FEASIBILITY STUDY SUSTAINABLE MATERIAL AND ENERGY RECOVERY FROM LANDFILLS IN EUROPE

W.J. VAN VOSSEN*, O.J. PRENT*

* *Royal Haskoning, P.O. Box 525, 5201 AM 's-Hertogenbosch, The Netherlands*

SUMMARY: The ultimate ambition is a world without waste, which is the ideal situation according to the principle of Cradle to Cradle®. From that perspective and also taking into account the scarcity of raw materials and (rare) metals, it can be justified to examine the added value of recycling our 'historical' waste, which has been landfilled all over Europe in the last 50 years. Europe counts over a 150,000 landfills, which represents an estimated total volume of 30 to 50 billion m^3 of waste. This huge quantity of waste also represents a huge potential of materials to be recovered and recycled. Therefore this present study focuses on the examination of the technical and financial feasibility of landfill mining by the recovery of materials. The results show that separation techniques are available and are proved in practice. These techniques are able to separate the excavated waste into different waste streams, which can be recovered and re-used. Therefore it can be stated that landfill mining is technically feasible. The cost reduction due to the benefits of only metal recovery can be considered as significant. When compared to the small amount of metals to be recovered (2.5% of the total landfill content), the reduction is 8.2% in the case of complete separation and 18% in the case of partial separation. Nevertheless a huge deficit remains to be covered by additional benefits to make a landfill mining project a profitable one. Benefits such as re-using the freed landfill capacity as new landfill, re-using the landfill area for urban development and last but not least selling of the other recovered material streams can make landfill mining more profitable. Acquiring these additional benefits strongly depends upon specific local circumstances and conditions. In the optimal case, these additinal benefits might compensate the total costs and might generate a return on investment of 10 to 20%. From this point it cannot be excluded that a landfill mining project might become financially profitable.

1. INTRODUCTION

The ultimate ambition is a world without waste, which is the ideal situation according to the principle of Cradle to Cradle®. However it will take some time before this will become reality. In the meantime a transition-process is currently taking place from traditional waste management (recycling, incineration, landfilling) to sustainable material management. Or in other words: a shift in awareness from reducing the negative impact of waste management to the added value of the positive impact of resource recovery and chain management. During this transitional process, and taking into account the approaching scarcity of raw materials and precious metals, we should try to manage our waste as sustainable as possible.

From this perspective it also can be justified to examine the added value of recycling our 'historical' waste, which has been landfilled all over Europe in the last 50 years. In the 27 EUmember states almost 40% of all MSW is still landfilled. In the CEE-countries even more than 75% of waste is landfilled (up to 100% in Bulgari). Europe counts over 150,000 landfills, which represents an estimated total volume of 30 to 50 billion m^3 of waste. This huge quantity of waste also represents a huge potential of materials to be recovered and recycled (MFL[1]), and/or of energy from additional biogas (methane and carbon dioxide) to be recovered using the concept of sustainable landfill management (SLM[2]).

Of course a profitable exploitation of resource recovery and/or energy recovery from landfills depends on a lot of factors, such as the spatial distribution of the landfills, the specific local circumstances such as tax regime, supply and demand of raw materials, and the market prices of raw materials and precious metals. This varies per EU-country. Nevertheless, in times of climate change and an approaching shortage of raw materials and precious metals, it is an opportunity to deal with our existing landfills in an environment-friendly way, fitting in the framework of resource recovery and chain management.

2. OBJECTIVES

The final objective is to examine the technical and financial feasibility and viability of material recovery from European landfills. This is to be based upon an extensive inventory of the number of landfills, volumes and composition of landfilled waste, recyclable waste streams, presence of precious metals, costs and benefits, and so on.

3. BACKGROUNDS, VISION AND STRATEGY

3.1 Landfill categories

1. Old landfills, exploited before 1980 and installed without any measures to protect the environment. All kinds of waste have been disposed (no separation of waste in that period).
2. Present landfills, exploited in the last 30 years. These landfills meet the requirements of the EU-directive (1999) on the landfilling of waste (i.e. bottom- and top liners to avoid inadmissible emissions to groundwater and atmosphere.
3. New sustainable depots to store not yet recyclable products.

