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Contemporary practices and findings essential to the development of effective MSWI ash reuse policy in the United States

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ABSTRACT

Municipal solid waste incineration (MSWI) in the United States generates a significant amount (~6.6 million mtons) of ash annually, yet the utilization of this ash in beneficial use applications is nearly non-existent. In some European and Asian nations, policy regulates the use of MSWI bottom ash in construction with an accepted degree of environmental and human health risk. Both federal and state-level solid waste policy in the United States largely does not address ash reuse. U.S. MSWI industry practices have been adapted to avoid hazardous waste generation and primarily practice ash disposal in monofills. Numerous case studies and laboratory experiments have characterized MSWI ashes with regard to the potential environmental contaminants and have demonstrated the efficacy of bottom ash in specific reuse scenarios. In reviewing these studies, and by analyzing the reuse policy in several nations, the authors identify key aspects of effective MSWI ash reuse. These are discussed within the framework of available data and information, and examples are provided. Moving toward the sustainable management of resources such as MSWI bottom ash will require U.S. state-level policy to address the conditions under which ashes may or may not be reused. Suggestions on practices (often already occurring in many other areas of the world) to facilitate the reuse of MSWI ashes are provided.

1. Introduction

The United States manages approximately 12% of its municipal solid waste (MSW) through combustion (US EPA, 2013a) (also commonly referred to as waste-to-energy (WTE) or municipal solid waste incineration (MSWI)), and while the relative contribution of this technology to overall MSW management is smaller than some European and Asian nations, the larger volume of waste generated in the U.S. makes it one of the largest producers of MSWI ash in the world. Unlike many other nations that practice MSWI, however, little or no ash is beneficially reused in the United States (International Solid Waste Association, 2006). Despite the growing emphasis on sustainable materials management (SMM) by U.S. regulatory agencies (U.S. EPA, 2009a), and the

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experience of MSWI ash recycling in other countries, the majority of ash generated in the U.S. is disposed of in secure landfills. The reuse of MSWI ash (and other thermal process residuals) has been a subject of discussion in the United States for several decades (Wiles, 1996; Wiles and Shepherd, 1999) and continues to be a focus of many who have the desire of developing a circular economy. More recently, at the federal level, the U.S. Environmental Protection Agency (EPA) has promulgated new leaching tests specifically developed to provide a more detailed characterization of waste materials that can be used in a beneficial use assessment (US EPA, 2013b).

From an environmental perspective, the presence of potentially harmful trace elements in MSWI ashes warrants concern, especially in regard to the beneficial use of these ashes. Many elements, including antimony, arsenic, cadmium, lead, and mercury, are sparsely present in MSW yet are concentrated during the combustion process to much higher levels; some, based on their volatile nature, partition largely to the air pollution control residues [defined as the particulate matter captured from the flue gas along with the residues generated from the removal of acid gases and other pollutants (e.g. Hg) during the emission control process (APCR)]. While bottom ash (the heavier portion of the material that is collected from the bottom of the furnace following combustion) contains potentially harmful constituents in non-trivial quantities, MSWI APCRs (herein referred to as fly ash) exhibit concentrations of arsenic, cadmium, lead, and mercury in much greater magnitudes (Chandler et al., 1997). This lends to greater risk associated with the handling and management of MSWI fly ash, and this in part has resulted in the current ash disposal practices seen today in the U.S.

Johannessen (1996) published a legal review of the history of MSWI ash management in the U.S. in 1996. This article came following the Supreme Court decision on the management of MSWI ashes in 1994 (U.S. Supreme Court, 1994) and emphasized the hazardous waste status and delineation of MSWI ash. Also in 1996, Wiles (1996) published an article summarizing the then current state of the knowledge of MSWI ash and its management. More recently, Lam et al. (2010) conducted a review on the reuse of MSWI ash; the review covered the chemical characteristics of bottom and fly ashes and contained a cursory description of reuse in practice, focusing on the technical aspects of reuse scenarios and applications. The specific objectives of this analysis are to illustrate the current state of MSWI ash management in the United States, discuss the environmental and regulatory aspects of its reuse, and present suggestions for ash reuse policy considerations. The authors strive to do this in a manner intended to promote a dialogue on whether MSWI ash recycling should be a target of future development in the United States, and to illustrate what steps could be taken to move the issue forward in the realm of policy.

1.1. *Municipal solid waste incineration in the United States*

In 2010 there were 86 waste to energy facilities operating in the United States; that year those plants combusted approximately 26 million metric tons of MSW (Energy Recovery Council, 2010), corresponding to the production of roughly 6.6 million metric tons of ash, all of which was disposed of in secure landfills (US EPA, 2013a). In the United States fly ash and bottom ash are not managed as separate waste streams, instead a single stream of commingled ash (mixed fly and bottom ash) is produced by combining fly ash and the quenched bottom ash within the four walls of the facility (while recovering the ferrous and non-ferrous metals in process). Disposal of this ash is often in an onsite monofill or landfill that accepts predominantly MSWI ash, to limit landfilling concerns related to co-disposal (ash and MSW disposed of at the same facility). Table 1 displays the elemental composition of commingled ash from the State of Florida over the last decade, alongside this data is the total concentration data of fly and bottom ashes from the United States and Europe. In the commingled ash, arsenic, cadmium, and mercury are in higher concentrations (mg/kg) than in bottom ash alone; this is due to the inclusion of the fly ash that contains these volatile elements in much higher concentrations. Note, the Florida commingled ash data was derived from a test method that determines the environmentally available fraction of the elements within the ash and does not represent the ''total'' elemental composition, reported for the fly and bottom ashes separately.

Though fly ash contains elevated concentrations of the aforementioned trace elements with respect to bottom ash and conventional MSW (due to the volatilization of these elements during the combustion process and the subsequent deposition onto the much smaller mass of APCR, resulting in an enrichment of the heavy metal concentration), and is likely to warrant management as a hazardous waste in the United States, the commingling of MSWI fly and bottom ash produces a waste that can be managed as non-hazardous. Combining bottom and fly ash is not a common practice in other developed countries where combustion is the main avenue for MSW management, in fact it is banned in some countries, as will be discussed below. The in-process mixing technique of fly and bottom ashes is a result of federal (U.S.) hazardous waste policy, and while the commingled ash does not warrant management as a hazardous waste, it limits opportunities for the potential for reuse of this material when compared to segregated bottom ash.

2. Methodology: review of ash reuse practices and policy frameworks

This section provides a review of the commonly explored and implemented avenues for reuse of MSWI ash. The physical and environmental behaviors of different ashes have been the subject of much research, as has the life-cycle impact of beneficially using ash in comparison to virgin materials. In general, combustion residuals of various origins are commonly reused in a diverse set of applications, due to the dual benefits of landfill diversion and raw material replacement. These applications include: use as a construction soil or grading material, an ingredient in an industrial process (such as the manufacture of cement), use as a chemical admixture, or use as a soil amendment. Some residuals, such as coal fly ash, exhibit pozzolanic (a material that in the presence of water and a calcium hydroxide source (cement) displays