Introduction

In 2002, approximately 28.5 million tons or 7.7% of the 370 million tons municipal solid waste (MSW) in the U.S. were combusted in Waste-to-Energy (WTE) facilities for the generation of electricity and heat [1]. During the process about 25-30% of solid residues (by weight, or 10-12% by volume of the MSW) is produced in form of bottom and fly ash, which are mostly combined in the plant. Since 1996, there have been no new WTE facilities in the U.S. because of environmental and political pressure. The major concern has been the perceived release of hazardous toxic substances into the environment. In the past, primary focus of environmental groups has been on air emissions, especially of dioxins/furans and heavy metals. However, after the U.S. EPA enforced the implementation of the Maximum Available Control Technology (MACT) regulations in the 1990s, WTE emissions have been reduced to a point that the U.S. EPA named waste-to-energy “one of the cleanest sources of energy” [2].

Prior to the 1990s, combined WTE ash was found to contain high levels of lead and cadmium.
and the U.S. EPA classified it as “potentially hazardous waste”, thus requiring analytical testing for toxicity within the WTE facilities, prior to its disposal or reuse. A compilation of analytical data has shown that all the ash samples tested in the last decade have been found to be non-hazardous [3] and have been allowed to be disposed in MSW landfills or in monofills. However, the dioxins and heavy metals that are removed from the process gas by means of the MACT equipment are collected in the fly ash component of the combined ash (about 15% of the total ash for mass burn processes).

In addition to the importance of this issue for existing WTE facilities, that spend a considerable part of their income on landfilling ash, successful ash management will be a key factor for developing and siting new WTE plants. It is expected that the focus of opposition to new WTE facilities will shift from air pollution to fate of contaminants in the ash residues. Having decreased dramatically the air emissions by introducing better air pollution control systems, the U.S. WTE industry has yet to develop a strategy to avoid ash landfilling and to contradict the perception that health risks have been transferred from air emissions to potential emissions from the landfilling of ash.

Thus, the disposal or beneficial use of ash remains the last obstacle in establishing WTE as a clean and sustainable waste management option that offers the additional benefit of recovering energy from the waste stream. Several strategies for reusing the WTE residues have been proposed and developed with only partial of local successes. However, in view of the classification of WTE ash as potentially hazardous material public acceptance of ash processing and of ash-containing products continues to be a major concern.

In 2003, the Waste-To-Energy Research and Technology Council (WTERT, [4]) founded the University Ash Consortium to combine research efforts at Columbia University, the State University of New York at Stony Brook (SUNY), Temple University, and other academic and industrial groups concerned with sustainable WTE ash management. The interdisciplinary research of the UAC comprises three research areas: 1) WTE ash characterization and comparison with residue from coal-fired power plants; 2) the use of WTE ash in construction applications such as granular fill, asphalt, or cement blocks; and 3) the use of WTE ash for brownfield or min remediation.

WTE combustion residues

WTE ash can be divided in the following groups (after [3]):

1) Bottom ash as discharged from the bottom of the furnace (mainly the grate) and fallen through the furnace grates;
2) Heat recovery ash (HRA) as collected in the heat recovery system including boiler, economizer, and superheater. HRA is frequently discharged into the bottom ash stream and thus is often included in a broader definition of bottom ash;
3) Fly ash as carried over from the furnace and removed before sorbents are injected to clean the flue gas;
4) Air pollution control (APC) residues as collected in the APC equipment (e.g., scrubbers, electrostatic precipitators, and baghouses) including fly ash, sorbents, condensates, and reaction products. In U.S., the term “fly ash” usually includes APC residues;
5) Combined ash as a mixture of the above categories. In the U.S., the majorities of WTE facilities combine their ashes to one residue stream.

WTE residues can be processed with either dry or wet ash handling systems. Most facilities employ wet systems because it is easier to control fugitive dust emissions and air leakages. In May 1994, the U.S. Supreme Court ruled that the WTE ash was not exempt from testing to determine whether it is hazardous. This ruling created a major obstacle in the development of standard specifications for reuse of
Also, as noted earlier, anti-incinerator organizations have started to expand their objections from dioxin emissions to combustion residues. For example, Greenpeace reported that 97% of the total dioxin emissions from an incinerator would be present in the ash after a theoretical assessment of releases from an incinerator in Sweden [5]. Yet, dioxins and furans (PCDDs and PCDFs) are generally considered to become strongly absorbed on the surfaces of ash particles and therefore highly insoluble in aqueous environments. Hence, it seems unlikely that they will leach to a significant extent [6]. Concentrations of PCDDs and PCDFs in leachate collected from ash residue monofills have characteristically been reported to range from non-detectable to parts per quadrillion (ppq) levels, i.e. at levels that are presently considered to be below regulatory concern [6]. Also, modern well-operated WTE facilities are net-reducers of dioxins/furans [7].