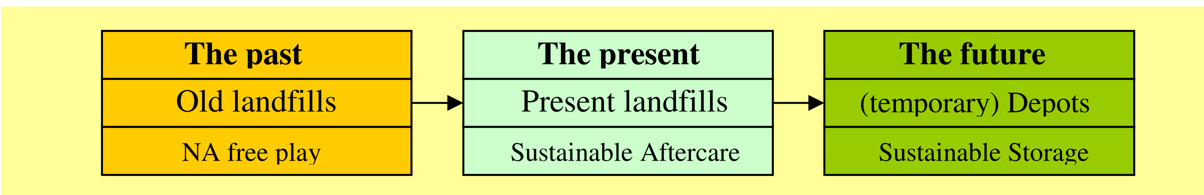


Figure 1. Landfills categories

[1] **MFL** stands for **M**aterials **F**rom **L**andfills

[2] SLM is based upon our **SANA**-model, which stands for **S**ustainable **A**ftercare based on **N**atural **A**ttenuation (NA). NA stands for Natural Attenuation and represents all natural processes, which are able to neutralize concentrations of contaminants to admissible emission or discharge levels. The three dominating processes are microbial decay, chemical precipitation and sorption to organic matter and silt particles.

3.2 Landfill hierarchy

In order to apply the modern waste hierarchy in the landfill management work-field, the landfill hierarchy flowchart as shown in figure 2 was composed. The flowchart clearly shows the most sustainable ways to manage future and current landfills. The landfill hierarchy corresponds with the modern waste hierarchy as composed by the EU. In the landfill hierarchy clear pathways can be seen. The most preferred option is on the top left while the less preffered options are below. Although all three options end at the ROLS-concept, the MFL-concept is obviously the best with respect to the most sustainable solution.

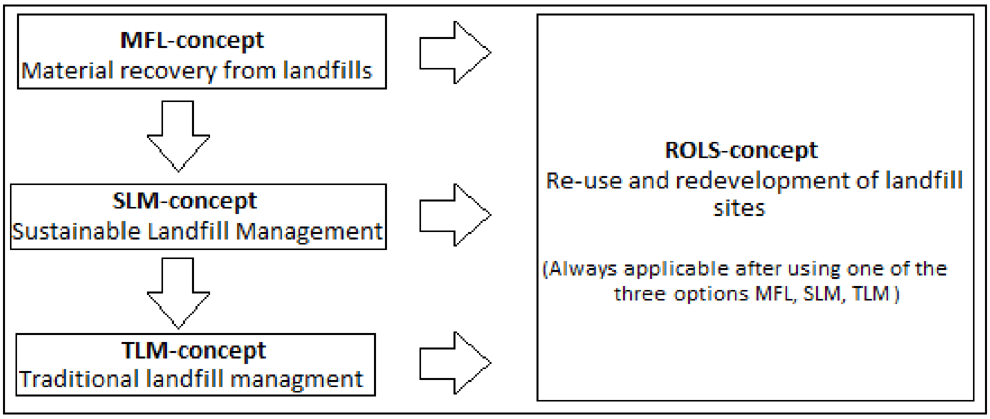


Figure 2. Landfill hierarchy

3.3 The sustainable process

Figure 3 shows an overview of the various possibilities for sustainable solutions for material recovery, from historical waste and waste not yet recyclable.. It is a flowchart, by which the best sustainable option(s) can be selected, given the local circumstances.

Of course the choices to be made depend on the landfill category, the spatial position of the landfill, and the types and volumes of waste streams. Another factor to consider is the local market with respect to demand and supply of energy and recyclables, in relation to the availability and costs of primary raw materials.

3.4 The sustainable products

Applying the steps in the flowchart of figure 3 will result in the following sustainable products:

- recycled raw materials and precious metals from ‘historical waste’;
- recycled raw materials and precious metals in the long term from stored products and waste not yet recyclable;
- a reduction of methane emissions at present landfills by means of sustainable aftercare;
- energy recovery from additional biogas due to sustainable aftercare at present landfills;
- energy recovery by incineration of energy sources, mined from old landfills;
- a clean-up of old landfills (no environmental hazards, no costs of aftercare anymore);
- re-use and redevelopment of former landfill sites into residential and industrial area;
- no burden to next generations due to the unsolved environmental problem of old landfills.

