# LANDFILL MINING

## Process,Feasibility,Economy, Benefits and Limitations

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Reno Sam

RenoSam will, when opportunity offers, publish reports
and contributions relating to environmental research

This report is a desk study which compiles experiences from a range of landfill mining projects throughout the world. Therefore please note that the content of the publication does not necessarily reflect RenoSams views on landfill mining in general.

The reports is, however, published because RenoSam finds that the studies represent a valuable baseline study for further debate on environmental policy concerning landfill mining in Denmark.

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# 1 Abstract

Many LFM projects have been carried out throughout the world during the last 50 years, but it is very difficult to find good liable data.

In general, a mining project involves a significant financial investment and is not free of risks. Therefore, the respective mining companies will demand an accurate insight in its profit potential before making the final decision on initiating the project.

Factors affecting the economic feasibility of reclamation differ for each site and each reclamation goal. It is usually believed that the recyclables recovered provide economic revenue which is a fact depending on several aspects, such as the quality of the separated fractions, local situation and the market price, In specific circumstances, recovery focused on ferrous metals, aluminum, plastic and glass as well as fine organic and inorganic material can have economic significance if they represent significant enough volume for recovery.

The costs are often offset by the sale or use of recovered materials, such as recyclables, soil, and waste, which can be burned as fuel. Other important benefits may include avoided liability through site remediation, reductions in closure costs, and reclamation of land for other uses.

It is well known that landfill mining reduce or eliminate closure costs and in most cases reduce the long term environmental problems. Despite its many benefits, some potential limitations exist to LFM.

Facility operators considering the establishment of a landfill reclamation program must weigh several benefits and drawbacks associated with this waste management approach before getting started, and is describes in this paper.

# 2 Introduction

Landfill mining (LFM) and reclamation is a process whereby solid wastes which have previously been landfilled are excavated and processed typically from an active or closed landfill.

The function of landfill mining is to reduce the amount of landfill mass encapsulated within the closed landfill and/or temporarily remove hazardous material to allow protective measures to be taken before the landfill mass is replaced. In the process mining recovers valuable recyclable materials, a combustible fraction, soil, and landfill space. The aeration of the landfill soil is a secondary benefit regarding the landfills future use. The overall appearance of the landfill mining procedure is a sequence of processing machines laid out in a functional conveyor system. The operating principle is to excavate, sieve and sort the landfill material (Wikipedia 2008).

Processing typically involves a series of mechanical processing operations designed to recover one or all of the following: recyclable materials, a combustible fraction, soil, and landfill space. In addition, LFM can be used as a measure to remediate poorly designed or improperly operated landfills and to upgrade landfills that do not meet environmental and public health specifications (D.J. van der Zee, et al 2003).

Typical equipment used in simple LFM operations are excavators, screens, and conveyors. Complex LFM operations recover additional materials and improve the purity of recovered materials, and therefore have equipment in addition to that of simple operations.

LFM projects have been carried out throughout the world during the last 50 years (Hogland 2002).

The main purposes have been:

1. Conservation of landfill space
2. Reduction in landfill area

3. Expanding landfill lifetime
4. Elimination of a potential source of contamination
5. Mitigation of an existing contaminated source
6. Energy recovery
7. Recycling of recovered materials
8. Reduction in management system costs
9. Site redevelopment

Landfill mining was first described in 1953 in an article that documented the processes used at a landfill operated by the City of Tel Aviv, Israel (Wikipedia 2008), but projects and pilot studies have been carried out in EU, USA and Asia (Rettenberger et. al 1995, Cossu et al. 1995, Hogland et al. 1998).

Landfill Mining for remediation of old landfill sites has become more and more common in Europe today. A large number of landfills require some form of measure to be taken, for various environmental reasons.

Excavation of landfill is associated with varying financial conditions, depending on the composition of the waste deposited at the landfill and opportunities for the reuse of materials found there.

The Council directive 1999/31/EC of 26. April 1999 on the landfill of waste will change the situation in Europe for the future. The directive must be followed by the EU member states and those countries and those countries that intend to join the EU must be prepared to follow the Directive.

The directive intends to prevent or reduce the adverse effects of the landfill of waste on the environment, in particular the surface water, groundwater, soil air and human health. It defines the categories of waste (municipal waste, hazardous waste and inert waste) and applies itself to all landfills, defined as waste disposal sites for the deposit of waste onto and into land.

The EU Landfill Directive promotes the reduction of landfilled waste by making provisions that the quantity of biodegradable material to be landfilled should be reduced to 35 % of 1995 levels by 2016. Biodegradable waste counts for approximately two thirds of total municipal waste quantities.

In Denmark about 3500 old landfills exist, about 20 % of which is considered as an immediate threat to the environment (Miljøstyrelsen 1986). In 2007 about 140 landfills were active in Denmark (RenoSam 2007), Finland 366, Estonia 361, Latvia 550, Lithuania 800 and Germany 2984 (Hogland 2002). Both new and old landfills must be treated in accordance with the Directive.

The mixed-waste landfill is the most common landfill type worldwide. In the USA organic waste continues to be landfilled, and in the developing world traditional mixed-waste landfills are the most likely form of waste treatment selected for the increasing waste arisings. In recent years there has been a reduction in the percentage of waste being disposed of, linked with an increase in recycling rates.

However, landfill remains the prevailing option in many EU countries; there is a clear distinction between ‘landfilling’ and ‘non-landfilling’ countries, with the choice of options depending on factors such as traditional practice, public acceptance and the availability of land for landfill sites.

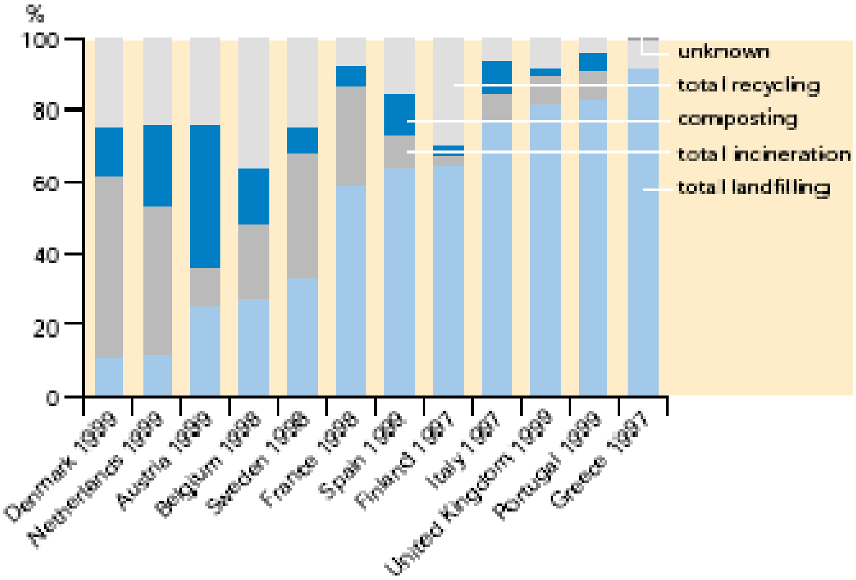

Figure 2.1: Treatment of municipal waste in selected European countries (Eurostat 2001)

## 2.1 Objectives and aims

The overall objective of this study is to increase the knowledge of LFM by investigating worldwide practice.

Is there an actually potential economic and environmental benefit to gain from mining waste? This study addresses environmental and financial aspects associated to LFM.

The aim of the project is to:

- Investigate worldwide LFM practice.
- Describe the economic aspects of LFM.
- Describe the benefits and limitations.
- If possible assess the feasibility of LFM in Denmark and if it’s economically viable.

# 3 The process of LFM

LFM is a relatively new approach used typically to expand municipal solid waste (MSW) landfill capacity and avoid the high cost of acquiring additional land or other environmental purposes. Projects are typical not done just for an economic point of view.

The process and basic principles of LMFR is described very fundamental in this chapter.

## 3.1 The reclamation process

Landfill reclamation is conducted in a number of ways, with the specific approach based on project goals and objectives and site specific characteristics.

The equipment used for reclamation projects is adapted primarily from technologies already in use in the mining industry, as well as in construction and other solid waste management operations.

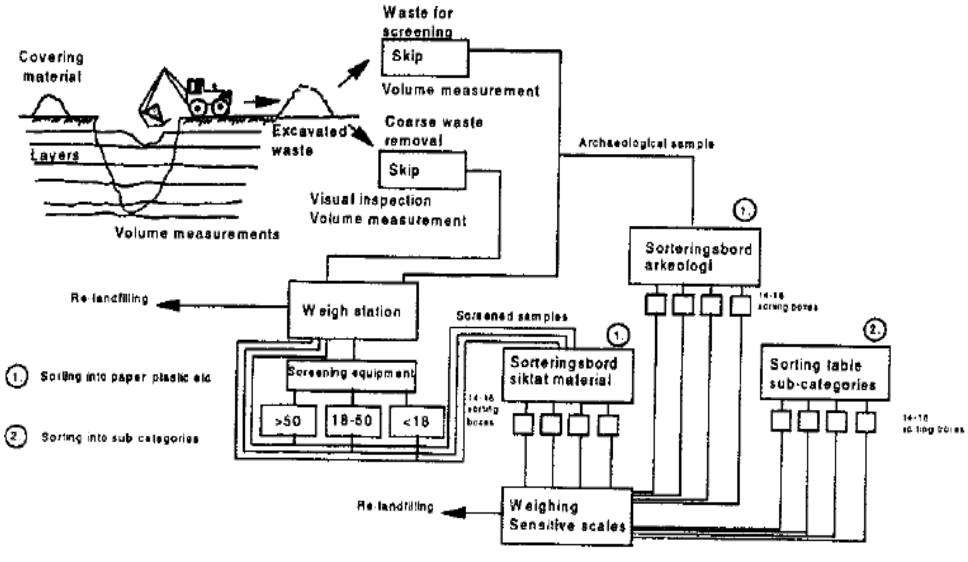

Figure 2.1: Scheme over the excavation pit and organization of the work (Hogland et al, 2002).

### 3.1.1 Tools and machinery

The parts of the mining process are the different mining machines. Depending on the complexity of the process more or fewer machines can be used. Machinery is easily transported on trucks from site to site, mounted on trailers. The following machines are added in order in increase of mining complexity (Wikipedia 2008):

- Excavators
- Moving floor and elevator conveyor belts
- A coarse rotating trommel screen
- A fine rotating trommel screen
- A magnet
- Front end loader
- Odour control sprayer

An excavator or front end loader uncovers the landfilled materials and places them on a moving floor conveyor belt to be taken to the sorting machinery. A trommel is used to separate materials by size. First, a large trommel separates materials like appliances and fabrics. A smaller trommel then allows the biodegraded soil fraction to pass through leaving non-biodegradable, recyclable materials on the screen to be collected.

An electromagnet is used to remove the ferrous material from the waste mass as it passes along the conveyor belt.

A front end loader is used to move sorted materials to trucks for further processing (re-landfilling or recycling processes).

Odour control sprayers are wheeled tractors with a cab and movable spray arm mounted on a rotating platform. A large reservoir tank mounted behind the cab holds neutralizing agents, usually in liquid form, to reduce the smell of exposed wastes.

### 3.1.2 Excavation and separation (screening)

Excavators dig up waste mass and transport it, with the help of front end loaders, onto elevator and moving floor conveyor belts. The conveyor belts empty into a coarse, rotating trommel (i.e., a revolving cylindrical sieve) or vibrating screens separate soil (including the cover material) from solid waste in the excavated material. The size and type of screen used depends on the end use of the recovered material. For example, if the reclaimed soil typically is used as landfill cover, a 2.5-inch screen is used for separation. If, however, the reclaimed soil is sold as construction fill, or for another end use requiring fill material with a high fraction of soil content, a smaller mesh screen is used to remove small pieces of metal, plastic, glass, and paper.

