NEW-MINE

EU TRAINING NETWORK FOR RESOURCE RECOVERY THROUGH ENHANCED LANDFILL MINING

European Training Network for Resource Recovery Through Enhanced Landfill Mining (NEW-MINE)

D1.1 Final report on WP Innovative landfill exploration and mechanical processing

This project has received funding from the European Union's EU Framework Programme for Research and Innovation Horizon 2020 under Grant Agreement No 721185 - http://new-mine.eu/

Confidential

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1. Introduction and objectives

There are between 150,000 and 500,000 landfill sites in the EU-28[1]. Whereas most of the still-operational landfills are "sanitary" landfills equipped with liner systems as well as collection and treatment systems for gas and leachate, and several countries prohibited the landfilling of untreated municipal solid waste (MSW), **more than 90 % of closed landfills are "non-sanitary" landfills**[2] which have poor or no protection technologies and might cause distinct environmental problems.

For the management of closed MSW landfills different options exist (Figure 1).

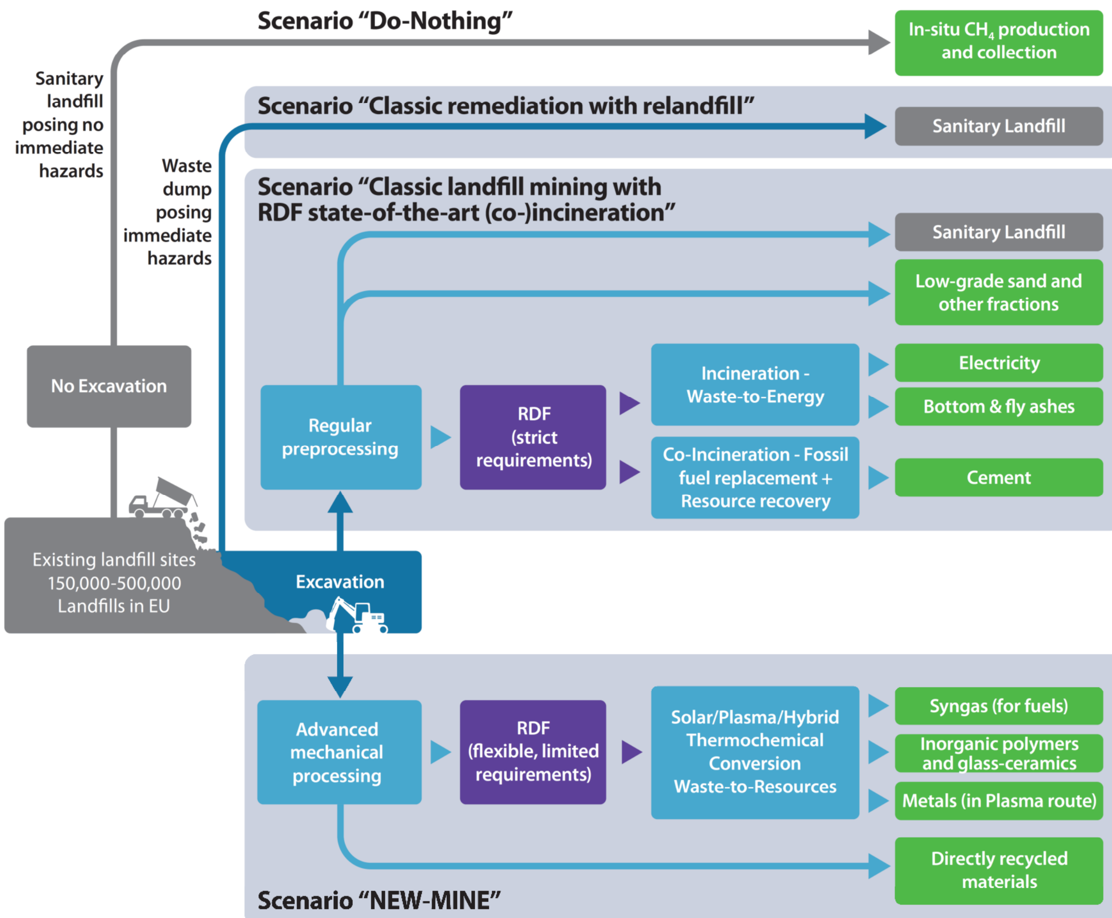

Figure 1. Comparison of different scenarios for landfill management.

