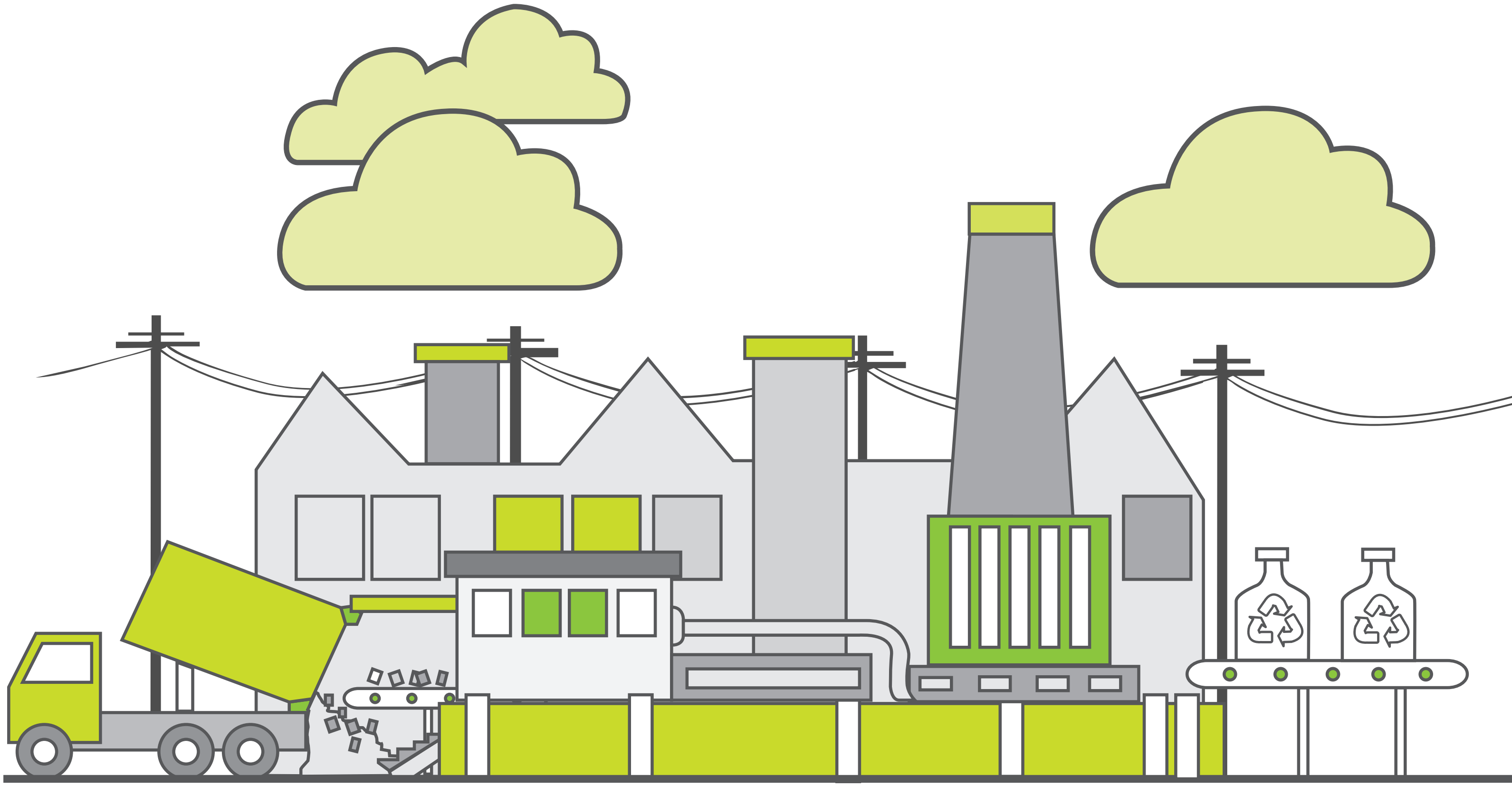

INTEGRATED SOLID WASTE MANAGEMENT FOR LOCAL GOVERNMENTS

A Practical Guide

ASIAN DEVELOPMENT BANK

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Unless specified, all photos and figures by Lyndsay Chapple.

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FOREWORD

Bambang Susantono
Vice-President for Knowledge Management
and Sustainable Development
Asian Development Bank

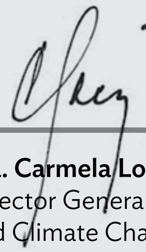
Asia has the fastest-growing population in the world, rising by 29% over the past 2 decades. This equates to more than 120,000 people every day moving to Asian cities. By 2050, urban areas will account for more than 65% of Asia's total population, doubling to more than 3.3 billion people. Globally, more than 10 billion metric tons of solid waste is generated annually from urban households, commerce, industry, and construction, of which Asia accounts for less than 25%. This is forecast to make up over 50% of global solid waste production by 2030. In fact, according to the *Global Waste Management Outlook* published by the United Nations Environment Programme and International Environmental Technology Centre in 2016, lower-income cities in Asia will double their solid waste generation within 15–20 years.

