending rate refers to the percentage of ash, by weight, in the product.
 2. Fly ash from waste-to-energy facilities with acid-gas air-pollution control systems contains calcium oxide that is reactive. Laboratory studies have shown that swelling may be a particular problem in Portland cement products made with fly ash containing unreacted lime.

Table 5-2**SUMMARY LISTING OF ENGINEERING CONCERNS****ASSOCIATED WITH THE PHYSICAL****CHARACTERISTICS OF ASH**

Characteristics	Concern	Corrective Measure(s)
1. High Fines Content	Minus 200 sieve too high for use as an unbound aggregate, in bituminous or Portland cement applications	Blend with other natural aggregate materials; use coarser bottom ash fraction; further process ash into straight sized aggregates
2. High Moisture Content	Too high for use in bituminous or Portland cement application	Dry ash or blend with drier aggregate materials
3. High Organic Content	Too high for use in Portland cement aggregate applications as measured by organic impurities	Blend with other aggregates; remove residual organic matter
4. High Glass Content	Potential difficulty in asphalt paving applications (i.e., stripping, stability); alkali-silica reactions with Portland cement	Blend with other aggregates; add anti-stripping agents; use low-alkali cements
5. Marginal Durability	May not pass existing coarse aggregate specifications	Blend with other aggregates; use only as fine aggregate substitute
6. High Absorption Rates	Frost susceptible in unbound applications; high asphalt cement demand in bituminous concrete applications, difficulty in managing moisture content in Portland cement concrete applications	Blend with other materials; place above groundwater level in unbound applications; consider use of absorption-resistant additive
7. Swelling Properties	Volumetric expansion with time; potential dimensional instability in aggregate or final Portland cement or bituminous cement products	Store ash to permit hydration reactions to complete; use bottom ash - less susceptible than combined ash; consider ash washing prior to use
8. Weak Cementitious Properties of Scrubber Ash	Cementitious reactions alter properties of materials; stockpile and storage problems due to cementing of particles	Use bottom ash without scrubber and baghouse or precipitator ash
9. High Salts Content	Salts could potentially inhibit Portland cement reactions; potential efflorescences in final products; anticipated swelling due to salt (see Swelling Properties); leaching of salts could result in metal corrosion problems	Use of bottom ash only reduces water-soluble component; for corrosive problem avoid use in unbound form above metal structure without proper cathodic protection; consider ash washing prior to use

Ash may not pass certain tests (e.g., durability) for existing aggregate specifications. It may, however, perform suitably in properly designed field applications. Therefore, the determination of the suitability of ash for use should be based on performance as well as aggregate properties. Field demonstrations will be required to evaluate the performance of ash in selected applications and to establish relevant design criteria and specifications for ash use.

Examination of physical test data, together with a review of previous bench-scale and field-demonstration data, indicate that from an engineering perspective ash could be designed into applications in such a manner that it would perform satisfactorily as a substitute for natural aggregate materials. These applications include use in:

- Daily landfill cover;
- Road base material;
- Miscellaneous fill;
- Bituminous concrete paving;
- Portland cement concrete ready mix;
- Portland cement concrete block;
- Artificial reef or erosion control structures; and
- Final landfill cover.

Section 6

ENVIRONMENTAL ASSESSMENT

The feasibility of substituting municipal solid waste (MSW) combustor ash for aggregate materials in construction applications in the United States depends on accumulating laboratory test data and, to an even greater extent, on acquiring persuasive real world or field evidence that potential environmental releases and consequent impacts to air, water and land resources associated with ash use can be managed and will not be significant.

A generic environmental assessment of MSW combustor ash use technologies was undertaken to identify the significance of potential impacts resulting from environmental releases due to the use of MSW ash in construction applications and to assist in determining whether ash use activities are environmentally acceptable.

Environmental releases include the solid or particulate emissions and gaseous or liquid discharges that may occur as a result of the processing, storage, or use of ash in the manufacture of a product, as a consequence of wear or exposure during product use, and as a result of product disposal or recycling at the end of its service life.

Aggregates or substitute aggregate materials are typically subjected to a series of operations during their preparation and use as construction material. Many of these operations, including aggregate screening, conveying, loading, unloading, spreading, compacting, or drying, can result in the release of particulate matter into the air. Airborne particulate releases also can result from wind erosion of the storage piles. The release of particulates or dust into the air can affect the quality of the ambient air environment, worker air environment, and adjacent soils.

In addition to the airborne transport of particulates, both the soluble and insoluble fraction of ash particles can be released to groundwater and surface water by means of rainfall and subsequent runoff or leaching from aggregate storage piles. Runoff or leachate can affect the quality of groundwater and surface water.

Products incorporating aggregates, such as concrete building materials used in structures or roadways, can abrade and erode, resulting in the release of aggregate materials into the immediate environment. Finally, at the completion of the useful product life, the aggregate product may be recycled or discarded. As a result of these activities, emissions or discharges from the product may be released into the environment.

Since MSW combustor ash contains higher concentrations of some trace metals and trace organics than natural aggregate materials, the environmental and health impacts of ash particles or ash-product releases into the environment warrant close examination for potential adverse impacts. Such impacts can occur if emissions or discharges resulting from ash use release contaminants in sufficient concentrations so that impacts to air, water or soils exceed levels considered protective of human health and the environment.

The general approach used in the assessment involved the quantification of potential environmental releases and the projection of their impact on the ambient environment using emission exposure modeling, wherever possible. The results of these analyses were used to estimate the significance of these impacts based on a comparison of the increases in ambient levels of particulates or chemicals and allowable standards or guidelines established by federal agencies (i.e., U.S. EPA, Occupational Safety and Health Administration (OSHA) or U.S. Housing and Development Agency) or state agencies (i.e., New York or New Jersey) for concentrations in air, water, soil, the workplace, or the indoor environment.

Two sets of regulatory criteria were used. Primary pollutant criteria consist of established federal or state standards or other legal limits for a given constituent in a given environmental medium. Secondary pollutant criteria consist of federal or state guidelines or proposed standards for a given constituent in a given medium.

Early on in the course of the assessment it became apparent that limited field data were available on environmental releases associated with ash use activities and operations. This meant that much of the assessment had to be based on laboratory data generated during the course of the investigation, supplemented by available laboratory data from other reliable sources and field data from operations involving materials such as sand and gravel, which

behave similarly to MSW combustor ash in some respects.

