Dumpsite Rehabilitation and Landfill Mining

ARRPET

Anna University

Asian Institute of Technology

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Preface

The Asian Regional Research Programme on Environmental Technology (ARRPET) funded by Swedish International Development Cooperation Agency (Sida) is aimed at research programmes on environmental concerns relevant to Asia. The issues covered include wastewater, air pollution, solid and hazardous wastes. The project, involving National Research Institutes (NRIs) in eight countries, is coordinated by the Environmental Engineering and Management Programme, Asian Institute of Technology (AIT), Thailand.

The present report is one of the outputs, essentially literature based, of the project on Sustainable Solid Waste Landfill (SWLF) management in Asia under ARRPET. Four NRIs namely National Engineering Research Center for Urban Pollution Control, Tongji University, China; Centre for Environmental Studies (CES), Anna University, India; Faculty of Agriculture, University of Peradeniya, Sri Lanka and Faculty of Engineering, Kasetsart University, Thailand representing the respective countries were coordinated by AIT for this joint research to investigate suitable methods for sustainable SWLF management.

Primary focus is given to the upgrading of the operating/existing dumpsites, improving firstly both liquid and gaseous emissions from there. Subsequently the future use of the upgraded location is considered after rehabilitation and additional volumes for future sanitary landfills. Key technical issues addressed are enhancement of waste degradation in landfills, subsequent generation of landfill gas/leachate and methane oxidation in landfill cover. In combination with these issues, emphasis is also given to simple and efficient pre-treatment technologies like composting, enhanced leaching, anaerobic digestions, etc.

The report is a literature review based compilation of the research conducted on “Dumpsite Rehabilitation and Landfill Mining” to support the worldwide initiatives on Sustainable Landfill Management. The document provides guidance on characterizing, investigating and rehabilitating open dumps to provide adequate protection to public health and safety. Also incorporated are the results from the studies on “Rehabilitation of Dumpsites” carried out under the ARRPET Project and focuses on the concepts and utility of landfill mining as a key part to a new approach for sustainable landfill management, especially for the rehabilitation of MSW dumpsites in developing countries.

Sustainable landfill management in Asian region can be a reality in the long term. The emphasis shall be on a phased approach to the implementation of more sustainable processes that make up the desirability hierarchy of waste management in addition to solving immediate problems. It is hoped that this report will be useful for the government agencies and policy makers involved in urban planning and development, in general, and in the MSWM, in particular to plan and implement sustainable urban solid waste management programme.

We take this opportunity to thank Sida for financing this phase of an important and opportune research. We look forward to adoption of integrated methodology for MSWM in the study countries as well as in other Asian countries.

In conclusion, we express our thanks to Dr. William Hogland, Professor of Environmental Engineering, Kalmar University, Kalmar, Sweden, and Dr. K.R. Ranganathan, Member Secretary, Loss of Ecology for (Prevention & Payments of Compensation) Authority for the

State of Tamil Nadu, Ministry of Environment & Forests, Government of India, Chennai, India for critically reviewing this report and their valuable suggestions.

This report also includes the outcome of many discussions with those involved in MSWM in the South Asian countries, literature review and project activities during the study period. The project team acknowledges with thanks the contribution of the participants in the discussions.

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Abstract

Municipal solid waste management is an important part of the urban infrastructure that ensures the protection of environment and human health. The accelerated growth of urban population, increasing economic activities and lack of training in modern solid waste management practices in the developing countries complicate the efforts to improve this service sector. Although the urban residents of the developing countries produce less solid waste per capita than the high-income countries, the capacity of the cities to collect, process or reuse and dispose solid waste is limited. The most prevalent way of disposing MSW in most of the developing countries is open dumping which is the easiest and considered to be the cheapest method of removing waste from the immediate environment. The increasing awareness on public health and environmental quality concerns are expected to provide the impetus that is needed to develop and implement a sustainable approach to manage solid wastes and rehabilitation of the existing open dumps.

The traditional model of a landfill as a permanent waste deposit in which decomposition processes are not optimized is giving way to the concept of a controlled decomposition process managed as a large-scale bioreactor. Such a bioreactor landfill is seen a flexible, cost effective, and a sustainable option for current waste disposal problems; more so when combined with material recovery either before or after the biological treatment step.

The present report focuses on the concept and utility of landfill mining as a key part of this new approach for sustainable waste management, especially for the rehabilitation of the Municipal Solid Waste (MSW) dump sites in Developing Countries. "Landfill mining" is the process of excavating existing or closed solid waste landfills or dumpsites, and sorting the excavated materials for recycling, processing, or other disposition. It is the process whereby solid wastes which have previously been landfilled are excavated and processed with the objectives of rehabilitating the dump sites, conserving of landfill space, reducing landfill area, eliminating of potential contamination source and recover resources. The success of materials recovery is dependent on the composition of the waste, the effectiveness of the mining method. Advantages and limitations of landfill mining, supported by case studies are presented.

Recommendations for the phased approach to move from open dumps to sustainable landfills have been made taking into account the different physical and economic situations prevailing in developing countries.

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List of Abbeviations

AIT	Asian Institute of Technology
AOX	Absorbable Organic Halogens
ARRPET	Asian Regional Research Programme on Environmental Technology
BOD	Biochemical Oxygen Demand
CES	Centre for Environmental Studies
COD	Chemical Oxygen Demand
DOC	Dissolved Organic Carbon
EC	Electrical Conductivity
EIA	Environment Impact Assessment
HDPE	High Density Poly Ethylene
HHVs	High Heating Values
KDG	Kodungaiyur Dumping Ground
LCSWMA	Lancaster County Solid Waste Management Authority
LFMR	Landfill Mining and Reclamation
MITE	Municipal Innovation Technology Evaluation
MRF	Materials Recovery Facility
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
NHDES	New Hampshire Department of Environmental Services
NRIs	National Research Institutes
NPC	National Productivity Council
NYSERDA	New York State Energy Research and Development Authority
PADGER	Pennysylvania Deportment of Environmental Resources
PDG	Perungudi Dumping Ground
PMC	Pune Municipal Corporation
RDF	Refuse Derived Fuel
RRF	Resource Recovery Facility
SIDA	Swedish International Development Cooperation Agency
SWLF	Solid Waste Landfill
TCL	Target Compound List
TCLP	Toxicity Characteristic Leaching Procedure
TDS	Total Dissolved Solids
TPD	Tonnes per day
TS	Total Solids
USA	United States of America
USEPA	United States Environmental Protection Agency
VOCs	Volatile Organic Compounds
WHO	World Health Organisation

CHAPTER 1

INTRODUCTION

1.0 General

Safe and reliable disposal of municipal solid wastes and residues is an important component of integrated waste management. Open dumps, commonly found in Asian countries, are land disposal sites at which solid wastes are disposed of in a manner that does not protect the environment, susceptible to open burning, and exposed to disease vectors and scavengers. Waste disposal sites which are planned, designed and constructed according to good engineering practice, and operated so that they cause minimum environmental impacts, are called sanitary landfills. Landfill mining involves the excavation, screening and separation of material from landfills into various components. One major objective of landfill mining is dumpsite rehabilitation, which is defined as excavation of a portion or all of the dumpsite with the ultimate goal of reducing its volume through separation of materials into recyclable, reusable, and combustible components; reducing closure and post-closure costs by complete or partial exclusion of the landfill; creating capacity; and reducing environmental impacts.

In many Asian countries, solid waste disposal method still remains as open dumping for reasons such as:

- ignorance of the health risks associated with dumping of wastes;
- acceptance of the status quo due to lack of financial resources to do anything better; and
- lack of political will to protect and improve public health and the environment.

Many old landfills and dumpsites existing throughout the developing countries pose a threat for human health. Dumpsite closure would help moderate the environmental impact of such improper disposal practice. Rapid exhaustion of available space for land filling is creating a crisis in solid waste management. The growing concerns about public health, environmental quality and the risks associated with the existing and newly designed MSW landfills are making it nearly impossible to site new landfills in many parts of the world (Lee *et al*, 1989a). This calls for a new approach involving the following steps for sustainable management of landfills:

- Practice of waste minimization and recycling to conserve the remaining space in currently used landfills
- Landfill mining operations to free new landfilling space at currently used and closed landfills/dumpsites
- Integrating the concepts of dumpsite rehabilitation and landfill bioreactor system combined with landfill mining to enable responsible and protective management of municipal solid waste without locating new landfills

Public health and environmental quality anxieties, escalating costs of monitoring and remediation would provide the impetus needed to develop and implement this sustainable approach to the management of solid wastes and landfills.

1.1 Scope for Dumpsite Rehabilitation

The state of dumpsites in Asian countries is all too similar: indiscriminately dumped, seemingly unplanned heaps of uncovered wastes, most of the times open burning (Figure1.1); pools of standing polluted water (Figure 1.2); rat and fly infestations, domesticated animals roaming freely (Figure 1.3); and, families of scavengers picking through the wastes (Figure 1.4).

Dumpsite rehabilitation projects are required due to one or a combination of reasons such as market value of excavated materials, directed closure of the facility and minimization of post closure, monitoring costs.

To have a properly closed landfill, two basic goals must be kept in mind. These are (1) minimizing the need for continual maintenance of the landfill site, and (2) placing the landfill in a condition that will minimize future environmental impacts. Upgradation and rehabilitation of dump sites to sanitary landfills will have to be done in a phased manner depending on the risk and financial aspects of each dump. It is clear that changing from open dumping to high standards of sanitary landfilling, cannot be achieved overnight. The key to such change is today's scientific knowledge and the introduction of small incremental improvements in the standards of disposal, in line with the financial resources available.

Figure 1.1 Dumpsites - a burning problem

Figure 1.2   Dumpsites - potential source of water pollution

Figure 1.3   Dumpsites – animals roaming

Figure 1.4 Dumpsites – scavenging

1.2 Brief History of Landfill Mining

Landfill mining projects have been used throughout the world during the last 50 years as a 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 United States of America (USA) to obtain fuel for incineration and energy recovery (Hogland, 1996, Cossu et al., 1996, Hogland et al., 1996). Pilot studies carried out in England, Italy, Sweden, Germany (Cossu et al., 1995; Hogland et al., 1995), China and India are also reported.

The primary objective of the Tel Aviv Landfill Mining Project in Israel was to excavate the waste for recovery of soil amendment (Shual and Hillel, 1958). The excavation equipment consisted of a front-end loader and a clamshell and the processing equipment included several conveyors and a rotating trommel screen. In the process, waste material was excavated and transported to a conveyor belt. The conveyor belt transferred the waste to a trommel screen of about 7 m long, 2 m in diameter and rotated at about 13 rpm. The screen had openings of approximately 2.5 cm and the material that passed through the screen openings was used as soil amendment. The material retained in the screen was transported by conveyor belt to a resource recovery area where manual separation was used to recover ferrous metals and other recyclable materials. The soil amendment was used primarily in citrus groves.

Two developments took place in the USA between 1950 and 1980 that impacted on landfill mining. One was the emergence of a modular processing system designed to process mixed waste as it arrived at landfills or at transfer stations, primarily for the purpose of recovering steel containers. The second development took place in the late 1960s/early 1970s, and dealt with the assessment of the technical feasibility of composting landfilled MSW *in situ* (Strange, 1998). The project involved the construction of specially designed cells in a landfill. Some of the cells were filled with sorted MSW and others with mixed MSW and covered with a soil layer. A forced aeration system was set up to supply oxygen for the process. The project was not implemented at full-scale because of technical infeasibility. Although the project was not executed, it provided information on the acceleration of the degradation of organic matter in a landfill and the importance of a multi-cell structure in a sanitary landfill (Strange, 1998). Subsequently, there have been six landfill mining projects in the USA (Lee and Jones, 1990). Murphy (1993) has reported a research project that investigated different aspects of MSW aerobic digestion and reclamation. Landfill mining has been reported as a method of waste management planned or implemented in many developed and developing countries (Murphy, 1993; Nelson, 1995; Foster, 2001; Hull et al, 2001).

CHAPTER 2

DUMPSITES TO SUSTAINABLE LANDFILLS

About three-quarters of the countries and territories around the world use ‘open dumping’ method of disposal of MSW (Rushbrook, 2001). It thrives because of the mistaken belief that it is the easiest and cheapest disposal method to use in those countries with economies in difficulties or where there is insufficient political will to allocate adequate public resources to improve the prevailing disposal practices. Each municipality operates one or more open dumpsites situated close to the towns and are widely regarded as uncontrolled and unsafe operations. The dumpsites are often poorly sited, on fire and operated by inexperienced or disinterested staff. Only a handful of these sites have access to bulldozers and each site should be either immediately closed or rehabilitated into better-managed operations.

At present, there are only limited resources for upgrading or replacing these dumpsites and, equally, limited funds and technical competence to operate and maintain land disposal sites. The attainment of highly complex landfill design and construction as practiced in the developed world may not be possible immediately. Under such circumstances, the improvement of land disposal practices may be achieved by a step-by-step approach (Rushbrook, 1999, 2001). The stepped approach may involve four stages as depicted in Figure 2.1 to move from open dumps to sustainable landfills. Such a phased approach is being attempted in South Africa (Ball and Bredenhann, 2003). The steps to be taken may vary depending on local circumstances but all changes introduced should represent a progressive improvement over open dumping. It is best to identify those parts of the present land disposal operation that are unsafe or unsanitary and adopt ways to improve those using local materials and resources.

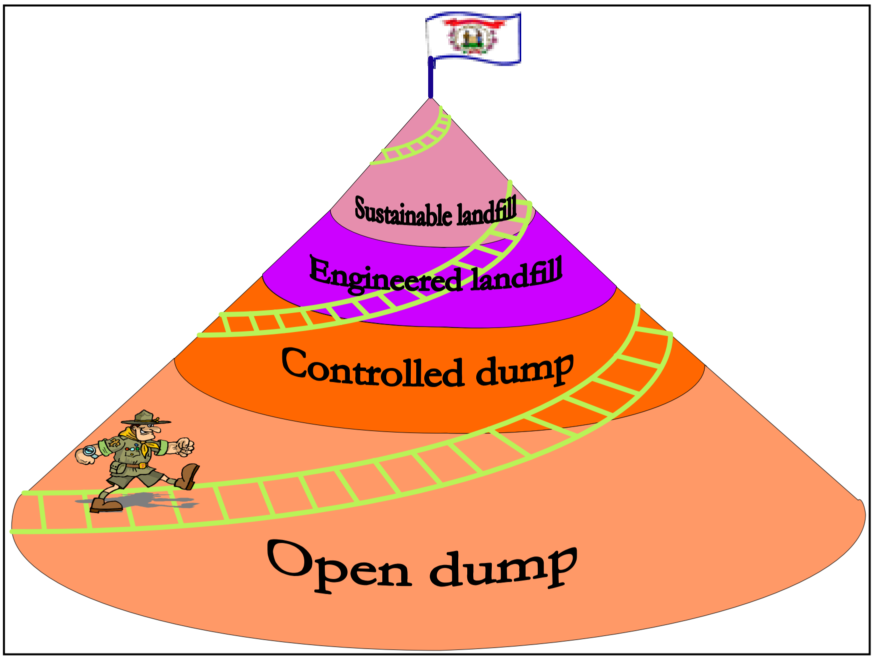


Figure 2.1 Phased approach to dumpsite rehabilitation

The general philosophy of the phased approach in addressing the challenge of ensuring sustainability is the internationally accepted Best Practicable Environmental Option approach. This approach assesses alternatives and aims to provide the most benefit or least damage to the environment as a whole, at an acceptable cost in the short and long term. "Attainability and Sustainability" should be the key parameters when setting standards for the upgradation of the dumpsites.

2.1 Open Dumping

Open dumping is the most common method of MSW disposal in many middle and lower-income countries and such practices must be brought to an end. Characteristics of a typical dumpsite in these countries are listed in Box 2.1.