Strategy 2020, the long-term strategic framework of the Asian Development Bank (ADB), highlights infrastructure and environment as two of the five core areas of operations, and private sector development and private sector operations as one of five drivers of change. ADB's Urban Operational Plan 2012–2020 calls for increased investment in solid waste management and the adoption of innovative financing mechanisms. However, solid waste management remains one of the most neglected areas of municipal services and infrastructure in Asia, with ADB funding only a small number of projects greater than 1,000 metric tons per day over recent years, mainly as part of opportunity-based activities integrated with other urban infrastructure, and with limited strategic focus.

Relevant and practical integrated waste management approaches for medium to large cities remain a pressing need in most developing member countries to help them attain environmental sustainability and improve the quality of life of their citizens. It is thus evident that ADB needs to raise its effort to help developing member countries develop holistic, citywide solid waste management strategies and translate those into technically feasible and commercially viable projects.

There are many public health and environmental impacts of poor waste management practices. Overall, the cost of inaction to society exceeds the financial cost of proper waste management by a factor of up to 10. The potential impact of improved waste management on reducing greenhouse gas emissions alone is estimated at 15%–20% across the economy. However, the benefits of improved solid waste management are much more than just economical and environmental. A clean city is a successful city, presenting a healthy, pleasant, and safe place to live; it is a good place to do business and visit as a tourist; and, equally important, it fosters a sense of community and belonging. Indeed, addressing waste management as a priority will facilitate early progress toward more than half of the Sustainable Development Goals in the post-2015 development agenda.

To this end, I am very pleased to support *Integrated Solid Waste Management for Local Governments: A Practical Guide*, which draws upon the extensive practice and lessons learned from ADB's projects, experience, and research. This compendium of practice briefs will guide municipalities, ADB project officers, and other practitioners in ensuring that proper solid waste management is applied widely in Asia's cities. I trust that you will find these briefs particularly useful and instructive as we all work toward a sustainable future.



Ma. Carmela Locsin
Director General, Sustainable Development
and Climate Change Department
Asian Development Bank

Today's rapid urbanization, particularly in developing Asia, makes it an immense challenge to meet urban infrastructure and service needs efficiently and effectively, while also balancing environmental considerations and sustaining inclusive economic growth. Local officials, city managers, practitioners, and citizens alike all have a role to play in addressing this herculean task.

The Asian Development Bank (ADB) is a partner in this goal as we strive to implement highly innovative and proactive programs that lead to more livable cities. Under the Sustainable Development and Climate Change Department, our Urban Sector Group is actively developing a new approach to better engage with cities in Asia and the Pacific and enhance investment results. The Future Cities Program seeks to expand the development impact of our current infrastructure investment program in key cities, strengthen the relationship with city partners, broaden the cross-sector investment pipeline through the facilitation of internal and external knowledge and financial resources, and ultimately enhance cities' livability.

Asian cities of the future face a significant increase in population associated with an explosion in solid waste generation—accounting for over 50% of global solid waste generation by 2030. Currently, more than two-thirds of their collected solid waste is not disposed of properly. The far-reaching impacts are worrying. However, equally disconcerting are the lack of funds and technical skills of local agencies and the inadequate policies to attract finance for holistic solid waste management planning. It is essential that ADB's long-term engagement with cities, through country programs and approaches such as Future Cities, include practical, rational, and comprehensive methodologies for managing the waste stream from beginning to end, using innovative technology and financing mechanisms.

Integrated Solid Waste Management for Local Governments: A Practical Guide is a timely publication under the Future Cities Program. A culmination of studies and field experience across five cities as part of the regional technical assistance project Mainstreaming Integrated Solid Waste Management in Asia, it presents a comprehensive yet accessible approach to improve waste operations—from waste minimization and collection to landfill operations and waste to energy—by breaking down sector silos, providing relevant and technical knowledge, and even showing how to maximize private sector participation. This guide is indeed a combination of future thinking well beyond our financing framework.

Furthermore, readers of the publication will be pleased to know that the team of authors and experts have included successful solutions and best practices that not only encourage environmentally sound solid waste management, but also ways to sustain a long-term information, education, and communication campaign that will promote behavioral change in how resources are consumed and disposed of across generations.

The urban transformation of Asia lies in a multifaceted approach. Integrated solid waste management is only one, yet essential, component. Interventions in the waste sector can have positive impacts in improving urban efficiency, climate resilience, energy security, environmental protection, and water quality. Hence, both local government units and ADB project officers will gain much from reading this guide as it will greatly inform and strengthen their operational practice. I look forward to more Asian cities adopting more efficient and effective solid waste management practices.

I would like to express my appreciation to the technical assistance team and authors on this commendable undertaking. This is the first of its kind in sharing practical solutions in an oft-ignored area of development. The corresponding USB flash drive including all linked documents and references is sure to be useful for on-the-go waste professionals. I hope that the innovative approaches and best practices presented in this guide will help influence adoption of integrated, comprehensive, and practical solutions to waste management across Asia.

PREFACE

This publication is a reference guide for Asian Development Bank (ADB) staff and consultants as well as municipal leaders. It introduces the key concepts of integrated solid waste management and identifies crosscutting issues in the sector.

Significant resources have been allocated to waste management in the past, but they have not always succeeded in achieving stepwise improvements. As a result, having a package of practice briefs was considered essential to assist in mainstreaming integrated solid waste management throughout Asia and the Pacific. These practice briefs are derived from the technical assistance project, Mainstreaming Integrated Solid Waste Management in Asia, as well as from experiences of the consulting team, ADB officers, and external reviewers.

