Waste Management xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Landfill mining: Case study of a successful metals recovery project

Travis P. Wagner [a,*], Tom Raymond [b]

[a] Department of Environmental Science and Policy, University of Southern Maine, 106 Bailey Hall, Gorham, ME 04038, USA
[b] ecomaine, 64 Blueberry Road, Portland, ME 04102, USA

ARTICLE INFO

Article history:
Received 6 April 2015
Revised 6 June 2015
Accepted 23 June 2015
Available online xxxx

Keywords:
Urban mining
Landfill mining
Incinerator ash
Metals recovery
Ashfill

ABSTRACT

Worldwide, the generation of municipal solid waste (MSW) is increasing and landfills continue to be the dominant method for managing solid waste. Because of inadequate diversion of reusable and recoverable materials, MSW landfills continue to receive significant quantities of recyclable materials, especially metals. The economic value of landfilled metals is significant, fostering interest worldwide in recovering the landfilled metals through mining. However, economically viable landfill mining for metals has been elusive due to multiple barriers including technological challenges and high costs of processing waste. The objective of this article is to present a case study of an economically successful landfill mining operation specifically to recover metals. The mining operation was at an ashfill, which serves a MSW waste-to-energy facility. Landfill mining operations began in November 2011. Between December 2011 and March 2015, 34,352 Mt of ferrous and non-ferrous metals were recovered and shipped for recycling, which consisted of metals >125 mm (5.2%), 50–125 mm (85.9%), <50 mm (3.4%), zorba (4.6%), and mixed products (0.8%). The conservative estimated value of the recovered metal was $7.42 million. Mining also increased the landfill's airspace by 10,194 m^3 extending the life of the ashfill with an estimated economic value of $267,000. The estimated per-Mt cost for the extraction of metal was $158. This case study demonstrates that ashfills can be profitably mined for metals without financial support from government. Although there are comparatively few ashfills, the results and experience obtained from this case study can help foster further research into the potential recovery of metals from raw, landfilled MSW.

1. Introduction

A fundamental principle of sustainable materials management is to maximize the utility of materials to the greatest extent possible with disposal only as the last resort. Yet society has not yet fully embraced this fundamental principle. Between 1980 and 2002, collectively there was a 36% increase in global resource extraction; extraction of metals increased by 56% (Behrens et al., 2007). The US has consumed more resources in the past 50 years than in all previous history; it consumes 57% more materials than in 1975 and the vast majority of materials currently consumed are non-renewable (US EPA, 2009).

A consequence of this increased consumption is the simultaneous increase in the total and per capita generation and subsequent disposal of municipal solid waste (MSW). Estimates of the annual global generation of MSW vary, but are significant: Lacoste and Chalmin (2007) estimated that the annual global generation rate of MSW is 1.2 billion Mt, Hoornweg and Bhada-Tata (2012) estimated 1.3 billion Mt, and UNEP (2010) estimated between 1.7 and 1.9 billion Mt. By 2025, the estimated global annual generation of MSW will be 2.2 billion Mt (Hoornweg and Bhada-Tata, 2012). The member countries of the Organization of Economic Co-operation and Development (OECD) continue to generate the highest portion of the global amount of MSW (Hoornweg and Bhada-Tata, 2012). The US, an OECD member, generated 227.6 million Mt of MSW in 2012 (US EPA, 2014).[1] Between 1960 and 2012, the total amount of MSW generated in the US increased by 164.3% and the per capita MSW generation rate increased by 64.2% to 1.98 kg per day (US EPA, 2014). The current annual per capita generation rate of MSW in the US is approximately 723 kg, which is the highest in the world.

In spite of the adoption of the waste management hierarchy of reduce, reuse, and recycle for MSW, worldwide, landfilling continues to be the most common management of MSW (Lacoste and Chalmin, 2007). An accurate count on the number of legal landfills and illegal or unregulated dumps worldwide is infeasible.

* Corresponding author.
E-mail addresses: twagner@usm.maine.edu (T.P. Wagner), raymond@ecomaine.org (T. Raymond).

[1] BioCycle's biennial's *State of Garbage in America* (Van Haaren et al., 2010) claim that the US EPA's model underreports the national generation weight of MSW by some 43%.

http://dx.doi.org/10.1016/j.wasman.2015.06.034
0956-053X/

According to Hoornweg and Bhada-Tata (2012), 60% of the MSW generated by OECD countries is landfilled and nearly all of Africa's MSW is landfilled or dumped. In the EU alone there are an estimated 150,000–500,000 closed and active landfills with an average size of 8000 m^2 (Krook et al., 2012). Ratcliffe et al. (2012) estimated that the more than 150,000 landfills in Europe contain 30–50 billion m^3 of waste. In 2012, there were 1908 operating MSW landfills in the US (US EPA, 2014).

