LANDFILL MINING - CASE STUDY: Characterization and treatment of excavated waste from Austrian sanitary landfill sites and estimation of the resource potential

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ABSTRACT

Noticeable changes in the availability of mineral raw materials (e.g. ores, coal) were observed during the last years due to the enormous raw material demand of developing countries (e.g. China). These led to an evident scarcity of raw materials, highly competitive markets and to a significantly aggravated accessibility to mineral resources. Landfill Mining represents one possibility for exploitation of secondary raw materials, as landfill sites can contain significant amounts of potentially recyclable and recoverable energy materials (REM). In this regard, to evaluate the secondary raw material potential (resource potential) of Austrian landfills, two sanitary landfill sites were chosen for closer investigation. The scope of this investigation constituted waste characterization by realization of sorting analyses of excavated waste and a large scale mechanical treatment experiment. The results obtained by the hand sorting show that approximately 32 - 52 w% of the total deposited amount consists of REM theoretically. However, due to a high water content of the materials (~ 42 %) and a high proportion of fines (68 w%), a proper mechanical separation of these materials is hindered as shown by the large-scale experiment. Consequently, no plastic fraction and about 1 w% metals were recovered compared to 18 w% plastics and 5 w% metals found during hand sorting. To increase the output of REM from mechanical treatment processes, further investigation has to be established in the future.

KEYWORDS

Landfill Mining, secondary raw material, excavated waste, resource potential, waste characterization, sorting analyses, mechanical treatment efficiency

INTRODUCTION

According to the Raw Material Initiative of Austria (Weber et al. 2012), noticeable changes in the availability of primary mineral raw materials (e.g. ores or energy resources like coal and gas) occurred during the last years, due to the enormous demand of developing countries (e.g. China). Furthermore, few resources for specific mineral raw materials (e.g. iron ore and steel refiners, non-ferrous metals or hydrocarbons) are amenable in the European Union and Austria. These led to a distinct scarcity of raw materials, highly competitive markets and to a significantly aggravated accessibility to mineral resources. Consequently, a steady increase of raw material prices has been recorded since 2003, which was only interrupted by the financial crisis of 2008. (Weber et al. 2012)

To decrease the import dependence of Europe and to increase the resource efficiency, recycling must be promoted to reduce consumption of primary raw materials (European Commission – Enterprise and Industry 2010). Hence, in addition to “Mining”, which describes the classical mining as exploration, extraction and treatment of mineral resources, the impact of “Urban Mining” becomes increasingly important. One branch of Urban Mining is Landfill Mining in which anthropogenic created deposits are used as secondary raw material mines, as they can contain significant amounts of potentially recyclable and recoverable energy materials (REM). In course of a landfill mining project deposited materials are dug out, sorted and treated to obtain a possibly high amount of excavated waste which can be used for material or energy recovery. Only the non-recyclable waste (usually the fine fraction) is re-installed in a compressed landfill. Based on the idea of winning potential secondary raw materials out of old landfill bodies, it is assumed that especially metals, glass, minerals and a fraction with a high net calorific value are qualified for recovery. Hence, the sum of all REM i.e. metals, glass, minerals, wood, leather, rubber, plastics, PPC, composites and textiles will be denoted as “resource potential” in the paper.

To obtain a reasonable amount of reusable materials, however, the considered location for a landfill mining project must first be accurately analyzed and assessed. Traditionally, these investigations are mostly based on historical data (e.g. administration files, old business permissions as well as licensing and registration documents, registers or newspapers) or theoretical considerations of waste composition (sorting analyses of waste prior to disposal). Through this approach, the theoretical resource potential and the relative proportion of each REM fraction (e.g. metals and plastics) as well as the amount of non-recyclables (e.g. fines and problematic substances) can be determined. Moreover, potential risks or hazardous substances can be identified and suitable measures taken to promote both, human and environmental safety. The accuracy of these investigations for estimating the amount of REM within landfills is however limited, as the presence of organic compounds in waste deposits allows for chemical and biological degradation processes to take place within bioreactor-type landfill bodies. In these reactions, degradable organic substances are mainly converted to carbon dioxide and water under aerobic conditions and to methane and carbon dioxide under anaerobic conditions. The degradation of these biologically degradable materials (e.g. paper, textile), results in a lower resource potential than predicted using historical data or sorting analyses of waste before disposal. Therefore, to obtain reliable information about the actual onsite composition and condition of a specific landfill body, an initial assessment should include drilling or test pitting followed by classifying and sorting of the excavated materials.