The practice briefs are divided into seven categories: solid waste management planning, waste categories, waste containers and collection, waste processing and diversion, landfill development, landfill operations, and contract issues. There are over 40 practice briefs, each with links to resource documents providing more detail for readers as required. Each brief can be read individually for a quick, topical reference or can be read collectively as one instructive toolkit for the entire integrated solid waste management cycle.

The approach taken for this guide is based on contemporary waste management planning. Looking at collection services, commonly there has been a transition from manually loading waste from open primary dumping areas or bins to haulage trucks. This is very inefficient and brings with it significant aesthetic and health issues. Quite often, the next stage in the improvement of waste collection is to move to hook-lift bins which have to be hauled regardless of whether they are completely full or not and no compaction is provided. The contemporary approach is to leapfrog hook-lift bins and move to small skip bins. These can be mechanically loaded into a compactor vehicle, meaning that only compacted full loads are hauled to the disposal site or reprocessing facility. This approach is detailed in the practice briefs and supporting resources, and is only one of several solutions provided in this publication.

Integrated solid waste management must address reprocessing and resource recovery, not just end-of-pipe disposal of residuals. Practice briefs are provided on the usual recycling and composting activities, as well as contemporary information on refuse-derived fuels and waste-to-energy options. These latter options are increasingly being considered by a wide range of municipalities across the region and the practice briefs herein provide some contemporary independent advice on these waste diversion options.

Regarding residual waste disposal, many previous reports and guidelines have focused on the approach of best available treatment when it is not economically achievable and sustainable by the municipality. As a result, excessive expenditure has often been directed to constructing facilities that are too complex and too costly for small to midsize municipalities to operate appropriately. Eventually, these landfill facilities very often revert back to uncontrolled open dumping, negating the effectiveness of the capital development.

The contemporary approach to landfilling is to provide an appropriate level of socioenvironmental protection and simplify the operation as well as the ongoing costs to encourage an acceptable standard of operation going forward. This also relates to economically remediating and extending the life of the old dumpsites, as well as avoiding the need for full leachate treatment plants where possible. Practice briefs are provided not only on the design but the operation of appropriate disposal facilities.

The practice briefs also address wide-ranging themes such as integrated solid waste management planning; information, education, and communication plans; and privatization contract management issues.

In summary, these practice briefs provide readily accessible insight into the full cycle of contemporary waste management.

ACKNOWLEDGMENTS

This publication was prepared under the technical assistance (TA) project, Mainstreaming Integrated Solid Waste Management in Asia, headed by Andrew McIntyre, Asian Development Bank (ADB) senior urban development specialist, and with guidance from ADB Technical Advisor (Urban) Vijay Padmanabhan of the Sustainable Development and Climate Change Department (SDCC), Urban Sector Group.

The practice guide is the summation of the lessons gained in this TA project and the industry experiences of the author, environmental engineering consultant Lyndsay Chapple, as well as the technical consultants who provided insights: solid waste management public-private partnership (PPP) specialist and former ADB head regional business development (Central Asia and South Caucasus) Stephen Wermert; AECOM's Matthew Ko, Chun Yue Delton Ng, Yu To Oles Kwong, and Cristina Gregorio; and, Squire Patton Boggs Singapore's Ignatius Hwang.

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Lastly, the team recognizes ADB Vice-President for Knowledge Management and Sustainable Development Bambang Susantono and SDCC Director General Carmela Locsin for the direction and encouragement they have given for this publication and the aims of this integrated solid waste management technical assistance.

ABBREVIATIONS

ADB	Asian Development Bank
ASTM	American Society for Testing and Materials
BOD	biochemical oxygen demand
BOT	build–operate–transfer
COD	chemical oxygen demand
DBO	design–build–operate
EfW	energy-from-waste
EIS	environmental impact statement
EMMP	environmental monitoring and management plan
EPC	engineering procurement construction
GCL	geosynthetic clay layers
GHG	greenhouse gas
GWP	global warming potential
HDPE	high-density polyethylene
IEC	Information, Education, and Communication
IRA	internal revenue allotment
ISWM	integrated solid waste management
kg	kilograms
mj	megajoules
mm	millimeter
MMDA	Metro Manila Development Authority
MSW	municipal solid waste
O&M	operation and maintenance
PET	polyethylene terephthalate
PPP	public–private partnership
RDF	refuse-derived fuel
SWM	solid waste management
WTE	waste-to-energy

A member of a waste cooperative cleans discarded plastics for recycling. Photo: ADB

Integrated Solid Waste Management for Local Governments: A Practical Guide is a compendium of more than 40 practice briefs that has been prepared to assist both municipalities and Asian Development Bank (ADB) staff on the key issues in contemporary solid waste management.

The briefs are based on experience gained from the regional technical assistance project, Mainstreaming Integrated Solid Waste Management in Asia. The lessons learned from studying the five cities under this technical assistance were collated and supplemented with general industry experience of the consulting team, ADB staff, and external reviewers. Case studies from the five cities are also part of the overall knowledge package, providing specific guidance on the likely issues and lessons learned from individual city investigations.

The aim of the practice briefs is to provide easily accessible information in a very targeted manner, with links to resource documents should the reader wish to obtain more information on a topic. The products are written in reasonably plain English to encourage access by a broad cross section of users and not just waste management professionals.