Due to the scarcity of field data, conservative assumptions, hypothetical conditions, and evaluation methodologies were selected in an attempt to overstate rather than understate potential environmental impacts. As a result, it is likely that the assumptions and the resulting conclusions and recommendations may be overly or unnecessarily restrictive and may adversely affect near-term opportunities for beneficial use. However, until there are a number of carefully monitored demonstrations and a credible body of data documenting the actual field behavior of ash, reliance on conservative scenarios is environmentally responsible and appropriate.

Volume 5 presents a detailed description of the procedures used and the results and conclusions of the environmental assessment. Specific ash use technologies examined in the assessment were divided into three general categories: low-, medium-, and high-technology recycling applications.

In low-technology applications, minimal processing is required. The ash is screened and ferrous metal is removed to produce an unbound aggregate material for use in construction applications. Low-technology ash recycling applications include the use of ash as a miscellaneous fill, road base, or landfill cover material.

Medium-technology applications require additional processing in that the screened, ferrous-free ash is mixed with either a bituminous cement, Portland cement, or other binder material to produce a solidified or stabilized product in which the ash is encapsulated and/or treated to reduce its contact with external elements and/or its leachability. Medium-technology applications include the use of ash in bituminous concrete, Portland cement concrete, or stabilized fill (e.g., soil cement) applications.

High-technology applications refer to processes designed to significantly modify and improve physical and chemical properties of raw ash material prior to use. Ash melting or vitrification, and heavy metal extraction technologies are examples of high-technology applications.

Tables 6-1 through 6-4 present a brief outline of the results of the assessment. Each table highlights the major environmental issues with regard to ambient air, soils, groundwater, worker health, and indoor environmental quality. The following activities and technology applications were included in the assessment:

- Processing, Storage, and Blending Activities;
- Low-Technology Applications:
 - Road Base Material,
 - Landfill Cover Material, and
 - Miscellaneous Fill Material;
- Medium-Technology Applications:
 - Bituminous Concrete,
 - Portland Cement Concrete, and
 - Stabilized Fill; and
- High-Technology Applications:
 - Vitrification, and
 - Heavy Metal Extraction.

In certain instances, estimates indicate the level of activity; that is, the quantity or rate of ash processing, handling, or use above which impacts could be significant. These estimates are presented to emphasize the difference between small and large operations in respect to their potential for impacting ambient air, soils, groundwater, worker health, and the indoor environment, and to call attention to the possible need for mitigating measures.

Table 6-1 summarizes the results associated with processing, storage and blending operations. Any use of ash will involve some screening, storage, and blending activities. These operations constitute a potential source of environmental releases and consequent impacts. Unless equipped with runoff, leachate, or dust emission controls, storage and blending represent the ash use activities with the greatest potential for environmental impacts.

Table 6-1

**PROCESSING, STORAGE AND BLENDING ACTIVITIES
SUMMARIZED CONCLUSIONS**

Area of Concern	Main Environmental Issues	Mitigating Actions	Future Study
Air	<ul style="list-style-type: none"> Large uncontrolled operations greater than 300 to 400 tpd could increase local on-site total suspended particulate (TSP) dust concentrations and possibly impact local on-site air quality 	<ul style="list-style-type: none"> Process indoors with dust collection system Use dust suppressants Use moisture control Use bottom ash only 	<ul style="list-style-type: none"> Percentage of TSP and PM10 (<10μ particles) present in ash Trace metal and trace organic content in dust sized particles Fraction of Cr(VI) in ash Ash-specific emission factors
Soil	<ul style="list-style-type: none"> Large uncontrolled operations greater than 300 to 400 tpd could measurably increase local on-site particulate deposition and soil trace metal concentrations 		
Groundwater	<ul style="list-style-type: none"> Large uncontrolled operations on the order 2,000 to 4,000 tons using CA could impact Pb and TDS surface and groundwater concentrations in the immediate vicinity and downgradient of the site Large uncontrolled operations on the order 4,000 to 5,000 tons using BA could impact Pb and TDS surface and groundwater concentrations in the immediate vicinity of the site Large uncontrolled operations greater than 10,000 tons using BA could also impact groundwater Cd concentrations in the immediate vicinity of the site 	<ul style="list-style-type: none"> Perform operations in a controlled environment Place ash in enclosure or cover tarps Perform operations in non-sensitive groundwater areas Collect and treat runoff Control alkalinity of ash and pH of runoff and leachate 	<ul style="list-style-type: none"> Field runoff and leachate quality values
Worker Health	<ul style="list-style-type: none"> Large uncontrolled operations could generate fugitive dust emissions 	<ul style="list-style-type: none"> Ensure proper ventilation Use moisture control Provide personal dust protection 	<ul style="list-style-type: none"> Concentrations of fugitive dust in stockpile and processing environments Crystalline silica content of dust-sized particles
Indoor	<ul style="list-style-type: none"> Poor ventilation could increase dust concentrations to levels approaching U.S. Occupational Safety and Health Administration (OSHA) standards 	<ul style="list-style-type: none"> Ventilate areas Use dust controls Provide personal dust protection 	

Proper management of storage and blending operations, which could include suitably covered storage areas, runoff collection systems, moisture control, and/or the use of dust suppressants or medium-technology stabilization reagents, could assist in mitigating a large portion of the potential impacts associated with these operations. However, if the ash is permitted to dry and is handled in an uncontrolled manner, storage and blending of large quantities of ash could produce local fugitive dust problems. It is also likely that the trace metal content of soils adjacent to an uncontrolled storage and blending operation would increase as a result of ash deposition at these locations.

The outdoor accumulation or storage of large quantities of untreated ash in a single location for long periods of time could increase local groundwater salt and trace metal concentrations to levels that might exceed drinking water standards. This is of particular concern where there is rapid access to local groundwaters without the attenuating effect of percolation through overlying soil formations (e.g., fractured rock formations). Although operations involving combined ash generally pose a greater risk than those involving bottom ash, due to higher lead content and solubilities associated with the combined ash, the handling of large quantities of stockpiled bottom ash also has the potential to impact local groundwater.