However, as the topic of landfill mining has been raised in Austria very recently, little data about the real onsite composition and condition of Austrian landfill sites (e.g. Knapp & Bockreis (2010)) is available. In this regard, it was tried to estimate the composition and the resource potential by reviewing results of studies concluded elsewhere (see Table 1). It should be noted that for the sake of consistency with the approach of the paper (see chapter "Materials and Methods"), studies included in the table were limited to European sanitary landfill mining projects in which a sieving step (cut-off point) between 35 and 50 mm had been implemented. Furthermore, deposited materials of all mentioned landfills contained non-hazardous waste i.e. mainly household and municipal solid waste as well as less amounts of demolition waste (Nispel 2012, Hogland et al. 1995, Raga & Cossu 2014, BMBF 1995, Hogland 2002).

Results show that the amount of coarse fraction comprises a wide range of 25 – 45 w% and represents a resource potential of approximately 71 – 100 w%. Furthermore it is declared, that the relative proportion of particular materials can differ (e.g. abundance of PPC in the coarse fraction of Hechingen 0.6 w% vs. up to 18.7 w% in Northern Italy), due to varied consumerism, waste accumulation, demographic developments or pre-treatment of waste, even when the landfill sites are located in the same country (e.g. composition of Filborna and Masalycke). As shown in Table 1 the main part of excavated materials is constituted by the fraction of fines with a range of 55 – 75 w% which seem to contain lower amounts of REM (resource potential < 40 w%). To estimate the total resource potential of the particular landfill body, i.e. mixture of coarse fraction and fines, the results provided from Nispel (2012), Raga & Cossu (2014) and BMBF (1995) were recalculated in this paper and subsequently refer to the total amount deposited (see total resource potential in Table 1). Based on the data found in literature, the total resource potential in household and municipal solid waste landfills of central and northern Europe can be roughly estimated with 20 to 52 w% (see Table 1).

However, due to the wide range of the amount of particular REM and non-recyclables shown in Table 1, an exact estimation of the resource potential of Austrian landfill sites based only on data provided by literature seems difficult.

Therefore, in course of the objective project, two Austrian sanitary landfill sites – in Austria defined as "mass-waste landfills" (BMLFUW 2008) – were chosen for closer characterization based on defined criteria (e.g. accessibility, no surface sealing and possibility of using existing operational plants or infrastructure).

As REM need to be separated from non-recyclables before being suitable for material or energy recovery, a treatment process has to be applied after excavation. In general, this is realized by a mechanical process, which separates waste into recyclables, energy recoverable materials and to be disposed of materials. Modern treatment plants, however, are mostly designed for processing one specific waste stream (e.g. household waste) with a certain stream quality. Variations in waste composition can lead to processing problems and it is therefore questionable if excavated waste from landfill sites can be treated in suchlike facilities. Hence, the second aim of the paper was the examination of the separation efficiency (regarding REM recovery) of a conventional state of the art mechanical treatment plant when processing excavated materials. In this regard, challenges and problems which occurred during the process were identified additionally.

Table 1. Summarized literature results on the composition of sieve overflow and underflow fractions of deposited materials at different landfill sites (w%)