The practice briefs are grouped into the following categories:

(i) **Solid waste management planning.** This group of practice briefs provides information on the types of waste characterization audits that may be required and a number of recommended methodologies to ensure that statistically valid data are obtained for subsequent input to any planning activities. Competent waste management studies do not just address the collection, haulage, and end-of-pipe issues, but must investigate issues such as waste minimization, in particular management of plastic waste which is a significant problem globally. Details are provided on information, education, and communication plans which are essential in supporting the physical interventions proposed in any plan for upgrading solid waste management services. Finally, all solid waste management plans must be regularly reviewed and information is provided on appropriate evaluation and diagnostic tools.

(ii) **Waste categories.** There are four different categories of waste that may or may not be accepted at a municipal solid waste facility such as a controlled landfill. The categories and typical components are described in this section, noting the always acceptable and prohibited items commonly found in the municipal context. Separate practice briefs deal with difficult wastes and special wastes likely to be encountered. These latter categories also include liquid waste, which may or may not be acceptable under some circumstances, as well as other materials such as asbestos and medical waste. Proper control of these types of waste is critical at any waste management facility.

(iii) **Waste containers and collection.** The practice briefs in this chapter is provided to guide municipalities in selecting the standard of service appropriate for their location, which leads to decisions on waste container types. These decisions relate to the appropriate collection fleet mix for providing the correct balance between controlling cost, minimizing public nuisance, and maximizing efficiencies. Because of the interrelation between these many components, all issues are contained in one practice brief rather than separating out the levels of service, container types, and haulage vehicle fleet decisions.

(iv) **Waste processing and diversion.** These briefs pertain to essential waste management interventions between the collection and disposal of residuals. Recycling is discussed in detail, together with pragmatic recommendations on the appropriate roles of government versus private sector and the most likely materials for economic recycling. Composting is usually a key issue for municipalities and the three-scale options are presented. Included also are some real-world examples of experience with the sustainability of large centralized facilities. Waste-to-energy approaches are attracting increasing levels of interest from a range of municipality sizes. Practice briefs are provided on treatment requirements before waste-to-energy is possible as well as the options for managing the emissions, which are often a concern to the community and civil society. Refuse-derived fuels and mass burn waste-to-energy facilities are also discussed.

(v) **Landfill development.** Even with significant effort directed toward waste avoidance, minimization, recycling, reprocessing, and diversion, there will always be residual requiring disposal. Practice briefs are provided on siting landfills and geotechnical assessments that may be required. Guidance is likewise provided on selecting an appropriate standard for the waste disposal facility based on contemporary pragmatic solutions that offer much greater sustainability than the previously supported best available treatment (highest technology) option. Other practice briefs provide details on a suitable approach to landfill sizing and key design elements for a controlled landfill, including inputs on appropriate landfill lining systems. More details are given on contemporary management approaches for landfill leachate, which is usually the main environmental concern at substandard facilities. This is further expanded upon in the specific brief on leachate collection and leachate lagoon systems.

(vi) **Landfill operations.** Ten practice briefs are provided in this chapter. This is because most landfills fail due to poor operation rather than poor design. Improved operations do not necessarily require a massive increase in budget, just an understanding of the required operational targets and the correct approaches. Practice briefs are presented on the key issues of stormwater runoff management and landfill gas control options. Guidance is also provided on how to lay out and stage landfill cells, as well as an overall operational overview for running a landfill. Critical elements such as waste compaction, litter management, and fire and pest control are also presented. The option of having waste pickers or scavengers on a controlled landfill is also presented, together with some appropriate management interventions. Guidance is provided on appropriate landfill reporting and complaints registers, again with links to a sample landfill operations manual as a resource document. Guidance on the development and implementation of a suitable environmental monitoring and management plan is also presented. The contemporary approach to remediating open and uncontrolled dumping is discussed, focusing on maximizing the life of old disposal sites rather than simply abandoning them, as well as minimizing environmental impact in parallel.

(vii) **Contract issues.** A key focus of the overall study was to support private sector involvement in appropriate phases of solid waste management. Experience gained from undertaking this study as well as general experience is presented in practice briefs dealing, for example, with packaging options for privatization. Some possible implementation issues with public–private partnerships are presented, as well as background details to contractual obligations of such partnerships. The major issue of contingent liabilities associated with termination fees and the impact on municipal finance planning are also presented. Information can be found on public–private partnership packaging issues where there are potential internal conflicts between contractors and shareholders leading to potentially substandard partnership outcomes.

Types of Municipal Solid Waste Characterization Audits

Issue

All aspects of solid waste management (SWM) planning are predicated on sound knowledge of the waste components and quantity that need to be managed. Many municipalities have access to previous waste characterization audits. However, in many cases, the data are very poor and cannot provide the integrity essential to good planning.

Therefore, audits are undertaken to verify the quality of the information available and to provide robust data in the absence of suitable waste characterization datasets.

These audits are also an opportunity to determine if prohibited waste is currently entering the disposal facility and take appropriate remedial action as required.

Separating mixed waste into categories.

Interventions

There are two different approaches to waste characterization audits, as described below:

Characterizing individual waste streams followed by aggregating data

The first option is to have the collection trucks alter their usual collection route and have each vehicle collect from only one waste source, such as domestic waste or just commercial waste. Alternatively, waste can be hand-collected from a small number of households or other specific waste generators over a defined period.