State-of-the-art is "landfill aftercare" which includes collection and treatment of landfill gas and leachate, but also advanced methods such as focused irrigation[3]. However, for many old landfills no accruals for landfill aftercare have been created, which results in a "Do-Nothing" scenario. In some cases contaminated sites have resulted from disposal of MSW which require remediation, either ex-situ or in-situ[4]. "Classic remediation" costs in the EU-28 account for €100 billion to €1 trillion[5]. **Landfill**

[1] Jones et al (2013) *Journal of Cleaner Production* 55, 45-55
[2] Bottom-up inventory assembled by EURELCO, http://www.eurelco.org/infographic
[3] Pöschl et al. (2019) *Geophysical Research Abstracts* 21, 1
[4] Sedlazeck et al. (2020) *Environmental Science and Pollution Research* 27, 14465-14475
[5] Personal communication Eddy Wille, Flemish Public Waste Agency

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mining[6] might cover a part of the costs for ex-situ remediation. "Classic Landfill Mining" (LFM) involves the excavation and separation of the waste into metals and refuse derived fuel (RDF). However, as the price for RDF is negative and most of the excavated material needs to be re-landfilled, LFM is commonly not economically feasible[7].

Comprehensive research has been conducted on the excavation of landfilled MSW[8], the processing of excavated waste using state-of-the-art technology[9], the quality of the produced RDF[10] and the combined economic, ecological and socio-economic evaluation of LFM[11]. **Longstanding knowledge gaps** exist regarding the upstream and downstream methods, i.e. geophysical exploration and thermochemical conversion and beneficiation of its residues, respectively, as well as regarding the application of novel processing technologies. Therefore, the **objective** of NEW-MINE is to close these gaps to valorize a larger share of excavated MSW (**Enhanced Landfill Mining, ELFM**)[1].

2. Methods

Work package (WP) 1 covers the **geophysical exploration** and the **mechanical processing** of the excavated waste. In Exploration, electromagnetic and magnetic methods, as well as corresponding probabilistic data inversion approaches, were investigated and applied to several landfills and reference materials. Test excavations were conducted at **Halbenrain landfill**, Austria, and **Mont-Saint-Guibert (MSG) landfill**, Belgium. State-of-the-art mechanical biological treatment (MBT) was applied at Halbenrain, whereas at MSG a combination of a **novel ballistic separator** and lab-scale processing was tested. The light fraction of the windsifter (Halbenrain) and the 2D fractions of the ballistic separator (MSG) represent calorific fractions (Figure 2) delivered to WP 2[12,13].

[6] Krook et al (2012) *Waste Management* 32, 513-520
[7] Winterstetter et al (2015) *Resources, Conservation and Recycling* 96, 19-30
[8] Raga et al (2015) *Waste Management* 46, 420-429
[9] Wolfsberger et al (2016) *Waste Management & Research* 34(4), 356-367
[10] Wolfsberger et al (2015) *Waste Management & Research* 33(11), 962-974
[11] Hermann et al (2016) *Waste Management & Research* 34(11), 1157-1163
[12] Zaini et al (2017) *Energy Procedia* 142, 723-729
[13] Zaini et al (2019) *Waste Management* 97, 149-163

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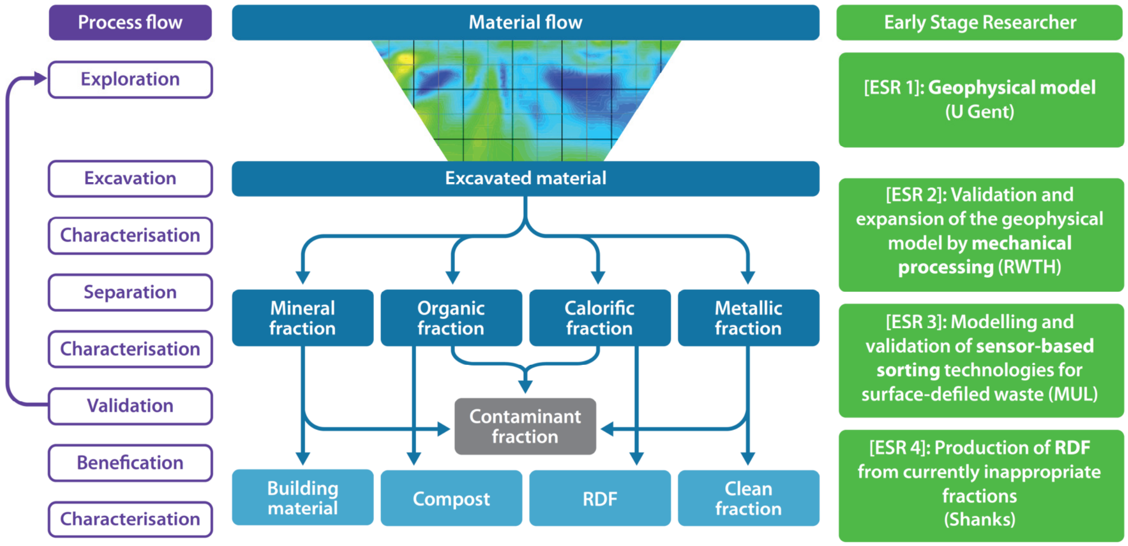

Figure 2: Methodology of WP 1.