Waste Material	Hechingen, Germany (Nispel 2012)		Filborna, Sweden (Hogland et al. 1995)		Northern Italy (Raga & Cossu 2014)*		Schöneiche, Germany (BMBF1995)		Masalycke, Sweden (Hogland 2002)	
	Coarse	Fines	Coarse	Fines	Coarse	Fines	Coarse	Fines	Coares	Fines
Mineral Waste	**12.3**	**13.1**	**19.0**	**-**	**18.5**[3]	**10.6**	**14.9**	**27.7**	**10.3**	**-**
Glass	**1.5**	**5.8**	**0.5**	**-**	**-**		**-**	**6.7**	**0.1**	**-**
Metals	***8.6***	***1.5***	***7.9***	-	***4.0***	***0***	***14.3***	**-**	***4.9***	-
Wood, Leather, Rubber	***5.7***	***1.9***	***15.7***	-	***3.1***	***0.5***	***23.2***	***2.0***	***19.4***	-
Plastics	***32.2***[1]	***8.7***	***19.6***[1]	-	***39.3***	***2.3***	***25.3***	***1.1***	***6.5***	-
PPC	***0.6***	***0.1***	***12.4***[2]	-	***18.7***	***1.4***	***11.9***	***0.3***	***28.7***	-
Textiles	***17.3***	***2.7***	***4.5***	-	***16.4***	***0***	***6.9***	**-**	***1.2***	-
Composites	**0.3**	**0.2**	**-**	**-**	**-**		**3.5**	**-**	**-**	**-**
Problematic Substances	0.2	0.0	-	-	-		-		2.4	-
Others	1.5	0.0	1.8[4]	-	-		-		9.6[4]	-
Sorting Residue	20.0	65.8	18.6	-	-	85.2	-	62.1	16.9	-
Resource Potential (REM)	**79**	**34**	**80**	**-**	**100**	**15**	**100**	**38**	**71**	**-**
Total Resource Potential (REM)	**50**		**20 - 36**		**46**		**52**		**-**	
Further Information										
Sieve size	35 mm		40 mm		50 mm		40 mm		50 mm	
Fines (w%)	65		55 - 75		63		77		-	
Period of filling	1982-2004		1984-1994		1970s-1983		1977-1979		1975-1980[5]	

1 ... Includes Plastics, Milk- and Juice packages

2 ... Includes Newspapers, Office waste and Cardboard

3 ... Includes Glass

4.... Includes Garden waste, Food waste, Nappies and Electronic scrap

5....(Dhir et al. 2003)

* ....Results summarized for materials > 100 and > 50 mm

MATERIALS AND METHODS

In course of the reported project, the resource potential of two selected sanitary landfill sites in Austria was investigated. The scope of this investigation contained the steps of excavation, sampling procedure and hand sorting of the waste samples. A detailed description of the locations, the examination methods applied and the hand sorting process is depicted in the chapter “Landfill Sites and Sorting Analyses”. Furthermore, to evaluate the efficiency of conventional treatment technologies, material from one landfill site (landfill site 1) was fed into a mechanical treatment process. The aim of the large scale experiment was to win information about the recovery rate of REM when processing excavated materials of a landfill body without any pre-treatment. Information on the mechanical treatment process is provided in the chapter “Mechanical treatment”.

Landfill Sites and Sorting Analyses

Landfill site 1 (LFS 1), located in Lower Austria, was operated for tipping of mainly municipal solid waste (MSW) and household similar commercial waste (HCW) from 1982 until 2003. The permitted air space volume for disposal amounts to 950,000 m³ of which 680,000 m³ were filled. The landfill covers an area of about 78,000 m² and is divided into four compartments. The deposited waste was not treated prior landfilling. In course of the objective investigation, six locations (see Figure 1) were chosen for closer investigation based on a geophysical examination. In this regard, bore holes were drilled in April 2013 in compartment 2, which – according to information received from the operator – holds approximately 180,000 tons of MSW and HCW deposited between 1990 and 2000 on an area of 16,800 m².

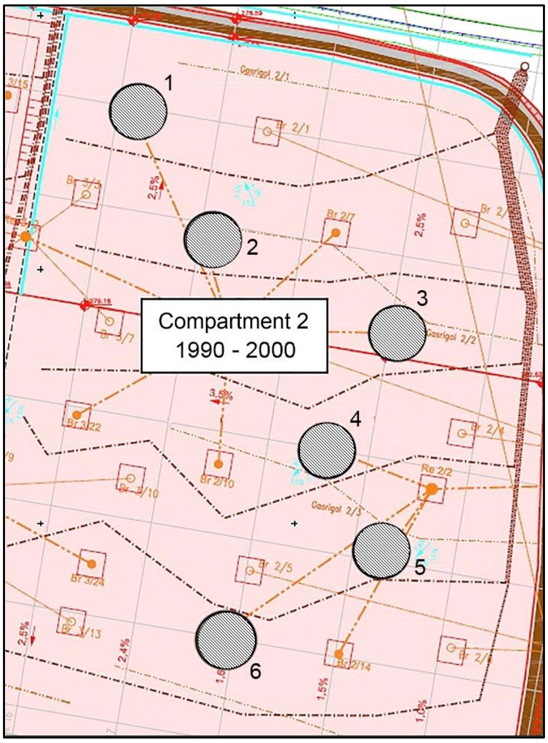

Figure 1. Landfill site 1, compartment 2 with locations of bore holes

Bore holes were established by means of a gripper with a port diameter of 80 cm. The depths of the drilled holes varied from 7 to 18 meters and samples were taken every second meter. In total about