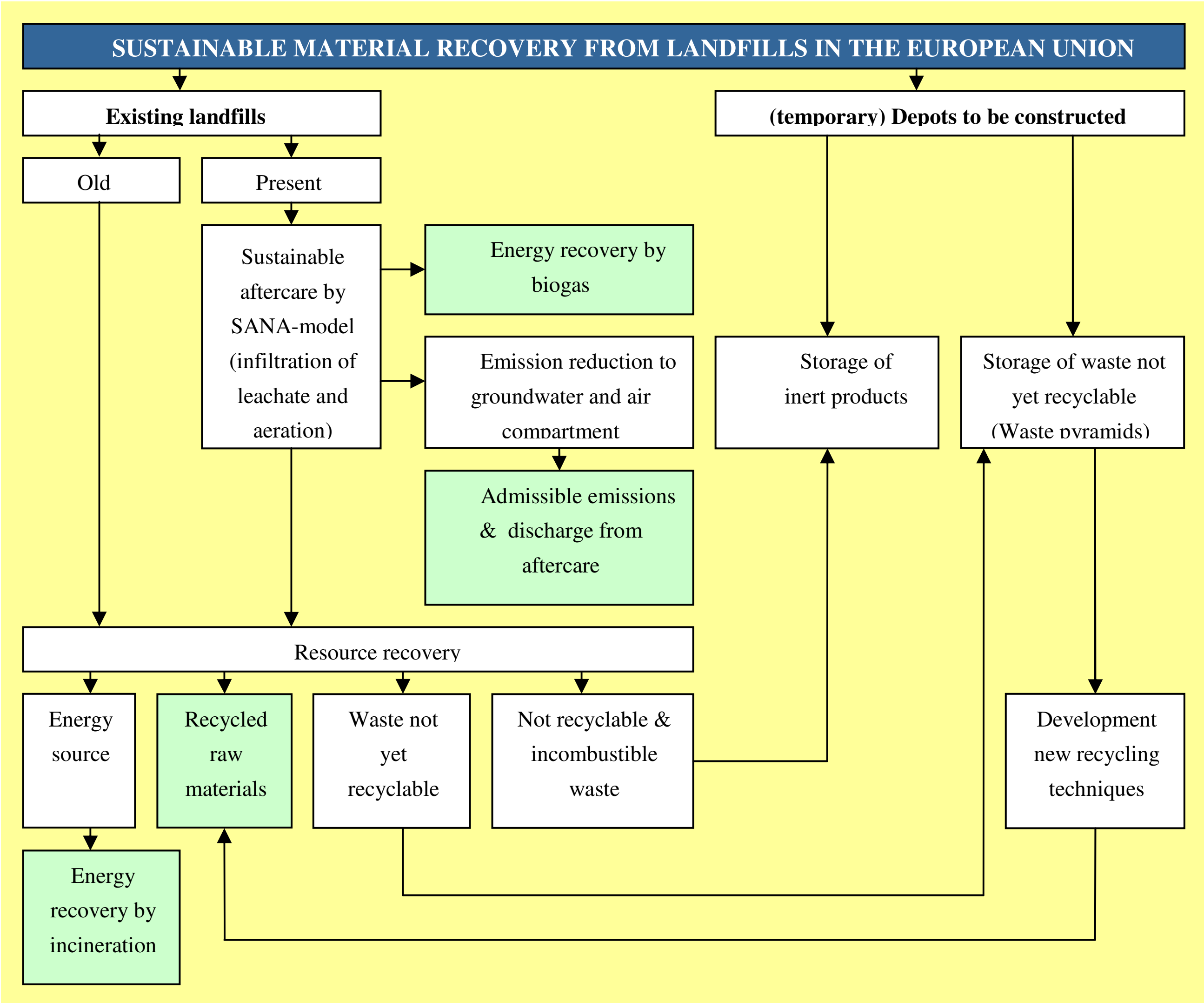


Figure 3. Flowchart sustainable process of material recovery from landfills

4. RESULTS

4.1 Landfill mining projects

The total number of landfill mining projects found in literature is 60. The first landfill mining operation dates back to 1953 at the Hirya landfill site in Israel. From this literature research it became clear that recycling and recovering materials are not the most common goals of the landfill mining projects. Mostly landfill mining projects are focused on increasing the landfill capacity or clearing the area for urban development. The reason for that is the financial benefit.