The windsifter heavy fraction and the 3D fractions were sorted into a mineral and a calorific fraction using **near-infrared (NIR) sorting**. The fine fractions (<90 mm) were screened and, after magnetic separation, a nonferrous metal (NFM) fraction was recovered by eddy-current separation and delivered to WP 3[14]. The non-metallic fractions were divided into a mineral and a combustible fraction using a windsifter and, finally, analysed for utilization as recycled building material or RDF. The finest fractions (<4.5 mm) were characterized for **pseudo-total contents, leachability and mineralogy,** and their suitability as soil substitute and for low-aftercare re-landfilling was evaluated.

3. Results

Geophysical exploration at the MSG landfill using induction methods (electromagnetics) yielded an accurate **prediction of the boundary between construction and demolition (C&D) and MSW** (Figure 3). On the other hand, a straightforward correlation between iron content and magnetic susceptibility of waste mixtures was not found[15]. However, fundamental studies on geophysical measurement sensitivity and depth of investigation of geophysical data[16], the application of a Kalman ensemble generator (KEG) to 1D probabilistic multilayer inversion of frequency-domain electromagnetic (FEDM) data[17], the extension of FDEM forward and inverse modelling by systematic error parameters[18], as well as joint inverse modelling of FDEM and direct current (DC) data[19], might be used in the future to better characterize landfills prior to excavation as anthropogenic resources with respect to quality, quantity and "bonitaet"[20].

[14] Lucas et al (2019) *Detritus* 8, 79-90
[15] Vollprecht et al (2019) *Detritus* 8, 31-46
[16] Bobe et al (submitted) *Geophysical Prospecting*
[17] Bobe et al (2020) *IEEE Transactions on Geoscience and Remote Sensing* 58(5), 3287-3297
[18] Bobe et al (2019) *International Workshop on Gravity, Electrical and Magnetic Methods and Their Applications,* 312-315
[19] Bobe et al (submitted) *Algorithms*
[20] Fettweis et al (1985) *Mitteilungen der Österreichischen Geologischen Gesellschaft* 78, 23-40

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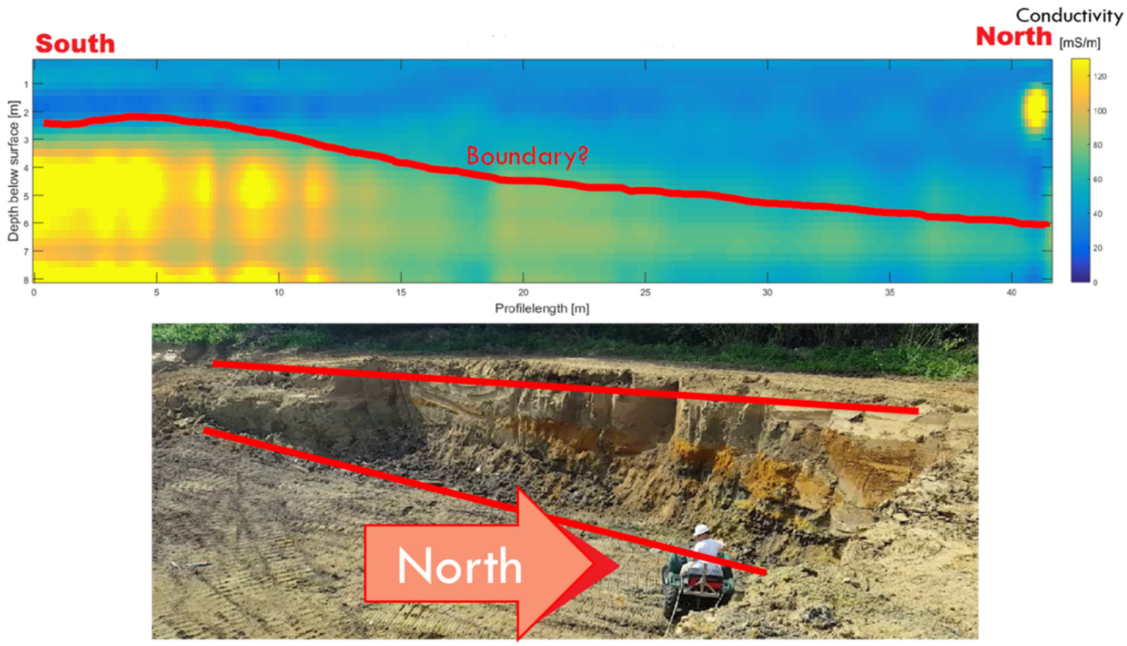