Trommel screens are more effective than vibrating screens for basic landfill reclamation. Vibrating screens, however, are smaller, easier to set up, and more mobile. The large holes in the screen allow most wastes to pass through, leaving behind the over-sized, non-processable materials. The over-sized wastes are removed from inside the screen. The coarse trommel empties into the fine rotating trommel. The fine rotating trommel allows the soil fraction to pass through, leaving mid-sized, non-biodegradable, mostly recyclable materials.

The materials are removed from the screen. These materials are put on a second conveyor belt where an electromagnet removes any metal debris. Depending on the level of resource recovery, material can be put through an air classifier which separates light organic material from heavy organic material. The separate streams are then loaded, by front end loaders, onto trucks either for further processing or for sale. Further manual processing can be done on site if processing facilities are too far away to justify the transportation costs.

### 3.1.3 Processing for reclamation of recyclable material or disposal

Depending on local conditions, either the soil or the waste may be reclaimed. The separated soil can be used as fill material or as daily cover in a sanitary landfill. The excavated waste can be processed at a materials recovery facility to remove valuable components (e.g., steel and aluminum) or burned in a municipal waste combustor (MWC) to produce heat and energy.

The percentage recovery of a landfilled resource depends upon:

- The physical and chemical properties of the resource
- The effectiveness of the type of mining technology
- The efficiency with which the technology is applied

The types of materials recovered from an LFM project are determined by the goals of the project, the characteristics of the landfilled wastes, and the process design. In a typical LFM operation, once the oversize non-processibles, the dirt fraction, and the ferrous metals are removed, the remaining material may be recovered as fuel for a waste-to-energy facility, processed for recovery of other recyclables, or landfilled as residue.

The soil fraction recovered by mining typical landfilled MSW will probably comprise the largest percentage by weight of all materials. The ratio of soil to other materials depends upon the type of waste landfilled, landfill operating procedures, and the extent of degradation of the landfilled wastes (World Resource Foundation 1998).

The major difficulty in marketing mined materials is in producing the necessary high quality. Another obstacle is the limited number of waste-to-energy facilities in some areas to serve as a market for combustible materials. (World Resource Foundation 1998). That is not considerated a problem in Denmark.

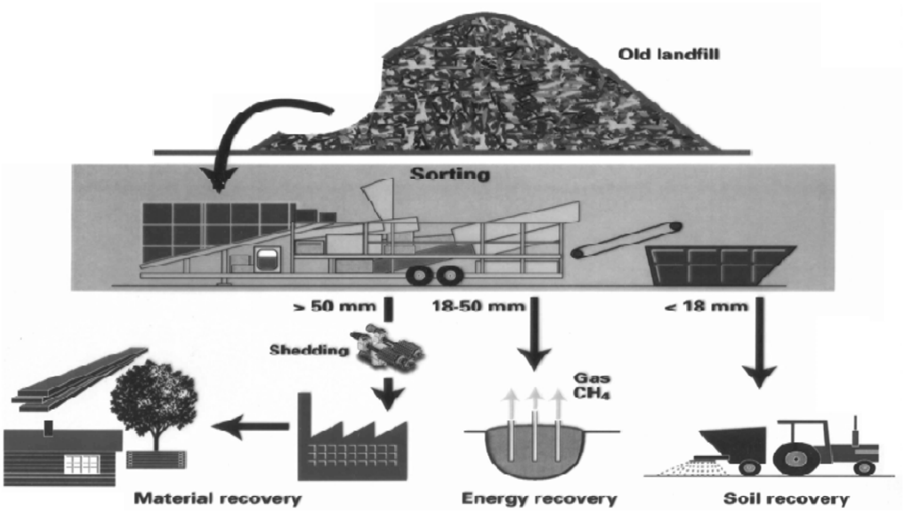

Figure 2.2: Screened waste and potential use of recovered material (Lee and Jones, 1990; Hogland et al, 1997; Carius et al, 1999; Cossu et al, 1999).

## 3.2 Steps in project planning

Before initiating a landfill reclamation project, facility operators should carefully assess all aspects of such an effort. The following is a recommended approach:

- Conduct a site characterization study
- Assess potential economic benefits
- Invest regulatory requirements
- Establish preliminary worker health and safety plan
- Assess project costs

### 3.2.1 Conduct a site characterization study

The first step in a landfill reclamation project calls for a thorough site assessment to establish the portion of the landfill that will undergo reclamation and estimate a material processing rate. The site characterization should assess facility aspects, such as geological features, stability of the surrounding area, and proximity of ground water, and should determine the fractions of usable soil, recyclable material, combustible waste, and hazardous waste at the site (USEPA 1997).

Site-specific conditions will determine whether or not LFM is feasible for a given location. Keyconditions include:

- Composition of the waste initially put in place in the landfill
- Historic operating procedures
- Extent of degradation of the waste
- Types of markets (price) and uses for the recovered materials

### 3.2.2 Assess potential economic benefits

Information collected in the site characterization provides project planners with a basis for assessing the potential economic benefits of a reclamation project. If the planners identify likely financial benefits for the undertaking, then the assessment will provide support for further investing in project planning. Although economics are likely to serve as the principal incentive for a reclamation project, other considerations may also come into play, such as a communitywide commitment to recycling and environmental management(USEPA 1997).

The environmental and economic benefits of landfill mining include the following:

- Use of recovered soil fraction as landfill cover material;
- Recovery of secondary materials
- Reduction of landfill footprint and, therefore, reduction in costs of closure and post-closure
- Reclamation of landfill volume for reuse.

Most potential economic benefits associated with landfill reclamation are indirect; however, a project can generate revenues if markets exist for recovered materials. Although the economic benefits from reclamation projects are facility-specific, they may include any or all of the following:

- Increased disposal capacity
- Avoided or reduced costs of:
  - Landfill closure.

    - Post closure care and monitoring.
    - Purchase of additional capacity or sophisticated systems.
    - Liability for remediation of surrounding areas.
- Revenues from:
    - Recyclable and reusable materials (e.g., ferrous metals, aluminum, plastic, and glass).
    - Combustible waste sold as fuel.
    - Reclaimed soil used as cover material, sold as construction fill, or sold for other uses.
- Land value of sites reclaimed for other purposes.
- Current landfill capacity and projected demand.
- Projected costs for landfill closure or expansion of the site.
- Current and projected costs of future liabilities.
- Projected markets for recycled and recovered materials.
- Projected value of land reclaimed for other uses.

In chapter 6 the economic aspects of LFM process and projects are described more investigative.

### 3.2.3 Invest regulatory requirements

Before undertaking a reclamation project, however, local authorities should be consulted regarding any special regulatory requirements or permitments.

### 3.2.4 Establish a preliminary worker health and safety plan

After project planners establish a general framework for the landfill reclamation effort, they must account for the health and safety risks the project will pose for facility workers. Once potential risks are identified from the site characterization study and historical information about facility operations, methods to mitigate or eliminate them should be developed. This information then becomes part of a comprehensive health and safety program. Before the reclamation operation begins, all workers who will be involved in the project need to be well versed in the safety plan and receive training in emergency response procedures (USEPA 1997).

Drawing up a safety and health plan can be particularly challenging given the difficulty of accurately characterizing the nature of material buried in a landfill. Project workers are likely to encounter some hazardous materials; therefore, the health and safety program should account for a variety of materials handling and response scenarios.

Although the health and safety program should be based on site-specific conditions and waste types, as well as project goals and objectives, a typical health and safety program might call for the following:

- Hazard communication (i.e., a ”Right to Know" component) to inform personnel of potential risks.
- Respiratory protection measures, including hazardous material identification and assessment; engineering controls; written standard operating procedures; training in equipment use, respirator selection, and fit testing; proper storage of materials; and periodic reevaluation of safeguards.
- Confined workspace safety procedures, including air quality testing for explosive concentrations, oxygen deficiency, and hydrogen sulfide levels, before any worker enters a confined space (e.g., an excavation vault or a ditch deeper than 3 feet).
- Dust and noise control.
- Medical surveillance stipulations which are mandatory in certain circumstances and optional in others.
- Safety training that includes accident prevention and response procedures regarding hazardous materials.
- Recordkeeping.

The program should also cover the protective equipment workers will be required to wear, especially if hazardous wastes may be unearthed. The three categories of safety equipment used in landfill reclamation projects are:

- Standard safety equipment (e.g., hard hats, steel-toed shoes, safety glasses and/or face shields, protective gloves, and hearing protection).
- Specialized safety equipment (e.g., chemically protective overalls, respiratory protection, and self-contained breathing apparatus).
- Monitoring equipment (e.g., a combustible gas meter, a hydrogen sulfide chemical reagent diffusion tube indicator, and an oxygen analyzer).

### 3.2.5 Assess project costs

Planners can use information collected from the preceding steps to analyze the estimated capital and operational costs of a landfill reclamation operation. Along with the expenses incurred in project planning, project costs may also include the following:

Capital costs:

- Site preparation.
- Rental or purchase of reclamation equipment.
- Rental or purchase of personnel safety equipment.
- Construction or expansion of materials handling facilities.
- Rental or purchase of hauling equipment.

Operational costs:

- Labor (e.g., equipment operation and materials handling).
- Equipment fuel and maintenance.
- Landfilling non-reclaimed waste or noncombustible fly and bottom ash if waste material is sent off site for final disposal.
- Administrative and regulatory compliance expenses (e.g., recordkeeping).
- Worker training in safety procedures.
- Hauling costs.

Part of the cost analysis involves determining whether the various aspects of the reclamation effort will result in reasonable costs relative to the anticipated economic benefits. If the combustible portion of the reclaimed waste will be sent to an offsite MWC, for example, planners should assess whether transportation costs will be offset by the energy recovery benefits. Planners also need to consider whether capital costs can be minimized by renting or borrowing heavy equipment, such as excavating and trommel machinery, from other departments of municipal or county governments. Long-term reclamation projects may benefit from equipment purchases (USEPA 1997).

# 4 Material recovery and composition of waste

LFM is a process whereby solid wastes which have previously been landfilled are excavated and processed typically from an active or closed landfill, in order to achieve environmental, economic or social benefits.

In continuation of the excavation recycling of materials from landfills can be used for etc. recreative purposes:

- On the spot.
- In new constructed cells.
- Moved and transported to another landfill.
- Incinerated to produce heat and energy.

After mining or recycling the landfill the area can be used for different purposes. Landfilling new waste, commercial and recreative purposes or back to its natural status.

It is very important to note, that moving of pre-landfilled material contains a potential environmental risk. The aims or advantages may be various and depend on local conditions:

- Material removal for area or volume reduction for continued operation, or total sanitation (removal of the whole landfill.
  - Alternative landuse, industry etc.
  - Creating landfill capacity
  - Reduce the negative influence on the environment
  - Reduce the aftercare and monitoring costs
- Removal of contaminated waste and upgrading of the contaminated area.
- Inspection/Installation of gas, drainage pipes and establishing bottom layer.
- Recycling of pre landfilled material
  - Daily cover material/other useful uses

- o Energy production
- o Metals

### 4.1.1 LFM projects around the world

Limited information is available on landfill mining projects that have been carried out on a worldwide basis. Projects have been used throughout the world during the last 50 years as at tool for sustainable landfilling.

The first reported landfill mining project was an operation in Tel Aviv, Israel in 1953, which was then a method used to recover the soil fraction to improve the soil quality in orchards (Shual and Hillel, 1958; Savage et al., 1993). It was later employed in USA to obtain fuel for incineration and energy recovery (Hogland, 1996, Cossu et al., 1996, Hogland et al., 1996). Pilot studies carried out in etc. England, Italy, Sweden, Germany (Cossu et al., 1995; Hogland et al., 1995), Asian projects are also reported.