Box 2.1 Characteristics of existing dumpsites

- No planning
- No one on site who can exercise authority
- No access control or control over the type of waste entering the site
- No control of waste deposition
- No confinement of the waste body
- Uncontrolled burning of waste

It is also possible that no proper siting or site investigation and no engineering design are done for the site. It will therefore have no groundwater protection and drainage controls, among others. Thus, the first task will be to decide if the site should be closed and/or remediated or rehabilitated. To determine whether to rehabilitate and close, or to remediate, upgrade and operate a dumpsite, the environmental risks posed by the site must be assessed. These may involve technical investigations and Environmental Impact Assessments (EIAs), including consultation with the interested and affected parties, specifically in the adjacent communities.

Technical investigations assess the siting of the dumpsite and identify any flaws e.g., sites situated in floodplains, watercourses or groundwater; or sites that adversely affect the environment and, because of insufficient buffer zones, adversely affect the quality of life of adjacent residents. The key steps towards upgrading the dumping sites may include evaluation of some criteria to assess the risk of the current practices and to prepare an action programme for the dump rehabilitation (Box 2.2).

Box 2.2 Criteria for upgrading dumpsites

- Characteristics of the dumps, such as the depth and characteristics of solid waste and degree of compaction that took place, variability of wastes within the site, the size of the dumps as defined by the total amount of solid waste disposed of and the areal extent of the dumps
- Environmental and health impacts of the existing dumps and definition of current contamination
- Potential for "mining" decomposed organic materials (compost) from the existing dumps
- Potential of using the compost mined or developed from the land dumps as the daily cover material
- Occupational health of landfill scavengers and scope for assimilating these scavengers into the onsite activities during the upgradation of dumps
- Number of people and especially any sensitive populations that could be influenced by the release of pollutants from the landfill and the duration of exposure

The investigations should also consider the integrity and effectiveness of landfill design and the need for remedial design. They should also assess the operation in terms of standards and resource constraints. Finally, whenever a site has a limited life, this promotes the closure alternative. However, closure can only be considered if a replacement site is available. If the decision is to rehabilitate or upgrade the site, then steps should be taken to move from open dumping to the next stage of "**controlled dumping**".

2.2 Controlled dumping

The controlled dumpsite is still an unacceptable operation as it does not comply with the fundamental landfill principles of waste compaction and covering. However, it is a step higher than the open dumpsite as there are certain "Basic Control Measures" (Box 2.3) in place. It therefore meets fewer of the definitive criteria for dumpsites.

Box 2.3 Basic control measures for controlled dumping

- A person in authority is on site
- Control of vehicle access to the site
- Control over the types of waste entering the site
- Control over where vehicles may drive and deposit waste on the site
- Waste will be deposited in a single controlled area where basic waste handling techniques will ensure a controlled and consolidated waste body
- Uncontrolled waste burning will be eliminated
- There will also be preliminary drainage control measures
- Control will be exercised over salvaging operations
- Foraging animals will be driven out of the site

This is the stage of landfill development that can be achieved in most middle and lower-income countries in the short term at the existing municipal open dumpsites. Such measures can be done without much additional investments and will significantly improve the site and reduce its adverse impacts and associated nuisances. While the World Health Organisation (WHO) suggests one year for this progressive upgrade steps (Rushbrook, 2001), it may vary depending on the original status and local conditions. Success depends mainly on the commitment of the concerned authorities and capacity building in the responsible organization through training, to ensure sustainability.

2.3 Engineered Landfill

An engineered landfill is a disposal site where, through planning before construction or through modifications at an existing site, there is a gradual and obvious adoption of engineering techniques (Box 2.4).

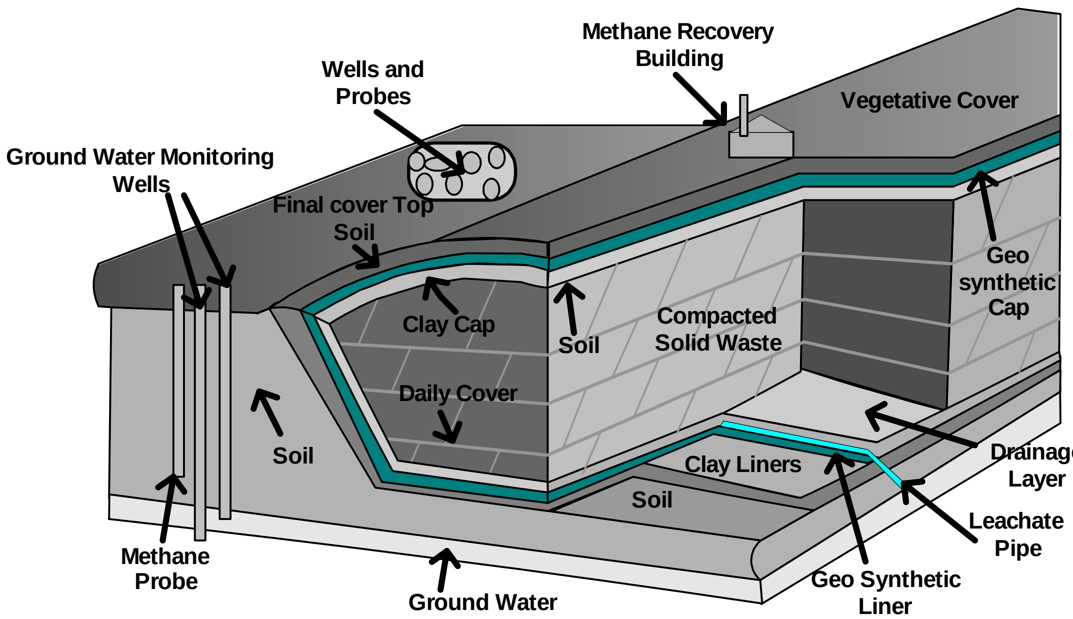
Box 2.4 Engineered landfill techniques

- Control and avoidance of surface water entering the deposited wastes by installing a well designed and constructed surface drainage system
- Extraction and spreading of soil materials to cover wastes
- Spreading and compacting wastes into smaller layers
- Collection and removal of leachate away from wastes into lagoons or similar structures.
- Passive venting of landfill gas out of the wastes
- Improvements in the isolation of wastes from the surrounding geology

It is based on the concept of isolating the landfilled wastes from the environment until the wastes are stabilized and rendered innocuous as much as possible through the biological, chemical and physical processes of nature. Essentially, the landfill design should incorporate the components enumerated in Box 2.5 and depicted in Figure 2.2.

Box 2.5 Components of engineered landfill

- **Liner system** at the base and sides of the landfill - prevents migration of leachate or gas to the surrounding environment;
- **Leachate collection and treatment system** - collects and extracts leachate from within and from the base of the landfill and treats to meet regulatory requirements;
- F**inal cover** of the landfill - enhances surface drainage, prevents infiltration of water and supports surface vegetation;
- **Surface water drainage system** - collects and removes all surface runoff from the landfill site;
- **Environmental monitoring system** - periodically collects and analyses air, surface water, soil and ground water samples around the landfill site;
- **Organized and well qualified work force and detailed record keeping system; and**
- **Landfill closure and post closure monitoring.**



Source : P.O'Leary and P. Walsh, University of Wisconsin-Madison Solid and Hazardous Waste Education Center, reprinted from Waste Age 1991-1992

Figure 2.2 Cross section of a typical engineered landfill

Movement from open dumping to sanitary landfills may be a long-term goal since sufficient physical and financial resources are only likely to be available in a limited number of places over the next few years to reach this standard of waste disposal.

Reliance on heavy equipment such as landfill compactors to achieve high density may not be critical if the wastes are already dense with less bulky material. In areas where the supply of fuel or electricity may be interrupted, gravity and natural systems should be preferred for leachate management over mechanical systems. The principle of ‘keep it simple’ and ‘make it sustainable’ should be adopted rather than a ‘high tech’ solution.

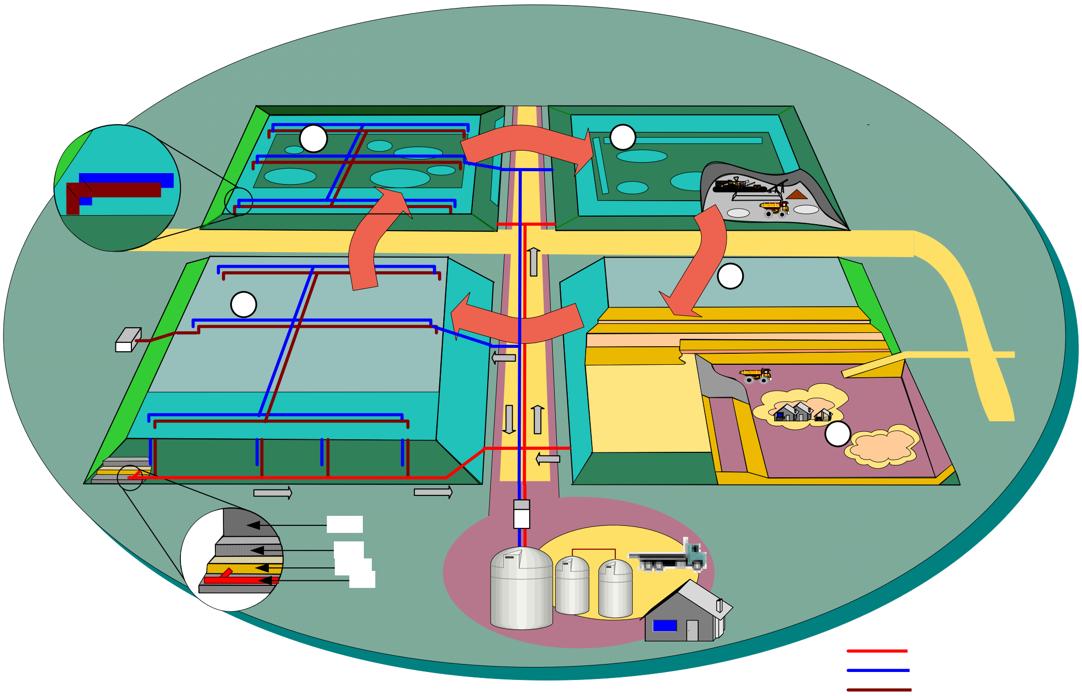
2.4 Sustainable Landfill

Till recent years, the driving principle of landfill management has been to prevent saturation of the waste to minimize the likelihood of leachate leaking into the surrounding ground as in an Engineered Landfill. This has resulted in very slow rates of waste degradation, with projected stabilization times of the order of hundreds of years. Degradation could in principle be accelerated by circulating fluids through the waste in a controlled manner, and operating the engineered landfill as a bioreactor. This approach is more consistent with the aims of a sustainable waste management policy than the conventional “dry tomb” approach, which leaves landfilled wastes in a potentially polluting state for many generations.

In sustainable landfills, airspace, processes, control and/or use of products and residues are at an optimum and where minimal negative effects on the environment takes place. The goal is to treat the waste within a lifetime. This can be achieved when the waste within a landfill becomes stabilized and the stabilized waste is mined to make available the space for refilling. Landfill mining in a sustainable landfill should be attempted when the land filled wastes are sufficiently stabilized. The attainment of this level depends to a large extent upon parameters that control the chemical and biological processes (e.g., moisture content, temperature, microflora, and compaction rate) occurring in the landfill waste (Zurbrugg, 1999).

Two new methods of landfill disposal, often called the *anaerobic bioreactor* and the *aerobic biocell*, are attempts in this regard (Reinhart and Timothy, 1998). The anaerobic bioreactor is similar in design to an engineered landfill and the basic difference is in operational practices which involves leachate recirculation to enhance waste stabilization. It has a leachate collection and recirculation system, geomembrane liners, final cover, and gas collection system. In this type of system, the gas that is predominantly produced is methane, which can be collected and purified for sale and/or use. The level of methane production will be related to the level of organic waste present in the landfill. On the other hand, the aerobic biocell is set up just like the anaerobic except for the presence of an air circulation system. Unlike the anaerobic bioreactor, the ultimate objective is to maximize the speed of decomposition of the contents. Air is percolated through the landfill to encourage aerobic decomposition and the accompanying preferential production of carbon dioxide instead of methane. Since methane production is not the aim of this landfill, the level of organic waste will not affect its performance as much as the anaerobic system is affected.

Environmental Control Systems, Inc. (2001) of South Carolina, provides a method for treating biodegradable waste material in a sustainable landfill by aerobic degradation (Figure 2.3). The purpose of this approach is to greatly accelerate the natural degradation of the waste, as aerobic processes can degrade wastes up to 30 times faster than under anaerobic conditions. In the end, the "stabilized" waste mass has limited methane and odour



Source : ECS, 2001

Figure 2.3 Schematic of sustainable landfills

production, produces less harmful leachate that can impact groundwater, and settles to the point whereby the landfill "recovers" valuable landfill airspace. In addition, the waste is in a safer condition to mine and recycle, paving the way to "reusable" or "sustainable" landfills and lowering life-cycle landfill costs.

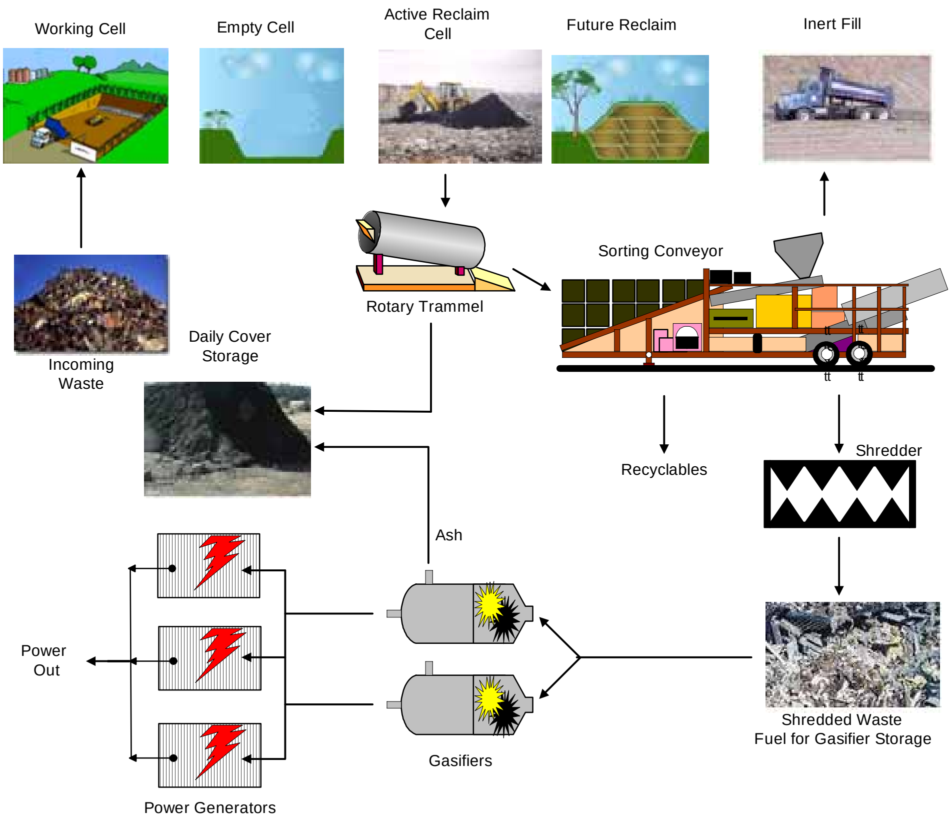
The effect of degradation in altering the density, moisture content and the permeability of the waste to both gas and water are important considerations in the bioreactor system since efficient management of the system requires that fluids be extracted from and circulated around the bulk waste phase. Waste placement methods, cell size, design of drainage and leachate circulation systems are all critical engineering decisions and must be made with reference to the effects of the degradation activities which take place in the waste.