Figure 3: Results of an induction survey at MSG landfill (top) and the corresponding profile in the pit after excavation.

Excavation, processing and characterization of wastes from Halbenrain[21] and MSG[22] landfills demonstrated that both processing chains are suitable to recover metals and calorific fractions, but **ballistic separation** has advantages regarding effectiveness, wear and energy consumption. The **heavy fraction** of the windsifter and the **3D fractions** of the ballistic separation were mainly composed of mineral materials, but the purity was insufficient. Based on studies on the effect of surface roughness and moisture[23], mechanical delabelling[24], oxide layers[25], as well as throughput rate and input composition[26] recipes for **sensor-based (NIR) sorting** using were developed, whose application increased the purity to up to 99.6 wt%. The share of calorific materials in the **2D fractions** was only 39 to 55 wt%, and only 70 wt% of the metals in the NFM fraction occur in the metallic state[14]. Based on two literature studies[27,28], a processing scheme for the **fine fractions** <90 mm of MSG landfill was developed[29,30], which yielded 9 to 13 wt% of calorific fractions exceeding Austrian limit values of As, Cd, Co, Hg and Pb for co-incineration, and 36 to 37 wt% mineral fraction exceeding the limit values of hydrocarbons, Cd, Pb, Zn, NH_4^+ and anionic surfactants for recycled building materials[31]. In the fine fractions <4.5 mm, pseudo-total contents of Cu, Zn, Cd, Hg and Pb and leachable contents of Ni exceeded Austrian limit values for the production of soil substitutes from wastes. EPMA and XRD results revealed that the removal of Pb- and Zn-containing phases would be highly challenging due to the diverse mineralogy and fine grain size of few µm[32] (Figure 4).

[21] García Lopez et al (2018) *Detritus* 2, 29-45
[22] García Lopez et al (2019) *Detritus* 8, 5-23
[23] Küppers et al (2019) *Waste Management & Research* 37(8), 843-850
[24] Küppers et al (2019) *Detritus* 6, 39-46
[25] Pfandl et al (2020) *Waste Management & Research* 38(2), 111-121
[26] Küppers et al (2020) *Detritus* 9, 59-67
[27] Hernández Parrodi et al (2018) *Detritus* 2, 42-62
[28] Hernández Parrodi et al (2018) *Detritus* 3, 19-29
[29] Hernández Parrodi et al (2019) *Detritus* 8, 47-61
[30] Hernández Parrodi et al (2019) *Detritus* 8, 62-78
[31] Hernández Parrodi et al (2020, in press) *Detritus*, 1-18

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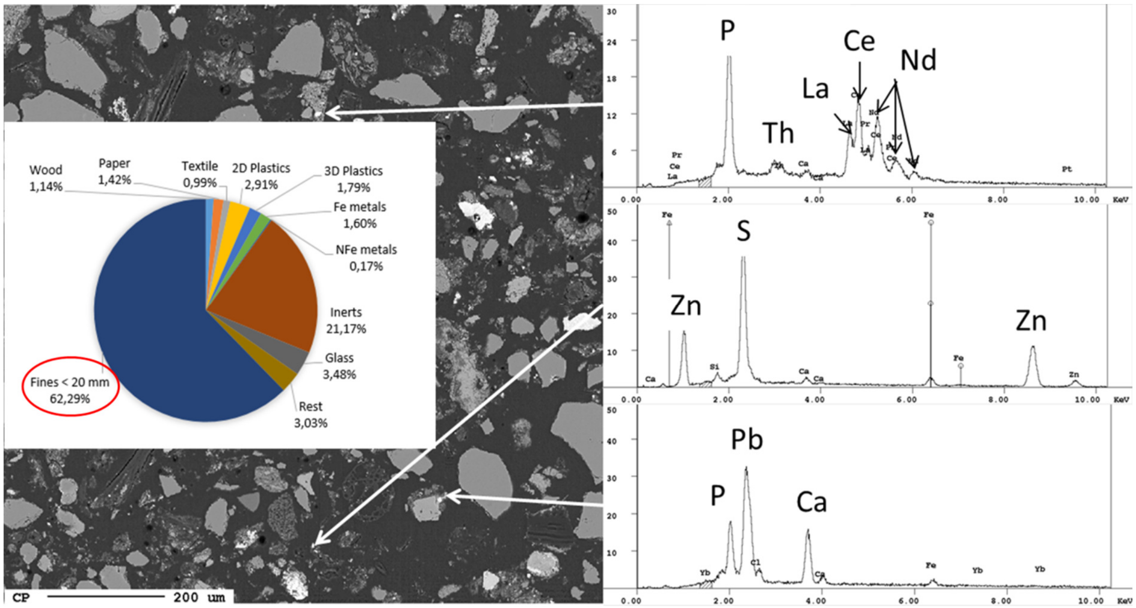