In table 4.1 below a number of projects that have been carried out around the world. The list is not a complete view.

| **Location** | **Reason for reclamation (ref)** |
|---|---|
| **North America** | |
| Bethlehem, Pennsylvania, USA | To remove the old waste (some which dated back to 1942), grade the site, and put in a new liner and reuse the site (Nelson 1995). |
| Collier County, Florida, USA | Reason not specified (USEPA 1997) |
| Horicon, New York, USA | Reason not specified (Hogland 2002) |
| Chester, New York, USA | Reason not specified (Hogland 2002) |
| Coloni, New York, USA | Reason not specified (Hogland 2002) |
| Sandtown, Delaware, USA | Reason not specified (Hogland 2002) |
| Edinburg New York , USA | Reason not specified (USEPA 1997) |
| Hague, New York, USA | To completely remove the waste from the landfill in order to avoid 30 years of monitoring and future unknowns (Nelson, 1994). |
| Martone Landfill, Barre, Massachusetts, USA | Recover landfill airspace (CIWMB, 1993) |
| Newbury, Massachusetts, USA | To reclaim the entire nine acre landfill footprint and create a new lined cell (Nelson, 1995). |
| Halifax, Vermont, USA | Waste was mined from the landfill which was not engineered correctly and so caused problems when it came to capping it because the sides were too steep. Once the gradient of the sides was reduced the mined wastes were returned to the landfill (Murray & Reeve, 1996). |
| Thompson, Connecticut, USA | To expand the life of the landfill (Nelson, 1995). |
| McDougal, Ontario, Canada | Remediate leachate problems when contaminants were found in monitoring wells (Nelson, 1995). |
| **EUROPE** | |

| | |
|---|---|
| Arnhem, Netherlands | In order to be able to develop an industrial area at the location of the landfill (Van der Zee et al., 2004). |
| Born, Netherlands | In order to be able to develop an industrial area at the location of the landfill (Van der Zee et al., 2004). |
| Apeldoorn, Netherlands | Avoidance of polluting the environment surrounding the landfill (Van der Zee et al., 2004). |
| Heiloo, Netherlands | To create new landfill capacity (Van der Zee et al., 2004). |
| Måsalycke landfill, Sweden | Mined as part of a research investigation evaluating the stage of degradation of buried waste and to address the potential of excavated material for recycling and energy recovery (Hogland et al., 1998). |
| Gladsax Landfill, Sweden | Mined as part of a research investigation evaluating the stage of degradation of buried waste and to address the potential of excavated material for recycling and energy recovery (Hogland et al., 1998). |
| Filborna, Sweden | In 1994 a ten year old part of the landfill was excavated as a pilot test. |
| Burghot, Germany | Reason for mining is not specified but was the first mining experience in Europe (Kurian et al., 2003). |
| Schoneiche, Germany | Reason not specified (Hogland 2002) |
| Dresden, Germany | Reason not specified (Hogland 2002) |
| Sengenbühl, Germany | Reason not specified (Hogland 2002) |
| Basslitz; Germany | Reason not specified (Hogland 2002) |
| Döbeln-Hohenlauft, Germany | Reason not specified (Hogland 2002) |
| Sardinia, Italy | Reason not specified |
| Strängnäs, Sweden | Mined in 200-2004 to gain capacity and recover waste |
| Söndermülldeponie Kölliken, Schweiz | Avoidance of polluting the groundwater 2007 - ongoing |
| Landskrona, Sweden | In 1993 a part of the landfill was excavated as a pilot test. |
| **ASIA** | |
| Deonar, India | Mined in 1989 on a pilot scale basis to enable the recovery of decomposed waste as compost (Kurian et al., 2003). |
| Non Khaem, Thailand | Reason not specified (World Resource Foundation 1998) |
| Nanjido landfill, Seoul, Korea | To reduce the environmental problems and create a recreative area (Twyford, Keith 2008). |
| Kodungaiyur, India | To evaluate the degradation status of solid waste and feasibility of recovering the soil fraction as compost and/or landfill cover material (Kurian et al., 2003). |
| Perungudi, India | To evaluate the degradation status of solid waste and feasibility of recovering the soil fraction as compost and/or landfill cover |

| | |
|---|---|
| | material (Kurian et al., 2003). |
| Sin Lin, China | Objectives after mining are soil fraction to be applied as fertility, residual inorganic fraction to use as source of energy, space for new waste and upgrading landfill (Kurian et. al 2004). |
| **Middle East** | |
| Tel Aviv, Israel | Landfill mining, first reported in Israel as a process where solid wastes dumped at landfills are excavated, processed and reused, has the objectives of conservation of landfill space, reduction in landfill footprint, elimination of potential contamination source, rehabilitation of dumpsites, energy recovery from recovered wastes, reuse of recovered materials and reduction in the cost of post closure care and monitoring of landfill sites (Shual and Hillel, 1958; Savage et al., 1993). |

Table 4.1: List of locations mined.

## 4.2 Composition of waste

The level of recovery depends on the chemical and physical conditions in the landfill, and the efficiency of the equipment used (Cossu et al, 1996). The soil to waste ratio reported at various excavated landfills differs due to the amount of daily and final cover material employed, the size of the openings of the screens, type of landfill and waste., degree of compaction, age of landfill, and local conditions like moisture content in waste and degree of composition. Ratios in the range between 20:80 to 75:25 were found in different projects (Tammemagi 1999). As given in table 4.2 depending on moisture content and decomposition rate (Hogland, 2002).

The amount of fines in various US projects have varied between 40% and 60% (Hull et al 2001). Geusebroek (2001) has reported the removal of two small landfills with the total volume of 85.000 t (54.000 m3). In total 80% of the excavated material was extracted for re-use. About 10.000 t of rubble was re-used in road-construction; 7000 t as soil amendment and 50.00 t of contaminated soil were remediated. Only 17.000 t was backfilled as waste and 1.000 t of recyclables was taken to recovery.

The most important variable in LFM is the amount of recovered fine soil fraction which could be used as cover or lining of new landfill or backfilled in a more sustainable way. (Hogland et. al 1999). It´s suggested (World Resource Foundation1998) that a landfill needs to be 15 years old before a successful mining project can be performed.

| Landfill | Soil-to-waste ratio (%) |
|---|---|
| Edinburg New York , USA | 75:25 |
| Horicon New York , USA | 65:35 |
| Hague New York , USA | 50:50 |
| Chester New York , USA | 25:75 |
| Coloni New York , USA | 20:80 |
| Sandtown Delaware, USA | 46:54 |
| Burghof Germany | 71:29* |
| Schoneiche, Germany | 77:23* |
| Döbeln-Hohenlauft, Germany | 62:38*, 21:79** |
| Dresden, Germany | 74:26*, 19:81** |
| Sengenbühl, Germany | 11:89*, 45:65** |
| Basslitz; Germany | 50:50*, 34:66** |
| Cagliari, Italy | 31:69* |
| Filborna, Sweden | 65:35 |
| * screen gauge 40 mm<br>Screen gauge is 24 mm unless otherwise indicated | |

Table 4.2: Soil to waste ratio in landfill mining (Hogland 2002)

Although the research indicates, that large amounts of soil can be extracted, the chemical composition must be carefully investigated. Geusebroek (2001) reported contamination of etc. mineral oil and PAH, but Hull (2001) emphasized the importance of analyzing of material for VOC´s, metals, pesticides and PCB´s.

Material contamination is a serious problem, and in order to re-use the soil it has to follow the national or local criteria’s. However, it is possible that high concentrations of hazardous substances and heavy metal could be found in local pockets. Several safety equipments and precautionary measures may be needed during a landfill mining project. This may include safety goggles, hard hats, respirators, first-aid kits, leather work gloves, hearing protection, back support, steel toed work boots, combustible gas meter, oxygen analyzer, hydrogen sulfide chemical reagent diffusion tube indicator, and water spray system to suppress dust. The traditional model of a landfill as a permanent waste deposit in which decomposition processes are minimized is expected to give way to the concept of a controlled decomposition process managed as a large-scale “bioreactor”.

The non-recyclable part of the intermediate-sized and oversized materials is typically reburied in the mined area of the landfill. If this portion is reburied without further processing, this landfill mining operation typically achieves about 70% volume reduction (Cossu et al, 1995, Hogland et al, 1995). Facility operators considering the establishment of a landfill mining and reclamation program must weigh the several benefits and drawbacks associated with this waste management approach (Kurian et al 2003).

## 4.3 Recovery efficiency

Judging from available information and mechanical processing efficiencies, recovery of soil could be expected to fluctuate between 85% and 95%, ferrous metals from 70% to 90%, and plastic from 50% to 75%. Purity of these materials could be expected to be 90% to 95% for soil, 80% to 95% for ferrous metals, and 70% to 90% for plastic. The higher percentage of purity for each material category would generally be attributed to relatively complex processing designs. (World Resource Foundation 1998.

Examples will be given later in this chapter

### 4.3.1 The potential for energy recovery

The recovered organic masses can directly be incinerated if talking about the coarse fraction (>50 mm) and sometimes with additional fuel for the medium (18-50 mm) fraction. The fine fraction (<18 mm) cannot be incinerated due to its low calorific value and very high ash content. Cossu et al (1995) found the energy value of excavated waste in Italy varied between 3,4 -8,7 MJ/kg with a mean value of 4,5 MJ/kg. Hogland et al (1995) described during an excavation in Sweden the energy value to vary between 6,9 – 7,9 MJ/kg for the light fraction and less than 2 MJ/kg for the fine fraction. Obermaier and Saure (1995) obtained a value of 11MJ/kg and Cossu et. al (1995), Rettenberger (1995) and Schilinger et al (1994) found values up to 20 MJ/kg in the unsorted light fraction, being 84 TJ equivalent to 2000 ton of oil or 13.500 barrels of oil to value of about 100 USD pr. barrel (2008 data)

## 4.4 Experiences from projects around the world

In the following a short description and conclusions is presented from selected projects around the world.

### 4.4.1 Naples Landfill, Florida USA

Collier County, Florida In 1986, the Collier County Solid Waste Management Department at the Naples Landfill conducted one of the earliest landfill reclamation projects in the country. At that time, the Naples facility, a 33-acre unlined landfill, contained MSW buried for up to 15 years.

In an evaluation performed by the University of Florida on 38 of the state's unlined landfills, investigators discovered that the Naples Landfill (along with 27 others) posed a threat to ground water. Moreover, the high cost of complying with the state's capping regulations for unlined landfills concerned many county officials. Florida’s capping regulations required the installation of a relatively impermeable cover or cap and post closure monitoring. Naples officials developed a reclamation plan with the following objectives: decreasing site closure costs, reducing the risk of groundwater contamination, recovering and burning combustible waste in a proposed waste-to-energy facility, recovering soil for use as landfill cover material, and recovering recyclable materials. Collier County never built the waste-to-energy plant. The project did prove successful, however, in recovering landfill cover material. The project proved less successful at recycling recovered materials (e.g., ferrous metals, plastics, and aluminum). These materials required substantial processing to upgrade their quality for sale, something the county chose not to pursue.

In 1991, the U.S. Environmental Protection Agency selected the Naples Landfill reclamation project as a demonstration project for the Municipal Solid Waste Innovative Technology Evaluation (MITE) program. The MITE program assessed the excavation and mechanical processing techniques used in the project for reclaiming cover material to be used in ongoing landfill operations. It also assessed the capacity and performance of equipment, the environmental aspects of the project, the characteristics of recovered materials, the market acceptability of recovered materials, and the probable costs and economics of the overall project. The MITE assessment found the processing techniques used in the Naples project effective and efficient for recovering soil but not for recovering recyclables of marketable quality.

During the MITE demonstration project, Collier County effectively and efficiently recovered a soil fraction deemed environmentally safe under Florida's MSW compost regulations. The 50,000 tons of reclaimed soil were suitable for use as a landfill cover material and as a soil medium for supporting plant growth.

Air quality monitoring indicated that landfill gas was not an issue at the reclamation site, apparently due to the high degree of waste decomposition that had already occurred. As a result of this finding, typical personnel protective gear worn during the project consisted of standard construction apparel.