A number of distinct and separate audits will then be conducted on the various waste streams. These individual audits will characterize each type of waste selected in the municipality, but not the combined waste stream.

Disaggregated data can be collected for a specific purpose, such as investigating composting organic waste from wet markets or commercial waste for refuse-derived fuel. Another use for domestic sampling is to check the effectiveness of any education campaigns regarding separating recycling products from domestic waste. The results can be used to amend education campaigns and delivery methods to best effect.

To determine the combined waste stream characteristics overall, the results of the individual waste type audits have to be combined. Combining the results of the individual waste audits must be done using the actual ratio of the individual waste stream components based on long-term monitoring of the mass contributions from the various ways sources.

Collection vehicles typically carry mixed waste and there is no simple but accurate method of determining the exact mass contribution of each individual waste type. If there are no long-term and very accurate specific weight data available, aggregating the individual waste stream data to give an overall waste stream characterization will result in major errors.

Recording weights of waste categories.

Measuring waste volume in every load.

Unfortunately, this auditing method is commonly used, while engineering judgment is used to combine the individual waste streams. The resulting aggregated data are essentially of no merit.

End-of-pipe Aggregated Audits

It is almost always better to ensure that a fully mixed waste sample is collected and then audited. This second option involves collecting a representative sample of a typical day's combined waste by mixing the entire day's production and quartering or by subsampling from every individual truckload.

With this method, there is no need to determine the relative mass contributions of the individual waste streams to obtain an accurate overall waste characterization.

Details on how to undertake the actual audit are summarized in the succeeding practice brief, Municipal Solid Waste Characterization and Tonnage Determination Procedures, with full audit procedures described in the appendixes of the Quezon City Integrated Solid Waste Management Plan.[1]

Quantity Required for Characterization

The American Society for Testing and Materials (ASTM), the world's largest source of voluntary consensus technical standards for materials, goods, services, and systems, has prepared the Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste (Designation: D5231 – 92).[2] This test method describes procedures for measuring the composition of unprocessed municipal solid waste (MSW) by employing manual sorting. The method applies to the determination of the mean composition of MSW based on the collection and manual sorting of a number of samples of waste over a selected time period.

The tabulated mean values and standard deviations are estimates based on field test data reported for MSW sampled during weekly sampling periods at several locations around the United States (US). These are used to determine the number of samples required to achieve the desired level of confidence in the characterization results. The data, however, are all US-based and do not reflect the waste characteristics of developing countries and, therefore, must statistically be applied very cautiously.

In reality, a team of 12 laborers can characterize many hundreds of kilograms of waste per day, which greatly exceeds the number of individual samples recommended through the ASTM procedure. The ASTM standards require a minimum sample weight of 80 kilograms (kg) for unprocessed MSW, and suggest at least 30 samples for residential waste and 40 for commercial generators.

Volume versus Mass Characterization

Many waste audits are conducted on a volume basis as this is easier than weighing the waste components. The resulting data are spurious as the waste components are usually shredded or compacted during haulage, processing, or disposal, making any volumetric data effectively irrelevant. All waste audits must be conducted on a mass basis.

Summary

Most municipalities have access to waste characterization data from previous audits. Almost inevitably, the data are spurious and municipalities are strongly encouraged to undertake an end-of-pipe waste characterization study to obtain valid data as a sound basis for SWM planning.

The only exception is if the municipality wishes to characterize a specific waste stream for processing or reuse purposes.

1 ADB. 2016. *Integrated Solid Waste Management Plan: Quezon City.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20160930/integrated-solid-waste-management-plan-quezon-city

2 American Society for Testing and Materials. *The History of ASTM International*. https://www.astm.org/ABOUT/history_book.html

Municipal Solid Waste Characterization and Tonnage Determination Procedures

Issue

All aspects of solid waste management planning are predicated on sound knowledge of the waste components and quantity that need to be managed.

Many municipalities have access to previous waste characterization audits. However, in many cases, the data are very poor. These results cannot provide the reliability and integrity essential to good planning (see Types of Municipal Solid Waste Characterization Audits practice brief, pp. 1–2).

Segregating the waste into categories.

Interventions

Waste audits should be conducted over a period of at least 3 days with the following aims:

- To determine the percentage by mass of various waste components by segregating and weighing a representative quantity of the mixed waste stream.
- To determine the total volume and mass of waste entering the site daily by determining average waste density by weighing known volumes of waste from selected loads. (This only applies if a weighbridge is not available to provide long-term waste tonnage data.)

Prior to the audit, it is essential to determine if the waste stream is the same every day or if some areas of the municipality are only serviced on certain days—for example, whether market waste is collected every day or only on certain days. Similarly, confirmation of the collection timing for any commercial, institutional, or industrial areas is required.

Large commercial or industrial waste producers of a consistent single waste type might be handled by a weighbridge and truck volume to give landfill volume requirements separately from a hand audit, as decided by the audit team. This might also apply for seasonal processors of crop or fruit waste to avoid skewing the annual landfill volume estimates. The periods of operation per year will need to be ascertained.

Typically, the waste is divided into the 14 industry standard components, as described in the detailed audit protocols in the appendixes of the Mandalay Integrated Solid Waste Management Plan.[3] The materials are separated by hand into

[3] ADB. 2016. *Integrated Solid Waste Management Plan: Mandalay.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161130/integrated-solid-waste-management-plan-mandalay

Quartering waste pile.