In the Thermogenics Landfill Reclamation System (Thermogenics, 1999), as shown in Figure 2.4, the landfilled material is recovered by front-end loaders in an operating sustainable landfill. The mined material includes all materials in a given cell plus the daily cover that is placed during the active life of the cell. By using a rotary trommel screen it is possible to separate the daily cover materials, plus broken glass, etc. from the balance of the waste. This recovered material is stored on-site and reused as daily cover for the active cell then receiving incoming waste. The remaining materials coming from the trommel screen are then sorted to remove metals, glass, and other inert material, which is either sent to recycling or returned to the active cell of the landfill. The final product from the sorting conveyor is organic material, which is then shredded and stored for use in the Gasifiers located on-site. This organic material is properly classified as Refuse-Derived-Fuel (RDF) and when used in the Thermogenics Gasifiers produce about 870 kWh per ton of fuel (Thermogenics, 1999). It is also feasible to construct a liquid fuels production module in addition to producing sufficient electrical power to operate the entire facility. The gas produced is fed directly to multiple engine-generator sets to produce excess power that can be placed back on the utility grid or sent to a local user. Waste products from the gasifier, such as ash can be used in the daily cover material and excess wastewater, if any, can be treated for discharge. All of the equipment used for this type of project can be moved to a new site once the entire landfill has been reclaimed and the empty cells upgraded for future use.

2.5 Integrated Approach to Sustainable Landfill Management

The concerted investigations from various Asian institutions have revealed that the sustainable landfill management in Asia could be achieved by an integrated approach as illustrated in Figure 2.5 (Kurian et. al, 2003). Dumpsite rehabilitation would be a paramount option to rehabilitate existing open dumps through landfill mining where the resource recovery might serve as a source of energy, recycle and reuse of metals, plastic and glass ware, use of compost as fertilizer for agriculture and as a cover material for future landfills. Because land close to the origin of the domestic waste is hard to find dump site rehabilitation might benefit in regaining a suitable site for an engineered landfill.

Pre-treatment of municipal solid waste prior to landfill through either aerobic or anaerobic, or a combination of both shall become necessary to reduce the total amount of waste to be disposed of and simultaneously diminish the leachate treatment, gas management, geotechnical problem of landfill settlements and reduced after care period.



Source : Thermogenics, 1999

Figure 2.4 Sustainable landfill reclamation process

The effects of pretreatment, compaction, and appropriate cover design would greatly minimize the pollution load to the environment. However, better understanding of the local climatic effect on enhanced degradation would help accomplish the better landfill leachate management through adapted operational conditions to different seasonal variations. Focus has to be given on the interaction of design and flexible operation, which needs trained and experienced staff, too. As environmental burden cannot be completely reduced, biologically enhanced methane oxidation and combined biological and low cost chemical-physical treatment of landfill leachate is a final practice of open-ended aftercare. A natural remediation technique such as phytoremediation using plants, though slow, is also worth considering.

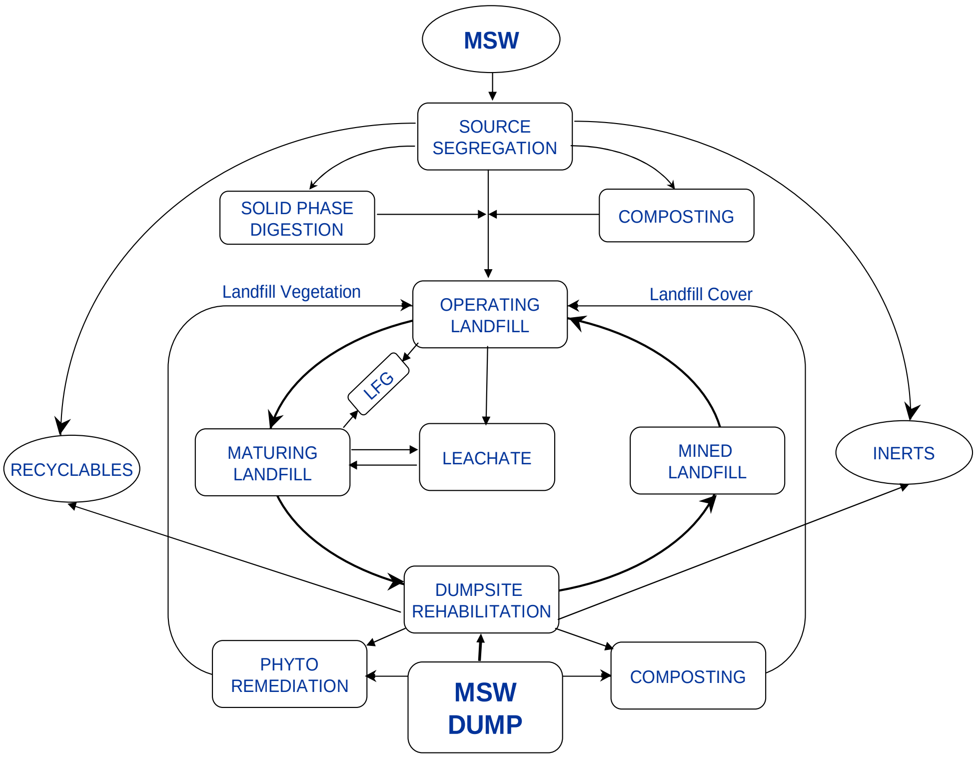


Figure 2.5 Integrated approaches to sustainable landfill management

CHAPTER 3

DUMPSITE REHABILITATION

3.1 Dumpsite Rehabilitation

The first priority in the integrated approach discussed in Chapter 2 should be to move from the widespread open dumping to controlled dumping. The purpose of dumpsite rehabilitation should be to convert these open dumps into a controlled dumpsite for the remaining duration of their operational lifetime. Dumpsite rehabilitation has three distinct stages of remedial activity:

- planning and designing the remedial works;
- undertaking the one-time physical improvements at the site; and
- changing subsequent operations at the site.

The World Health Organisation has recommended a list of the minimum standards to be achieved in each stage (Rushbrook, 2001). An estimate should be made of the approximate quantity of waste that the disposal site receives each day and the general types of wastes that arrive for disposal. An open dumpsite should not be converted to a more controlled operation if its estimated remaining lifetime is less than one year. Instead, efforts should be directed towards identifying a new temporary, better-controlled disposal operation or the development of a larger engineered landfill with an estimated lifetime of more than ten years.

3.1.1 Planning for dumpsite rehabilitation

The scope of a Dumpsite/Landfill Rehabilitation project will be determined by whether its goal is one or a combination of the following:

- Reduce landfill footprint and cover;
- Recover landfill space for continued operation; and/or
- Landfill upgradation or installation of landfill liner and relocation of the entire landfill.

The first step in planning a landfill mining and rehabilitation project should be a site survey to gather site-specific information such as its operating history, types of wastes present, dimensions, topography and physical characteristics (Salerni, 1995).

The next step of site investigation involves planning for preliminary excavation and obtaining the necessary regulatory approvals. At this point, a work plan must be developed to include:

- The number of pits and/or trenches to be dug;
- Equipment and material handling procedure;
- Labor requirements and their safety;
- Creation of a work zone with clearly marked boundaries; and
- Necessary analytical testing, measurements and data collection.

Some relevant factors that need to be addressed while planning dumpsite rehabilitation employing the concept of landfill mining are given in Box 3.1.

Box 3.1 Planning for dumpsite rehabilitation

- Proper time to begin extracting material from the landfill, taking into consideration the odour that will be produced
- Methodology that should be adopted to conduct feasibility studies
- Methodology in taking representative samples
- Development of methods of analysis of the mined samples
- Materials that can be recovered through mining of dump sites/landfills
- Expected quality of the recovered materials in terms of purity
- Variation of degradation with time, wastes and space
- Environmental and health risks of landfill rehabilitation works
- Enhancement of waste stabilization and integration of landfill design and operation

This plan has to provide the blueprint for every activity to be conducted during site investigation. The primary activity of the site investigation is to characterize the wastes in the areas to be excavated. This is accomplished by digging test pits and/or trenches and analyzing to determine material volumes, soil to waste ratio, waste composition and its state of decomposition. A trench exposes a larger area and can give a better idea of what is buried but may unleash odours than digging a pit (Salerni, 1995). Once the site investigation is completed, the information gathered should be analyzed to determine whether the proposed goals could be met within the projected cost framework. The issues to be addressed in this analysis include slope stability, access roads, leachate management, fire control, soil cover, waste reception, fencing, scavenger control, use of mechanical equipments, limiting the working face and waste disposal operations.

Slope stability

Over-steepened waste slopes should be identified for regrading and the quantity of waste to be moved estimated. Unless there are compelling local geotechnical reasons, in parts of the site not in use, no waste side slope should be steeper than 1 in 3 (33% gradient) and top slopes should not be more than 1 in 20 (Rushbrook; 2001). The slope stabilization activities should seek to redistribute waste within the confines of the existing dumpsite and not extend the external boundaries of the fill.

Access road

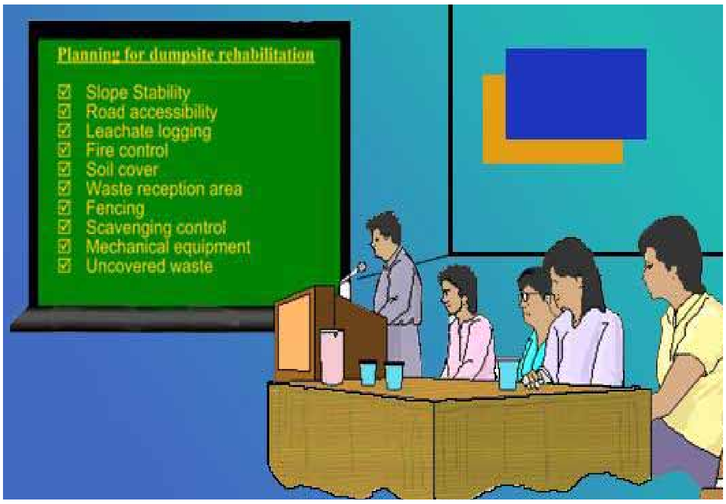
Access to a disposal site from the highway is essential. The access road should permit the passing of two trucks travelling in either direction. Roadside waste piles should be removed and the road upgraded to a sufficient standard to permit the easy passage of trucks carrying waste to the site. The running surface should be firm and not easily disrupted by traversing trucks. A minimum standard for the road surface is compacted earth or similar material with a top dressing of road stone. A durable, asphalt surface would be preferred, if resources are available.

Leachate accumulation

If accumulated leachate is identified on the open dumpsite then a plan should be made to drain or pump the leachate into a prepared lagoon not liable to flooding or recirculated back into the waste. The source of the leachate should be determined and the remedial works defined to prevent leachate accumulations reoccurring in the future.

Dumpsite fire control

Where fires exist at an open dumpsite, a plan should be prepared to extinguish them as the rehabilitation work progresses across the site. The method to be used for extinguishing fires should be presented in the plan. The use of water to extinguish fires should be avoided. Isolation and rapid natural burnout or smothering with soil is preferred.



Soil cover

Compared to the benefits of a better-controlled operation and improved compaction of waste, soil cover is expensive and may not be that beneficial, especially if the dumpsite is located in a remote area. In a situation where dumpsite volume is limited, the use of soil cover implies less site volume will be available for waste disposal. In case a decision is made to use cover material then the daily quantity of cover material (at least 5 cm depth of daily cover, 25 cm intermediate cover and 50 cm final cover) required should be estimated. Clay soils can be used as cover material.

Waste reception area

A reception area should be clearly defined to allow incoming vehicles to be stopped and checked by operating staff. The reception area should have an entrance gate or barrier to regulate the flow of vehicles to and from the disposal site and a gatehouse to store waste records and documents and provide landfill staff with protection from unfavourable weather conditions. The reception area should have sufficient space for at least two trucks to be parked and not interfere with the vehicle movements in and out of the site.

Fencing

The provision of perimeter fencing is desirable but may not be practicable to install around all rehabilitated open dumpsites. The purpose of simple fencing is to delineate the boundary of a site and to discourage unauthorised vehicular access and straying animals. Simple fencing will not deter scavengers from entering a site. As a minimum requirement all open dumpsites within 0.5 km of communities should be fenced. The perimeter at both sides of the site entrance should be fenced to a sufficient distance to prevent vehicles bypassing the official entry point to the site. The minimum form of fencing to control vehicular access and larger animals should be a stake-and-wire strand fence or an excavated perimeter ditch and bund planted with fast growing hedge-forming shrubs.

Scavenging Control

Inevitably, scavenging is disruptive to controlled and safe land disposal operations. Ideally, it should not be allowed to take place, but when difficult economic circumstances prevail it is not easy to eradicate it from a disposal site. A policy to tolerate the presence of scavengers requires decisions on how best to accommodate their activities without interfering with the waste emplacement operations. A decision to eradicate scavenging will imply the need to install additional site security measures.

Where scavenging is tolerated, a minimum approach is to separate scavengers from the mechanical equipment emplacing waste. The usual approach is to set up a temporary scavenging area near the waste emplacement area where trucks can discharge their loads. After the scavengers have finished searching the waste it is bulldozed to the emplacement area. At larger sites, a permanent scavenging area such as a raised platform, could be established and the remaining residues transferred to a truck or container below for transport to the emplacement area. It is also common to arrange for families or groups of scavengers to be licensed to enter the dumpsite and collect one or more types of materials.

Mechanical equipment

The preparations for dumpsite rehabilitation should include a list of equipment to be provided to the improved site. Mechanical equipment serves three basic functions at a controlled land disposal site:

- Functions related to soil (excavation, handling, spreading and compaction);
- Functions related to wastes (spreading and compaction)
- Support functions (maintenance of on-site haul roads, water clearance and drainage ditches and removal of trapped trucks from the landfill working area).

The number and type of equipment required will vary depending on the quantity of waste received each day and the resources available to maintain and operate the equipment. The following equipments are required for full operation of the disposal site:

- one bulldozer of sufficient size to handle the daily quantity of waste arriving at the site to spread and compact waste and soil cover;
- one tractor and trailer to carry soil to the working area and undertake some support activities;
- a supply of spare parts and consumable items for the mechanical equipment; and
- a supply of hand tools including shovels, brooms, wheelbarrows and rakes.

Additional items that would improve further the operation of the dumpsite are:

- One water tank on a trailer with a pump to carry leachate and spray water on roads to control dust; and
- A mechanical shovel to excavate the soil cover if soil has to be brought from a borrow area.

Area of exposed waste

All exposed and uncontrolled piles of waste should be compacted into layers. They may also be moved to other parts of the site if this facilitates the creation of the eventual final landform of the site. All uncovered areas of waste not expected to receive new deposits of waste, or at least not in the next few months, should be covered with an intermediate or final layer of soil material. The remaining area of exposed waste will form the initial working area for the emplacement of incoming waste. This area should not exceed 0.5 ha for sites receiving up to 250 tonnes per day and one hectare at sites receiving 250 to 500 tonnes per day. Two hectares may be appropriate at large sites receiving well over 500 tonnes per day.

All these preparatory aspects of the planning and design of open dumpsite remedial works should be presented to the relevant technical and municipal authorities in a 'Rehabilitation plan'. Once the project is deemed feasible, an expanded work plan must be created to address the material, movement, manpower and machine requirements. The work plan may address issues given in Box 3.2.

Box 3.2 Issues related to rehabilitation plan

- How much material has to be moved in a day to reach the project goals without exceeding the budget?
- Which part of the site will the equipments be placed?
- How will the materials be moved and stockpiled on site?
- How many workers will be needed to accomplish the tasks?
- What training do the workers require?
- What should be done with the wastes/recovered components after digging them up?
- What are the sampling and analysis protocols to determine the quality of excavated material?

Source : Salerni, 1995

Financial and economic analyses for producing the cost estimates of rehabilitation; the assessment of the financial and economic impacts of rehabilitation and forecasts of increases in the land price in adjacent areas subsequent to rehabilitation may also need to be prepared.

Once this plan is finalized, the activities may be carried out based on the plan. A daily review of the work plan is necessary to make adjustments to suit site requirements.