Ongoing reclamation activities at the Naples facility focus exclusively on recovering soil for use as landfill cover material. All excavated materials other than the reclaimed soil and small amounts of recyclables are re-disposed of in lined landfill cells. Reclamation activities are only performed on an as-needed basis. A 3- inch trommel screen is used to reclaim the soil cover material. The weight ratio of reclaimed soil to covers (i.e., materials caught by the screen), after white goods and tires are separated, is 60 to 40. This indicates that the Collier County landfill reclamation project is efficient given that 60 percent of the reclaimed material is reused as landfill cover material.

Based on 1995 prices, landfill cover material costs Collier County $3.25 per ton. According to Collier County's director of solid waste, the reclamation of cover material on an as-needed basis costs the county $2.25 per ton, a savings of $1 per ton.

According to county officials, the reclamation project yielded the following benefits: lower operating costs through reuse of cover materials, extended landfill life, reduced potential for ground-water contamination from unlined cells, and possible avoidance of future remediation costs.

### 4.4.2 Edinburg Landfill, New York USA

The New York State Energy Research and Development Authority (NYSERDA) and the New York State Department of Environmental Conservation sponsored projects to assess the feasibility and cost-effectiveness of undertaking landfill reclamation efforts to avoid closures and reduce the footprint of state landfills. NYSERDA established these projects in anticipation of the closure of numerous land fills in New York State, and based, in part, on the success of the Naples Landfill reclamation project.

NYSERDA's first demonstration project was conducted at a 5-acre MSW landfill in Edinburg, New York, which received waste from 1969 to 1991. NYSERDA chose the Edinburg Landfill because of its small size and lack of buried industrial waste. After NYSERDA chose to sponsor the reclamation of 1 acre of the 5-acre landfill, Edinburg town officials expanded the project to reclaim 1.6 additional acres.

NYSERDA divided the Edinburg demonstration project into three phases. The first phase, started in December 1990, included the excavation of 5,000 cubic yards of waste from a 12-year-old section of the landfill at an average depth of 20 feet. The second phase, initiated in June 1991, included the excavation of 10,000 cubic yards of waste from a 20- year-old section of the landfill at an average depth of 8 feet. The first two phases of the demonstration project cost an estimated $5 per cubic yard for excavation and processing. This cost included the inspection and supervision of a fully contracted operation and was based on an average excavation rate of 1,000 to 1,200 cubic yards per day.

The third phase of the Edinburg project occurred from August to September 1992. NYSERDA provided the majority of the project funding, with the remaining funding (primarily for phase three) provided by the town of Edinburg. This third and final phase reclaimed an additional 1.6 acres (31,000 cubic yards) in 28 days. Because the town supplied required equipment and labor, the contracted cost for this phase decreased from $5 per cubic yard excavated to $3 per cubic yard. Subsequently, the town looked into reclaiming the remaining 2.4 acres of the landfill and completely eliminating the footprint. The proposed fourth stage proved unviable, so the remaining portion of the landfill will be capped.

The Edinburg Landfill is located in a soil-rich area that provides ample amounts of landfill cover material. For this reason, officials tested and approved the reclaimed soil (75 percent of the reclaimed material) for offsite use as construction fill in non-surface applications. A test burn performed on the reclaimed waste found the British thermal unit (Btu) value to be lower than desired because of the high degree of waste decomposition and stones remaining in the screened material.

The recovered non-soil materials, representing 25 percent of the reclaimed waste, were hand-sorted for potential recyclables. Although 50 percent of the non-soil material was considered recyclable, cleaning the materials to market standards was not feasible. Some tires, white goods, and ferrous metals, however, were separated and recycled. The remaining materials were sent to a nearby landfill. NYSERDA officials developed a worker health and safety plan for the
Edinburg project that established work zones, personnel protection requirements, and other operating procedures. The inspectors, as well as all personnel working at the site, were required to wear respirators, goggles, helmets, and protective suits. Excavation equipment was used to separate suspicious drums and other potentially hazardous material for evaluation by the safety inspector using appropriate monitoring equipment. In the event that hazardous materials were encountered, the health and safety plan provided for a project contingency plan, a segregated disposal area, and special waste handling procedures. No significant quantities of hazardous materials, however, were unearthed.

The Edinburg Landfill Reclamation Project was successful both in securing offsite uses for the reclaimed soil and in reducing the landfill footprint to decrease closure costs. The economic benefits would be enhanced further if the avoided costs for post closure maintenance and monitoring, as well as potential remediation and the value of recovered landfill space, are also considered.

### 4.4.3 Frey Farm Landfill, Pennsylvania USA

In 1990, the Lancaster County Solid Waste Management Authority constructed an MWC to use in reducing the volume of waste deposited in the Frey Farm Landfill, a lined site (double layers of 60-mil high density polyethylene sheeting on a 6-inch clay sub-base) containing MSW deposited for up to 5 years. After building the MWC, the quantity of waste received at the facility declined, leaving a significant portion of the MWC capacity unused. In an effort to increase the energy production and efficiency of the MWC, officials initiated a landfill reclamation project to augment the facility’s supply of fresh waste with reclaimed waste. The reclaimed waste had a high Btu value (about 3,080 Btu per pound). To achieve a more efficient, higher heating value of 5,060 Btu per pound of waste, four parts of fresh waste, which included tires and woodchips, were mixed with one part reclaimed waste.

Between 1991 and 1993, approximately 287,000 cubic yards of MSW were excavated from the landfill. These reclamation activities processed 2,645 tons of screened refuse per week for the MWC. As a result, Lancaster County converted 56 percent of the reclaimed waste into fuel. The county also recovered 41 percent of the reclaimed material as soil during trommeling operations. The remaining 3 percent proved noncombustible and was reburied in the landfill. By the end of the project in 1996, landfill operators had reclaimed 300,000 to 400,000 cubic yards of material.

Before the reclamation work began, officials prepared a safety plan for work at the site and assigned a fulltime compliance officer to oversee the operations. During reclamation, workers took precautions to avoid damaging the site's synthetic liner, since it would be reused following the reclamation operations. An initial layer of protective material surrounded the synthetic liner system, aiding worker precautions by acting as a buffer between the liner and the excavation tools. Continuous air monitoring for methane, both in the cabs of vehicles and in the reclamation area, enhanced the operation’s safety operations.

Benefits of the project at Frey Farm Landfill include: reclaimed landfill space, supplemented energy production, and recovered soil and ferrous metals. Drawbacks include: increased generation of ash caused by the high soil content found in reclaimed waste, increased odor and air emissions, increased traffic on roads between the MWC and the landfill, and increased wear on both the landfill operation and MWC equipment (i.e., due to the abrasive properties of the reclaimed waste).

Costs for the resource recovery portion of the project were relatively low for the following reasons:

- The distance for transporting both the reclaimed waste and the ash was only 18 miles each way.

- The management authority avoided commercial hauling prices by using its own trucks and employees to transport the reclaimed waste and the ash.
- The landfill and MWC were operated by the same management authority, thus no tipping fees were required. (Generally, a higher tipping fee can be charged at an MWC for reclaimed waste because of its abrasiveness and higher density, which increases the wear and tear on equipment.)

By 1996, MWC facility operators no longer needed supplemental feed materials from Frey Farm Landfill to run at full capacity. Thus, landfill officials concluded the reclamation project in July of that year.

### 4.4.4 Perungudi and Kodungaiyur Dumping Grounds, India

The composition of the solid samples from Perungudi dumping ground and Kodungaiyur dumping ground are presented in table 4.3. The results are compared with reported results of Deonar, Filborna and Edinburg landfills for combustible, non-combustibles and soil.

| Constituents (%) |  | Perungudi | Kodungaiyur | Deonar[a] | Filborna[b] | Edinburg |
|---|---|---|---|---|---|---|
| Category | Particulars | India* | India** | India | Sweden | USA |
| Combustible | Textile | 2,3 | 0,6 | NA | 4,5 | NA |
|  | Wood | 11,6 | 0,5 | 0,6 | 14,2 | 5,0 |
|  | Plastic | 11,0 | 1,9 | 1,5 | 18,1 | 22,0 |
|  | Rubber & Leather | 14,5 | 0,5 | 0,6 | 1,5 | NA |
| Non combustible | Metal | 0,2 | 0,1 | 0,4 | 7,9 | 17 |
|  | Glass | 0,8 | 0,4 | NA | 0,5 | 8,0 |
|  | Stone | 18,5 | 28,3 | 31,5 | 19,0 | NA |
| Soli | Coarse | 40,1 | 67,8 | 63,5 | 55,0 | NA |
|  | Sieve size | <20 mm | <20 mm | <8 mm | <40 mm | NA |

* - Average of 12 samples
** - Average of 46 samples
NA - Not available
a – Lessons from India in Solid Waste management (Ed. Coad), pp E1.7, 1997
b -Sardinia 95´ 5th Landfill Symposium pp 783-794, 1995
c - Seminar on Waste management and the environment, Kalmar, Sweden pp 1-14, 1997

Table 4.3: Composition of mined samples of municipal solid wastes (Kurian et al 2003)

The combustible constituents such as textiles, wood, rubber and plastics are less in Kodungaiyur and Deonar landfills, indicating the stabilized status of the sampled site of the landfill. In Perungudi, the combustible constituents are higher, indicating the in complete degradation, which is further supported by the percentage of soil fraction (40-55 %). The non-combustible constituents for these landfills range from 20 to 30 %. Soil fraction for the landfill in Kodungaiyur and Deonar are around 65 % and is comparable to the soil to waste ratio summarized from different landfill mining studies as shown I table 4.2.

MSW from PDG contains 40 % combustible, 20 % non- combustible and 40 % soil fraction. In the case of KDG combustibles constitute about 4 %, non-combustible 28 % and soil fraction 68 %. This large difference may be attributed to the age of MSW at the sampling locations. In Kodungaiyur, it was about 10 years old; whereas in Perungudi fresh wastes were also observed at the sampling points due to the unorganized dumping practices. A comparison of the constituents in the samples from PDG and KDG is presented in Figure 4.1. Variation in composition of samples obtained from auger sampling was compared with bulk sampling and depicted in Figure 4.2. Significant variation was not noticed in the results of auger and bulk sampling.

Table 4.4 presents the temperature, moisture content, pH, volatile organic matter, ash content, total organic carbon and dry density of the soil fraction of the solid wastes. These are compared with the results obtained from Deonar and Filborna landfills. In most cases, the TOC values are around 50% of the VOM. Low pH and high TOC values indicate incomplete biodegradation. The results of heavy metal analyses of these samples are presented in Table 4.5. Comparison of the results with Indian Standards for compost shows that Cr, Cu, Hg, Ni and Pb are exceeding the limits. When compared with USEPA standards, all are within the standard limits for the compost. Hence, this fine fraction can be applied as compost to non-edible crops or as cover material after determining the geotechnical suitability.