Figure 4: Material composition of the excavated waste from MSG landfill (pie chart), backscattered electron image (left) and energy-dispersive X-ray (EDX) spectra of heavy metal bearing mineral phases in the fine fraction (modified after [32]).

In summary, considering the average composition of the MSG landfill (Figure 4), only **1.8 wt%** of the material, the metals, **may be recycled**, and only **8.3 wt%**, the calorific fractions, **may be used for energy recovery**. Due the lack of specific overarching legislation at EU level, the extent of the valorization of the inert and organic fractions, i.e. the **remainder of the material**, is still largely dependent upon national and local regulations[31,32].

4. Conclusions and lessons learnt

Geophysical exploration methods using novel data inversion approaches may help to identify landfills suitable for ELFM, and **novel processing technologies** for excavated materials may increase yield and purity of calorific and mineral fractions. However, novel findings in these fields have **limited effect on the feasibility of ELFM projects** for three reasons:

Firstly, **contaminants**, especially heavy metals, hindering the valorisation of calorific fractions for co-incineration and of mineral fractions as recycled building materials or soil substitutes, are neither explored by geophysical methods nor sufficiently removed by processing techniques. Since waste management aims firstly for the protection of human health, secondly for the protection of the environment, and only in third regard for resource efficiency, the **removal or immobilisation of contaminants** from wastes is a prerequisite for a sustainable circular economy. Removal would be highly challenging due to the diverse mineralogy and fine grain size of heavy-metal bearing mineral phases[32] whereas **immobilisation heavy metals in stable crystalline or glassy phases** has been investigated in WP 3[33] and may justify ELFM projects from an ecological perspective.

Secondly, the most valuable fraction, NFM, typically has a very low share in MSW landfills and the large fractions have a very low value, even if they are not contaminated. This applies especially to the soil-like **fine fraction**, considering that in Austria 76 % of all excavated soils are landfilled and even for

[32] Vollprecht et al (2020, in press) *Detritus*, 1-18
[33] Rabelo Monich et al (2018) *Journal of Cleaner Production* 188, 871-878

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the highest quality class this applies to 69 %[34]. It has to be mentioned that the **manufactured products have to compete**, regarding price and quality, **with those obtained from primary raw materials**, which is highly challenging considering the high processing costs, e.g. for the sensor-based and thermochemical technologies, and due to the still remaining variable and impure chemical composition, the NEW-MINE approach has been controversially discussed[35].

And thirdly, the **industrial application** of the employed novel methods as well as excavation and on-site processing **in a bigger scale** need further development due to the logistic challenges and specific requirements for a semi-mobile processing. In this context it has to be mentioned that knowledge of the composition and origin of the waste (MSW, C&D, etc.) is necessary to evaluate the possibilities of ELFM in each landfill as high varieties in the different landfills as well as in different sections of the same landfill are one of the main influences on the economics of ELFM. Therefore, the results of full-scale (E)LFM can significantly differ with respect to those obtained in the NEW-MINE project, which was mainly performed in laboratory, small and pilot scales.

However, the results of WP 1 are **highly relevant** for the utilisation of geophysical methods and processing technologies **outside the ELFM context**, e.g. for mining exploration and mechanical processing of lightweight packaging waste, respectively. Therefore, it seems likely that future research on the investigated technologies will completely decouple from the ELFM framework.

[34] Bundesministerium für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie. Die Bestandsaufnahme der Abfallwirtschaft in Österreich. Statusbericht 2020.
[35] Quicker (2019) *Müll und Abfall* 5, 221

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