This study focuses on the technical and economic feasibility of landfill mining with the goal of recycling the contents of landfills. The main reason for this approach is the rising material scarcity. In order to counter the metal scarcity metal extraction from landfills has been researched as an option. The basic goal of a landfill mining project is reclamation of raw materials. The freed area or the freed landfill capacity can necessarably be sold to try to compensate the possible deficit between the cost of the project and the benefit of selling the contents of the landfill.

4.2 Waste composition

From the 60 landfill mining projects found in relevant literature, the average waste composition was calculated. The result is presented in figure 4 and shows the various waste streams in percentages, including the soil fraction. The "soil" fraction is clearly the largest.

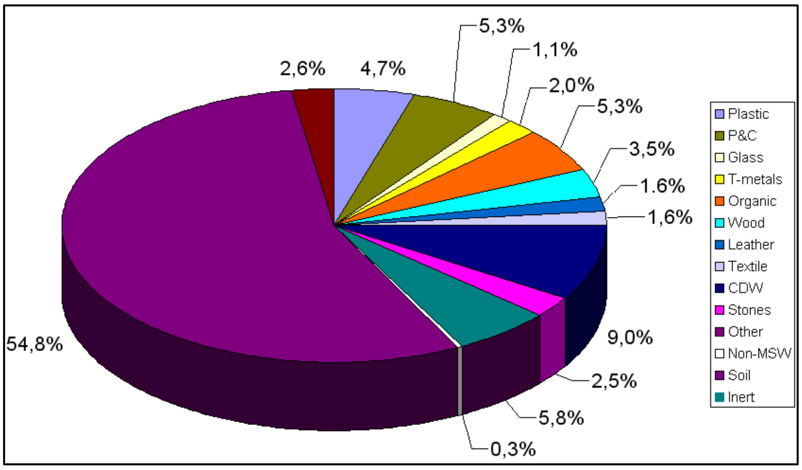


Figure 4. Average waste composition of the standard landfill

The possibility of applying the soil fraction in the close proximity of the landfill mining project will have a big influence on the overall viability of the MFL concept. The reason why the soil fraction is 54.8%, is because the soil fraction includes all the waste with a diameter of less than 24mm. It includes ashes, soil and pieces of the top layer of the landfill.

Table 1 shows the composition of the pure waste with and without the soil fraction, which represents the waste composition of *"the standard landfill"(volume of 500,000 ton and surface of 5 ha)*. The standard landfill composition (Soil/Waste 54,8%/45,2%) is highlighted in green. Furthermore the standard deviation, range and normal distribution are shown. The amount in tons, given in the last line, is based on the standard landfill volume of about 500,000 ton. The standard landfill composition was used to map the viability of the MFL concept. The composition scheme will not be accurate in all situations, but no data could be found to make a more accurate composition scheme.

Table 1. Average waste composition of the standard landfill of about 500,000 ton

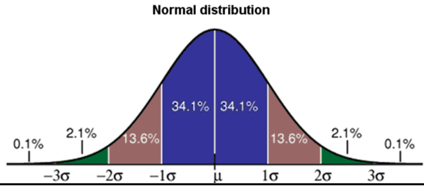
	Plastic	P&C	Glass	T-metals	Organic	Wood	Leather	Textile	CDW	Stones	Other	Non-MSW	Soil	Inert	*F-metals*	*Aluminium*	*Nf-metals*	***Total***
Pure waste (S/W 0/100)	10,3%	11,8%	2,5%	4,1%	11,6%	8,0%	3,5%	3,6%	19,9%	5,5%	12,8%	0,8%	0,0%	5,8%	*3,7%*	*0,3%*	*0,2%*	*100%*
Standard landfill (S/W 54,8/45,2)	4,6%	5,3%	1,1%	2,0%	5,3%	3,6%	1,6%	1,6%	9,0%	2,5%	5,8%	0,3%	54,8%	2,6%	*1,7%*	*0,1%*	*0,1%*	*100%*
St Dev	2,1%	3,3%	1,2%	0,9%	5,6%	2,2%	1,2%	0,8%	7,3%	2,3%	4,2%	0,0%	21,9%	2,7%	*0,8%*	*0,3%*	*0,1%*	
Range	16,0%	17,3%	6,1%	6,8%	23,8%	11,8%	6,5%	4,5%	32,3%	11,9%	23,2%	2,0%	0,0%	10,2%	4,0%	1,7%	0,2%	
Amount in tons	23010	26511	5502	10004	26511	18008	8003	8003	45019	12505	29012	1501	274116	13005	8504	500	500	