In order to evaluate the environmental effects of heavy metals, a comparison was made between the leachates collected from PDG and the water extract (1:10) obtained by 24 hours shaking. The results are presented in Table 4.6. In general, the heavy metal concentrations in water extracts are less than that of leachate. This indicates the poor solubility and slower leachability of the heavy metals in water. The differences in heavy metal contents between leachate and water extract are high in the case of Cu, Cr, Ni, Pb and Zn. There is no significant difference between leachates and water extracts of other heavy metals (As, Cd and Hg), which may be due to the very low concentration.

| Particulars | Perungudi | | India | Kodungaiyur | | India | Deonar | Filborna |
|---|---|---|---|---|---|---|---|---|
| | Min | Max | Ave | min | max | Ave | India[1] | Sweden[2] |
| Temperature | 32 | 39 | 35 | 30 | 34 | 32 | - | 17 |
| Moisture content (%) | 21,4 | 52 | 39,5 | 15,5 | 46 | 24,4 | 14 | 30-38 |
| pH | 7,6 | 8,6 | 8,06 | 6,9 | 8,1 | 8,0 | 7,2 | 4-5 |
| VOM (g/kg) | 89 | 158 | 117 | 89 | 207 | 138 | 145 | - |
| Ash content | 842 | 911 | 883 | 793 | 911 | 862 | - | 789 |
| TOC (g/kg) | 52,3 | 78,8 | 55,6 | 45 | 104 | 69 | 58 | 130 |
| Dry Density | 745 | 1147 | 965 | 853 | 1254 | 1106 | - | 400-500 |
| 1- Lessons from India waste Management (Ed. Coad). Pp E1.7, 1997<br>2 - Sardinia. 95´ 5th Landfill Symposium pp. 783-794, 1995 | | | | | | | | |

Table 4.4: Physico-chemical characteristics of the soil fractions of MSW. (Kurian et al 2003)

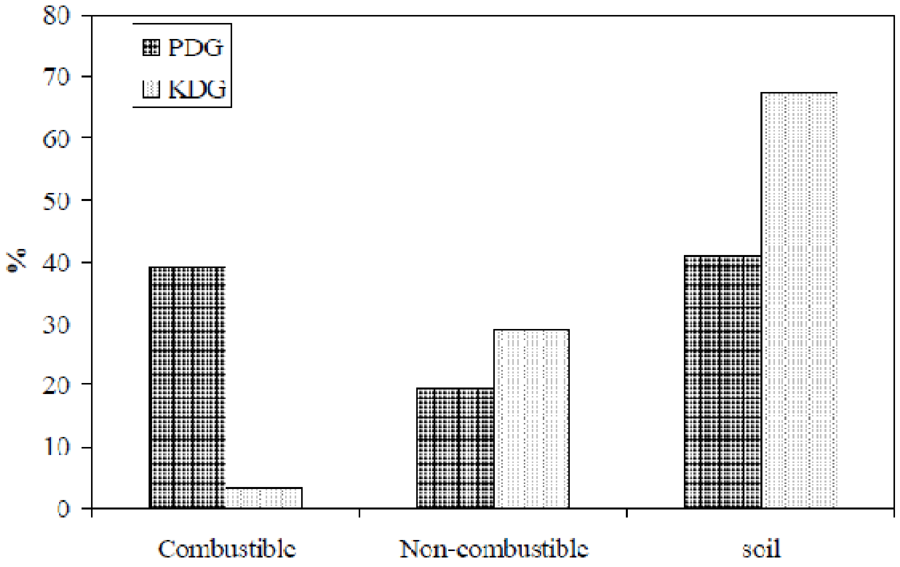

Figure 4.1: Comparison of constituents of MSW collected from PDG and KDG. (Kurian et al 2003)

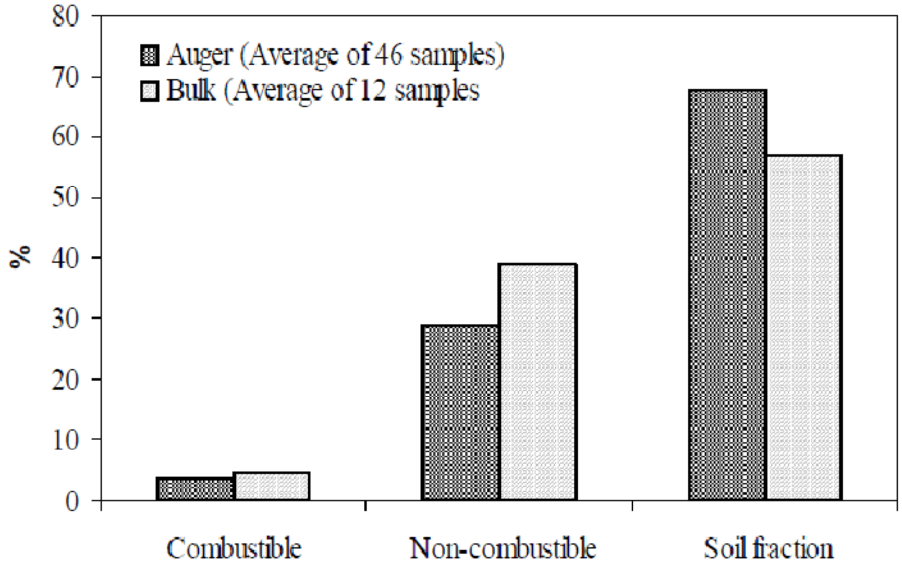

Figure 4.2: Comparison of auger and bulk samples from KDG (Kurian et al 2003)

| Heavy metal | Content in soil fraction (mg/kg) | | | Compost Standards (mg/kg) | | |
|---|---|---|---|---|---|---|
| | Perungudi | Kodungaiyur | India[a] | USEPA[b] | Canada[c] | Germany[d] |
| As | 0,077-1561 | 0,83-5,6 | 10 | 41 | 10 | - |
| Cd | 0,82-1,77 | 0,9-3,07 | 5 | 39 | 3 | 1,5 |
| Cr | 110-261 | 191-657 | 50 | 1200 | 50 | 100 |
| Cu | 75-217 | 127-968 | 300 | 1500 | 60 | 100 |
| Hg | 0,039-0,78 | 0,61-2,73 | 0,15 | 17 | 0,15 | 1 |
| Ni | 21-50 | 31-247 | 50 | 420 | 60 | 50 |
| Pb | 53-112 | 81-320 | 100 | 300 | 150 | 150 |
| Zn | 167-503 | 205-1070 | 1000 | 2800 | 500 | 400 |
| a- MSW Management and Handling Rules, 2000<br>b, c and d – Hogland et. al., Landfill Mining tests in Sweden, Sardinia 95´ 5th pp 783-794 | | | | | | |

Table 4.5: Heavy metals in soil fractions at Perungudi and Kodungaiyur, (Kurian et al 2003)

| | Heavy metal (ug/L) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Sample | As | Cd | Cr | Cu | Hg | Ni | Pb | Zn |
| Leachate | 2,5 | 16.13 | 75.63 | 69.80 | 5.20 | 407.4 | 319,9 | 101.7 |
| Water extract | 1.83 | 9.5 | 17.2 | 53.1 | 8.7 | 134.4 | 139.5 | 48.3 |

Table 4.6: Heavy metals in Leachates and water extracts of fine fractions from Perungudi (Kurian et al 2003)

### 4.4.5 Måsalycke Landfill, Sweden

The Måsalycke landfill is located in the Southeastern part of Sweden and it was commissioned at the beginning of the 1970´s, when several older dumps in the area were closed down. Måsalycke landfill has currently been under investigation with regard to increasing its size to fulfill needs into the 21 st century. The landfill receives waste from municipalities of Simrishamn and Tomelilla, the total population of which was 33.000 in 1996. In the same year the landfill received about 28.000 tonnes of waste, about 5000 which were recoverable. However just a minor part of the landfill was excavated and cannot be considerated representative for the whole landfill. More test pits covering different parts of the landfill and representing waste from different years must be excavated and analyzed before a full landfill mining project could start.

During excavation of the landfill, observations were made regarding the nature and composition of the waste. The volume of the pit was measured regularly as well as the temperature, amount of methane in the air and the conductivity/resistivity of the leachate. The unsorted material was first weighted and then taken to the screening station. The material was fed into the screening machine. Three size fractions were obtained : <18 mm, 18-50 mm and >50 mm. The various fractions were collected in skips, which were weighted when full.

Representative samples were taken from different layers of the excavated landfill and sent to an accredited laboratory.

The composition of waste in the present af Måsalycke is domineted by paper (28,7 %), wood (18,6 %) and mischellaneous (16,9 % as shown in figure 4.3. The dominating part of the last fraction mentioned is a mixture aof organic and inorganic material and can be considered to be a soil fractrion or indefinable materials.

Samlpes from the coarsest fraction (> 50 mm) contained large amounts of wood and paper, together constituting about 50% of the fraction. The medium-sized-fraction (18-50 mm) contained stones and indefinable soil-like material, while the fine fraction contained peat-like-material with some other small waste components.

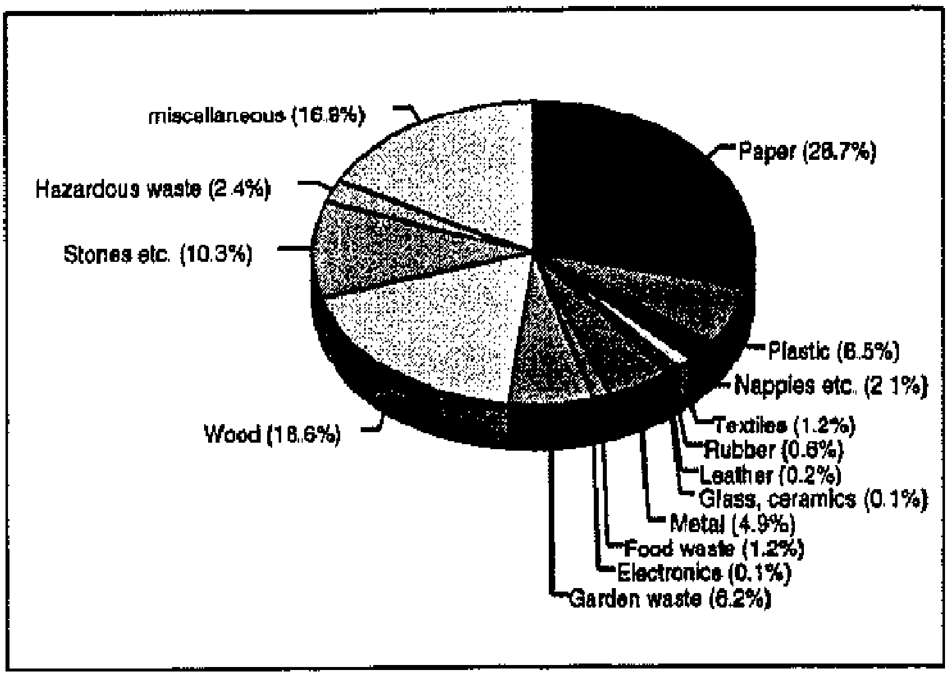

Figure 4.3: Composition of a representative sample of the excavated waste (Hogland 2002)

A large proportion of the samples consisted of fine particles, similar to soil, and this fraction is denoted “miscellaneous” . Apart from soil and sand this fraction contains partially decomposed particles of paper and garden waste, and some small particles of glass and metal. In table 4.7 the composition of the coarse fraction (> 50 mm) from various depth of the landfill is given.

| Coarse fraction >50 mm distribution, % | | | | | |
|---|---|---|---|---|---|
| Depth | 0,5-2 m | 2-4 m | 4-6 m | 6-8 m | |
| Fraction | >50 mm | >50 mm | >50 mm | >50 mm | Mean |
| | % | % | % | % | % |
| Paper | 36,64 | 42,99 | 22,90 | 12,27 | 28,7 |
| Plastic | 7,01 | 6,77 | 7,45 | 4,92 | 6,5 |
| Nappies, san, towels | 2,51 | 4,68 | 0,73 | 0,48 | 2,1 |
| Textiles | 1,54 | 0,90 | 0,84 | 1,55 | 1,2 |
| Rubber | 2,47 | 0,00 | 0,01 | 0,03 | 0,6 |
| Leather | 0,81 | 0,00 | 0,02 | 0,00 | 0,2 |
| Glass, ceramics | 0,06 | 0,00 | 0,23 | 0,13 | 0,1 |
| Metal | 3,08 | 6,45 | 6,55 | 3,40 | 4,9 |
| Food Waste | 1,50 | 1,89 | 1,46 | 0,06 | 1,2 |
| Electronics | 0,00 | 0,10 | 0,23 | 0,00 | 0,1 |
| Garden waste | 7,38 | 4,48 | 7,80 | 4,97 | 6,2 |
| Wood | 17,95 | 17,78 | 29,44 | 9,38 | 18,6 |
| Stones, etc | 5,59 | 3,49 | 8,01 | 23,91 | 10,3 |
| Hazardous waste | 0,45 | 0,30 | 3,39 | 5,33 | 2,4 |
| Miscellaneous* | 13,01 | 10,16 | 10,93 | 33,57 | 16,9 |
| Sample wt kg | 49,4 | 40,2 | 102,0 | 78,9 | |
| * Fine Fraction | | | | | |

Table 4.7: Composition of samples from the coarse fraction (> 50 mm) obtained by screening waste from various depth s of the Måsalycke Landfill (Hogland 2002)

Coarse material that was too large to put into the screen or that might cause damage to the machinery was sorted out.

| **Material** | **Volume (%)** |
|---|---|
| Metal | 55 |
| Rubber | 30 |
| Wood | 10 |
| Other | 5 |

Table 4.8: Material found in the skip containing the coarse fraction which was removed before screening (Hogland 2002)

The recovery system include soli recovery for sol amendment, moistened organic fraction and re-landfilling in a bioreactor for energy production , a new prototype of shredder for the breaking up of plastic and plastic recovery for the production of polyplanks. Polyplanks is a system of plastic planks and wood fibres. The emphasis is directed towards production of construction materials from waste plastic found in excavated landfills with industrial recovered waste plastic for new production (Carius et. al 1999, Hogland et al 2001).