WTE ash management and treatment

Most of the U.S. WTE ash is disposed of in either monofills, designated divisions of landfills called monocells, or mixed landfills. An estimated 600,000 tons, or less than 10% of the total WTE ash, is used beneficially, mostly in landfill applications such as alternative daily cover or road base material [8]. In contrast, WTE plants in Europe generally do not combine the ashes because of relatively high contaminant concentrations in the fly ash. The bottom ash is considered non-hazardous and its rate of reuse is well above 60% in Denmark, France, Germany, and the Netherlands [9]. Most of the bottom ash is used in road construction. On the other hand, German WTE fly ash is mainly disposed of as fill material in extinct underground salt mines [10].

Prior to beneficial use application or disposal, WTE ash can be treated to improve its physical or environmental properties. Post-combustion materials separation is commonly practiced. Especially the number of WTE facilities that recover ferrous metals from the ash (for mass-burn processes typically in the range of 6-12% by weight) is very high. Other materials such as non-ferrous metals are recovered only at a few plants, due to economic restraints.

Beneficial uses of WTE ash

Generally, the beneficial use of WTE combustion residues can be categorized in four main applications:

1) in landfills as daily cover or road base material,
2) as construction material,
3) for brownfield or mine remediation, and
4) in agricultural applications.

During regular landfill operations, daily cover is placed on all exposed solid waste at the end of each working day to control vectors, odors, dust emissions, and fires. Usually, natural soil is used but there have been efforts to use alternative daily covers (ADC) such as ash, auto shredder fluff, and foundry sand [14]. Similarly, at the end of their service life, landfills are required to be covered with a permanent cover. WTE ash seems suitable for both applications and has been utilized where permits allow such usage. Generally, daily cover accounts for 10-25% of the landfilled MSW volume [15]. On the basis of data presented in the most recent BioCycle “State of Garbage in America” survey [1] and of the assumption that the WTE ash represents 30% of the MSW feedstock, the annual volume of ash that could...
be used as ADC is about 7 million cubic yards. The compacted volume of MSW landfilled in states with WTE facilities is more than 300 million cubic yards so that, theoretically, all WTE ash could be utilized as ADC. However, with the long-run goal of the WTERT to minimize landfilling of solid wastes, the utilization of WTE combustion ash in landfill applications is not as attractive as other beneficial uses.

Various studies have shown that it is possible to use WTE ashes beneficially in construction; summaries of these investigations can be found among others in references [3, 16, 17]. Previous projects included the use of WTE ash as structural fill, aggregate in cement blocks, and as a constituent of asphalt or concrete [18 - 29]. Typically, there is a wide range for the ratio of WTE ash to aggregate in beneficial use applications. In case of the WTE ash of Polk County, MN combined ash replaced about 10% of natural aggregate in asphalt pavements while the Laconia project in New Hampshire utilized 50% bottom ash [25, 28]. Similarly, cement blocks have been produced with relatively small fractions of ash to replacing the entire aggregate with ash. Generally, the amount of fines, content of unburnt material, water adsorption capacities, fugitive dust emissions, and aesthetics limit the amount of ash to be used. On the other hand, granular fill can be entirely composed of WTE ash.

A survey by Rogoff and Settar [30] reported physical and chemical characteristics of WTE ash that lend the ash capable for use in several applications, including the remediation of acid mine drainage sites. At Temple University, zeolite-like materials have been successfully synthesized from combined WTE ash. Their high alkalinity suggests using these ash-derived products for the remediation of abandoned mines, where acidic leachates could be neutralized. WTE ash possesses characteristics that may lead to the development of other beneficial uses, such as the remediation of contaminated water and soils [31, 32]. WTE residues contain some nutrients, yet it will be very difficult to gain public acceptance for projects on using combustion ashes for agricultural purposes.

**Overview of the University Ash Consortium**

With the assistance of the WTERT and the industrial members of the Integrated Waste Services Association (IWAS, [7]), the UAC will evaluate the technical, economic and environmental feasibility of converting WTE ash into a valuable resource. The organizational structure of the UAC is shown in Figure 1. Currently, the UAC comprises mainly three universities (Columbia, SUNY, and Temple) but its structure is sought to be dynamic in order to allow for other institutions to join. The close collaboration of industry and multiple academic groups with different foci enables the UAC to combine scientific and applied as well as analytical and experimental research that goes beyond developing a merely technical (and often local) solution but includes other aspects during the implementation of beneficial ash applications, such as economic considerations, public and political acceptance, and environmental impact.