14 piles, which are then progressively weighed during the audit. It is helpful to have a small 5-10 millimeter screen available as in some cases, the street sweeping residues can account for a large percentage of the total waste stream.

A team of 12 laborers (with support from supervisors) should be able to weigh at least 6 metric tons of waste for the density determinations and a further 3 tons of waste as part of the waste characterization audit in a typical 3-day period.

It is critical to ensure that the samples collected from the incoming trucks are representative of the overall waste stream. The approach to collecting a representative sample varies depending on the quantity of waste being delivered to the site.

In this exercise, it is assumed that collection fleets are of one type: typically an open tray tipper truck. In cases where compactor vehicles are used together with tray trucks, the density in the compactors is typically three times that in the tray trucks. Furthermore, scavenging at curbside and in the open truck, as well as along the route from the urban area to the landfill, can divert many recyclables that are retained in closed compactor vehicles. If a weighbridge is available to get the tare and gross of service vehicles, then relative density can be described and the waste taken to audit can be proportioned to reflect all regions of the municipality collected. If a similar mix of open and compactor trucks services each neighborhood, then this is a lesser problem. Otherwise, it may be necessary to separately audit compacted waste and open truck waste multiplied by their vehicle trips per week to arrive at a municipal average mass and landfill volume or airspace requirement.

In some countries, the wet season and abundant green leaf growth in gardens and verges can be half the waste stream, and, therefore, an audit in the wet and dry seasons may be required to represent airspace requirements and recycling targets.

Small Municipalities (Hauling Less Than Five Truckloads a Day)

For small communities, all waste on the agreed day(s) should be delivered to a central location. The waste pile gathered will be mixed, preferably using mechanical equipment or, if not available, manually using shovels and rakes.

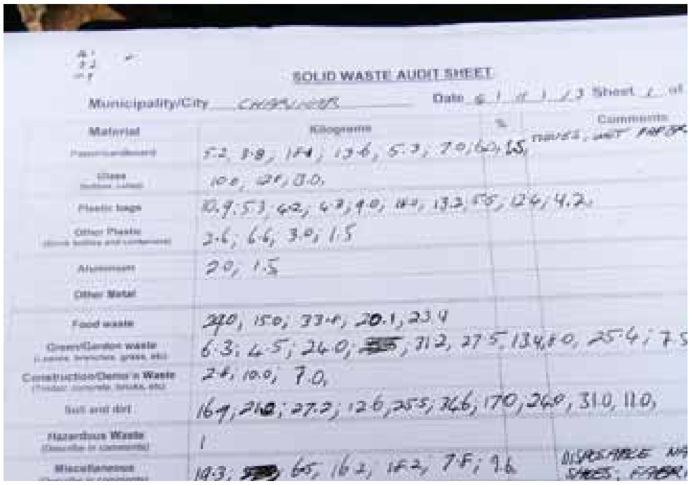
Afterwards, the pile will be quartered a number of times until a reasonable quantity of waste is selected for characterization on the following days.

Midsize Municipalities (Hauling 5–20 Truckloads a Day)

For a municipality of this size, it is recommended that every truck be diverted to dump the full load in a designated area, but that each individual pile should be kept as separate as possible. One or two large containers of waste are then selected randomly from each pile and taken to the waste characterization area for processing. As the waste characterization area is emptied, another round of containers is collected randomly from each of the waste piles.

To avoid any sample bias, there should be no residual waste in the actual audit area after every pile is audited and prior to getting more waste from the stockpiles ready to audit.

Dumping a full load to measure mass once volume has been determined in situ, after which waste density is checked.



Sample waste audit sheet.

Larger Municipalities (Hauling More Than 20 Truckloads a Day)

For these larger municipalities, a quantity of waste is selected from every truck entering the site. Quite often it is convenient to use a 100-liter plastic bin to collect this sample. The samples are then taken to a dedicated area and mixed. If the resulting sample pile is about equal to the quantity of waste that can be characterized during the audit period, the waste is progressively taken from the storage pile to the waste characterization area until the storage pile is empty.

However, if the quantity of waste in the storage area is far greater than the quantity that can be successfully audited within the time period available, the storage pile should be fully mixed and quartered, and only the waste from the nominated quarter should be taken to the waste characterization area.

Procedure Details: Density and Mass Determinations

Prior to the audit commencing, the average number of open trucks coming to site every day should be determined based on the best available municipal records. The number of trips made by each truck must be determined if different-sized vehicles are used.

Following this, it is necessary to measure the volume of waste in situ in all trucks entering the site on all 3 days and to make general observations on the waste type. These data will be used to determine the mass of waste delivered each day. (Do not just measure the external truck body dimensions as each waste load may only fill a fraction of the total capacity of the truck body.)

The selected trucks (which appear to contain waste typical of the overall waste stream being delivered to site) should be diverted to a second dumping area, where the volume of the full load is accurately remeasured while still in the truck.

The entire waste load should then be emptied onto a plastic sheet and then weighed bin by bin, noting that it does not need to be segregated. Only the total weight of the load has to be determined.

This combination of in situ volume and mass will allow the truck in situ density to be determined for these representative loads. Once the average waste density and the average total volume of waste entering the site are determined, the daily tonnage can be calculated.