Table 6-2 summarizes the results of the low-technology application assessment. For low-technology applications, the major issues are fugitive dust, runoff, and leachate associated with large-scale uncontrolled ash handling. These issues are similar in some respects to those associated with processing, storage, and blending site operations. The use of bottom ash in low-technology applications may be appropriate in areas where fugitive dust can be controlled, runoff or leachate containing high salt concentrations does not pose a problem, and neutral or slightly alkaline environmental conditions are ensured. Controlled environments, such as landfill sites and non-potable groundwater areas or coastal areas adjacent to brackish or marine waters, where the effects of low-technology leachate or runoff would be inconsequential, are suitable locations for low-technology bottom ash applications.

Table 6-3 summarizes the results of the medium-technology application assessment. Medium-technology applications using bottom ash as a substitute aggregate material can be designed to mitigate any significant dusting problems and reduce potential leachate contaminant

Table 6-2

**LOW TECHNOLOGY APPLICATIONS
SUMMARIZED CONCLUSIONS**

Area of Concern	Application	Main Environmental Issues	Mitigating Actions	Future Study
Air	Road Base	<ul style="list-style-type: none">· None envisioned where construction is limited to less than 1.5 lane-miles of construction per day· Any potential impacts in large construction operations would be of short duration	<ul style="list-style-type: none">· Use moisture control· Use dust suppressants	<ul style="list-style-type: none">· Percentage of TSP and PM10 present in ash· Trace metal and trace organic content in dust-sized particles· Fraction of Cr(VI) in ash· Ash-specific emission factors
	Landfill Cover	<ul style="list-style-type: none">· Operations on the order of 1000 TPD could potentially increase on-site TSP concentrations to levels that could impact local air quality		
	Miscellaneous Fill	<ul style="list-style-type: none">· Operations could produce localized TSP impacts		
Soil	Road Base	<ul style="list-style-type: none">· Construction operations could result in ash particulate loadings to adjacent soils, but the impact would be short-term and should not be significant	<ul style="list-style-type: none">· Use moisture control· Use dust suppressants	
	Landfill Cover	<ul style="list-style-type: none">· Operations could result in ash particulate loadings to adjacent soils on landfill site, but impact should be negligible		
	Miscellaneous Fill	<ul style="list-style-type: none">· Operations could increase particulate deposition to soils adjacent to activity		
Groundwater	Road Base	<ul style="list-style-type: none">· The use of CA in road base could generate a highly alkaline leachate with Pb concentrations that could potentially impact local groundwater· The use of BA and CA in road base in excess of 60-ft. in width could generate a relatively high TDS leachate concentration that could impact local groundwater· The use of BA in road base in excess of 60-ft. in width could generate Pb leachate concentrations that could potentially impact local groundwater in areas lacking the contaminant -attenuating benefits of overlying soil	<ul style="list-style-type: none">· Operations should occur in non -sensitive groundwater areas· Use only BA	<ul style="list-style-type: none">· Field runoff and leachate quality values

Table 6-2

(CONTINUED)

Area of Concern	Application	Main Environmental Issues	Mitigating Actions	Future Study
Groundwater	Landfill Cover	· Pb leachate concentrations associated with alkaline CA	<ul style="list-style-type: none"> · Place stored ash in enclosure or cover with tarps · Operations should occur in non-sensitive groundwater areas · Use BA only · Use CA only on lined landfills 	· Field runoff and leachate quality values
	Miscellaneous Fill	<ul style="list-style-type: none"> · Large uncontrolled operations using CA could impact the Pb and TDS groundwater concentrations in the immediate vicinity and downgradient of the site · Large uncontrolled operations using BA could impact the groundwater Pb, Cd, and TDS concentrations in the immediate vicinity 		
Worker Health	Road Base	· Large uncontrolled operations could generate fugitive dust emissions that could warrant the use of mitigating measures	<ul style="list-style-type: none"> · Use moisture control · Use dust suppressants · Provide personal dust protection 	· Crystalline silica content of dust-sized particles
	Landfill Cover	· Operations greater than 1,500 TPD could result in increased dust concentrations that would warrant the use of mitigating measures		
	Miscellaneous Fill	· Large uncontrolled operations could generate fugitive dust emissions that would warrant the use of mitigating measures		
Indoor	All Applications	· None envisioned	-	-

Table 6-3

**MEDIUM TECHNOLOGY APPLICATIONS
SUMMARIZED CONCLUSIONS**

Area of Concern	Application	Main Environmental Issues	Mitigating Actions	Future Study
Air	Asphalt Concrete	<ul style="list-style-type: none"> Production facility storage and blending issues are similar to those presented for the processing, storage, and blending activities in Table 6-1 Release of dust particles and volatile emissions 	<ul style="list-style-type: none"> Use moisture control Use dust suppressants Use pollution control equipment Maintain aggregate temperature control (less than 500°F) 	<ul style="list-style-type: none"> Percentage of TSP and PM10 present in ash Trace metal and trace organic content in dust-sized particles Fraction of Cr(VI) in ash Ash-specific emission factors
	Portland Cement Concrete	<ul style="list-style-type: none"> Production facility storage and blending issues are similar to those presented for the processing, storage, and blending activities in Table 6-1 	<ul style="list-style-type: none"> Use dust control equipment Use moisture control Use dust suppressants 	
	Stabilized fill	<ul style="list-style-type: none"> Operations could produce localized TSP impacts 	<ul style="list-style-type: none"> Use moisture control Use dust suppressants Use stabilizing agent with dust suppressing properties 	
Soil	Asphalt Concrete	<ul style="list-style-type: none"> Production facility storage and blending issues are similar to those presented for the processing, storage, and blending activities in Table 6-1 Utilization of ash products in applications subject to abrasion could result in particulate deposition and an increase in the trace metal concentrations of soil adjacent to the activity 	<ul style="list-style-type: none"> Mitigating measures for storage and blending issues are similar to those presented for the processing, storage, and blending activities in Table 6-1 Mitigating measures for the final product application include: <ul style="list-style-type: none"> use in subsurface applications use BA only use surface sealants limit % ash use in blend Mitigating measures for the milling or demolition include: <ul style="list-style-type: none"> use moisture control use dust suppressant 	<ul style="list-style-type: none"> Trace metal and trace organic content in dust-sized particles Ash-specific emission factors Rate of ash product abrasion
	Portland Cement Concrete	<ul style="list-style-type: none"> During concrete milling or demolition activities, particulate deposition could increase trace metal concentrations in soil adjacent to the activity 		
	Stabilized fill	<ul style="list-style-type: none"> Operations could increase particulate deposition on soils adjacent to the activity 	<ul style="list-style-type: none"> Use moisture control Use dust suppressants Use stabilizing agent with dust suppressing properties 	