In its first year, the UAC hosted a roundtable discussion at the WTERT Fall Meeting 2003 and applied for combined research funding. Because beneficial use applications seem to be hampered by lack of marketability rather than by technical and environmental feasibility, the UAC will investigate public acceptance and perception. In addition, risk management and liability have to be addressed. The economic incentives for ash reuse are provided mainly through avoided landfill costs and savings in virgin materials. The reuse of WTE ash will also save natural resources and prolong the life of existing landfills by further reducing the amount of material to be deposed. In sum, questions and prejudices against the use of WTE ash will be examined at the UAC in depth and the information derived will assist in the development of policies and markets for ash.
The interdisciplinary research of the UAC comprises three major research areas [33]:

1) WTE ash characterization and comparison with coal ashes (chemical and physical properties); the work includes data collection, organization, and statistical assessment from previous studies, and verification of the analytical results. The experimental program includes the chemical analysis of WTE ashes. Different samples of bottom, fly, and combined ash as well as residue from air pollution control system have been obtained and then examined by means of scanning electron microscopy and EDX elemental analysis. These methods help to gain a better understanding of the surface topology, structure, and chemical composition of the ash. It is planned to compare WTE ash properties with those of residues from coal-fired power plants and if necessary to develop, modify, or improve in-plant treatment methods for ash, in particular fly ash, to increase the opportunities for reuse. Columbia University (Dr. Saugata Datta, Dr. Karsten Millrath) will lead this project.

2) The use of WTE ash in construction materials; the work includes comprehensive data compilation of prior projects and extensive experimental testing of possible applications such as granular fill, embankments, road base material, and aggregate in either asphalt, concrete, or concrete masonry units (cement blocks). The experimental part will mainly be carried out under direction of Dr. Frank J. Roethel at the Waste Reduction and Management Institute (WRMI) of the State University of New York at Stony Brook [34] as a continuation of previous efforts [19-22]. It had been shown previously that processed ash imposes marginal health risks when used beneficially [22].

The paving and embankment demonstration program at the WRMI recently entered its second year. Field data obtained at a parking lot paved with processed WTE ash in Farmingville, NY is being assessed. Plans and bids are currently being finalized for a second demonstration project beginning this spring. Using construction quality cement blocks fabricated with processed ash aggregate, hangars at the Town of Brookhaven’s airport will be constructed. In addition, the program incorporates a detailed investigation of asphalt using processed WTE ash as an aggregate substitute in the apron and taxiways leading to and from the new hangars.
Through the assistance of State Senator Caesar Trunzo, the research program recently received additional funding from the New York State Legislature to continue a third phase of this investigation.

3) The use of WTE ash for remedial purposes; the work of the Department of Civil and Environmental Engineering at Temple University [35] on reclamation of brownfields and abandoned mine drainage will be continued [31, 32]. For his pioneering efforts into using WTE ash to remediate and solve difficult and costly environmental problems, the Environmental Protection Agency (EPA) presented a bronze medal to Dr. David Kargbo, leader of the research on WTE ash at Temple University [36]. His research has included the use of alkaline WTE ashes to synthesize zeolites and other new materials that are economically viable products for use in various industries and to neutralize acidity from abandoned mine sites (reclamation). Also, injection grouts for remedial purposes have been formulated and geotechnical testing and simulated weathering of the cured grouts are currently conducted to determine their long-term stability.

After the technical, environmental, and economical assessments of beneficial use applications the UAC will assist in the implementation of sustainable ash management plans and in specifying recommendations for ash standards as a key to for the WTE industry. The overall goal is to minimize the amount of material to be landfilled. The aims of the University Ash Consortium are described in the web page of the Waste-to-Energy Research and Technology Council [37].

**Conclusions and Outlook**

Environmentally acceptable yet economically viable residue management practices will play a key role in the advancement of WTE processes. Today, most U.S. WTE plants combine their bottom and fly ash and dispose of the mixture in co-disposal landfills or monofills. Although several studies on beneficial uses on ash have been carried out in the past, the rate of ash reuse in the U.S. has remained comparably low. The University Ash Consortium intends to develop sustainable ash management strategies based on the research on beneficial use applications for WTE ash. In a holistic approach, the UAC seeks to expand the research from finding local technical solutions to assessing the technical, economic, environmental, and also sociopolitical feasibility of ash reuse on a nationwide level.

The current projects underway at the UAC member institutions focus on non-landfill applications such as of WTE ash reuse in construction or remediation. Demonstrations projects for the beneficial use of ash include the production of asphalt paving and cement blocks to build an aircraft hangar in Long Island, NY. Zeolites have been synthesized that seem suitable to neutralize acidic spills during the reclamation of abandoned mines. The UAC will also investigate how to improve processing techniques for WTE ash in order to gain better public acceptance and marketability of ash product. A study on the influence of ash handling systems (wet/dry) on effective and economic post-combustion materials recovery will also be of interest for the WTE industry.

The UAC has worked closely together with representatives of the industry and other involved parties thereby combining academic and applied research. It is hoped to continue ongoing research projects, to facilitate synergy effects for future collaborations and proposals, to nourish knowledge exchange, to educate the public and collaborate with environmental and official organizations, and to lead the U.S. WTE industry to a sustainable ash management practice.
References


[34] Marine Sciences Research Center of the State University of New York at Stony Brook: “Homepage.” http://www.msrc.sunysb.edu