3.1.2 Waste disposal operations

Waste disposal operations at the site should be in accordance to a waste disposal plan prepared during the rehabilitation planning stage. A waste disposal plan should be prepared to provide clear instructions on the topics given in Box 3.3 related to site operation.

Box 3.3 Waste disposal plan

- Size and location of the first and subsequent sequence of areas to be filled with waste after the site has been rehabilitated, leading ultimately to the completion of the site and its final landform. Each waste emplacement area will have a unique reference number indicated on a scale drawing of the site
- Method of waste emplacement and soil covering to be used
- Structure, roles and responsibilities of the management and manual staff at the site
- Procedures for record keeping related to incoming vehicles, waste types and estimated quantities
- Procedures for record keeping related to on-site mechanical equipment, other routine maintenance and accident and defects reporting
- Traffic control at the site
- Fire prevention and smoking rules
- Maintenance and repair water drainage ditches
- Instructions for dealing with prohibited wastes that arrive at the site reception.

Waste reception

At the site entrance, all incoming loads should be registered and the following details are to be recorded for each load: date, time of arrival, vehicle identification number, vehicle owner, description of waste, estimated quantity of waste (weight or volume), and waste emplacement area used. The waste disposal site should have a sign at the main entrance providing the following details: name of site, opening days and hours, arrival instructions for drivers, no smoking markings and a short summary of the site's importance.

Waste placement

No vehicle driver should be allowed to choose where to deposit a waste load. The driver must be directed by the site entrance staff to the current waste emplacement area and discharge only at the location indicated by the traffic marshal. The installation of sufficient portable, temporary or permanent lighting should be considered if nighttime working at the dumpsite is planned.

Environmental monitoring

Box 3.4 gives the minimum environmental and health monitoring recommendations.

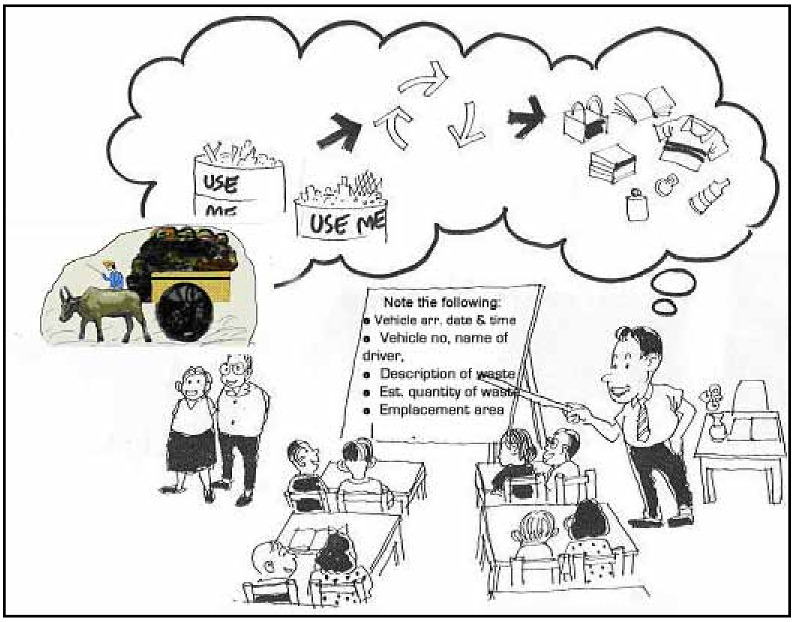
Box 3.4 Environmental and health factors

- Presence and distribution of surface discharges of leachate
- Quality of the receiving watercourse and diversity of ecological indicator invertebrate and fish species
- Presence of vegetation die-back or discolouration around the dumpsite that may indicate lateral gas migration
- Water quality in drinking water wells located within 500 m radius of the dumpsite
- Presence of vectors (e.g., rodents and insects) breeding in or near the dumpsite

3.1.3 Staff training

If the staff are not trained or given clear, written job descriptions then it is not surprising that they show little interest or competence in operating an organised and well-run waste disposal operation. It is also for site personnel to understand that with training and defined job descriptions comes the responsibility to perform properly the tasks they are given. Status, pay, employment contracts and working conditions also influence the ability and willingness of individual staff members to accept and carry out the responsibilities placed upon them. These personnel issues must also be addressed during the planning stage.

The minimum number of staff will vary depending on the quantity of waste received and the standard of disposal operation achieved. Suggested staffing arrangements for a site receiving between 250 and 500 tonnes per day are given in Box 3.5.



Box 3.5 Staff requirements

- A site manager with sufficient delegated authority to manage daily site activities and access to physical and financial resources to overcome day-to-day operational problems
- A gatekeeper/office clerk
- Security guards (if necessary)
- Traffic marshal(s) for directing trucks to discharge waste at the working part of the disposal site
- Mechanical equipment drivers (minimum of two)
- Manual labourers (minimum of ten)
- Maintenance mechanic(s) if it is intended to establish a maintenance facility at the disposal site.

3.2 Research on Dumpsite Reclamation

The ongoing research on "Sustainable Landfill Management" funded by SIDA has focused on the reclamation and upgradation of the dumpsites at Kodungaiyur (KDG) and Perungudi (PDG), in Chennai, India through Landfill Mining. These two dumpsites have been in operation for the past 15 years and currently receive about 3500 tonnes of MSW daily. The wastes are disposed through open dumping without use of any cover or compaction. Open burning of wastes is very common. This project started in 2001 under the Asian Regional Research Programme on Environmental Technology (ARRPET). The objective of this study is to evaluate the degradation status of solid wastes of different age in the MSW dumpsites. The data generated could be used for comparing the waste degradation status in open dumps and sanitary landfills and for assessing the potential of recovering useful materials such as compost and inorganic recyclables from the dumpsites.

The scope of the study is depicted in Figure 3.1. The methodology involved collection of samples from two dumpsites at intervals of 1 m depth from the top of the waste dumps and analyzing them to determine density, temperature, moisture content, particle size, organic and inorganic fractions, macro nutrients (N, P, K) and heavy metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc). The heavy metal content of the soil fraction is compared with the Indian and international standards for compost to check its applicability as compost.

The major conclusions drawn from the study are summarized in Box 3.6.

Box 3.6 Results of landfill rehabilitation research in India

- Excavation and Augur boring techniques (Figure 3.2) can be used for collection of samples of degraded waste. The techniques gave good results where the waste is homogeneous (Tables 3.1 to 3.3).
- Arsenic, Hg and Cd are found to be less than 3 mg/kg. For other metals, the descending order of metal content is Zn, Cr, Cu, Pb and Ni. (Table 3.4). Comparison of heavy metal contents 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.
- Water extractable pollutants are very less in the fine fraction of the solid waste collected from both PDG and KDG. Low BOD, COD and DOC indicate the poor leachability of organic pollutants in water (Table 3.5).
- For landfill leachates collected from PDG and KDG, pH varied from 7 - 8.5; in some cases the TDS was as high as 15000 mg/L; for most cases the BOD values were less than 100 mg/L while the COD varied from 100 – 8000 mg/L (Figures 3.3 and 3.4). The heavy metal contents in leachates are in microgram levels.
- The CH_4 level in landfill gas is less than 1%.

Source : Kurian Joseph et al., 2003; Esakku et al., 2003

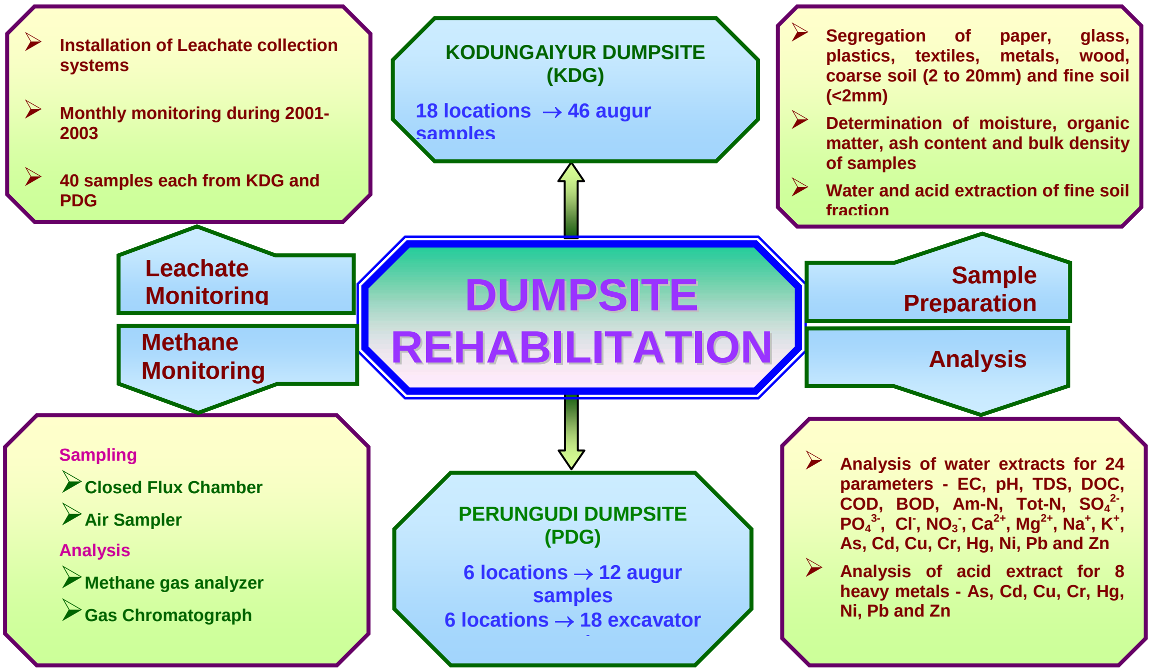


Figure 3.1 Scope of dumpsite rehabilitation research

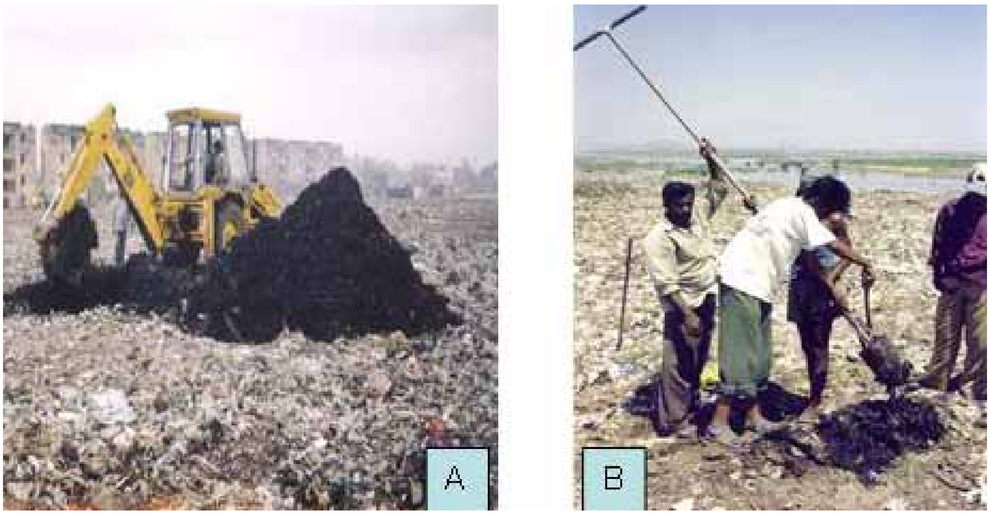


Figure 3.2 Sampling by excavation (A) and augur (B)

Table 3.1 Physical composition of augur and excavator samples from PDG and KDG dumping grounds

Site	Sampling method	No. of samples	Combustibles % ± SD	Non- combustibles % ± SD	Soil fraction % ± SD
PDG	Augur	12	39.4 ± 13.3	19.5 ± 6.2	41.0 ± 10.4
	Excavation	18	22.0 ± 14.1	44.7 ±13.3	33.29 ±6.8
KDG	Augur	46	3.5 ± 2.9	28.7 ± 11.9	67.7 ± 13.1
	Excavation	18	4.3 ± 1.9	39.3 ± 3.6	56.5 ± 4.3

Table 3.2 Physico-chemical characteristics of the soil fractions of MSW from PDG						
Particulars	**Augur ***			**Excavation ****		
	Min	**Max**	**Ave ± SD**	**Min**	**Max**	**Ave ± SD**
Temperature (°C)	32	39	35 ± 5	34	36	35 ± 1.4
Moisture content (%)	21.4	52	39.5 ± 9.5	19	40	30 ± 6.1
pH	7.6	8.6	8.06 ± 0.29	7.2	8.2	7.8 ± 0.28
VOM (g/kg)	89	158	117 ± 21	63	144	111 ± 21
Ash content (g/kg)	842	911	883 ± 21	856	937	889 ± 21
TOC (g/kg)	52.3	78.8	55.6 ± 9.4	30.2	69.1	53.2 ± 10.2
Dry density (kg/m^3)	745	1147	965 ± 132	809	1185	995 ± 85

* Average of 12 sample values ** Average of 18 sample values

Table 3.3 Physico-chemical characteristics of the soil fractions of MSW from KDG						
Particulars	**Augur ***			**Excavation ****		
	Min	**Max**	**Ave ± SD**	**Min**	**Max**	**Ave ± SD**
Temperature (C°)	30	34	32 ± 2.8	32	34	33 ± 1.4
Moisture content (%)	15.5	46	24.4 ± 6.1	15	33	23.1 ± 5.9
pH	6.9	8.1	7.6 ± 0.39	7.9	8.7	8.2 ± 0.2
VOM (g/kg)	89	207	138 ± 32.6	124	230	170 ± 29.1
Ash content (g/kg)	793	911	862 ± 32.6	770	876	830 ± 29.1
Dry density (kg/m^3)	853	1254	1106 ± 108	888	1136	987 ± 70

* Average of 46 sample values ** Average of 18 sample values

Table 3.4 Heavy metal content in fine fraction of dumpsite soil								
Particulars	**Hg**	**As**	**Cd**	**Ni**	**Pb**	**Cu**	**Cr**	**Zn**
Minimum	0.039	0.077	0.820	21.0	53.0	75.0	110.0	167.0
Maximum	0.78	1.561	1.77	50.0	112.0	217.0	261.0	503.0
Median	0.21	0.451	1.28	33	85	105	129.5	230.5
Mean ± SD	0.29 ±0.22	0.57 ±0.38	1.29 ±0.31	32 ±8	86 ±16	113 ±42	140 ±40	284 ±111
Indian CS*	0.15	10.0	5.0	50	100	300	50	1000
USEPA CS**	17.0	41.0	39.0	420	300	1500	1200	2800

All the values are in mg/kg. No. of samples: 12 CS - Compost Standards
* MSW (Management and Handling) Rules, 2000 ** US Composting Council, 1997

Table 3.5 Comparison of water extracts of dumpsite soil and leachates of KDG								
Sample	**No. of samples***	**pH**	**EC (µS/cm)**	**TDS (mg/L)**	**COD (mg/L)**	**BOD (mg/L)**	**Cl^- (mg/L)**	**Cr (µg/L)**
Water extract	46	7.5	1036	822	115	4	147	10
Leachate	26	7.7	7800	5222	788	43	1590	64