The total amount of MSW generated is increasing worldwide, valuable materials continue to be a significant portion of MSW, the per capita generation rate of MSW remains high, and the majority of waste generated continues to be landfilled—we continue to discard significant amounts of underutilized materials, including metals, in landfills. Given the current and expected global demand for materials, especially metals, and the negative environmental, social, and geopolitical aspects of excessive reliance on mining ores, there is recognition that significant amounts of comparatively concentrated, valuable materials reside in relatively shallow surface deposits in landfills that are relatively close to industrial centers with access to transportation. This is especially true for post-1960 landfills which are more likely to have greater percentages of recyclables and contain larger volumes of waste (Hermann et al., 2014). Although the discarding of high-value metals while simultaneously mining for these same materials is a highly unsustainable practice, the potential to recover these previously disposed metals represents an important resource that can offset the mining of virgin ores. Given this situation, there is increased attention worldwide to the potential to mine landfills to recover metals (Krook et al., 2012).

The objective of this article is to present a case study to address the following research question: Is it possible to successfully mine a landfill to recover a significant amount of metals specifically without financial assistance or mandate from the government?

2. Background on landfill mining

As discussed below, although landfill mining is not a new concept, its success and practice in material recovery have been limited. A contemporary definition of landfill mining is suggested by Krook et al. (2012), "a process for extracting materials or other solid natural resources from waste materials that previously have been disposed of by burying them in the ground." As suggested by Wolfsberger et al. (2014), landfill mining involves the mining of "anthropogenic created deposits," which are used as "secondary raw material mines" because of significant amounts of recyclable and recoverable materials.

2.1. Landfill mining history

An interesting aspect of landfill mining involves the evolution of the motivation to mine landfills. There is general agreement that the first existence of landfill mining occurred in Israel in 1953 with the early focus of landfill mining on the excavation of landfills to reclaim/expand landfill capacity (Savage et al., 1993). Historically, the motivation for landfill mining has been to extend the life of landfills by increasing landfill space, to conduct remediation on problem landfills, to reclaim land, and to extract methane gas (Krook et al., 2012; Frändegård et al., 2013). Interest in landfill mining in the US peaked during the 1990s primarily in response to the US EPA's promulgation of federal regulations that strengthened national, minimum criteria for MSW landfills, which included requirements for liners, leachate collection systems, groundwater monitoring, and remediation (Krook et al., 2012). Regulation, directly or indirectly, has been a constant driver in landfill mining (Van Passel et al., 2012). A Scottish study (Ford et al., 2013) identified 57 reported landfill mining projects worldwide, which included multiple demonstration and research projects; the US had the most projects. According to the Florida Department of Environmental Protection (FDEP, 2009), as of 2009, there were 32 current or former landfill mining projects in the US focusing on remediation of groundwater contamination, increasing landfill capacity and extending landfill life, reducing the cost of closure, and recovery of energy by using landfill materials as refuse derived fuel. However, the most common objective of landfill mining in the US has been to relocate previously disposed of waste from an unlined landfill unit to an adjacent lined unit without processing or recovery of materials (FDEP, 2009). Based on a survey of the literature, the recovery and reclamation of materials has not been the major driver (Ratcliffe et al., 2012).

In the late 2000s, the concept of enhanced landfill mining (ELFM) emerged. A key element of sustainable materials management is the closed loop system. This system involves the recovery and recycling of wastes generated through the creation of consumer products, the recovery and recycling of end-of-life products through urban mining, and the mining of landfills to recover and recycle legacy and future wastes through ELFM (Jones et al., 2013). Although pollution prevention is a foundation for sustainable materials management, ELFM is "the safe conditioning, excavation and integrated valorization of (historic and/or future) landfilled waste streams as both materials...and energy..., using innovative transformation technologies and respecting the most stringent social and ecological criteria" (Jones et al., 2013). In the end, only the non-recyclable portion of the landfill contents need to be relandfilled. With ELFM, landfilling is seen as long-term storage and represents the collection of billions of Mt of resources. Redefining landfills as storage units as opposed to disposal units, and the fact that recycling and energy technologies have and continue to improve in effectiveness and efficiency, there are increasing opportunities to recover the materials and energy value stored in landfills (Jones et al., 2013). Thus, it is a framework that views all the materials and energy potential in a landfill as a potential resource as compared to traditional landfill mining that focuses on specific resources such as metal.

Interest in landfill mining continues to focus on assessing its feasibility through government sponsored pilot studies investigating methods to reduce the cost while maximizing the recovery of valuable materials (Krook et al., 2012). However, thus far, costs generally have exceeded the revenues of recovered materials in standard MSW landfills making them infeasible without government mandates or funding (see for example, Hull et al., 2005; Van Vossen and Prent, 2011; Winterstetter et al., 2014).

2.2. Landfill mining potential in the US

The quantities of recoverable materials that have been landfilled is an important consideration is the quality and lost utility of the landfilled materials, especially refined metals. From a sustainable materials perspective, metals are important because they are not a renewable resource and their demand and consumption are continuously increasing meaning that the natural supply is decreasing rapidly (Kuo et al., 2007; Hermann et al., 2014). In 2012, there were 1908 operating MSW landfills in the US, which represented a 90.5% decrease in operating landfills since 1977 (US EPA, 1977, 2014). Between 1988 and 2005, 6270 MSW landfills closed in the US (US EPA, 2013). Between 1960 and 2012, more than 6 billion Mt of MSW were landfilled in the US (US EPA, 2014). In 2012, of the 227.6 million Mt of MSW generated in the US, only 34.5% of it by weight was recovered (compared to 6.4%