3.5 tons of waste or 32 samples with a volume of 240 liters each (waste density: ~ 0.5 t/m^3) were collected and subjected to a sieving process with a particle size (d_{95}) of 40 mm. Subsequently, sieve oversize and undersize material was hand sorted separately into the following fractions (according to the Federal Waste Management Act of Austria (BMLFUW 2011): iron and non-ferrous metals, plastics, PPC, minerals (e.g. concrete, stones), glass, composites (e.g. nappies), problematic substances (e.g. batteries), wood, textiles, others (e.g. foam materials) and sorting residue (decomposed and unspecified materials, which could not be visually identified). The sieving processes as well as the sorting analyses were executed separately for each of the samples.

Landfill site 2 (LFS 2), located in the federal state of Styria, has been in operation since 1979 and was used for tipping mainly municipal solid and household waste as well as bulky waste until 2003. The landfill body comprises an area of approximately 10 hectares and is divided into four compartments, where compartments one and two (about 3.5 hectare in total) contain the oldest material (deposited between 1979 and 1988). A certain amount of the delivered waste has always been pre-treated by a MBT-process before being disposed of at the landfill. In the MBT-plant, the waste was shredded, led to a magnetic separator and sieved with a d_{95} of 80 mm subsequently. Oversize materials, as well as bulky waste (not treated), were dumped directly. Screen underflow was mixed with sewage sludge, subjected to an aerobic biological treatment and afterwards disposed of as MBT-stabilized compost-like material. To investigate the area accurately and to gain representative waste samples, 50 test pits were excavated in a grid-layout of 25 x 25 meters and a depth of five to six meters in compartments 1 and 2 (see Figure 2).

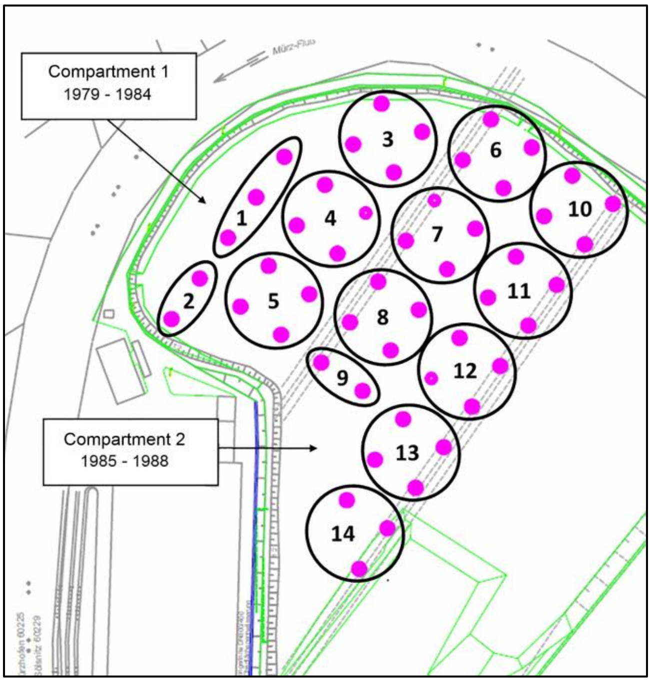

Figure 2. Landfill site 2, compartment 1 and 2 with locations of investigated test pits and mixed samples (1 - 14)

Out of these 50 pits, 14 mixed samples were prepared by means of an excavator for mixing and quartering. About 500 to 700 kg of each mixed sample (in total 8.3 tons) were subjected to a sieving process, in which the materials were sieved with a d_{95} of 40 mm. Subsequently, both grain size fractions were hand sorted into the already mentioned material fractions conformable to the Federal Waste Management Act of Austria (BMLFUW 2011). It shall be declared, that due to an optically determined homogeneity of sieve underflow material (materials < 40 mm) ca. 1.5 tons were led to the hand sorting process.