Legenda

P&C	Paper and cardboard
T-metals	Total metals (ferrous, non-ferrous and aluminium)
CDW	Construction and demolition waste
Non-MSW	Non municipal solid waste
F-Metals	Ferrous metals
Nf-metals	Non Ferrous metals
NA	Data not available
S/W	Soil to waste fraction
St Dev	Standard deviation

*Total may nog add to 100% because of rounding off of numbers

Normal distribution



4.3 Waste separation

In order to be able to separate the waste as completely as possible, the following sequential separation steps are considered. Handpicking, shredder, drum sieve, magnet, drum separator, eddy current and air knife. The waste remaining after complete separation is relandfilled and/or incinerated. Table 2 shows the various separation steps, the resulting waste stream per separation step and the costs (Dutch market) of each separation step.

Table 2. Separated waste streams per separation step and costs per separation step

Separation step	*Separated waste streams*	*Costs per step (€/ton)*	*Cumulative costs (€/ton)*
Handpicking	Non processables	1	1
Shredder		10	11
Drum sieve	Soil	3	14
Magnet	Ferrous metals	3	17
Drum separator	Paper, plastic , light fraction C&D, stones, glass, heavy fraction Wood, organic, textile, medium fraction	7	24
Eddy current	Non ferrous metals	6	30
Air knife	Plastics , wood	15	45

After the separating processes the waste is split in multiple waste streams. The application of waste differs per waste stream. Ferrous and non-ferrous metals can be sold to metal recyclers and scrap yards. The non-processables will have to be re-landfilled. The inert, C&D (contruction & demolition waste), glass, soil and stones can be applied as construction materials. Organic materials can be used in an incinirator or a fermentation installation in order to generate thermal energy or biogas. Plastic might be applied in the recycling plants depending upon the quality of the plastic.

4.4 Financial analysis (costs and benefits)

Financial calculations were executed for complete separation as well as for partial separation. The first scenario of complete separation counts for all the costs of separation up to € 45/ton. The second scenario only counts for the cost of seperation up to the steps which results only in the separated ferrous metals. These separation costs are limited to € 17/ton. Before the waste can be separated, standard costs have to be made. These standard costs are presented in table 3 and have to be made in order to make any landfill mining project possible.

Table 3. Standard costs (Dutch situation)

Action	*Costs*	*Unit*
Preparation work	€ 200.00	In total
Construction and Environmental permit	€ 80.00	In total
Unforeseen costs	€ 1.000.000	In total
Excavation	€ 5	Per ton
Transport on-site	€ 2.50	Per ton
Transport off-site	€ 70	Per truck (21m3)

Of course also varying benefits and costs are selected. The varying costs linked to the MLF concept are the costs of applying or selling the reclaimed materials. The benefits vary in unit rate due to location differences, quality of the waste stream, purity of the waste stream and to the market value of the materials. In table 4 the benefits or costs per separated waste stream are given with an average amount. Only the benefits of metals have been taken into account in order to meet the focus of this study, which is to get insight in the contribution of metals to the viabilty of the MFL-concept. This does not necessarily mean that there are no financial benefits to other waste streams.

Table 4. Costs and benefits of separated waste streams (standard landfill of 500,000 ton)