**Table 6-3
(CONTINUED)**

Area of Concern	Application	Main Environmental Issues	Mitigating Actions	Future Study
Groundwater	Asphalt Concrete	· No significant groundwater quality impacts associated with ash pavements or structures are anticipated	· Mitigating measures for storage and blending issues are similar to those presented for the processing, storage, and blending activities in Table 6-1.	
	Portland Cement Concrete			
	Stabilized fill	· Large uncontrolled operations could impact local groundwater but impacts are likely to be attenuated due to the properties of the stabilizing agent	· Operations should occur in non-sensitive groundwater areas · Use BA only · Use stabilizing agent with leachate controlling properties (e.g. low permeability)	
Marine Waters	Portland Cement Concrete	· No significant impacts envisioned for use in a marine environment for shore protection/construction applications · Uncertainty concerning likelihood of contaminant uptake by biota artificial reef application		· Field behavior of shore protection structures in marine environment · Biological impacts of large-scale reef construction
Worker Health	All Applications	· Issues with regard to storage and blending operations at production facility site similar to those presented for the processing, storage and blending site in Table 6-1 · During concrete milling or demolition activities, potential increase in dust concentrations could impact worker environment	· Mitigating measure for storage and blending issues are similar to those presented for the processing, storage, and blending activities in Table 6-1 · Mitigating measures for the final product application include: - use in subsurface applications - use BA only - use surface sealants - limit % ash use in blend · Mitigating measures for the milling or demolition include: - use moisture control - use dust suppressants	
Indoor	Portland Cement Concrete	· Surface wear could produce particulates and unacceptable abraded Pb load in the indoor environment	· Use BA only · Seal surfaces · Use on outside walls only	· Rate of ash product abrasion through field tests

concentrations to levels that would not pose any significant risk to groundwater quality. Abrasion of medium-technology ash products could potentially increase the trace metal concentrations of adjacent soils. The magnitude of this increase in metals concentrations would depend on the degree of abrasion and the percentage of ash in the product. In situations where abrasion of the ash product is likely, an evaluation of adjacent soils and groundwater vulnerability should be undertaken to determine whether or not potential impacts may be significant.

The use of medium-technology bottom ash products recycled back into similar end use applications following their initial useful life should pose no threat to the environment. However, there may be environmental impacts associated with the disposal of ash products or processing them for recycling into new or rehabilitated products.

Table 6-4 summarizes the results of the high-technology applications assessment. High-technology applications offer the promise of eliminating most environmental concerns associated with use of the resulting products. Ash vitrification, which can produce a glassified granular product, offers the potential for significantly reducing leaching and dusting concerns. Ash washing involves processing ash in aqueous liquids to extract some trace metals and salts. Ash washing offers the potential to produce a better ash-aggregate and to recover trace metals extracted in the process. Ash vitrification, however, has not been commercially demonstrated on the scale required to manage ash in the United States. Similarly, ash washing has not been demonstrated, and even less is known of its potential benefits. There is also concern over potential emissions that may be generated from vitrification or ash washing production facilities. Additional demonstrations are needed to assess the cost and environmental effectiveness of these technologies more fully.

Table 6-4

**HIGH TECHNOLOGY APPLICATIONS
SUMMARIZED CONCLUSIONS**

Area of Concern	Application	Main Environmental Issues	Mitigating Actions	Future Study
Air	Vitrification	<ul style="list-style-type: none">· Production facility storage and blending activities are similar to those presented for the storage and blending site in Table 6-1· Management of process emissions	<ul style="list-style-type: none">· Use moisture controls· Use dust suppressants· Use emission control system	<ul style="list-style-type: none">· Emissions from production facilities· Percentage of TSP and PM10 present in ash· Amount of Cr(VI) in ash <ul style="list-style-type: none">· Availability of trace metals in vitrified product· Effectiveness of ash washing in reducing available trace metal concentrations
	Washing			
Soil	Vitrification	<ul style="list-style-type: none">· Utilization of vitrified ash or washed ash in abrasive applications could result in particulate and corresponding trace metal loadings to adjacent soils	<ul style="list-style-type: none">· No mitigating actions may be necessary since trace metals may be sufficiently unavailable from vitrified product· No mitigating actions may be necessary since trace metal content may be below levels of concern	
	Washing			
Groundwater	Vitrification	<ul style="list-style-type: none">· Pb and Cd leachability from product· Wastewater and solid residue management of by-products from the ash treatment facilities	<ul style="list-style-type: none">· No mitigating actions may be necessary since trace metals may be unavailable from vitrified product· No mitigating actions may be necessary since trace metal content may be below levels of concern	
	Washing			
Worker Health	All Applications	<ul style="list-style-type: none">· Issues with regard to processing, storage and blending similar to those presented for the processing, storage and blending site in Table 6-1· Potential fugitive dust issues associated with final application	<ul style="list-style-type: none">· Use emission control system and proper ventilation· Use moisture controls· Use dust suppressants· Provide personal dust protection	
Indoor	Vitrification	<ul style="list-style-type: none">· None envisioned		
	Washing			

Section 7

ECONOMIC ANALYSIS

The economic benefit of ash use primarily depends on the difference between the costs associated with processing ash into a usable material and the cost of ash disposal. This can be expressed mathematically in a cost-benefit equation:

$$S = C_D - C_R + C_p$$

where

- S = cost savings expressed in terms of dollars per ton of combined ash,
- C_D = cost of combined ash disposal expressed in terms of dollars per ton of combined ash,
- C_R = cost of processing ash into a usable product (or the cost of ash recycling) expressed in terms of dollars per ton of combined ash, and
- C_p = revenues received from the sale of the usable product or by-products expressed in terms of dollars per ton of combined ash (where C_p in most instances will be much less than C_D or C_R)

The cost of combined ash disposal expressed in terms of dollars per ton (C_D) is site-specific and dependent on local conditions. C_D represents the estimated community-specific disposal cost to comply with current federal landfill regulations (as defined by 40CFR Part 258 - Subtitle D of the Resource Conservation and Recovery Act dated August 1991) or state landfill regulations (as defined by NYSDEC 6 NYCRR Part 360 criteria dated October 1993) for ash landfill disposal; or the cost for exporting and disposing of the ash at a non-local disposal facility. For local landfill disposal on Long Island at present, C_D values can be expected to range from \$50 to \$100 per ton, depending on specific landfill construction, dimensions, and local transportation requirements. If ash must be transported long distances (e.g., out of state) for disposal, costs can be vary greatly. For example, from 1987-1992, off-Long Island disposal costs have ranged from approximately \$65 to \$130 per ton. Some factors affecting export costs include the state of the economy (e.g., a recessionary economy producing less waste tends to lower the cost of disposal), the scheduled implementation of Subtitle D land disposal requirements (e.g., the implementation of uniform disposal standards nationwide

would tend to increase the cost of disposal), and the expansion or contraction of out-of-state disposal capacity.