In general the amount of pollutants increased with depth, but many substances were found at higher concentrations at a depth of 6 m than at the bottom of the landfill at 9 m. One reason might be that the landfill area excavated was relatively dry and the percolation of rain water through the material has been low, which also resulted in low decomposition. The waste material was sampled randomly and analyzed with regard to moisture content as % dry solids (DS), ash content, calorific value and the chemical composition as shown in table 4.9.

| Fraction | DS % | Ash % DS | Cal Value MJ/kg | C % | N % | H % | Ptot Mg/kg DS | Hg Mg/kg DS | Cd Mg/kg DS | Pb Mg/kg DS | Cr Mg/kg DS | Ni Mg/kg DS | Cu Mg/kg DS | Zn Mg/kg DS | As Mg/kg DS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18-50 mm (2-4 m) | 75,8 | 95,9 | -0,2 | 32,2 | 0,5 | 4,3 | 1600 | 1,6 | 1,2 | 120 | 31 | 14 | 42 | 480 | <0,9 |
| 18-50 mm (6-8 m) | 77,7 | 89,3 | 1,0 | 38.0 | 0,5 | 5,0 | 1200 | 0,3 | 1,1 | 90 | 33 | 10 | 41 | 510 | <1,0 |
| <18 mm (2-4 m) | 77,5 | 90,2 | 0,4 | 6,6 | 0,3 | 0,9 | 820 | 0,3 | 0,9 | 270 | 47 | 15 | 34 | 230 | <0,4 |
| <18 mm (6-8 m) | 71,2 | 87,3 | 0,9 | 19,2 | 0,5 | 1,3 | 1500 | 0,2 | 1,2 | 110 | 78 | 14 | 36 | 180 | <0,4 |
| Bottom | 79,5 | | | | | | | 0,0029 | 0,1 | 47 | 4,7 | 3,1 | 5,5 | 91,0 | <0,2 |
| * No analyses were made on the coarse fraction | | | | | | | | | | | | | | | |

Table 4.9: Analysis results of the screened fractions from Måsalycke landfill. (Hogland 2002)

Moisture content and density of samples from the top and bottom of the landfill were also measured.

| | | Moisture wt% | Density Wet material Kg/m$^3$ | Density dry material Kg/m$^3$ |
|---|---|---|---|---|
| 0 – 0,55 m | Covering material uppermost | 4 | 1282 | 1227 |
| 9 - 9,5 m | Bottom | 17 | 1358 | 1133 |

Table 4.10: Moisture and density of cover material if the landfill and the bottom layer pit (Hogland 2002)

It can be seen that the moisture content of the cover as well as the bottom layer in the pit was low. The waste materials found were decomposed very little and no methane production was registered.

The heavy metal content of the screened samples was determined using spectral analysis (XRF-X ray fluorescence) as shown in table 4.11 and figure 4.4.

| Sample | Layer | As | Cd | Cr | Cu | Ni | Pb | Zn |
|---|---|---|---|---|---|---|---|---|
| Fine fraction <18 mm | 0,5-2 m | <30 | <10 | <50 | <50 | <50 | 70 | 690 |
| Medium fraction 18-50 mm | | <30 | <10 | <50 | <50 | <50 | 70 | 1000 |
| Fine fraction <18 mm, sample taken from under conveyor belt | 2-4 m | <30 | <10 | <50 | <50 | <50 | 80 | 690 |
| Fine fraction <18 mm, sample taken from under conveyor belt | 2-4 m | <30 | <10 | <50 | <50 | <50 | 90 | 890 |
| Medium fraction 18-50 mm | 2-4 m | <30 | <10 | <50 | <50 | <50 | 30 | 260 |
| * X-ray fluorescence, X-met 920 (Metorex Oy), isotopes $^{240}$AM (cadmium only and $^{109}$Cd (other metals) measuring time 200 s | | | | | | | | |

Table 4.11: Analysis results of the screened fractions from Måsalycke landfill. (Hogland 2002)

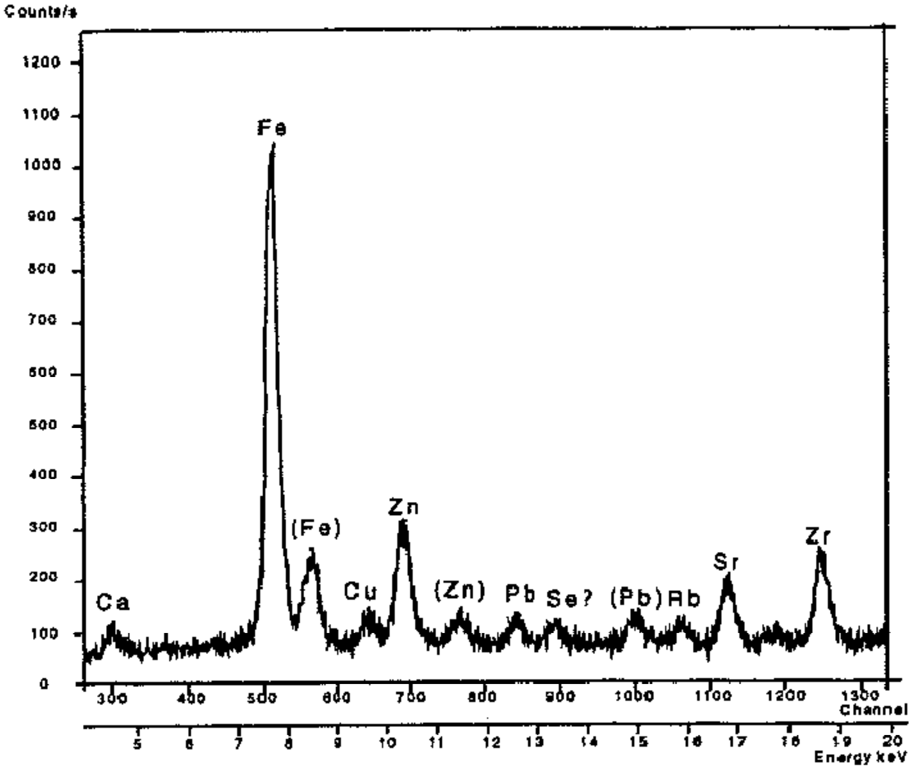

Figure 4.4: Examples from the spectral analysis (Hogland 2002)

In the upper layers, 0,5 -2 m and 2-4 m, the concentrations of heavy metals were low . Only the Zn concentration in the coarse fraction varied more than it did in the other two fractions. Apart from the metals listed in table 4.11 other metals, mostly iron and Sr, Zr and Rb, as well as Ca and Ba were found. No unexpected results were registered.

Even though the waste material in the pit was providing a very small amount of leachate, it could be sampled and analyzed (table 4.12). The Måsalycke landfill is in the methanogenic phase and the leachate concentrations are typical of landfills in the methanogenic phase. The methanogenic phase is characterized by very low concentrations of volatile fatty acids, neutral/basic pH, low BOD, low BOD/COD ratio, high contents of $NH_4$.

| Analysis | 2 m | 6m | 9 m | Uncertainty Measurement % | Spinosa et al 1991 Stegman and Ehrig 1989* | Flyhammar 1995 ** |
|---|---|---|---|---|---|---|
| Conductivity 25°C mS/s | 315 | 541 | 701 | 5 | | 242-295 |
| Ph | 7,0 | 7,3 | 7,3 | 0,2 | 7,5-9,0 (8) | 7,2-7,4 |
| Cl mg/l | 83 | 390 | 600 | 5 | 20-550 (2100) | 305-313 |
| $NO_3$ mg/l | 0,79 | 0,61 | 0,82 | 5-10 | | 0,055-4,5 |
| $NH_4$ mg/l | 150 | 450 | 540540 | 5-15 | 30-3000 (750) | 35-42 |
| Total N mg/l | 180 | 610 | 950 | 5-14 | 50-50000 (1250) | 95-46 |
| Fe mg/l | 150 | 130 | 350 | 5-10 | 3-280 (15) | 21-14 |
| Mn mg/l | 2,3 | 2,9 | 9,9 | 2-10 | 0,03-45 (0,07) | 5,7-1,69 |
| S mg/l | 15 | 27 | 70 | - | | |
| COD Cr mg/l | 5700 | 4200 | 9400 | 5-10 | 500-4500 (3000) | 909-723 |
| $BOD_7$ mg/l | 290 | 180 | 1900 | 10 | 20-550 (180) $BOD_5$ | 476-148 |
| Total P mg/l | 25 | 24 | 19 | 7-9 | 0,1-30 (6) | 3,3-1,5 |
| B mg/l | 1,4 | 1,0 | 2,4 | 2-5 | | |
| Al mg/l | 120 | 85 | 77 | 2-10 | | |
| Cd mg /l | 0,096 | 0,019 | 0,024 | 5-25 | 0,0005-0,140 (0,006) | 0,069-0,196 |
| Cu mg/l | 0,49 | 0,75 | 0,43 | 2-5 | 0,004-1400 (0.080) | 0,027-0,037 |
| Co mg/l | 0,058 | 0,089 | 0,098 | 2-5 | | |
| Cr mg/l | 0,16 | 0,36 | 0,26 | 2-5 | 0,030-1600 (0,300) | 0,067-0,051 |
| Ni mg/l | 0,13 | 0,27 | 0,14 | 2-5 | 0,020-2050 (0,200) | 0,068-0,044 |
| Pb mg/l | 1,7 | 2,8 | 1,4 | 2-10 | 0,008-1.020 (0,090) | 0,420-0,061 |
| Zn mg/l | 65 | 8,1 | 10 | 2-5 | 0,030-4 (0,600) | 0,360-0,313 |
| Hg mg/l | 0,75 | 4,6 | 10 | 7-10 | | 1300-51 |
| As mg/l | 42 | <0,2 | <0,2 | - | | |

* Characterization of leachate when landfill is in the methanogenic phase, mean values are given in parentheses after Spinosa et. al (1991) Stegman and Ehrig (1989)

** Characterization of leachate characterization from Swedish landfills with an age of 5 years and older , after Flyhammar 1995

Table 4.12: Composition of leachate (mg/l) collected at three depths (m below cover) in the pit of Måsalycke (Hogland 2002)

In young landfills simple compounds are formed such as fatty acids, amino acids and carboxylic acids. The leachate during this phase is characterized by: high concentrations of volatile fatty acids, an acidic pH, high BOD, high BOD/COD ratio, high contents of $NH_4$ and organic N (Montelius 1996). Due to the heterogeneous nature of the waste, such acid leachate can continuous for several years after disposal.

The excavated material was moisturized with leachate from the landfill back into the pit. Sorted material from 18-50 mm fraction was filled into cell 1 and unsorted material into cell 2. The cells were designed in a simple AND COST SVING WAY. Temperature, methane and flow were measured in pipes established in the cells. The production of landfill gas in the excavated material began immediately after the refilling of the test pits and the installation of the collection pipe. The methane content in the landfill gas was about 50-57% in the sorted material with a flow of 8-17l/min and 38/57% in the unsorted fraction with flow of 2-13 l/min. In cell 2 the gas production was very low after 3 months and the methane content decreased in the landfill gas. In the sorted waste fraction the production was more stable and continued more than 1,5 year. It is likely the gas production declined because of the waste material dry up. Furthermore a higher production of methane in cell 1 was expected.