* Values are average of number of samples presented

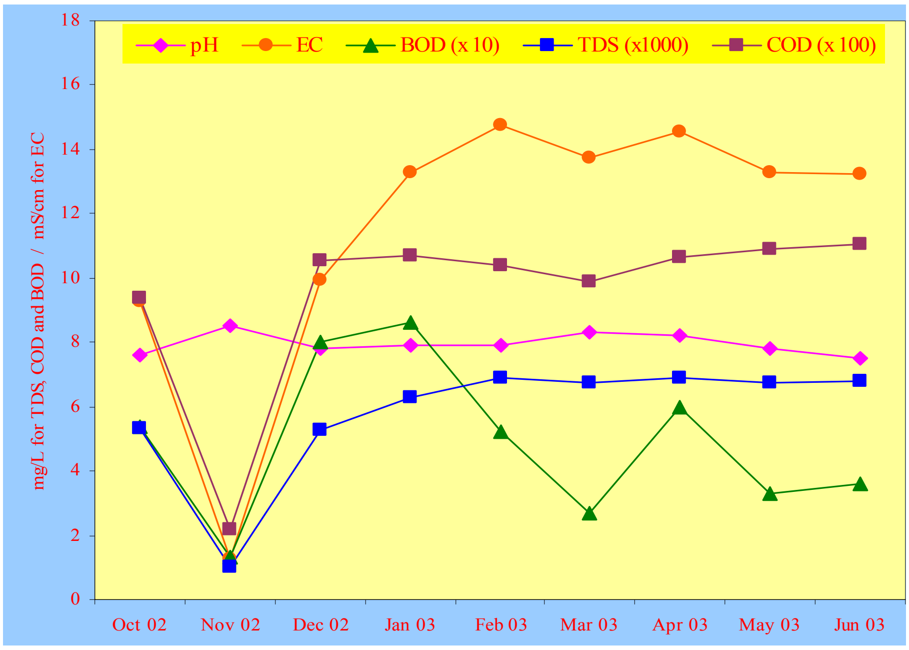


Figure 3.3. pH, EC (mS/cm), BOD (mg/L), TDS (mg/L) and COD (mg/L) of leachate collected from PDG

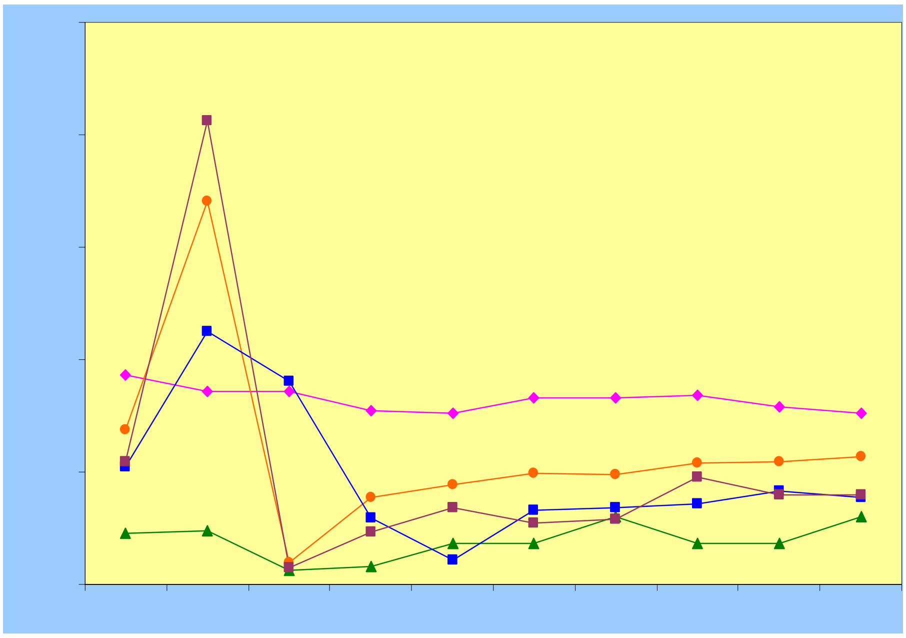


Figure 3.4 pH, EC (mS/cm), BOD (mg/L), TDS (mg/L) and COD (mg/L) of leachate collected from KDG

Studies to ascertain the aspects highlighted in Box 3.7 are in progress.

Box 3.7 Studies in progress

- Fractions of exchangeable, carbonate bound (acid extractable), reducible (bound to Fe/Mn oxides) and oxidisable (bound to organic matter/ sulphide) heavy metals in the dumpsite soil (compost).
- Fate of refractory organics (Phenolics, AOX, pesticides, herbicides etc.) at the dumpsite.
- Enhancement of stabilization and reduction of heavy metal / hazardous organic toxicity through flushing or leachate recirculation as in a bioreactor landfill.
- Feasibility of using the soil fraction from dumpsite as the cover soil for landfills.

3.3 Dumpsite Rehabilitation in Pune, India

The city of Pune generates approximately 1000 tons MSW per day. Like most of the other municipalities in India, the Pune Municipal Corporation (PMC) has been resorting to dumping of the MSW in open land and abandoned quarries. One such site is in the village of Uruli Dewachi, about 5-6 km beyond PMC limits off Saswad road. The site was originally a stone quarry and had deep excavated areas. The daily waste coming to the site is about 750 tons/day (TPD). Dumping at this site was in progress to full capacity since the last 4 years. When serious ground water contamination was observed in wells on the down stream slopes up to 2 km away from site, the PMC adopted a strategy of rehabilitating the dumpsite by capping and construction of a sanitary landfill over the capped site (Purandare, 2003)

The task of rehabilitating the dumpsite was undertaken by M/s. Eco Designs India Pvt. Ltd., Pune in February 2002. After all the preliminary data were collected, the landfill was designed as per the MSW 2000 rules. The design included the following tasks:

- Closure/capping of the existing dumpsite;
- Design of a landfill above the capped waste, with a volume to handle waste for a period of one year; and
- Design of a landfill adjacent to the capped waste, with a volume to handle waste for a period of 5 years.

The waste had been randomly deposited without any spreading or compaction. A preliminary inspection found that the waste heap was very unstable primarily because of the face angle of the waste, which was in excess of the stable angle of repose. It was therefore necessary to change the slopes as well as compact the waste, so that it would be permanently stable. The waste was evenly spread out and compaction was carried out on the slopes and the top by using heavy duty bulldozers. The closure covered an area of about 34,600 m^2. The height of waste was as much as 18 m at the edge after proper levelling.

Once the waste was graded and compacted, a 0.75 mm thick Very Flexible Polyethylene (VFPE) liner was installed above it to avoid ingress of rain water. This was protected with a geotextile overlaid by 300 mm thick soil layer. The soil layer was finally covered with sweet earth for planting of grass, which would prevent erosion of the cover soil. Drains were provided on the slopes so that the storm water could be drained and collected at the bottom, where a gutter along with a toe wall was provided. Gas vents were provided to allow for the release of gases that could be potentially formed within the covered landfill.

The capped landfill had a top plain surface area of about 18,500 m^2. The cost of dumpsite closure was Rs.10,080,000 (about US $ 0.2 million). PMC had no other acquired land on which to develop a new landfill facility. It had started composting the organic waste and was still generating large amounts of waste to be landfilled. Hence it was decided that until a larger landfill was constructed in the adjoining property, a smaller landfill would be constructed over the capped waste. This served the purpose of not only buying some time until the new facility was built, but also in developing some confidence about being able to build and operate a sanitary landfill. The construction of the landfill has now been completed and is in operation. Figure 3.5 shows different photographs taken before, during and after this dumpsite rehabilitation process.

A – Dumpsite; B – Work in progress; C – Cover and storm drains; D – After reclamation

Source : Purandare, 2003

Figure 3.5 Photographs of dumpsite rehabilitation in Pune, India

3.4 Dumpsite Upgradation in Kanpur, India

Kanpur, an important industrial city of Uttar Pradesh, India located at the bank of the river Ganga, is spread over an area of 299 km^2 with an estimated population of 3 million. An estimated quantity of 1000 t/day of MSW is generated from the city out of which about 700 t/day reaches the dumpsites. Panki site, presently the only active site in Kanpur, is spread over an area of 8 hectares and has been existing for the past 10-15 years. The average depth of the waste is around 4-5 m above ground level. The New Delhi National Productivity Council was engaged by the local authorities for assistance in upgradation of this dumpsite site in line with the requirements of MSW Rules (2000). Based on a detailed environmental impact assessment of the site the upgradation plan suggested by NPC is presented in Table 3.6. **(**Saxena and Bharadwaj, 2003).

Table 3.6 Upgradation plan for Panki Dumpsite, Kanpur
Proposed Activities
Shifting of waste: Waste lying on the northern side of the road has to be shifted to the southern side.
Closure of waste body created in one half area of site The waste body has to be closed scientifically which includes the following activities: • Bund formation • Grading of waste • Compaction and slopping of waste • Drainage channel construction • Capping consisting of clay liner, HDPE liner, drainage layer, gas vent system, top soil etc. • Growing of vegetation cover over the top soil • Laying of green belt at the periphery of site
Development of excavated area as Scientific Landfill The excavated area has to be developed into a scientifically designed landfill facility where the municipal waste can be disposed and managed in proper way. This may include the following activities: 1. Leveling of base and side slopes of the landfill and achieving the desirable grades at the base of landfill. 2. Construction of temporary embankments and surface water drains along the perimeter of the landfill. 3. Laying of single composite bottom and side liner consisting of the following: • A compacted clay/amended soil barrier of 1 m thickness ($K<10^{-7}$ cm/sec); • HDPE/geomembrane layer $\geq$ 1.5 mm thick along with the 20 cm compacted clay (protection layer) over it; • Leachate drainage layer 30 cm thick made of granular soil ($K>10^{-2}$ cm/sec); and • A leachate collection system comprising of a perforated pipe collector system (with 2% slope) inside the drainage layer, sump collection area and a removal system. 4. Installation of leachate treatment facility. 5. Providing infrastructure facilities at the site such as: • Power supply • Dozers • Compactors • Backhoes and front end loaders • Tractor trailors • Weighing scale • Office • Environmental Monitoring facilities • Security • Fencing etc. 6. Installation of two monitoring wells at the up gradient and three at down gradient

3.5 Dumpsite Rehabilitation in Ampang Jajar, Malaysia

In the early eighties, the open dumpsite at Ampang Jajar in Malaysia has witnessed constant fire, smoke and malodor from the disposed waste; neither had any leachate collection system nor defined space available for dumping. The site covers a total area of about 1.5 ha and has been incessantly dumped with about 50 tons of solid waste (both municipal and industrial waste) per day. This indiscriminate dumping of solid waste has resulted to a potential source of pollution, especially effecting the groundwater quality and air pollution. Figure 3.6 shows the condition of the Ampang Jajar dumpsite in 1988. In 1996, a particular type of semi-aerobic landfilling method, known as the "Fukuoka Method" was initiated and has been successful in rehabilitating the dumpsite. In this method, leachate is collected in leachate collection ponds through properly sized perforated pipes embedded in graded boulders (Figure 3.7).

Figure 3.6 Dumpsite in Ampang Jajar

Although the landfill was based on the semi-aerobic concept, leachate stabilization was principally through anaerobic biological degradation of methanogenic phase in the pebble layer surrounding the leachate collection pipes and gas vents. After one year placement of the solid waste inside the landfill, leachate sampling indicated that the landfill was generating low strength leachate containing BOD and COD of around 400 mg/L and 2,000 mg/L, respectively. Gas samples indicated 60% of methane content. The pebble layer acted as an anaerobic bio-filter at the bottom of the landfill. Pollution control at the landfill was provided by the design of the landfill on clay soil, and the leachate collection and gas venting facilities. Leachate stabilization was achieved through the semi-aerobic biological process over a few years after landfill operation. From the low strength of leachate generated it can be concluded that *in-situ* treatment of leachate can be achieved even for young landfills. The treatment is mainly by anaerobic process of methanogenic stage in the pebble layer which acts as a fixed-bed bio-filter (http://fsas.upm.edu.my/~sas/envpage/Research.html).

The Ampang Jajar dumpsite is now a model landfill using semi-aerobic process with leachate treatment through aeration and recirculation. It was operated based on the area method of filling with a main leachate collection pipe connected to leachate feeding lines of bundled bamboo pipes arranged perpendicular to the main pipe at 50 m intervals. Both the main pipe and the bamboo pipes were covered with a layer of pebbles for leachate screening and securing the pipes. Figure 4.8 reflects the rehabilitated dumpsite area in the year 2000 with improved management system.

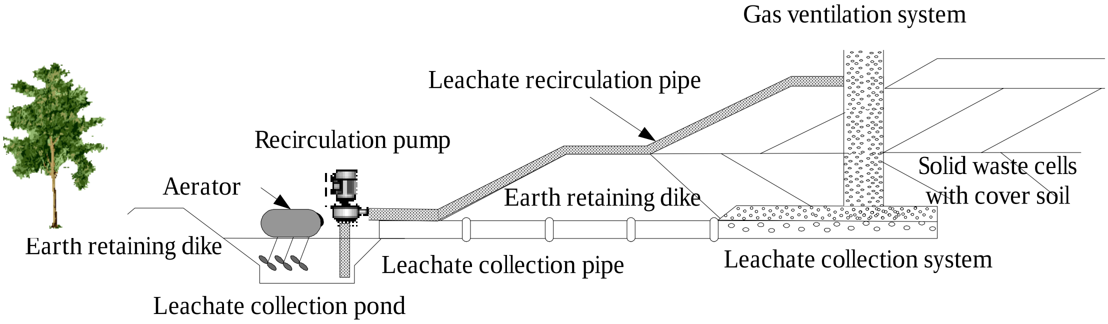


Figure 3.7 Re-circulatory semi aerobic landfill (Fukuoka Method)

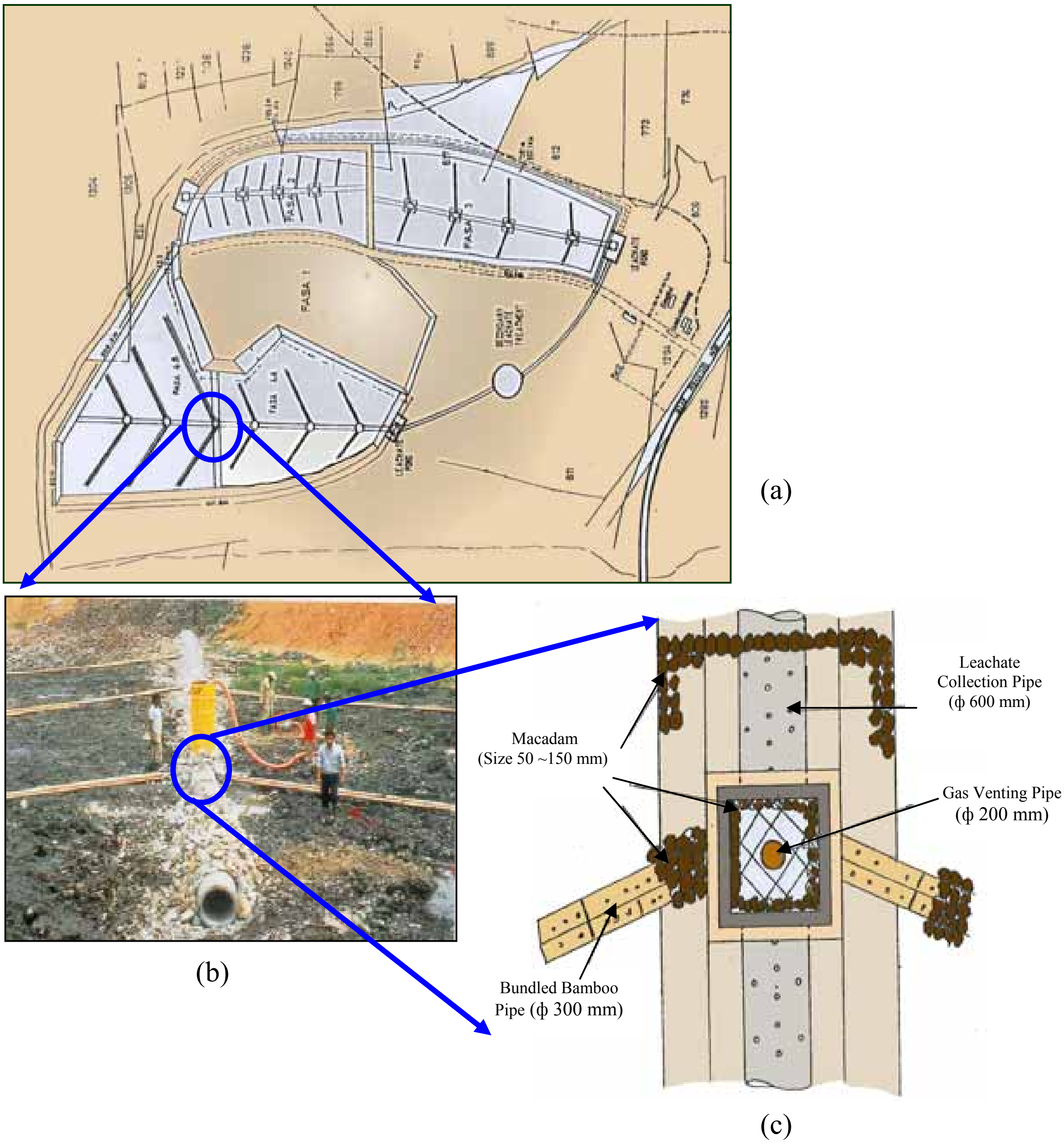


Figure 3.8 Re-circulatory semi aerobic landfill using (a) concrete pipe, (b) bamboo and (c) used steel drums

CHAPTER 4

LANDFILL MINING AND RECLAMATION

4.1 Landfill Mining Process

Landfill mining is the process of excavating from operating or closed solid waste landfills, and sorting the unearthed materials for recycling, processing, or for other dispositions (Lee and Jones, 1990; Cosu et al, 1996; Hogland et al, 1998; Carius et al, 1999). It is the process whereby solid waste that has been previously land filled is excavated and processed (Strange, 1998). Typical landfill mining processes are presented in Figures 4.1 and 4.2.