The cost of processing ash into a usable product (C_R) is specific to the level of technology (i.e., low-, medium-, or high-technology application), and regulatory criteria or requirements that could affect ash recycling costs. Specific regulatory criteria of interest include those governing the types of ash that may be approved for use (e.g., bottom or combined ash), ash storage requirements (e.g., enclosed facilities, drainage and ventilation requirements), and ash monitoring/quality control procedures that may be required of the ash generator or user. In addition, processing costs expressed in terms of dollars per ton may also depend on the size of the recycling operation (e.g., larger operations tend to result in lower unit costs).

An economic analysis was undertaken to assess the economic benefits of ash recycling. Details are presented in Volume 6. As part of this analysis, values of C_D , C_R and C_P were derived for several ash recycling technology applications, and the potential cost savings were calculated. Technology applications considered included:

Case I: Low- and Medium-Technology Application -- Combined Ash Use;

Case II: Low- and Medium-Technology Application -- Treated Combined Ash Use;

Case III: Low- and Medium-Technology Application -- Bottom Ash Use and Disposal of Fly Ash (with three subcases for fly ash disposal [Cases IIIA, IIIB, and IIIC]);

Case IV: Medium-Technology Application -- Artificial Reef Construction Using Bottom Ash with Disposal of Treated Fly Ash in a Subtitle D Landfill;

Case V: High-Technology Application -- Combined Ash Vitrification; and

Case VI: High-Technology Application -- Bottom Ash Vitrification with Disposal of Treated Fly Ash in a Subtitle D Landfill.

The results of the economic analysis suggest that the economic incentive for ash recycling is primarily a function of the disposal cost that could be avoided if ash were used instead of being landfilled.

Of specific interest to the potential ash recycler is the break-even cost, or the disposal cost at or below which recycling offers no net financial benefit (i.e., $S=0$). Estimated break-even disposal costs for each of the applications examined and for facilities with solid waste throughput capacities of 750 tpd, 1,500 tpd, and 2,250 tpd, respectively, are listed in Table 7-1. The costs presented in Table 7-1 are based on the assumption that 75 percent of the total ash generated at each size facility (i.e., 750 tpd, 1,500 tpd, and 2,250 tpd) is usable and that 60 percent of the usable ash is actually recycled.

For communities recycling 60 percent of the usable ash fraction, employing low- and medium-technology applications without any special bottom ash or combined ash treatment and with disposal of treated or untreated fly ash in a Subtitle D landfill (i.e., Cases I, IIIA and IIIB), break-even combined ash disposal costs for facilities of all sizes were less than \$30 per ton. For larger facilities (i.e., 2,250 tpd) break-even costs were less than \$20 per ton.

If special combined or bottom ash treatment is required (i.e., Case II), ash use would be economically viable at break-even disposal costs ranging from approximately \$25 to \$40 per ton, depending on the size of the facility.

Subtitle C disposal of fly ash (i.e., disposal at a licensed hazardous waste disposal facility) as part of a low- or medium-technology strategy would increase this break-even disposal cost range to approximately \$45 to \$55 per ton (Case IIIC).

For bottom ash use in artificial reef applications to be economically viable, with treated Subtitle D disposal of fly ash, depending on the size of the facility, break-even costs between \$40 and \$60 per ton would be required (Case IV). Subtitle C disposal of fly ash would increase this break-even disposal cost range to approximately \$70 to \$90 per ton.

Table 7-1

**ESTIMATED COMBINED ASH
BREAK-EVEN DISPOSAL COST ^{1,2,3}**
(\$/ton)

Case	Description	Break-Even Disposal Cost for Following Facility Sizes in tons per day (tpd)		
		750 tpd	1,500 tpd	2,250 tpd
I	Low- and Medium- Technology Application -- Combined Ash Use	\$ 23	\$ 15	\$ 13
II	Low- and Medium- Technology Application -- Treated Combined Ash Use	39	29	26
IIIA	Low- and Medium- Technology Application -- Bottom Ash Use and Fly Ash Disposal (Subtitle D)	22	15	11
IIIB	Low- and Medium- Technology Application -- Bottom Ash Use and Treated Fly Ash Disposal (Subtitle D)	29	21	18
IIIC	Low- and Medium- Technology Application -- Bottom Ash Use and Fly Ash Disposal (Subtitle C)	52	46	45
IV	Artificial Reef with Bottom Ash Blocks and Treated Fly Ash Disposal (Subtitle D)	58	46	42
V	Direct Vitrification with Combined Ash	96	80	71
VI	Direct Vitrification with Bottom Ash and Treated Fly Ash Disposal (Subtitle D)	105	87	78

1. Disposal cost at or below which recycling offers no net financial gain. Assumes that 75 percent of the total ash is usable and 60 percent of the usable ash is actually recycled.
2. Subtitle D disposal represents disposal in non-hazardous waste landfills; Subtitle C disposal represents disposal in hazardous waste landfills.
3. All processing costs (C_R) used in the economic analyses represent 1992 dollars.

For combined ash vitrification to be economically viable (Case V), break-even disposal costs of \$70 to \$100 per ton would be required. Bottom ash vitrification with Subtitle D disposal of treated fly ash (Case VI) would require break-even costs between \$75 and \$105 per ton, depending on the facility size. Bottom ash vitrification strategies with Subtitle C disposal of fly ash would likely increase break-even disposal costs to between \$100 and \$120 per ton.

Table 7-2 lists unit cost savings, expressed in terms of dollars per ton of combined ash, that could be achieved if communities currently paying disposal costs of \$75 per ton were to recycle 60 percent of their usable ash. Using the unit cost saving values presented in Table 7-2, and given the current conditions on Long Island, recycling 60 percent of the ash produced could result in significant ash management cost savings. Potential cost savings for each operating waste-to-energy facility on Long Island are presented in Table 7-3. The data presented are based on the recycling of bottom ash in low- and medium-technology applications, and fly ash treatment prior to disposal in a Subtitle D landfill (Case IIIB). The results suggest a potential cost savings of approximately \$12.4 million per year. The estimates presented in Table 7-3 are predicated on the assumption that combined ash disposal space is available at \$75 per ton.