# 5 Benefits and limitations

Reclamation costs are often offset by the sale or use of recovered materials, such as recyclables, soil, and waste, which can be burned as fuel. Other important benefits may include avoided liability through site remediation, reductions in closure costs, and reclamation of land for other uses.

Despite its many benefits, some potential drawbacks exist to landfill reclamation. Facility operators considering the establishment of a landfill reclamation program must weigh several benefits and drawbacks associated with this waste management approach.

## 5.1 Benefits of landfill mining

LFM extends the life of the current landfill facility by removing recoverable materials and reducing waste volume through combustion and compaction. The potential benefits of landfill mining are summarized below:

- Recovered materials such as metals, aluminum, plastic, and glass can be sold if markets exist for these materials.
- Reclaimed soil can be used on site as daily cover material on other landfill cells, thus avoiding the cost of importing cover material. Also a market might exist for reclaimed soil use in other applications such as compost
- Combustible reclaimed waste can be mixed with fresh waste and burned to produce heat and energy
- By reducing the size of the landfill “footprint” through cell reclamation, the facility operator may be able to either lower the cost of closing the landfill or make land available for other uses.
- Hazardous wastes if uncovered during LFM, especially at older landfills could be managed in an environmental sound manner.

Methane and CO2 emissions are relevant for global climate changes and the total bill for the global warming has not yet come, but it´s possible to transfer the damage or the economic value of the landfill emissions by using CO2 credits and transfer it for financial support of the LFM projects and land reclamation. Economic compensation for disturbances of the neighborhood by Odors and vectors form the landfill might be limited to a one time or an annual compensation to each household of some few 1000 Euros or more for continuous emissions from pyrolysis and/or deep fires occurring giving gases and smoke pollution to the air. (Hogland et al 2008)

## 5.2 Limitations of landfill mining

One major limitation of dumpsite mining is that it requires a lot of machinery and manpower.

Other limitations include odor and air emissions at the reclamation site, increased traffic on roads between the dumpsite and resource recovery facility, extra mixing and handling of waste at the resource recovery facility, and the handling of additional inert materials. Reclamation activities shorten the useful life of equipment, such as excavators and loaders, because of the high density of waste being handled. Moreover, the high particulate content and abrasive nature of reclaimed waste can increase wear of equipment. Lack of knowledge about the nature of waste buried might be a limitation regarding safety issues.

Other safety issues include physical injury from rolling stock or rotating equipment; exposure to leachate, and hazardous material or pathogens during mining or processing; subsurface fires and landfill gas emissions. Health risks to the general public appear to be minimal.

Cell excavation may raise a number of potential problems related to the release of landfill gases such as methane and sulphur dioxide. Excavation of one dumpsite area can undermine the integrity of adjacent cells, which can sink or collapse into the excavated area. There is considerable concern about the personal hazards to workers as part of dumpsite mining because of the burial of hazardous materials in many dumpsites and the presence of explosive gases such as methane.

The limitations of landfill mining are summarized below:

- Poor quality of recovered materials
- Ineffectiveness of substituting recovered material
- Low-value and limited applications of recovered materials
- Poor separation of recovered materials
- Emission of landfill gas
- Health hazardous
- Bad logistics at the excavation and sorting area

- Increasing wear on excavation and MWC equipment

### 5.2.1 Public health and environmental protection measures

Excavation and disposal operations at dumpsites may have adverse public health and environmental impacts during excavation, materials handling, off-site transfer or on-site disposal due to:

- Air pollution, through the emission of hazardous particulates, fibres and gases
- Surface and groundwater pollution through the discharge of contaminated solids, sludges and liquids
- Transfer of contaminant off-site due to inadequate vehicle de-contamination or sheeting of vehicles
- Noise and vibration
- Odors
- Traffic movements and congestion

| Origin of hazard | Type of hazard | Example |
|---|---|---|
| Presence of contamination | Toxicological | Installation of hazardous substances, e.g. asbestos fibre, metal oxides, hydrogen sulphide, carbon dioxide, volatile hydrocarbons etc.<br>Ingestion of contaminated food Inhalation of contaminant combustion products through smoking<br>Direct contact with toxic, carcinogenic (e.g. PAHs,<br>henzene) or corrosive (e.g. chlorates, acids and alkalis substances |
| | Asphyxiation | In oxygen-depleted atmospheres |
| | Explosion/ combustion | Organic vapours, elemental white phosphorous, subterranean fires |
| Pond ground conditions | Physical | Collapse of sides of excavation at depth, in unconsolidated ground or due to poor drainage Unexpected mineshafts or underground workings, wind due to underground combustion Insecure footing of personnel e.g. due to slippery soils or soft ground. |
| Use of heavy equipment and plant | Physical | Overlapping: collision; cuts, grazes or more serious injuries |

Table 5.1: Hazards which may be encountered during excavation of dumpsites (Kurian et al 2008)

The severity of these effects depend on a number of factors including: the nature of the contamination; the scale and duration of the remedial operation: weather conditions; the proximity and sensitivity of potential targets such as neighboring residential populations, surface or groundwater resources and ecologically significant habitats; and the extent to which mitigating measures are taken to eliminate or reduce the impacts. Mitigating measures for use in connection with excavation of dumpsites and landfills are indicated in Table 5.4

Mitigating measures should be consistent with both the magnitude of the risks involved, and the scale and extent of the operation. Where excavated material has a significant potential to affect public health or the environment, consideration should be given to the use of active containment of the operational area (e.g. mobile tents with controlled air movement). The use of temporary cover on a daily basis is likely to be required for friable contaminated materials undergoing on-site disposal.

| **Impact** | **Mitigating measures** |
|---|---|
| Air pollution | Restriction of operations of favorable weather conditions<br>Fine water sprays, temporary containment of excavation, materials handling, and deposition area monitoring<br>Temporary covering of exposed surfaces<br>Careful selection and operation of plant and equipment (e.g. sheeting of vehicles, control over vehicle speeds on-site) |
| Contaminant transfer | Site zoning, restriction of operation to favorable weather conditions. Fine water sprays. Vehicle decontamination measures, temporary covers, Dust control on haul road and<br>operational areas |
| Surface and groundwater pollution | Temporary surface drainage. Use of physical/hydraulic measures to control local groundwater regime collection and treatment/authorized disposal of liquid effluent. Containment and monitoring of storage/residual contamination-site disposal areas |
| Noise and vibration | Carcial selection of location for noisy equipment on site. Restrictions on working hours |
| Traffic movements and congestion | Use of rail transport where available, Careful positioning of site<br>entrance and internal access routes, Careful selection of external access routes<br>Observance of planning, conditions regarding vehicle movements |

Table 5.2: Mitigating measures in connection with dumpsite excavation (Kurian et al 2008)

### 5.2.2 Site services

For excavation operations lasting for periods longer than a couple of weeks or for particularly hazardous operations, power, water and drainage services will be needed to:

- Support office and sanitary accommodation for the workforce
- Support any on-site laboratory facilities
- Provide water for an environmental protection measures such as water sprays, wheel wash.
- Provide foul water drainage for site accommodation, operational and storage areas

Special provision may have to be made for ‘fixed’ materials handling facilities such as weighbridge, rail sidings, wheel washers etc. Telephone links should be considered for health and safety reasons.

### 5.2.3 Storage

Areas for the temporary storage of excavated solid materials, recycled material and contaminated surface and groundwater may have to be accommodated on the site.

Areas designed for the storage of contaminated material should be located on untreated parts of the site. Some form of containment may be necessary to prevent contaminants leaching out of stockpiles and exacerbating ground conditions beneath. Temporary cover, such as tarpaulins, plastic sheeting etc. may be needed to reduce infiltration of rainwater into stockpiles or prevent the release of dust.

Storage areas for uncontaminated excavated material, clean recycled hardcore, or imported replacement fill, should be established on the treated or otherwise uncontaminated areas of the sites (keep out the sorted material separately so that they are not mixed again, storm water shall not flow between the heaps and add new contaminates to the materials).

### 5.2.4 Site security

The security requirements of the site will vary depending on local conditions and existing provision. Appropriate measures should be taken at the site boundary to prevent unauthorized access, particularly by children, and in respect of individual operational areas where necessary. Access restraint, in the form of temporary fencing, visual markers etc., should be used around excavations greater than 1.2 m in depth which are left unattended for any period of time.

### 5.2.5 Plant and equipment

A wide variety of plant and equipment may be required to undertake excavation and disposal operations (table 5.3).

| Unit Operation/support Activity | Example |
|---|---|
| Boundary definition | Temporary/permanent posts and linkage paint markers on permanent structures e.g. walls, buildings |
| Site preparation | Office and sanitary facilities<br>Lifting, earth warming and compaction equipment for site preparation including: access and base preparation: surface<br>drainage installation: storage area preparation: effluent treatment plant; on site disposal facility physical barriers and associated<br>installation equipment for in-ground containment Lining materials for storage areas; on-site disposal area<br>Equipment and materials for gas and leachate control systems for on-site disposal Health and safety clothing and equipment. |
| Excavation | Excavation and breaking plant |
| Materials handling | Lifting and loading plant, dumper and tipper trucks<br>Concrete crusher and screening plant<br>Treatment plant for solids and water. Separation and dewatering plant |
| Disposal off-site | Off-site transport vehicles<br>Loading, lifting and dumping plant for on-site disposal, compactors, Intermediate cover materials |
| Requirement | Replacement materials<br>Loading, lifting and dumping plant<br>Compactors |
| Monitoring,health and safety and Environmental protection | Portable air monitoring equipment; mobile laboratory: vehicle/equipment decontamination plant; wheel-wash; in-site observation wells for on-site disposal |

Table 5.3: Examples of plant and equipment needs for excavation and disposal (Kurian et al 2008)

- Plant involved only in the excavation of materials
- Plant that can only excavate and load material
- Plant that can only haul and deposit materials
- Plant that can excavate, load, haul and deposit

| **Excavation** | **Excavation and load** | **Haul and deposit** | **Excavation, load, haul and deposit** |
|---|---|---|---|
| Rippers | Dragline | Dumpers | Dozers |
| Drill and Blast | Face showel | Dump trucks | Tractor-drawn scrapers |
| Impact Hammers | Forward loaders | Lorries | Motor scrapers |
| Hydraulic Breakers | Grabs | Conveyors | Dredgers |
| Skimmers | Bucket wheel | | |
| | Excavator | | |

### 5.2.6 Labatory support

Laboratory analysis plays a major role in excavation and disposal operations in four main areas:

1. Additional site characterization, both before and during operation activities
2. Compliance monitoring (e.g. excavated materials for disposal, effluents to sewer)
3. In support to public health, occupational health and safety, and environmental protection monitoring
4. Post-treatment management (e.g. post-excavation validation, long-term monitoring of on-site disposal areas)

In some applications, sampling and analysis requirements may be significant in terms of the numbers of samples and tests to be processed often within a very short period of time e.g. on-site testing during excavation works to delineate the edges of contamination, or detailed monitoring prior to the off-site disposal of excavated material where the authorities has requested additional testing in support of site investigation data.