Technically, landfill mining employs the method of open cast mining for sorting out the mixed material from the landfill according to their size by using a screening machine. The oversized materials are prescreened by another sorting machine which separates the larger objects like tyres and rocks from cardboards and other smaller unearthed materials. The objectives of landfill mining are summarized in Box 4.1.

Landfill mining also provides the opportunity to remediate public health and environmental quality problems associated with the existing or closed facility (e.g. groundwater contamination). It will allow the placement of a lining system in unlined dumpsites and landfills so that future processing and solid waste management activities undertaken at the site might not present any unmanageable risk to public health and environmental quality (Lee and Jones, 1989a, b).

Box 4.1 Objectives of landfill mining

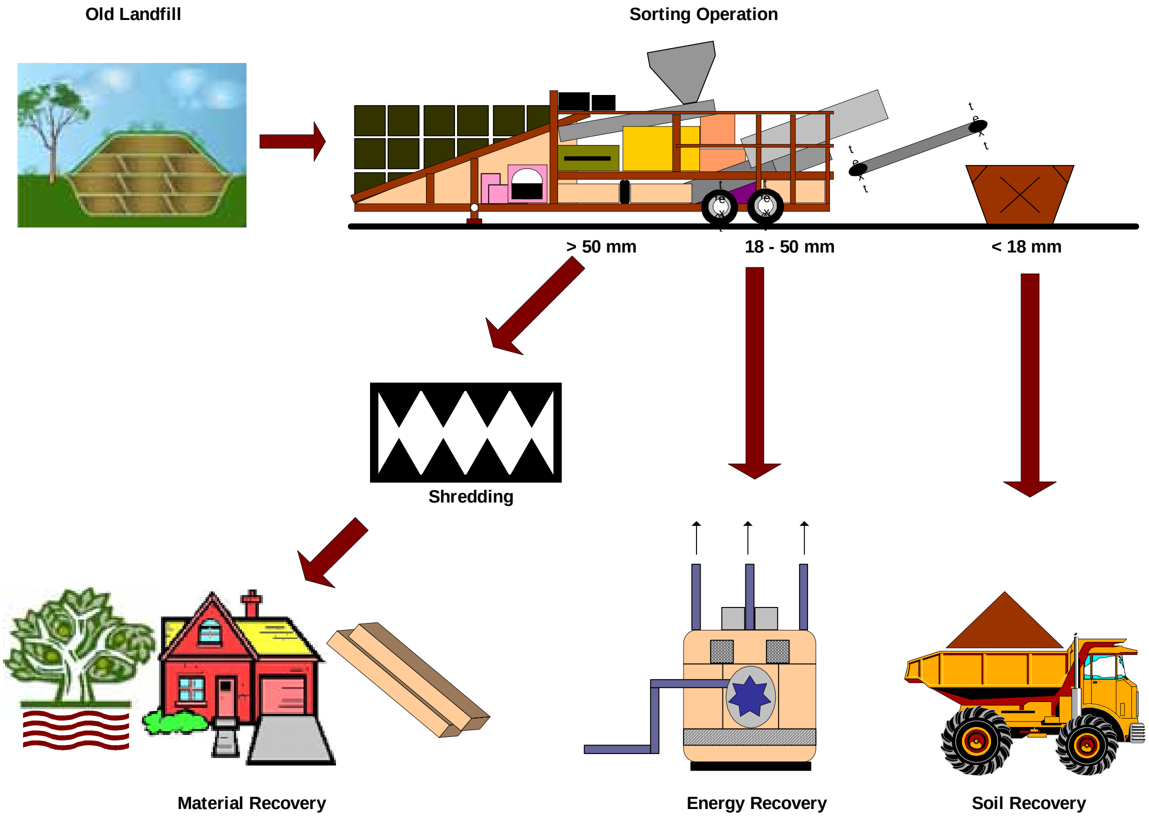
- Conservation of landfill space.
- Reduction in landfill area.
- Elimination of potential contamination source.
- Rehabilitation of dump sites.
- Energy recovery from recovered wastes.
- Reuse of recovered materials.
- Reduction in waste management costs.
- Redevelopment of landfill sites.

Source : USEPA, 1997; Lee and Jones, 1990; Hogland et al., 1997

Landfill mining process typically involves a series of mechanical operations to recover one or all of the following:

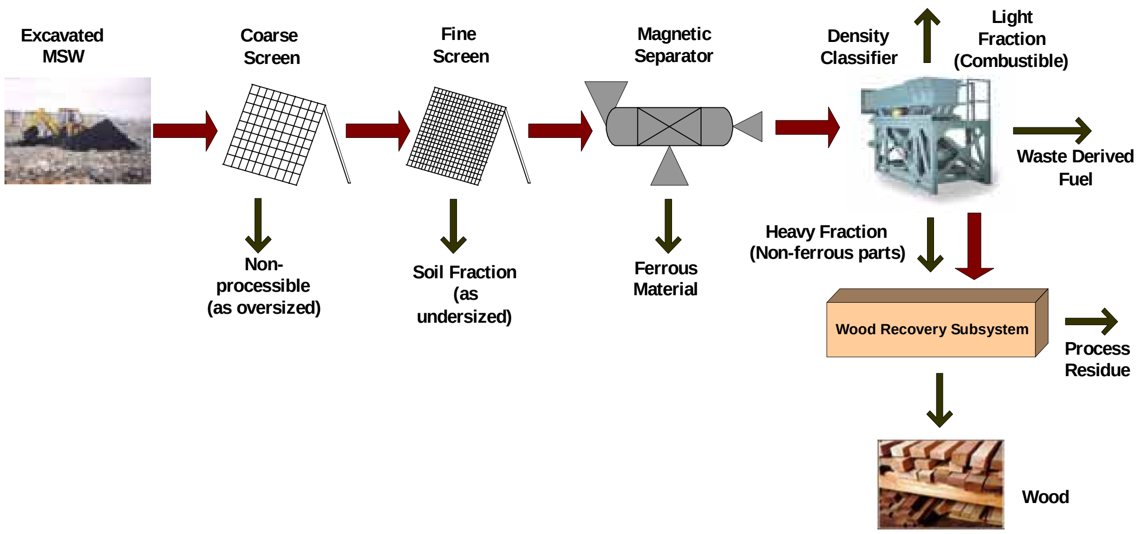
- Wood for the production of wood chips;
- Concrete, bricks and mortar material for road construction;
- Metals such as iron, aluminium, copper etc., for recycling;
- Compost/Soil; and
- Landfill space.

The key to landfill mining operation is a set of conveyers and screens that sorts the solid wastes into three size fractions: oversized material, intermediate-sized waste, and dirt/humus. The oversized materials consist of recyclable metallic goods, white goods, plastics and rubber. The intermediate-sized materials consist of partly decomposed organics, combustibles, recyclables and the fine fraction will mostly be stabilised soil. The main part of the process is the screening where the main separation is done for the oversized and the soil elements. Ferrous metals are generated from the main stream by employing a magnetic separator and the non-ferrous parts using an air classifier, which leaves behind the residue that could be combusted.



Source : Carius et al, 1999

Figure 4.1 Schematic of a landfill mining process



Source : Savage and Diaz, 1994

Figure 4.2 Process scheme for a landfill mining plant

In landfill mining operations, an excavator removes the contents of the landfill cell. A front-end loader then organizes the excavated materials into manageable stockpiles and separates out bulky material. A trommel (a revolving cylindrical sieve) or vibrating screen separates soil (including the cover material) and solid wastes from the reclaimed waste. Trommel screens are more effective than vibrating screens for basic landfill mining (Murphy, 1993). The size and type of screen used depends on the end use of the recovered material. For example, if the reclaimed soil were to be used as landfill cover, a 6.25 mm screen is used for separation. A smaller mesh screen (2.5 mm) may be used to remove smaller pieces of metal, plastic, glass, and paper, if the reclaimed soil were meant for construction fill, or for another end use requiring fill material with a high fraction of soil content. The separation of dirt/humus material from the intermediate-sized waste is made using a screen grid with 6.25 mm openings. The success of materials recovery is dependent on the composition of the waste, the effectiveness of the mining technology and the efficiency of the technology (Cossu et al, 1996). The recovery of various materials ranges from 50 to 90% of the waste (Strange, 1998). The average soil fraction in recovered municipal waste from landfill tends to be around 50-60%. However, it can vary between 20 and 80% as given in Table 4.1 depending on moisture content and decomposition rate (Hogland, 2002). The soil fraction could be used as cover or lining of new landfill. Strange (1998) suggested that a landfill needs to be 15 years old before a successful mining project can be performed. The success of a project depends on the composition of the decomposed waste.

Table 4.1 Soil to waste ratio in landfill mining

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**
Schoneiche, Germany	20-80*, 30:70**
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 ** Screen gauge 8-40 mm *Source: Hogland, 2002*
Screen gauge is 24 mm unless otherwise indicated

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.

4.2 Benefits of Landfill Mining

Landfill mining for reclamation (LFMR) 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 in Box 4.2.

Box 4.2 Advantages of landfill mining

- Recovered materials, such as ferrous 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 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 LFMR, especially at older landfills, could be managed in an environmentally sound manner.

Source : USEPA, 1997; Lee and Jones, 1990; Hogland et al, 1997

Most potential economic benefits associated with landfill mining are indirect and may include any or all of the following:

- Increased disposal capacity;
- Avoided or reduced costs of landfill closure and post closure care and monitoring;
- Revenues from recyclable and reusable materials, e.g., ferrous metals, aluminum, plastics, and glasses. Combustible waste and reclaimed soil are sold as fuel and construction fill, or for other uses; and/or
- Land value of sites 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.

4.3 Limitations of Landfill Mining

One limitation of landfill 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 landfill 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 landfill 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 landfill mining because of the burial of hazardous materials in many landfills and the presence of explosive gases such as methane (Box 4.3).

Box 4.3 Limitations of landfill mining

- Poor quality of recovered materials
- Ineffectiveness of substituting recovered tin cans for scrap aluminum cans
- Low-value and limited applications of recovered plastic products
- Poor separation of plastics /glass, based on their base material
- Emission of landfill gas
- Health hazardous

4.4 Landfill Mining Projects in the Asian Region

4.4.1 Landfill mining in China

An opportunity to combine existing Chinese landfills and horticulture activities include landfill mining and greenhouse growing systems (Sino - Australian Mission on Integrated Solid Waste Management, 1997). Initial trials were carried out at San Lin, where the reclaimed wastes were screened to get soil fraction and a residual inorganic fraction. An inspection of the degraded wastes *in-situ* at San Lin, revealed that the soil fraction could provide a very fertile growing medium, while the inorganic fractions could be used as a source of energy. Old cells were excavated to recover more space. The excavated material was screened to produce three fractions, namely biodegraded organics, combustible inorganics, and non-combustible residuals. Excavated cells were prepared for refilling with new waste, allowing for the use of artificial lining of old cells, reduction in bund wall dimensions and upgrading of leachate and gas collection systems. The non-combustible residuals were returned to the prepared cell. Biodegraded organics from old cells were combined with freshly excavated silts and bund wall trimmings to make a rich and fertile growing medium as final cover and the basis for the horticulture program. The completed cells were managed as *in-situ* bioreactors with upgraded leachate drainage and collection plus leachate recycling to achieve faster and more complete biodegradation of cell organics and higher gas yields. Horticulture activities were conducted in greenhouses constructed on completed cells. A waste to energy plant on the site was used to combust the methane produced from the bioreactor cells plus the combustible inorganic fraction recovered from the excavation of old cells. The waste to energy plant produced electricity, for local use or sale into the grid with waste heat for use in greenhouses to maintain constant elevated temperatures for year round growth of high value added crops. Figure 4.3 illustrates the landfill mining operation in China.

4.4.2 *Landfill mining in India*

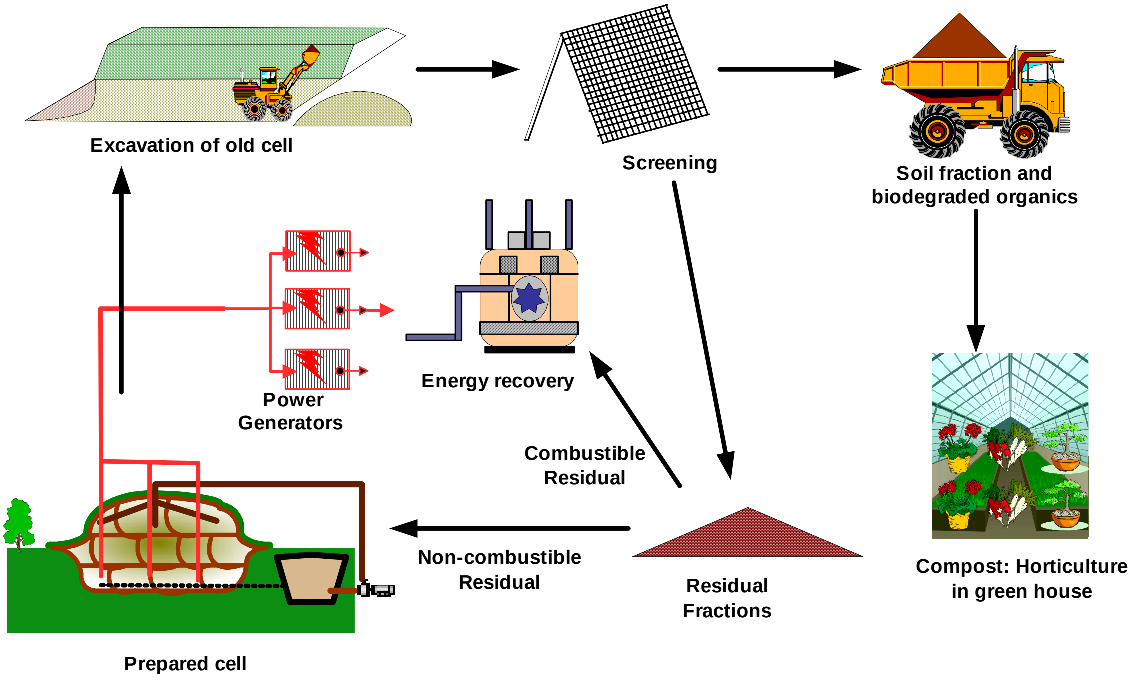


Figure 4.3 Landfill mining in China

Manfred Scheu and Bhattacharya (1997) reported on the reuse of decomposed waste from the solid waste dumpsite in Deonar, near Mumbai, India. The site has been in use since the turn of the 20th century holding large amounts of waste, much of it at an advanced state of decomposition. Decomposed waste from a portion of this dumpsite between 4 and 12 years old was excavated manually, sun dried and screened with apertures of about 8 mm as shown in Figure 4.4. The fine material was bagged and removed from the site. The coarse material was left in the dumpsite itself. Two companies were involved in this work. The Municipal Corporation was paid Rs.106/- (US $ 2.2) per ton as a lifting and truck weighing charge. Estimates of the amount of screened material removed in this way varied from 80 to 150 tonnes per month to 30 tonnes per day.