Table 7-2

**ESTIMATED UNIT COST SAVINGS PER
TON OF COMBINED ASH PRODUCED^{1,2}**
(\$/ton)

Case	Description	Unit Cost Savings for Following Facility Sizes in tons per day (tpd)		
		750 tpd	1,500 tpd	2,250 tpd
I	Low- and Medium- Technology Application -- Combined Ash Use	\$ 32	\$ 36	\$ 38
II	Low- and Medium- Technology Application -- Treated Combined Ash Use	22	28	30
IIIA	Low- and Medium- Technology Application -- Bottom Ash Use and Fly Ash Disposal (Subtitle D)	29	33	34
IIIB	Low- and Medium- Technology Application -- Bottom Ash Use and Treated Fly Ash Disposal (Subtitle D)	24	29	30
IIIC	Low- and Medium- Technology Application -- Bottom Ash Use and Fly Ash Disposal (Subtitle C)	14	18	19
IV	Artificial Reef with Bottom Ash Blocks and Treated Fly Ash Disposal (Subtitle D)	9	15	17
V	Direct Vitrification with Combined Ash	(19)	(4)	(3)
VI	Direct Vitrification with Bottom Ash and Treated Fly Ash Disposal (Subtitle D)	(23)	(9)	(2)

1. Represents unit cost savings in terms of dollars per ton of combined ash assuming 75 percent of the total ash produced is usable, 60 percent of the usable ash is actually recycled, and combined ash disposal costs of \$75 per ton.
2. All processing costs (C_R) used in the economic analyses represent 1992 dollars.

Table 7-3

LONG ISLAND COST SAVINGS BY FACILITY¹

Facility	Facility Size (tpd)	Tons per Year of Combined Ash Produced	Annual Cost Savings (\$ million)
Glen Cove	250	22,800	0.5 ²
Hempstead	2,505	228,600	6.9 ³
Long Beach	200	18,300	0.4 ²
Babylon	750	68,400	1.6 ²
Huntington	855	78,000	1.9 ²
Islip	518	47,300	1.1 ²
Totals	--	463,400	12.4

1. Represents Case IIIB with 75 percent of total ash available for use, 60 percent utilization, and a combined ash disposal cost of \$75 per ton.
2. Based on unit cost savings for 750 tpd facility presented in Table 7-2
3. Based on unit cost savings for 2,250 tpd facility presented in Table 7-2

Section 8

LEGAL AND INSTITUTIONAL ISSUES

At the present, legal and institutional impediments pose a far greater barrier to the use of MSW ash as a secondary material than any failure on the part of the scientific community to devise the technologies needed to make the processing of ash and the products containing it environmentally acceptable.

As is often the case with a new activity, neither the legal, regulatory, and institutional structures, nor the public perception, have yet caught up with the rapidly evolving technology. Ash use is hampered by legal and regulatory confusion, inadequate scientific data for rational decision-making, inaccurate public perceptions and their political consequences, and economic disincentives.

Years of uncertainty regarding the status of ash under federal law may soon be ended by a new decision of the Supreme Court. Meanwhile, many states have chosen to develop their own ash management laws and regulations. Depending on the location of the facility generating ash, the ash may be:

- A solid waste or a special waste;
- Subject to testing or presumed non-hazardous, and therefore exempt from testing;
- Managed in accordance with stringent requirements respecting disposal and use; and/or
- Regulated on a case-by-case basis, or not regulated at all.

New York State has declared ash a solid waste subject to specific management criteria set forth in 6 NYCRR Part 360. The provisions pertaining to ash disposal are clear and precise; those pertaining to use, although recently improved, generally remain somewhat open-ended. Since the regulations provide some information on how to proceed, but little guidance as to the

criteria that will be used to determine the acceptability of a proposed technology or product, a petitioner for a New York State Beneficial Use Determination (BUD) cannot make an a priori estimate of the costs in time and money needed to gain approval.

Although the existence of federal or other nationally accepted science-based criteria or standards for approval of proposed beneficial uses could serve to reduce the attendant uncertainties and consequent economic disincentives, the near-term establishment of such criteria or standards does not appear likely.

Incomplete understanding of the behavior of ash under field conditions of use constitutes a significant impediment to beneficial use. To date, developers of ash use policies, laws, and regulations have placed too little emphasis on the identification of the scientifically relevant questions, the refinement of analytical protocols, and the development of a comprehensive, credible database -- all prerequisites of cost-effective environmental protection. Initial regulatory approaches limiting or prohibiting beneficial uses based exclusively on drinking water standards or other standards for permissible concentrations of metals in ash products need to be expanded to include consideration of the factors affecting contaminant release and mobility, exposure pathways, and the presence or absence of sensitive receptors. Without the detailed science needed to document the rationality of numerical environmental standards, the policies, laws, and regulations affecting ash use are more likely to be shaped by public perception and the resulting political climate.

Public perceptions and their political consequences may also discourage or even thwart environmentally safe recycling of ash. To a considerable degree, acceptance of beneficial uses of ash depends and will depend on local and national attitudes toward waste-to-energy facilities. Unwillingness to allow beneficial uses appears to be based in part on uninformed assumptions regarding the nature of ash and its behavior in the environment and in part on a conscious effort to eliminate combustion as a viable waste management technology by making it impossible to dispose of ash except at very high cost.

Would-be users of ash often must face the opposition of a core group of persons residing near a proposed ash-use site, small but articulate groups of environmental and anti-tax activists,

advocates of competing technologies, or one or more elected officials or candidates for office. Often with different long-term agendas, they generally share a common short-term goal.

The media also play a significant role in shaping public perceptions of solid waste management issues, including ash-use proposals. Public perception of ash-use proposals can be impacted adversely by media coverage of ash-use issues that is limited to succinct "sound-bite" statements of opponents without including consideration of results of scientific research efforts, which are harder to reduce to sound bites.

The technical community whose research findings support the use of ash has had little success in communicating its knowledge to the opponents of specific projects and to the reporters who cover them. Reactive rather than proactive, the technical community has not yet learned to present its data in brief, readily comprehensible terms.