Mechanical Treatment

To evaluate the REM separation efficiency of conventional treatment facilities for processing of excavated waste materials without any pre-treatment, about 69 tons of waste from LFS 1 were transported to a mechanical treatment plant (MTP). This plant is usually used for conditioning of HCW for recovery of a high calorific fraction or medium quality solid recovered fuels (hot-disc fraction) for the hot-disc incineration chamber in a cement industry (hot-disc technology is extensively discussed in Pomberger (2008)) and/or fluidized bed incinerators and for recovery of a plastic fraction that finally can be used as solid recovered fuels (SRF) in cement production plants. Because of a confidentiality agreement executed between company and university, the detailed process scheme cannot be presented in this paper. The fundamental treatment process, however, comprises the steps of magnetic and eddy current separation, the shredding and sieving of the waste materials as well as the separation of extraneous materials (e.g. concrete, bricks and stones). Thus, the input materials are mechanically divided into the following output flows: iron, non-ferrous metals, plastic fraction, hot-disc fraction, fines, and extraneous materials. All output flows were weighted by means of a weighbridge after processing the materials from LFS 1. To evaluate the REM separation efficiency of the process, the results for the fractions plastic and metals (i.e. iron and non-ferrous metals) were compared with the results gained from the hand sorting process. Due to the use of a different sieving cut-off point and a crushing step implemented upstream of the process, no further results can be compared with the findings from the hand sorting. Additionally, challenges for processing excavated materials in conventional treatment facilities like described above were identified.

RESULTS AND DISCUSSION

Sorting Analyses

The results obtained for waste originating from LFS 1 (summarized for all 32 investigated samples) and LFS 2 (shown separately for sector 1 and 2) can be seen in Table 2. According to the findings, materials > 40 mm (i.e. sieve overflow) add up to approximately 32 w% for LFS 1 and 16 – 23 w% for LFS 2. Hence, the fraction < 40 mm (i.e. sieve underflow) can be estimated with 68 w% (LFS 1) and 77 – 84 w% (LFS 2), respectively. Due to a mechanical-biological pre-treatment (MBP) prior landfilling, the content of fines (< 40 mm) in LFS 2 is higher than in LFS 1.

As the hand sorting results show, the resource potential in the coarse fraction of LFS 1 can be estimated with approximately 91 w%. Similar results were obtained for the coarse fraction of LFS 2 (resource potential between 88 and 91 w%). In both cases, this fraction is mainly formed by plastics and textiles. In comparison to LFS 1 the content of metals in LFS 2 seems very low. This also can be explained by the MBP, where iron has always been separated since the beginning of operation LFS 2.

The amount of REM in fines adds up to 33 w% for LFS 1 and to about 21 – 34 w% for LFS 2 which indicates a lower resource potential compared to the coarse fractions. The portion of non-recyclables (i.e. sum of the fractions problematic substance, others and sorting residue) amounts to approximately 9 w% in the coarse fraction and 67 w% in fines for LFS 1. The portion of non-recyclables in LFS 2 accounts for 66 to 79 w%. Due to the high proportions of non-recyclables in both fractions (determined during the hand sorting process), the total resource potential (i.e. considering REM amount in coarse fraction and fines) can be stated with 52 w% for LFS 1 and 32 to 47 w% for LFS 2.

Table 2: Summarized results on the composition of sieve overflow and underflow fractions of deposited materials at LFS 1 and 2 (w%)