Source: Manfred Scheu and Bhattacharya (1997)

Figure 4.4 Dumpsite mining at Deonar, India

The fine material was mixed with cow dung, dolomite, gypsum, and neem cake (the residue after the extraction of oil from neem seeds) and sold as a mixed fertilizer. The company which also sold agricultural chemicals, marketed the product in an attractive way, claiming that it would:

- increase root aeration and yield;
- reduce pest and weed nuisance;

- increase microbial activity;
- correct micronutrient and secondary nutrient deficiency;
- increase water retention; and
- increase fertilizer use efficiency.

Results of the analysis of the blended product, carried out by the supplier, are presented in Table 4.2 while Table 4.3 shows the analyses of decomposed waste samples. It is interesting to note that the percentages of "other materials" such as plastic, glass and metal were very small.

Table 4.2 Analysis of decomposed waste soil conditioner

Parameter	Value
Moisture	10% to 12%
pH (dilution 1 : 10)	7 to 8
Organic carbon	15% to 17%
Organic matter	30% to 34%
Total Nitrogen as N	0.9% to 1.3%
Phosphorus as P_2O_5	1.5 % to 1.9%
Potassium as K_2O	0.5% to 0.8%
Sulphur as S	0.55% to 0.7%
Calcium as Ca	5% to 7.5%
Magnesium as Mg	0.5% to 0.8%
Copper as Cu	200 ppm
Zinc as Zn	900 ppm
Iron as Fe	900 ppm
Manganese as Mn	250 ppm
Boron as B	120 ppm

Source: Manfred Scheu and Bhattacharya (1997)

Table 4.3 Characteristics of decomposed waste from Deonar Dump, India

Description	Result
Density of wet sample	960 kg/m^3
Percentage passing 8 mm mesh	63.5%
Stones greater than 25 mm	31.5%
Evaporation and sieving losses	1.1%
Moisture content, fine material	14%
Organic matter, fine material	14.5%
Other materials	
Plastic (soft)	0.4%
Rags	1.1%
Glass and ceramic	0.9%
Metals	0.4%
Rubber and leather	0.6%
Coconut and wood	0.6%

Analysis of fine material	
pH	7.2
Organic carbon	5.8%
Nitrogen	0.5%
Sulphur	0.4%
Calcium carbonate	12.6%
Soluble aluminum	1000 ppm
Soluble manganese	270 ppm
Soluble iron	4800 ppm

Source: Manfred Scheu and Bhattacharya (1997)

4.5 Landfill Mining - Case Studies from Developed Countries

Cossu et al (1996) reported on the technical and practical experience gained on several commercial landfill mining projects in USA and pilot / research experience from Europe. Landfill mining studies from developing countries are not found in literature, possibly due to the fact that landfills are rare in these countries. However, there exist a large number of potential dumpsites for mining. Salient features of some of the landfill mining case studies in developed countries are presented in this section.

4.5.1 Collier County, Florida

The objectives of landfill mining of Naples Landfill in Collier County, Florida, were to reduce the potential for groundwater contamination; recover and reuse cover material, decrease site closure costs, recover recyclables and reclaim landfill capacity (Stein, 1993). With the County generating more than 400,000 tons of garbage each year, it was originally estimated that the landfill would be full in nine years (Tammemagi, 1996). It was reported that the smaller fraction, the "dirt-humus," was about 75 to 80% of the mined waste after removal of the oversized materials, or about 60 to 70% of the total mined waste (Lee and Jones, 1990). The intermediate-sized fraction was about 5% of the total processed waste. The remaining intermediate-sized waste, representing about 15% of the total waste mined, was primarily composed of plastic, rubber, wood, glass, brass, aluminum and cloth and had considerable calorific value. These fractions had the potential for further processing for recovery or recycling. By reclaiming waste from unlined sections of the 20-year-old landfill, Collier County reduced landfill-operating costs by recovering saleable materials, and extending the life of the site. The project's most significant benefit was the increased environmental protection through removal of dangerous and toxic wastes.

A comprehensive field test evaluation of the Collier County landfill mining system was conducted in 1992 under the US EPA's Municipal Innovation Technology Evaluation (MITE) Program (USEPA, 1997). The mined wastes were relatively well decomposed. The soil fraction recovered from the process (i.e. cover material plus fine decomposed wastes) accounted for about 60% of the in-feed material. With the exception of the soil fraction, the degree of purity of the recovered materials was in the order of 82% or lower. Thus, the ferrous and plastics fractions contained substantial levels of contamination that would probably impact their marketability. In the case of the soil fraction, the concentrations of metals were found to be below the limits imposed by the State of Florida for unrestricted use of waste-derived compost. The mining operations reclaimed 50,000 tons of soil suitable for use as a landfill cover material. Based on 1995 prices, the reclaimed cover soil had a cost saving of $1 per ton compared to conventional cover.

4.5.2 Lancaster, Pennsylvania, USA

The Lancaster County Solid Waste Management Authority (LCSWMA) operates the landfill and transfer stations in the county (Figure 4.5). The Frey Farm landfill, located in Manor Township, was opened for waste disposal in September 1988. Construction of a three-train, mass burn facility, with a design capacity of 1,100 tons/day, was completed in December 1990. Since the initial delivery of waste was less than anticipated, previously land filled wastes were excavated from the first 7 ha. cell and added to fresh MSW as supplementary fuel for the mass burn facility (Nelson, 1995). Mined material was combusted with raw MSW in a ratio of about 1:3 (weight basis). Earlier tests using unscreened mined material required a ratio of 1:7 or 1:8 in order to maintain design conditions for combustion, due to the relatively low heating value of mined wastes. The facility yielded about 660 kWh/ton of raw MSW, based on a heating value of 12,200 kJ/kg. When mined material was combined with fresh MSW for combustion, the yield decreased to about 500 kWh/ton of fuel burned. Ash yield from mined material was about 35%. Combustion of mined MSW did not have a negative impact on the permits for either the source recovery facility or the landfill. The Pennsylvania Department of Environmental Resources (PADER) monitored the mining. Concerns initially expressed by PADER included the potential for changes to storm water runoff, extra leachate generation, and gas releases from the mining operation. However, none of the concerns became a problem. The only negative impact has been the additional traffic generated by the delivery of mined material to the project. The LCSWMA's objective in landfill mining has been to minimize the area of landfill in use. The energy value of the mined material was estimated to be US $33/ton. Material recovery is economically less attractive and, therefore, it was not a component of the operation.

Between 1991 and 1993, approximately 219,500 m^3 of MSW were excavated from the landfill. As a result, Lancaster County converted 56 percent of the reclaimed waste into fuel. The county also recovered 41% of the reclaimed material as soil during trommel operations. The remaining 3% proved noncombustible and was reburied in the landfill (USEPA, 1997).

LCSWMA recommendations for the reclamation operations at the landfill and resource recovery facility are given in Box 4.4.

Source : www.lcswma.org

Figure 4.5 Landfill mining operation at Lancaster County

4.5.3 Thompson, Connecticut, USA

In 1986, the municipal landfill in the town of Thompson, Connecticut initiated a landfill mining project with the objective of recapturing landfill volume and extending the life of the landfill temporarily while a permanent disposal alternative could be selected (Strange, 1998).

A local excavation contractor conducted the project, using a bulldozer, a pay loader, a truck, and a screen. The contractor first excavated about 20 test pits in the landfill. The area mined was a combination of the residuals from an old dump (which was set on fire periodically) and bulky wastes. No odors were detected as a result of the mining program. Waste decomposition was relatively incomplete and the materials were 15 years old or less. At the time of the mining project, the available disposal alternatives represented costs in the range of US$66 to US$88/ton, including transportation. The cost of the mining project was US$117,000, including grading the base of the mined area to receive new MSW. Representatives from the town estimated that the town saved US$ 1 million in tipping fees over an 18-month period.

4.5.4 Barre and Newbury, Massachusetts, USA

As part of a permit application to expand a private sanitary landfill in Barre, Massachusetts, a proposal was made to mine a section of the property that had been filled between mid-1950s and 1970. The sections to be mined were to be lined prior to any additional filling. Test pits were dug to evaluate the material that would be processed. Excavation showed that some of the cells had been constructed to be almost completely impervious to the external penetration of water. The contents of these cells showed little decomposition. The recovered soil fraction was retained for use as cover material (Strange, 1998).

At Newbury, Massachusetts, a 3.6 ha landfill serving a community of 6,400 people was reclaimed in 1993 to construct a new lined landfill of 1.6 ha. Two third of the mined material was soil which was stock piled for future use as cover material (Nelson, 1995).

4.5.5 Nashville, Tennessee, USA

The Nashville project, operated by American Ash Recycling of Tennessee removed 305,840 m^3 of soil and ash from a 2.8 ha ash monofil owned by the city for extending the life of the monofil and to use the recovered material as road base and asphalt aggregate (Nelson, 1995). The project, which commenced in 1993, was developed following the completion of a one-year pilot project in Sumner, Tennessee.

4.5.6 New Hampshire, USA

The New Hampshire landfill site in USA served small towns and rural tourist areas. Wastes were landfilled between 1979 and 1987. In 1989, the company that owned the landfill was sold and the new enterprise filed a permit to expand the landfill. The New Hampshire Department of Environmental Services (NHDES) required that approximately 160 tons of material be relocated from the old, unlined portion of the landfill to the newly lined section. As part of the relocation process, NHDES allowed the company to mine the unlined landfill. Once the plans were approved, the NHDES included various requirements in the permit to build the new landfill that pertained specifically to the mining operation. Due to concerns regarding odors, the permit prohibited any mining or waste removal operations during June, July, and August and required that odor masking agents be applied to the wastes being processed (Strange, 1998).

Throughout the landfill mining process, the impacts on air quality and the quality of the storm water runoff were monitored. The monitoring process also included measuring the concentrations of oxygen, hydrogen sulphide, and volatile organics in the air. Water quality monitoring also focused on changes in conductivity and pH. Slight increases in conductivity were noted and no changes in pH were detected. Equipment used consisted of two excavators, one front-end loader, four dump trucks, two bulldozers, one trommel screen, and one odor control sprayer.

4.5.7 Edinburg and Hague, New York, USA

In 1988, the New York State Energy Research and Development Authority (NYSERDA) contacted more than 250 landfill owners and operators in the state to ascertain their interest in participating in a landfill mining demonstration project. The Town of Edinburg was subsequently selected by NYSERDA as the host site for a one-acre demonstration project. Edinburg is a small, rural community and has a relatively small landfill (Strange, 1998). NYSERDA's objectives in undertaking the Edinburg project are given in Box 4.5.

Box 4.5 Objectives of Edinburg project

- Determine equipment needs and develop optimal procedures for the excavation.
- Separation, handling, and storage of land filled materials.
- Determine appropriate uses for the reclaimed material.
- Identify available markets for the materials.
- Develop required processing needs for the reclaimed materials.
- Develop recommendations regarding health and safety requirements, and
- Conduct contingency planning for future landfill reclamation projects in New York.

Source : Strange, 1998

Screening of excavated wastes was the significant key unit operation employed during the Edinburg Landfill Mining project. Approximately 25% of the mined materials passed through a screen surface with 7.6 cm openings and was retained on a screen surface with 2.5 cm openings. This fraction consisted primarily of cans and bottles. Materials larger than 7.6 cm included plastics, textiles, paper, wood, and metal. A test burn of a sample of residue from the process was conducted at the Pittsfield, Massachusetts waste combustion facility. Results of the tests indicated that the higher heating values for the residue varied between 4,700 and 5,800 kJ/kg. Residue (i.e. material larger than 2.5 cm) from the screening of materials during a hand sorting phase of the project was evaluated. The evaluation indicated that more than 50% of the rejects could be taken to a Materials Recovery Facility (MRF) for recycling, although the excessive concentration of dirt in the residue could contaminate clean source-separated recyclables. White goods and scrap metal would require cleaning to remove soil, and then the material could be baled and sold. The assessment of manually-separated film and High Density Poly Ethylene (HDPE) plastic indicated that these materials could also be sold.

Materials were sampled and analysed. No significant contaminant concentrations were detected during tests for asbestos, compost parameters, Toxicity Characteristic Leaching Procedure (TCLP) parameters, Target Compound List (TCL) parameters, and pathogens. The soil fraction met the State of New York standards for Class I compost and qualified for off-site use in a variety of applications, including as clean fill in public construction projects and daily landfill cover. 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 (USEPA, 1997).

The first effort in USA to dig up and entirely remove an old landfill to return the site to its natural state was the Hague Landfill Reclamation Project which began in 1994 following a feasibility study (Nelson, 1995). The project aimed at removing a 2.7 ha landfill from the middle of a 52 ha site owned by the rural township for the purpose of using the land for recreational purposes. About 76,500 m^3 of was removed and separated for recovery of ferrous metal and for the beneficial use of soil fraction. The project budget was $ 1.3 million. Implementation of a full scale composting operation was shown to be feasible at the Hague reclamation project. Composting and re-screening resulted in a 31% weight reduction in material requiring off- site transportation (Steuteville, 1996).

4.5.8 Live Oak Landfill, Atlanta, Georgia, USA

In January 1997, a pilot-scale project to assess the feasibility of *in situ* aerobic bioreduction of municipal solid waste was initiated at the Live Oak landfill, located near Atlanta, Georgia (Smith et al, 2000). This project was carried out in a 10 m lined cell containing approximately 53,522 m^3 of MSW. The materials in the cell had been placed no more than three years before beginning this project. The materials contained a significant portion of biosolids from wastewater treatment plants. To simulate aerobic decomposition of the MSW, air and water (recycled leachate and additional fresh water) were injected into the fill material through wells. Routine monitoring of the process included temperature measurement; landfill gas composition; water volumes pumped and leachate generation; and physical, chemical, and biological characterization of leachate.

From October 1997 to 1998, small sections of the test cells were mined and separated to assess procedures, equipment needs and to characterize the materials recovered. The results showed that none of the wastes were stabilized at this time of sampling. Laboratory analysis of the trace metals of the humus fraction showed that As, Cd, Cr, Cu, Pb, Mo, Ni, Se and Zn were well within limits set by USEPA for high quality compost.

4.5.9 Dougal, Ontario, Canada

The Mc Dougal project started in 1994 and its goal was to remove the entire 3 ha landfill cell, line the site and put the waste back in after screening with a power screen trommel to remove soil fraction (Nelson, 1995). The project was undertaken to remediate leachate problems at the landfill when contaminants were found in monitoring wells. In addition, the project was expected to have enhanced the landfill capacity by 5-10 years. About 50% of the reclaimed waste was soil, most of which was used as daily cover and landscaping. The total budget including relining was $ 7 million.

4.5.10 Landfill Mining in Europe

The first landfill mining in Europe was in Germany, at the Burghof landfill site in 1993 (Rettenberger et al, 1995; Hogland et al, 1997). The main purpose of the excavation was environmental remediation and the construction of new landfills according to modern technology. A total of 53,700 tons of material was excavated and sorted from the landfill in 14 months. The mean bulk density of the material was 1,160 kg/m^3. About 70.5% of the reclaimed waste by weight was fine fraction and was reused at the landfill. 17.5% of the reclaimed waste was light fraction and was used at a waste-to-energy facility. The project helped achieve additional volume for waste deposition, improve the long term behaviour of the displaced waste, assess the technical and economical feasibility of landfill mining and to define more suitable measures for assuring optimal environmental conditions for workers and neighborhood (Cossu et al, 1996). Further research activities are in progress at the Schoneiche Landfill, one of the largest European sites, where domestic waste from the western side of Berlin was dumped for over 15 years.