Legal and institutional factors also impose economic constraints, since private sector interest and investment in the testing and development of beneficial uses depends in large measure on assumptions of economic feasibility. The open-ended character of the permitting process, together with the likelihood that it will be influenced to some degree by non-technical considerations, makes accurate estimation of start-up costs almost impossible. Unnecessarily stringent public agency specifications and perceptual impediments to market acceptance of ash or ash products constitute additional economic disincentives. Finally, potential individual and corporate liability for inadvertent health or environmental damage resulting from the non-negligent pursuit of permitted activities makes private sector investment in technology development, testing, and commercialization of beneficial use risky.

Public agency use of ash is somewhat less constrained by economic factors since the economics of governmental beneficial use, which are driven by unwanted supply rather than product demand, are characterized by fewer relevant disincentives. Avoided costs rather than the need to make a profit or to break-even can tip the balance in favor of beneficial use.

Given the existing legal and regulatory uncertainties, the need for an expanded ash database, a difficult political climate and current economic disincentives, near-term demonstrations of beneficial use will depend in large measure on governmental initiatives.

Section 9

CONCLUSIONS AND RECOMMENDATIONS

The preceding sections of this document have presented an overview of the investigations and findings of the LIRPB study of the Potential for Beneficial Use of Waste-to-Energy Facility Ash. This section provides a summary of the study's major conclusions. It also includes a listing of recommendations that the authors believe are necessary to provide future technical guidance and regulatory overview of ash recycling activities in the United States.

CONCLUSIONS

The conclusions have been grouped under three headings: general conclusions, conclusions that delineate acceptable conditions for ash use, and conclusions that focus on current impediments to ash use.

General

1. A significant portion of the ash produced by modern waste-to-energy facilities can and should be recycled. The results of the environmental analyses undertaken in this assessment indicate that there is no rational scientific basis for the widespread rejection of ash use as a viable ash management strategy.
2. The physical and chemical characteristics of ash and the existence of technologies for mitigating or eliminating potential adverse environmental impacts make ash use an attractive alternative to disposal.
3. Properly processed MSW combustor ash exhibits physical and engineering properties comparable to those of a silty sand and gravel material containing traces of organic matter. The engineering properties of ash make this material suitable for use in numerous construction-related activities.
4. The beneficial use of ash as a substitute for aggregate materials in construction

applications provides the most cost-effective long-term solution for the management of incinerator ash on Long Island and in many other locations. In most areas, the economic benefits of ash use are primarily associated with savings due to avoided disposal costs. On Long Island, beneficial use can provide a second and very possibly more important long-term benefit in the preservation of a finite, increasingly valuable commodity -- permitted or potentially approvable local ashfill space.

Conditions for Use

1. Not all components of MSW ash are equally acceptable in all applications and environments. Both combined and bottom ash produced at MSW combustors have potential for use; however, the data suggest that combined ash use generally poses a greater environmental risk than bottom ash use. This is primarily due to the relatively high pH associated with combined ash containing lime-based scrubber residue and its effect on lead solubility, and to the relatively high cadmium concentration in the combined ash as compared to the bottom ash. In addition, although sufficient data are not yet available to fully substantiate this, combined ash appears to have greater potential for fugitive dust emissions than bottom ash, due to the presence of finer particles contributed by the fly ash fraction. Data also suggest that the fly ash component, which contains higher concentrations of volatile trace metals and trace organics, may contribute to unacceptably high concentrations of these constituents in the combined ash. Furthermore, since bottom or grate ash contains a smaller proportion of fines and exhibits less reactivity than combined ash produced in new waste-to-energy facilities, it is a more desirable engineering material.
2. The concentration of trace metals in fly ash and less desirable engineering properties attributable to the presence of fly ash in some engineering applications warrant separation of the grate ash and fly ash streams if ash is to be recycled outside a landfill environment. This will necessitate separate handling and possible treatment of fly ash prior to disposal.
3. Until product changes, improved source separation, or post-burn ash beneficia-

tion technologies reduce the likelihood of unacceptable trace metal concentrations, the increased risks associated with combined ash warrant elimination of its use in low- and medium-technology applications, except in a controlled environment such as a landfill site.

4. The use of combined ash in an unbound aggregate form as a daily or intermediate landfill cover, or the use of treated combined ash in landfill closure or other landfill construction applications is not expected to result in any significant adverse environmental impact.
5. Although lead concentrations in bottom ash are generally lower than those in fly ash, lead content is the primary environmental concern associated with bottom ash use.
6. Medium- and high-technology applications are generally preferable to low-technology or unbound uses. The use of bottom ash in low-technology applications may be appropriate in areas where fugitive dust can be controlled, high salt concentrations do not pose a problem, and neutral or slightly alkaline environmental conditions are ensured. Controlled environments, such as landfill sites, and non-potable groundwater areas or coastal areas adjacent to brackish or marine waters, where the effects of leachates or runoff associated with the specific beneficial use would be inconsequential, are suitable locations for low-technology bottom ash applications.
7. Medium-technology applications using bottom ash as a substitute aggregate material can be designed to mitigate any significant dusting problems and reduce potential leachate contaminant concentrations to levels that would not pose significant risk to groundwater or surface water quality.
8. Any low- or medium-technology use of ash will involve some screening, storage, and blending activities. Unless properly managed, these operations constitute the single greatest potential source of environmental impacts.

Properly managed storage and blending operations, which could include suitably covered storage areas, runoff collection systems, moisture control, and/or the use of dust suppressants or medium-technology stabilization reagents could mitigate a large portion of the potential impacts associated with these operations.

9. In most medium-technology beneficial use applications, the ash component of the product is blended with 50 to 90 percent natural aggregate and cementitious materials, then encapsulated in a relatively impermeable matrix. This treatment would result in significant reductions in measurable environmental releases and consequent impacts.
10. The abrasion of low- or medium-technology products used in surficial applications could impact adjacent soils. The magnitude of such an impact would depend on the degree of abrasion, the percentage of ash in the product, and the sensitivity of the depositional environment. In those situations where abrasion of the ash product is likely, an evaluation of adjacent soils and groundwater vulnerability as well as the likelihood of human exposure should be undertaken to indicate whether or not potential impacts may be significant.
11. The use of medium-technology bottom ash products recycled back into similar end use applications following their initial useful life should pose no threat to the environment. However, there may be environmental impacts associated with the disposal of ash products or processing them for recycling into new or rehabilitated products.
12. High-technology applications offer the promise of eliminating most environmental concerns associated with use of the resulting products. Ash vitrification, which can produce a glassified granular product, offers potential for significantly reducing leaching and dusting concerns. Ash washing offers the potential to produce a better ash-aggregate and to recover trace metals extracted in the process. Ash vitrification, however, has not been commercially demonstrated on the scale required to manage ash in the United States. Similarly, ash washing has not been demonstrated, and even less is known of its potential benefits. There also is concern over potential emissions that

may be generated from vitrification or ash washing production facilities. Additional demonstrations are needed to assess the cost and environmental effectiveness of these technologies more fully.