Waste compactor trucks usually have a density of around 400 kilograms per cubic meter.

Summary

Most municipalities have access to waste characterization data from previous audits. However, oftentimes, the data is unreliable. Local government units are strongly encouraged to undertake an end-of-pipe waste characterization study to obtain valid data, which will provide a sound basis for solid waste management planning.

The only exception is if the municipality wishes to characterize a specific waste stream for processing or reuse purposes or to direct recycling and educational programs to target specific waste components and monitor the effect of campaigns.[4]

[4] For the detailed audit methodology, see the appendixes of the *Integrated Solid Waste Management Plan: Mandalay.* http://k-learn.adb.org/materials/20161130/integrated-solid-waste-management-plan-mandalay

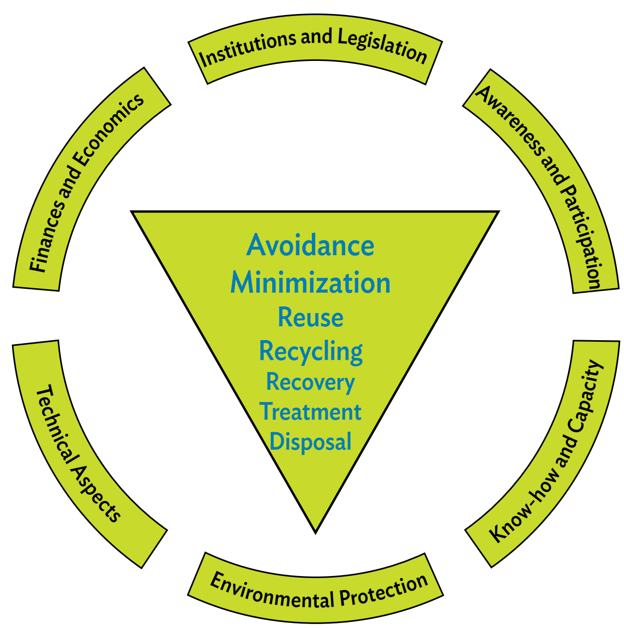
Waste Minimization

Issue

Source reduction or waste minimization is a necessary component of any solid waste management strategy (Figure 1). The benefits of waste minimization include pollution prevention, reduced need for waste treatment and disposal facilities, and cost savings.

Most waste minimization campaigns address the reduction of packaging material (paper and cardboard), plastic, and metal containers. Only relatively small quantities, however, of these materials are present (excluding plastic) in communities with low household incomes. As these incomes and community wealth increase, so will the packaging waste quantities, prompting a need for waste minimization activities.

Figure 1: Waste Management Hierarchy



Source: Author.

Interventions

Waste minimization includes not only volume reduction but also waste toxicity reduction. An appropriate response, therefore, is to minimize the sale of toxic products such as compact fluorescent light globes replaced by LED globes, and encouraging natural biodegradable and nontoxic products.[5]

Charging Policy

A major influence on the success of waste minimization and recycling is the pricing regime for waste disposal. But many municipalities and waste management authorities may not be charging enough to cover the real costs of waste collection, processing, and disposal, as well as the costs to provide for disposal site replacement and environmental costs.

Meanwhile, the public continues to discard rather than minimize waste or recycle.

On the other hand, if informed, the public is generally willing to participate in minimization programs based on environmental grounds, confident that recycling is conserving material resources.

One option to reduce waste is the introduction of compulsory charges for all plastic bags used at major shops and markets. Plastic, mainly bags, makes up a significant fraction of the current waste stream. Plastic bags comprise approximately 10%–15% of the total waste stream and are therefore a valid target for minimization interventions (Plastic Bags practice brief, pp. 8–10).

[5] A background on waste minimization, actual sample programs and appendixes can be found in *Integrated Solid Waste Management Plan: Quezon City.* http://k-learn.adb.org/materials/20160930/integrated-solid-waste-management-plan-quezon-city and the *Integrated Solid Waste Management Plan: Mandalay.* http://k-learn.adb.org/materials/20161130/integrated-solid-waste-management-plan-mandalay

Electronic waste or e-waste has become a serious concern worldwide due to increasing use of electronic equipment and its quick obsolescence.

Legislation

Policy can aid implementation of waste minimization. The aim is to shift management costs from the municipality to the manufacturers, so they internalize solid waste management disposal costs.

One option is extended producer responsibility, wherein suppliers are responsible for a product's life cycle; especially, for phones, printers, and computer parts that are considered e-waste once discarded.

Legislation has been utilized in many parts of the world in order to control the generation of waste.