### 5.2.7 Planning

Excavation and disposal operations require detailed planning and management. The complexity of the planning and design stage clearly depends on the scale and nature of the operation: the small-scale removal of a few hundred cubic metres of superficial fill moderately contaminated with copper and zinc will not require the same detailed planning and design as an operation involving the removal of thousands of cubic metres of fill contaminated with beryllium, or deposits of radioactive or asbestos-bearing residues. However, good planning and management should address t he basic issues listed in table 5.4 below.

| Unit operation | Operational requirement | Support |
|---|---|---|
| Pre-operational period | • Environmental impact Assessment | • Base-line monitoring<br>• Community consultation |
| Site preparation | • Site services (power/water/drainage)<br>• Site access/internal access/working platforms<br>• Temporary storage/ recycling/materials treatment areas<br>• Disposal area (use below)<br>• Site security<br>• Wheel and vehicle washing<br>• Weigh bridge | • Environmental protection measures (whole area, operational areas)<br>• Monitoring (equipments/support facilities)<br>• Health and safety requirement/emergency support area) |

| | | |
|---|---|---|
| | • Haul roads<br>• Railway sidings | |
| Excavation | | |
| Excavation (Contd.) | • Rate of excavation (material flows)<br>• Number, types and variability of material to be handled<br>• Segregation, separation and dewatering needs<br>• Material flows<br>• Numbers and types of vehicles or other transport means<br>• Plant and equipment needs | • Health and safety (equipment/procedures)<br>• Record-keeping procedure |
| Materials handling | • Volume, types and variability of material to be handled<br>• Segregation, separation and dewatering needs<br>• Material flows<br>• Numbers and types of vehicles or other transport means<br>• Plant and equipment needs | • Environmental protection for operational areas<br>• Monitoring (QC on material flows, in support of health and environmental protection)<br>• Health and safety (equipment/procedures)<br>• Record-keeping procedures |
| Replacement | • Method of placement<br>• Plant and equipment required<br>• Protection against further migration | • Environmental protection for operational areas<br>• Monitoring (QC on material flows, in support of health and environmental protection)<br>• Health and safety (equipment/procedures)<br>• Record-keeping procedures |
| Final disposal off-site | • Transport arrangements | • Environmental protection for transit vehicles/trains etc.<br>• Monitoring (QC on materials, in support of health and environmental protection measures)<br>• Health and safety (equipment/procedures)<br>• Record-keeping procedures |
| Final disposal on-site | • Technical characterization of designated area<br>• Volumes and types of materials to be placed<br>• Engineering works to prepare area<br>• Equipment and procedures for placement<br>• Duration of operation, restoration | • Environmental protection (containment for soils/liquids/gases)<br>• Monitoring (QC on materials, in support of health & environmental protection measures) |

| | | |
|---|---|---|
| | requirement | • Health and safety (equipment/procedures)<br>• Record-keeping procedures |
| Post-treatment management | • Post-excavation validation for excavated area<br>• Periodic review and maintenance of on-site disposal area | • Collection of long-term monitoring data from on-site deposits<br>• Record-keeping procedures |

Table 5.4: Planning for excavation and disposal (Kurian et al 2008)

# 6 Economic aspects

This chapter addresses the environmental and financial aspects associated to landfill mining. It is well known that landfill mining reduce or eliminate closure costs and in most cases reduce the long term environmental problems.

Traditionally, the economics of landfill mining often is dependent on the depth of the waste material and the ratio soil-to-waste due to the fact that as deeper the waste is buried the more expensive a site is to reclaim per hectare Furthermore, the lower the soil-to-waste ratio is, the more material will need to be either reburied or transported for disposal off site., It is usually believed that the recyclables recovered might provide economic revenue which is a fact depending on several aspects, such as the quality of the separated fractions, local situation and the market price, In specific circumstances, recovery focused on ferrous metals, aluminum, plastic and glass as well as fine organic and inorganic material can have economic significance if they represent significant enough volume for recovery. This might be true for industrial landfills as for the car fragmentation industry and scrape dealing industry. Industrial landfill with toxic contents as those related to old glass factories and battery factories might be very expensive to reclaim. Even though it can be estimated the existence of hundreds of thousands of sites good candidates for landfill mining and land reclamation, such strategy is seldom applied, mainly due to lack of information and the way of making the economic evaluations of' the projects. Factors affecting the economic feasibility of reclamation differ for each site and each reclamation goal.

The accounting of economic benefits of a landfill mining project must be comprehensive and include reduction or elimination of' the need of' capping, long-term monitoring and after case, maintenance and potential remediation costs, effective use and logistics of machinery, increased value of the reclaimed land and avoidance of finding a new site and infrastructure costs in the case the reclaimed land is used for constructing a new landfill. A positive aspect only recently appreciated related to landfill mining is that companies are able to earn carbon credits stopping methane and carbon dioxide escaping to the atmosphere. New tools to facilitate the financial reviewing and following-up the operational phase of the landfill mining must be developed Legislative peculiarities must be considered related to the activities according to the local and EU regulations. Landfill mining can be seen as part of' the integrated solid waste management, which means that in Europe, the fraction to be disposed in the new landfill shall be sorted out for recoverable and treated for organic waste.

## 6.1 Cost/benefits of landfill mining

The costs and benefits of landfill mining vary considerably depending on the objectives (closure, remediation, new landfill etc.) of the project, site-specific landfill characteristics (material disposed, waste decomposition, burial practices, age and depth of fill) and local economics (value of land, cost of closure materials and monitoring) (Cossu et al, 1996; Van der Zee et. al, 2004). Cost heads related to project planning including capital and operational costs of the landfill mining project are as summarized in table 6.1 below.

**Capital costs:**
- Site preparation
- Rental or purchase of reclamation equipment
- Rental or purchase of personnel safety equipment
- Construction or expansion of materials handling facilities
- Rental or purchase of hauling equipment

**Operational costs:**
- Labor (e.g., equipment operation and materials handling)
- Equipment fuel and maintenance
- Administrative and regulatory compliance expenses (e.g., record keeping)
- Worker training in safety procedures
- Hauling costs

Table 6.1: Cost of landfill mining (USEPA 1997)

The most potential economic benefits associated with landfill reclamation are indirect. However, a project can generate revenues if markets exist for recovered materials. Although the economic benefits from reclamation projects are facility-specific, they may include any or all of the following:

- Increased disposal capacity
- Avoided or reduced costs of:
  - Landfill closure
  - post closure care and monitoring

  - Purchase of additional capacity or sophisticated systems
  - Liability for remediation of surrounding areas.
- Revenue from:
  - recyclable and reusable materials (e.g., ferrous metals, aluminum, plastic, and glass)
  - combustible waste sold as fuel
  - reclaimed soil used as cover
  - materials sold as construction fill or sold for other uses
  - land value of sites reclaimed for other uses

While the rate of mining with a single piece of processing equipment may be as high as 180 tons/h, typical operation is at a rate of 50 to 150 tons/h. Based on the information developed by Landfill Mining, Inc. from its operation in the Collier County at 1995 prices, the cost of landfill mining is expected to be less than about US $10/ton of waste mined. A large amount of that cost is associated with rental of the processing equipment. The rental fee is typically between US$16,000 to 19,000/month. For a large scale operating plant in Europe, a cost of $ 75-100 per cubic meter was reported (Cossu et al, 1996). The cost of landfill mining at the Filborna landfill in Sweden in 1994 was US $6.7/ton.

The results of an analysis of the weekly production data, project costs and assets realized during 1992 and 1993 at the Frey Farm Landfill of Lancaster County showed that 33% of the project costs was associated with excavation and trommeling operations at the landfill.

Transportation of reclaimed waste to the resource recovery facility and hauling ash residue back to the landfill incurred 30% of the cost. The balance of the project costs was associated with processing fees paid to the landfill mining operator, resource recovery facility and landfill host communities. Revenues obtained from the sale of electricity from the resource recovery facility and recovered ferrous metal offset these operating costs and resulted in net revenues of US$ 3.94 for every ton of reclaimed material delivered to resource recovery facility. Additional assets recovered included cover soil and landfill volume making the overall profit to US$ 13.30 for every ton of material excavated.

In general, the economics of landfill mining depend on the depth of the waste material and the ratio of wastes to soil. The deeper the waste is buried, the more expensive it is to reclaim a landfill, per unit area (Salerni, 1995). In most cases, the presence of hazardous materials will also affect the economic feasibility. Thus, this step in project planning of analyzing the economics of landfill mining calls for investigating the following areas:

- Current landfill capacity and projected demand
- Projected costs for landfill closure or expansion of the site
- Current and projected costs of future liabilities
- Projected value of land reclaimed for other uses
- Projected markets for recycled and recovered materials
- Projected value of land reclaimed for other uses

The major benefit from this approach is the extension of useful life of the existing landfills by many years besides avoiding the cost and time to locate, design, permit, and construction of a new landfill.

| | **Worst -case** | **Realistic case** | **Best-case** |
|---|---|---|---|
| **Costs** | | | |
| • Research | 20.000 | 15.000 | 10.000 |
| • Mining | 1.000.000 | 800.000 | 600.000 |
| • Re-dumping | 300.000 | 200.000 | 100.000 |
| **Benefits** | | | |
| • Regained land | 1.000.000 | 1.250.000 | 1.500.000 |
| • Recyclables | 50.000 | 80.000 | 100.000 |
| **Profit** | -270.000 | 315.000 | 890.000 |

Table 6.2. Scenario analysis for a landfill (fictitious data) in US dollar (Van der Zee et al 2004)

Analyzing the economics of dumpsite mining calls for investigating the current capacity and projected demand of the landfill, projected costs for landfill closure or expansion of the site, current and projected costs of future liabilities, projected markets for recycled and recovered materials and projected value of land reclaimed for other uses. Major factors influencing the cost of such projects will include the volume and topography of the dumpsite; equipment parameters; soil conditions; climate; labor rates; the regulatory approval process; excavation and screening costs; sampling and characterization; development costs; the contractor's fees; hazardous wastes disposal; and revenue from the sale of commodities such as compost and recyclables.

In practice, the environmental costs and benefits should be added to the project costs and benefits before using decision criteria like Net-Present Value, Benefit-Cost Ratio, or the Internal Rate of Return of the project. The main challenge is to estimate the environmental costs and benefits properly. Unlike project costs and benefits which are more tangible, estimating environmental costs and benefits is not so easy. As such no data are currently available to monetise the local environmental benefits that will arise out of the project from the control of smoke and air pollution due to open burning of garbage and control of odor and fly nuisance as well as ground water pollution due to leachate.

Benefits fall into two main categories: the benefits related to more efficient operation of landfills, and the benefits resulting from recyclables and regained land. On the other hand costs are distinguished in capita costs and operational costs. Some remarks on the overview are:

- Costs and benefits from reclamation projects are facility-specific, any or all may appear in a specific mining project.
- Subsidies from (local) authorities or third parties are not mentioned as a potential benefit. Also efforts involved in researching costs and benefits of mining projects are not made explicit in the overview.
- A pro-active market approach towards landfill mining may also imply the purchase of landfills.
- The overview implies a strict division in capita costs and operational costs. In some cases this is not too clear. For example, worker training in safety procedures may concern a one-time exercise, however, it may also refer to an activity that is carried out on a regular basis – to guarantee a certain routine in conforming to standards.

In general, a mining project involves a significant financial investment and is not free of risks. Therefore, the respective mining companies will demand an accurate insight in its profit potential before making the final decision on initiating the project. This insight has to be obtained as the net result of a rather elaborate investigation preceding the actual mining activities. It involves a multitude of research efforts like the analysis of samples of the contents of landfills, and the acquirement and interpretation of local regulations and development plans.

For a single project such efforts may be acceptable. However, for a large set of projects this is no feasible alternative, given the required time and the amount of costs and resources involved. In this subsection we try to solve this dilemma by (strongly) reducing the number of landfills to be considered for a full investigation through the use of simpler research means.

# 7 Conclusion

As described in this paper LFM is a developing technology and method of waste management. Given its developmental status, only tentative conclusions can be drawn regarding LFM potential, and prospects for fulfilling that potential.

It ´s very important to note that factors affecting the economic feasibility of reclamation differ for each site and each reclamation goal.

In general it would be possible to do a LFM project in Denmark – but it would be advisable to do it in a small-scale as a pilot project first. The potential is estimated less attractive because of the waste politic and landfill strategy for many years. Despite everything older landfills do have a large LFM potential, but problem can be lack of information.

Doing LFM from only an economic point of view isn´t advisable because of the different drawbacks listed in chapter 5. Digging up an old landfill – you´ll never know what you find.

If the purpose is to improve the environment then LFM is not far from cleaning a potential contaminated ground, removing the contaminated masses and creating new areas with high value and new possibilities, which often is described as a very expensive operation.

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