Impediments to Use

1. Today, legal and institutional impediments constitute a far greater barrier to the use of ash as a secondary material than any failure on the part of the scientific community to devise the technologies needed to make the processing of ash and the products containing it environmentally acceptable. Legal and regulatory confusion with respect to Resource Conservation and Recovery Act (RCRA) status, permitting procedures and requirements, and relevant standards or guidelines; public and political opposition rooted more in fear than in fact; and economic disincentives, especially the laws governing liability for environmental impairment, all tend to discourage and on occasion preclude the beneficial use of ash even in pilot-scale demonstration projects.
2. Although the existence of federal or other nationally accepted science-based criteria or standards for approval of proposed beneficial uses could serve to reduce the attendant uncertainties and consequent economic disincentives, the near-term establishment of such criteria or standards does not appear likely.
3. With many states assuming or likely to assume responsibility for ensuring the environmental safety of beneficial use applications, there is an immediate need to develop national criteria or specifications that can be used to define relevant limitations for proposed beneficial uses of ash. These criteria should take into account chemical and physical characteristics of ash, including trace metal content, trace organic content and leachability; the effectiveness of the proposed technology in limiting environmental releases; the location or point-of-use of the ash or ash product; and the arrangements for future disposal or recycling.
4. There is a need for a series of pilot demonstration programs to provide

additional data for the development of environmental and engineering criteria and guidelines. However, the implementation of demonstration programs and the development of acceptable criteria to ensure the appropriate use of ash in private-sector applications will take several years. In the interim, there are several controlled or public-sector applications that could provide opportunities for ash use. Those that warrant particular attention include, but are not limited to, the use of treated ash in landfill capping and landfill construction applications.

Table 9-1 summarizes conclusions on environmental issues related to ash use.

MAJOR RECOMMENDATIONS

1. Municipal officials and others interested in beneficial use should
 - Use available technical information to publicize the fact that it is possible to recycle ash safely and, in so doing, save dollars, ashfill space, and natural aggregate.
 - Continue to press for and where possible undertake field demonstrations to monitor the "real world" behavior of ash in various applications and environments.
2. U.S. EPA, U.S. Department of Energy, or the National Academy of Sciences, acting through the National Research Council, should convene a committee of experts in the fields of environmental releases, public health risk assessment, engineering, and environmental regulation to develop scientifically based criteria to define the environmental acceptability of ash processing, product use, and product recycling under various conditions of site sensitivity and receptor exposure.
3. U.S. EPA and/or the states should adapt and adopt such nationally developed

Table 9-1

Environmental Issues

Summarized Conclusions

Type of Ash	Type of Application			Main Environmental Issues			Recommended Criteria
	Low Technology	Medium Technology	High Technology	Low Technology	Medium Technology	High Technology	
CA ¹	<ul style="list-style-type: none"> Not currently advised except in controlled and monitored environment (e.g. landfill) 	<ul style="list-style-type: none"> Not currently advised except in controlled and monitored environment (e.g. landfill) 	<ul style="list-style-type: none"> Acceptable subject to further evaluation of production facility environmental releases 	<ul style="list-style-type: none"> Highly alkaline leachate and runoff with relatively high Pb solubility Potential Pb, Cd, and salt leachability in groundwater sensitive areas Relatively high volatile metal (e.g., Cd) content Potential impact of fugitive dust emissions on local ambient air quality and impact of ash particles on the trace metal content of the soil 	<ul style="list-style-type: none"> Potential impact of abraded product deposition on adjacent environment during product use and disposal Potential impacts from processing, storage and blending like those shown for low technology 	<ul style="list-style-type: none"> Environmental releases from production facility Potential impacts from processing, storage and blending like those shown for low technology 	<ul style="list-style-type: none"> Specifications that define: <ul style="list-style-type: none"> Maximum acceptable levels of trace metals and organics in ash and leachate Maximum acceptable levels of trace metals and organics in ash product and leachate
BA ²	<ul style="list-style-type: none"> Acceptable in controlled and monitored environment (e.g. landfill) Subject to further evaluation of site-specific groundwater and surface water sensitivity and control of dust abrasion and leachate in off-landfill environment 	<ul style="list-style-type: none"> Acceptable subject to further evaluation of abrasion-related issues 	<ul style="list-style-type: none"> Acceptable subject to further evaluation of production facility environmental releases 	<ul style="list-style-type: none"> Potential Pb, Cd, and salt leachability in groundwater sensitivity areas Potential impact of fugitive dust emissions on local ambient air quality and impact of ash particles on the trace metal content of the soil 	<ul style="list-style-type: none"> Potential impact of abraded product deposition on adjacent environment during product use and disposal Potential impacts from processing, storage and blending like those shown for low technology 	<ul style="list-style-type: none"> Environmental releases from production facility Potential impacts from processing, storage and blending like those shown for low technology 	<ul style="list-style-type: none"> Site and land use acceptability Arrangements for recycling and final disposal of products Management of storage and blending operations

1. CA= Combined Ash

2. BA= Bottom Ash

criteria as part of an ash use permitting system based on clearly established performance standards.

4. U.S. Department of Transportation and its state counterparts should review and amend their materials specifications to facilitate the substitution of ash for a portion of natural aggregate wherever technically feasible.
5. The states, including New York, should act immediately not only to allow but to encourage the use of ash in the contained or controlled landfill environment. Regulations should specify the type of ash that may be used and the level of treatment required, based upon the potential for environmental releases and consequent impacts.
6. Proponents of beneficial use, municipal solid waste managers, and regulators should encourage product changes, up-front separation and diversion of problem items, and post-burn beneficiation of residue to increase environmental acceptability and enhance the engineering properties of ash as a secondary material, and to expand the opportunities for its use.

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