The first study of landfill mining in Italy was conducted at an old landfill site in Sardinia, in 1994 (Cossu *et al.*, 1995). The study was aimed at obtaining all the design parameters such as landfill characteristics and quality of old waste.

During the summer of 1994, a 10-year-old part of the Filborna landfill in Sweden was excavated as a pilot test in a research project (Hogland et al, 1995). The landfilled waste consisted of a mixture of household, industrial, construction and demolition waste. About 1,300 m^3 of waste was excavated to a depth of 8.5 m from a 10 year old part of the landfill. The excavation was made in two stages: down to 5 m level, and then to 8.5 m over a plot size of 30 m^2. There was no presence of dust or flies, however, a slight smell was observed. Hazardous wastes such as asbestos, batteries and cans containing unknown liquids and hospital wastes were found at different levels. Large amounts of biodegradable waste were found without any significant changes. Large areas in the fill were found to be very dry indicating that the lack of moisture in the landfill could have contributed towards the poor biodegradation. The characteristics of the material obtained from the landfill mining studies are provided in Tables 4.4 and 4.5. The major constituents of the leachate and its heavy metal contents are presented in Tables 4.6 and 4.7. Carius et al (1999) have reported development of thermoplastics from wastes recovered from landfills.

Table 4.4 Characteristics of the mined waste

Characteristics					**Coarse fraction: amount by volume, amount by weight, density and moisture**				**Fine fraction: amount by volume, amount by weight, density and moisture**			
Level below surface	pH	Temp °C	CH_4 %	CO_2 %	by vol. %	by wt. %	Density t/m^3	Moist. by wt %	by vol. %	by wt. %	Density t/m^3	Moist. by wt.
0 - 5 m	4-5	17	--	--	35	45	0.5	38	65	55	0.4	30
5 - 8 m	6.5	18-20	59	40	70	25	0.4	43	30	70	2.5	39

Source : Hogland et al, 1995

Table 4.5 Total solids, ash content, low calorific value and concentration of different constituents in the waste at 0-5 and 5-8 m below the surface

	Unit	Coarse fraction 0-5m	Fine Fraction 0-5m	Coarse fraction 5-8m	Fine Fraction 5-8m
Total solids	TS (%)	62.0	70.0	56.6	61.0
Ash content	% of TS	39.3	78.9	36.6	84.0
Calorific Value	MJ/kg sample	6.9	<2	7.9	<2
Carbon (C)	% by weight TS*	32	13	44	11
Nitrogen (N)	% by weight TS*	0.74	0.45	0.49	0.57
Sulphur (S)	% by weight TS*	0.39	0.71	0.27	0.56
Phosphorus P(tot)	g/kg TS*	0.77	0.72	0.66	1.5
COD_{Cr}	g/kg TS*	720	250	620	270
Magnesium (Mg)	g/kg TS*	0.84	1.6	0.99	1.6
Calcium (Ca)	g/kg TS*	12	17	7.6	15
Potassium (K)	g/kg TS*	1.4	0.99	0.85	1.3
Zinc (Zn)	g/kg TS*	1.9	0.50	0.33	0.58
Nickel (Ni)	mg/kg TS**	6.7	12	8.7	30
Copper (Cu)	mg/kg TS**	90	53	41	140
Chromium (Cr)	mg/kg TS**	0.39	36	8.1	39
Lead (Pb)	mg/kg TS**	88	160	18	100
Cadmium (Cd)	mg/kg TS**	7.1	1.6	0.57	3.4

TS – Total Solids; * Calculated based on the whole sample *Source: Hogland et al, 1995*
** Calculated based on the whole sample, but for the fractions metals, glass, stone etc.

Table 4.6 Main constituents in the leachate from landfill mining (mg/L)

Sample	1	2	4	8	9	10
pH	8.2	7.9	7.7	8.5	8.6	7.9
Cond. (mS/m)	348	205	788	1048	972	1080
Cl^-	270	135	585	800	730	780
SO_4^{2-}	--	196	139	88	88	93
Ptot	1.4	0.7	4.5	8.1	7.4	8.1
PO_4-P	0.7	0.6	4.5	7.0	5.9	6.7
Kj-N	252	122	616	798	728	798
NH_4-N	252	112	602	785	700	798
NO_x-N	4.0	4.2	3.4	5.9	5.4	5.4
BOD_7	60	173	80	85	55	70
COD	635	510	675	1055	1025	1065
Susp. Solids	2195	1132	582	652	634	382
Total Solids	3552	2180	3472	5384	5072	5294
Fixed Solids	2782	1620	2616	4304	4154	4194
FFA %	0.60	0.35	1.54	1.89	1.68	2.13
Fat	--	--	4.5	81.5	<1	<1

Source : Hogland et al, 1995

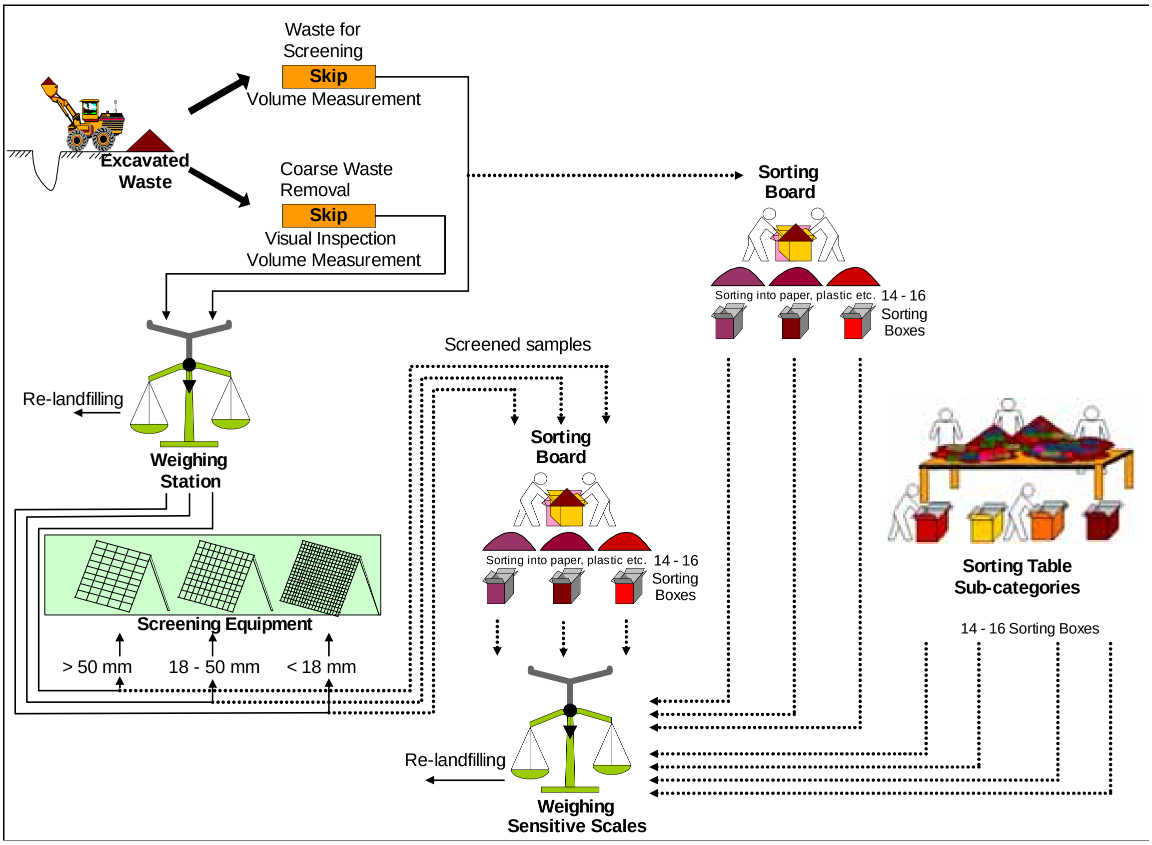
Table 4.7 Concentration of metals in the leachate during landfill mining						
Sample	**1**	**2**	**4**	**8**	**9**	**10**
Al	0.254	2.305	0.438	0.176	0.153	0.158
Ca	238.584	325.137	222.822	202.471	202.449	175.26
Cd	0.003	0.002	<0.001	<0.001	<0.001	<0.001
Co	<0.020	<0.020	<0.020	0.022	<0.020	<0.020
Cr	<0.007	0.029	0.068	0.132	0.134	0.117
Cu	0.034	0.052	0.021	0.043	0.029	0.022
Fe	70.23	62.44	5.93	9.3	11.89	7.57
K	181.383	82.133	297.289	418.872	386.641	414.91
Mg	55.688	40.324	84.882	103.995	99.361	104.382
Mn	0.557	2.096	0.574	1.079	1.163	1.113
Ni	0.029	0.024	0.037	0.089	0.053	0.074
Pb	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Zn	0.277	0.350	0.455	0.170	0.144	0.103
Ba	0.040	0.236	0.516	0.672	0.577	0.750
As*	0.63	2.43	1.91	3.24	3.00	2.13
Hg *	1.07	1.41	0.52	0.64	0.79	1.04
Na	235.07	146.34	555.33	1223.82	1077.51	1034.6

* *ppb*; others in *ppm*

Source : Hogland et al, 1995

The test screening and the recovery of material from the Måsalycke landfill (Figure 4.6) as well as a variety of projects showed that excavation is a realistic alternative for lifetime expansion and remediation of small and medium size landfills and can therefore be used in the Baltic Sea Region (Hogland, 2002). The Baltic Sea Catchment, with an area of 1,745,000 km^2, encompasses 14 countries (nine of them having a common borderline with the Baltic Sea) and has a population of 85 million people. The catchment is estimated to have 70,000-100,000 old landfill sites. The material excavated in the test was screened into the fractions: < 18 mm, 18-50 mm and > 50 mm. The coarsest fraction (> 50 mm) contained 50 % wood and paper. 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. The spectral analysis of heavy metals indicated only high concentrations of zinc and there was no significant difference between the fine and the medium-sized fractions. The medium sized and the unsorted fraction was moisturized and refilled into the pit. The methane content in the landfill gas from the pit was 50-57 % in the sorted material with a flow 8-17 L/min and 38-57% in the unsorted fraction with a flow of 2-13 L/min during the first 1.5 year.

The town of Veenendaal, in the Netherlands has removed two landfills through landfill mining with separation of partly reusable fractions (Geusebroek, 2001). Eighty percent of the excavated wastes were screened for reuse. The presence of asbestos in the waste material posed a problem for both working conditions and limited reuse possibilities.



Source : Hogland, 2002

Figure 4.6 Scheme of work for landfill mining studies in Måsalycke landfill

4.6 Cost 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). Expenses incurred in project planning including capital and operational costs of the landfill mining project are as summarized in Box 4.6.

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:

Box 4.6 Cost of landfill mining

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

- Increased disposal capacity
- Avoided or reduced costs of:
  - landfill closure;
  - post closure care and monitoring;
  - purchase of additional capacity or sophisticated systems; and
  - 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; and
  - 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 presented in Table 4.8 show 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 (RRF) 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, RRF and landfill host communities. Revenues obtained from the sale of electricity from the RRF 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 RRF. 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 markets for recycled and recovered materials
- Projected value of land reclaimed for other uses.

Table 4.8 LCSWMA reclamation weekly cost / revenue summary			
Item Description	**Totals (Averages)**		**Totals (Averages)**
Project weeks	95	REVENUES	
Total volume excavated (yd.^{3})	286,501	Ferrous sales	$370
Average excavated weekly (yd.^{3}/wk.)	3,016	Electricity sales	$27,304
Total tons excavated per week	2,645	TOTAL REVENUES	$27,674
Total tons reclaimed	140,207	$/ton reclaimed	&18.75
Average tons reclaimed weekly	1,476	NET REVENUES	$5,812
Tons of cover soil recovered per week	1,076	$/ton reclaimed	$3.94
Tons of noncombustibles landfilled per week	93	ASSET ADDITIONS	
Net volume recovered (yd.^{3}/wk.)	2,459	Reclaimed soil (1,076 tons @ $2/ton)	$2,152
COSTS: LANDFILL OPERATIONS		Reclaimed landfill volume (yd.^{3})	2,478
Excavation/sorting	$4,362	Current value @ $11/yd.^{3})	$27,258
Trommeling	$1,305	TOTAL ASSET ADDITIONS	$29,410
Fuel	$579	PROJECT PROFIT	
Refuse transport to RRF	$4,943 ($3.35/ton)	Asset additions + net revenues ($/wk)	$35,222
COSTS: REFUSE PROCESSING AT RRF		MISCELLANEOUS DATA	
Lime	$970 ($0.66/ton)	Average LF HHV (Btu/lb)	3,149
OMSL fee ($/ton waste processed)	$4,471 ($3.03/ton)	Ash tons per week	586 (352 yd.^{3})
Host fee ($/ton processed + ash tons landfilled)	$2,441 ($1.65/ton)	Ferrous tons per week	28
Ash transport to landfill ($/ton)	$1,846 ($3.15/ton)	Electricity (kWh, 2-year average)	528,845
Administration/compliance	$671	Reclaimed material	3568 kWh/ton
TOTAL COSTS	$21,862 ($14.81/ton)		

Source : Forster, 2001

4.7 Epilogue

Landfill mining as a method of waste management is yet to be widely practised. It is the excavation of buried MSW for its processing to recover material for beneficial use. The quantity and characteristics of materials recovered from a landfill are functions of the landfilled wastes. Given its developmental status, only tentative conclusions can be drawn regarding landfill mining potential, especially in Asia.

The recovery of a landfilled resource depends upon the physical and chemical properties of the resource, the effectiveness of the type of mining technology and the efficiency with which the technology is applied. Judging from available information and mechanical processing efficiencies, recovery of soil could be expected to fluctuate between 20% and 80% of wet waste by weight. The major difficulty could be in marketing mined materials due to its poor quality. Purity of the recovered 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 design.

Options for reuse of a landfill include everything from mining and using it again for waste disposal or planting trees on it and turning it into a park. Communities which mine their landfills may burn, compost, or recycle the waste, although recycling of cans and bottles tends to be impractical because they are heavily soiled. They may choose to start over, lining unlined cells and reusing liners where possible, or, like Hague, New York, they may prefer to close the landfill forever. Landfill mining for some localities has up-front economic benefits. Lancaster County, Pennsylvania, recovered soil and ferrous metals and sent the remaining materials to its waste-to-energy plant. Solid Waste Authority officials there estimated that adding together the value of the energy, ferrous metals, soil, and landfill space, minus the cost of the operation, the project yielded a profit of about $30,000 per week.

Based on the few studies reviewed in this report, the heavy metal content and other characteristics of the recovered soil fraction indicate that the fraction could be suitable for landfill cover. The compost standards are met for most parameters in the soil fraction of most studies. 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. This controlled bioreactor landfill is seen as being a flexible, cost effective, and sustainable approach to current waste disposal problems, particularly when combined with material recovery either before or after the biological treatment step. Indeed, it may no longer be necessary to view landfilling as a disposal system at all but rather to see it as a method for large-scale processing of waste to be combined with recovery and recycling processes. The concept of landfill mining and reclamation and related technology merits serious consideration. It may be relevant to consider the incorporation of the concept into landfill design so that the landfill waste can be readily accessible for mining a multi-disciplinary approach to landfill management, involving such professional groups as geochemists, geotechnical engineers, civil engineers, environmental engineers and microbiologists will lead to a rapid development of the concept of landfill mining as a sustainable technology.

The reality of financial resources earmarked for solid waste management in many developing countries would mean that solid waste managers must attempt to ameliorate open dumping practices and gradually upgrade the sites. Landfill mining will be an ideal option to be incorporated in the dump site upgradation process. The waste managers should aim at modest improvements to their landfill operations and gradually move from open dumps to sustainable landfills in a phased manner.

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