Material stream	*Amounts of waste stream*	*Cost of separation*	*Total cost of separation*	*Cost / benefit*	*Unit rate (per ton)*	*Total costs/ Total benefits*
Non-MSW	1.5 kton	€ 1/ton	€ 1.5 thousand	Cost	€ 5.00	€ 7 thousand
Other	29 kton	€ 14/ton	€ 0.4 million	Cost	€ 65.00	€ 1.9 million
Soil	274 kton	€ 14/ton	€ 3.8 million	Cost	€ 30.00	€ 8.2 million
Ferrous metal	8.5 kton	€ 17/ton	€ 0.14 million	Benefit	€ 250.00	€ 2.2 million
P&C	26.5 kton	€ 24/ton	€ 0.63 million	Cost	€ 65.00	€ 1.7 million
Non-ferrous metal	1 kton	€ 30/ton	€ 0.03 million	Benefit	€ 500.00	€ 0.5 million
Stones	12.5 kton	€ 35/ton	€ 0.44 million	Cost	€ 15.00	€0.18 million
CDW	45 kton	€ 35/ton	€ 1.6 million	Cost	€ 15.00	€ 0.68 million
Glass	5.5 kton	€ 35/ton	€ 0.2 million	Cost	€ 15.00	€ 82 thousand
Textile	16 kton	€ 35/ton	€ 0.6 million	Cost	€ 65.00	€ 1 million
Organics	26.5 kton	€ 35/ton	€ 0.9 million	Cost	€ 65.00	€ 1.7 million
Plastic	23 kton	€ 35/ton	€ 0.8 million	Cost	€ 65.00	€ 1.5 million
Wood	18 kton	€ 35/ton	€ 0.6 million	Cost	€ 65.00	€ 1.2 million

Based upon the above mentioned specifications of the standard costs, the costs of separation and the varying costs and benefits, the final outcome of the financial calculations are made. These are presented in table 5.

Table 5. Final cost-benefit analysis landfill mining scenarios (standard landfill)

Scenario	*Total costs*	*Total benefits (only metals)*	*Deficit*	*Cost reduction due to metal recovery*
Partial separation	€ 12.9 million	€ 2.3 million	€ 10.6 million	18%
Complete separation	€ 31.6 million	€ 2.6 million	€ 29.0 million	8.2%

In both scenarios the costs outweigh the benefits. This is due to the fact that only the benefits of metal recovery were taken into account. Compared to the small amount of metal to be recovered (only 2% of the landfill content), the cost reduction due to the benefits of metal recovery can be considered as significant. Nevertheless a huge deficit remains to be covered by additional financial benefits to make a landfill mining project a profitable one. The additional benefits might come from income generated by re-using the freed landfill capacity for landfilling again, from re-using the landfill area for urban development and last but not least from selling the other recovered waste streams. The potential of the additional benefits is presented in table 6.

Table 6. Additional benefits for standard landfill at complete separation (Dutch market)

Additional benefits	*Estimated unit rate*	*Total benefit*
Re-use freed landfill capacity	Sold for € 80/ton	€ 10 million
Re-use landfill area for urban development	Sold for € 200/m^2	€ 10 million
Plastics	Sold for € 7/ton	€ 3,1 million
CDW	Sold for € 10/ton	€ 1,13 million
Stones	Sold for € 10/ton	€ 0,3 million
Soil	Sold for € 10/ton	€ 10 million
Reduction in process costs of materials	Process cost reduction to € 15/ton	€ 6,93 million
Avoided aftercare costs	Only in case of complete mining	€ 1 million

Table 6 shows that total additional benefit in case of complete separation is € 32.5 million. If the financial benefits of metals are included, the total benefit would be estimated at € 35 million. This exceeds the total cost of € 31.6 million for the scenario of complete separation, which means a profit of € 3.4 million or a return on investment of 10.7 %. For the scenario of partial mining the final profit is then € 2.1 million (€ 15 million on benefits minus € 12.9 million on costs), which is a return on investment of 16.2%.

5. CONCLUSIONS AND RECOMMENDATIONS

Separation techniques which are able to separate the excavated waste into all kinds of waste streams to be recovered and re-used are available and proved in practice. Therefore it can be stated that landfill mining is technically feasible.

The cost reduction compared to the small amount of metal to be recovered, can be considered significant. There is a reduction of 8.2% in case of complete separation and 18% in case of partial separation.

Nevertheless a huge deficit remains to be covered by additional benefits to make a landfill mining project a profitable one. Benefits such as the re-using the freed landfill capacity for landfilling again, re-using the landfill area for urban development and last but not least selling of the other recovered waste streams. Acquiring these additional benefits strongly depend on specific local circumstances and conditions. In the optimal case, these additinal benefits might compensate the total costs and might generate a return on investment of 10 to 20%. From this point it can not be excluded that a landfill mining project might become financially profitable.

6. ACKNOWLEDGEMENTS

The authors wish to thank Sortiva, Afvalzorg, Rova, Omrin and the Province of Noord-Brabant for their time, knowledge and experience put into the project. Their valuable advices and critical remarks should be considered an added value to this present paper.