Waste Material	LFS 1		LFS 2 Comp. 1		LFS 2 Comp. 2	
	Coarse	Fines	Coarse	Fines	Coarse	Fines
Mineral Waste	**3.4**	**6.6**	**5.0**	**1.7**	**12.3**	**4.4**
Glass	**0.3**	**1.4**	**0.6**	**0.5**	**0.2**	**0.8**
Metals	***10.8***	***1.9***	***6.1***	***1.8***	***3.1***	***2.1***
Wood, Leather, Rubber	***16.9***	***5.9***	***7.7***	***1.5***	***7.8***	***1.9***
Plastics	***32.2***	***11.6***	***40.2***	***12.5***	***40.0***	***19.5***
PPC	***3.5***	***3.0***	***7.1***	***1.1***	***4.9***	***1.0***
Textiles	***13.8***	***1.9***	***12.6***	***1.4***	***13.8***	***3.2***
Composites	**9.9**	**1.0**	**8.3**	**0.3**	**9.3**	**0.7**
Problematic Substances	0.1	0.1	0.3	0.2	0.5	0.0
Others	2.0	1.1	7.8	0.1	5.0	0.3
Sorting Residue	7.0	65.6	4.2	79.1	2.9	66.0
Resource Potential	**91**	**33**	**88**	**21**	**91**	**34**
Non-Recyclables	**9**	**67**	**12**	**79**	**9**	**66**
Total Resource Potential *	**52**		**32**		**47**	
Further Information						
Sieve size	40 mm		40 mm		40 mm	
Fines (w%)	68		84		77	
Period of filling	1990-2000		1979-1984		1985-1988	

* Incl. Non-Recyclables

Mechanical Treatment

The purpose of the mechanical process was the assessment of the separation efficiency of REM of conventional treatment plants. For this examination material from LFS 1 was fed into the mechanical treatment plant. Results obtained can be seen in Table 3.

Table 3: Average results from hand sorting and processing of waste from LFS 1 in the investigated mechanical treatment facility

Fraction	Hand sorting (w%)	LFS 1 (w%)
Plastic fraction	18.1	0.0
Iron	3.8	0.8
Non-ferrous metals	0.9	0.2

As the results show, no plastic fraction and only about 1 w% of metals (see Table 3) were recovered in the process even when a crushing process step was added upstream. Consequently, based on the hand sorting results, which declare the amount of plastic and metals with about 18 w% and nearly 5 w% respectively (content in regard to the total deposited amount incl. fines), a low recovery efficiency can be assumed when processing excavated materials without any pre-treatment. Main challenges for the separation efficiency of REM were constituted by the condition of the excavated waste as well as its composition. Materials from LFS 1 were mixed, highly intertwined and showed a high water (average content of 42 %) and fines content (~ 68 w%) which led to agglomeration and hindered a proper separation of REM materials. Furthermore, to prevent congestion of the running belt-conveyor, only a relatively small amount of excavated materials (compared to HCW) could be fed into the machinery at a time, which in turn negatively impacted time efficiency and throughput rates. Additionally, to avoid spreading of impurities and contaminants (e.g. heavy metals) thorough cleaning of the used aggregates seems necessary after processing excavated landfill waste.

CONCLUSION

In light of the results achieved from previous landfill mining projects and the findings from sorting analyses reported in this paper, the average resource potential of sieve overflow materials (cut-off point around 40 mm) of sanitary landfill sites in Austria can be estimated with a range of 88 - 91 w%. Furthermore, it was shown that the resource potential of fines (< 40 mm) is very low (21 – 34 w%) and therefore a separation of this fraction (e.g. sieving) seems advisable.

However, as it was revealed by a large-scale mechanical treatment experiment, the separation of REM from excavated waste without any pre-treatment of the materials is difficult due to a high water (average content of 42 %) and fines content (~ 68 w%). Accordingly, only small amounts of excavated materials could be led to a conventional mechanical treatment process at once to prevent stagnancy of the running belt conveyor. Moreover, it was found that due to agglomeration, the separation of REM was hindered which resulted in a very low recovery efficiency compared to hand sorting results. Consequently now plastic fraction and only about 1 w% of metals were found, compared to 18 w% (plastics) and about 5 w% (metals) recovered during hand sorting.

Additionally, up to this point, it is not certain whether the potential secondary raw materials can be used for an effective material or energy recovery, as the quantity and quality of recovered REM can differ, attributed to different onsite conditions (e.g. water content, nutrition supply or temperature), varied consumerism, waste accumulation, demographic developments or pre-treatment of waste prior to landfilling. In this regard, further characterization of the waste has to be conducted by means of chemical analyses. Furthermore, to investigate the influence of different treatment and separation technologies (e.g. drying) on the quality of the materials, other large-scale experiments (mobile and stationary treatment) and software simulations shall be accomplished in the future.

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