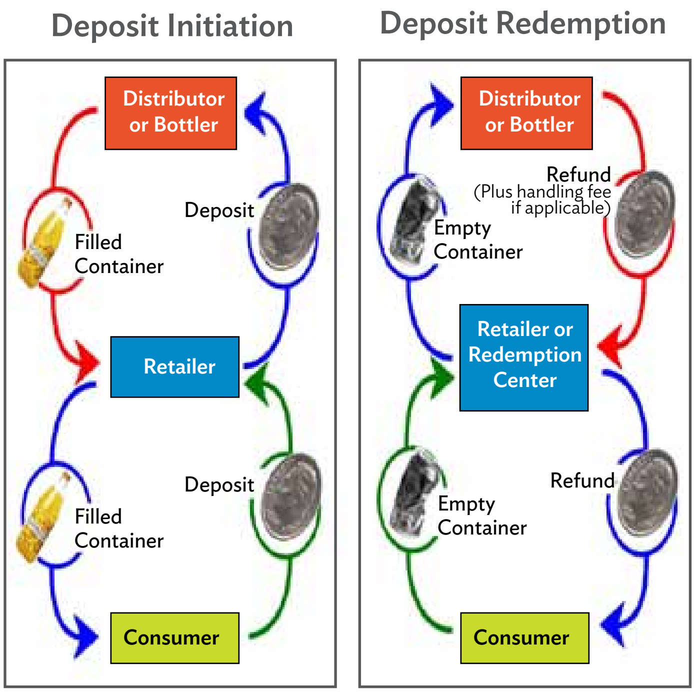
In particular, many countries, including developing countries in Asia and the Pacific, have container deposit legislation (CDL). This legislation typically requires a deposit to be paid for the purchase of products, such as beverages, with certain exemptions granted by regulation. A refund is eventually given when the container is returned at the point-of-sale or collection depots, where the containers are collected for reuse or reprocessing (Figure 2). The initial reason for the introduction of CDL was to control the amount of litter.

CDL was designed to ensure manufacturers take more responsibility for the packaging they create, by giving consumers the right to leave excess packaging behind or return it to the point-of-sale later. As a result, far greater pressure is placed on manufacturing, via retailers, to establish alternative collection schemes and ensure that their packaging is reusable and recyclable. However, in low-income communities with many small stores, even the smallest deposit coin charge is a burden on the poor. It also introduces security problems for stockpiled returned containers, since these are sometimes stolen to recover additional deposit refund.

Education

A major factor in any program seeking to reduce the quantity of waste going to disposal is education of the community, both general public and the business sector. A national government initiative is usually required to support education with respect to waste management, as it has to be very long term and mainstreamed into the school curricula to become effective. Such an effort could be best achieved through a combination of national and local campaigns, supplemented with funding for local-level education through nongovernment organizations.

Figure 2: Container Deposit Flowchart



Source: Author.

Energy Recovery

This has more application in poorer countries and for areas distant from recycling centers. Both polyethylene shopping bags and containers as well as polyethylene terephthalate "rocket bottom" containers burn cleanly with no toxins and have a fuel value equal to diesel. These aspects can be used to assist burning hospital waste, as fuel for cement kilns, or for producing charcoal or institutional heating in colder climes. Vehicle tires also have a useful fuel value for high-temperature cement kilns.

Summary

Integrated resource recovery is the recommended approach to waste management for any municipality. This aims to generally instill an understanding and garner support within the community for desirable waste management principles.

The most successful waste minimization schemes are those that are multipronged. The combination of education, pricing intervention, and legislation is required to achieve significant and sustainable waste minimization.

Plastic Bags

Issue

Plastic bags and polyethylene terephthalate (PET) beverage bottles often represent up to 20% of the total waste stream going to processing or landfill, with the majority being plastic bags.

The visual and environmental effects of these bags are far greater than the percentage would indicate, since these are easily windblown or washed off into local waterways resulting in significant negative impacts.

In addition, plastic bags have very low density, which means that transport costs for recycling or reuse are high, and in some cases insurmountable, so the focus on minimization is essential.

Recycling clean plastic bags in Viet Nam.

Interventions

Recycling and Processing

There is very little opportunity for recycling plastic bags apart from burning as a fuel source or bringing in shredding equipment and molds to make plastic items such as plastic seats. However, given that most plastic bags are soiled either with inorganic soil or organic material attachment, the overall environmental cost associated with having to clean and dry these bags, not to mention the higher labor content, make such a scheme generally unattractive at the present time. There are some exceptions in Viet Nam and Thailand, but generally recycling plastic bags is not economical.

In cities where solid waste collection requires residents to bring out waste to carts, trucks, or bulk bins of various sizes, plastic bags from the supermarket are commonly used to store wet waste, including disposable nappies and domestic cleaning waste. These collected garbage in plastic bags are transported and disposed in the bins. The reuse of plastic bags become limited and a substitute will need to be found for such duties.

In Timor-Leste, a nongovernment organization stretched the bags and plaited or crocheted them into waterproof placemats and carryalls, but this hardly solved the numbers disposed.[6]

Plastic bags, polyethylene containers, and PET "rocket bottom" containers can be used as a fuel source in refuse-derived fuels or in waste-to-energy facilities where partial processing is usually required. Both polyethylene and PET burn cleanly with no toxins and have a fuel value equal to diesel. They are

[6] ADB. 2015. *Preparing the Urban Services Improvement Sector Project: Final Report.* Consultant's report. Manila (TA 8750). http://k-learn.adb.org/materials/20151201/ta-8750-tim-preparing-urban-services-improvement-sector-project-final-report

Reusable fabric shopping bag.

Many types of degradable plastics are now available.

useful for domestic fire starters and for combustion support in hospital incinerators as well as cement kilns or commercial charcoal production and the like.

Plastic Bag Ban

Some cities have taken the step of simply banning the use of plastic bags, such as in parts of Metro Manila in the Philippines. This ban applies to both large supermarket outlets and smaller corner stores where all purchases have to be placed in paper bags or cardboard boxes. This plastic ban has also been extended as far as drinking straws, which now have to be made from waxed paper rather than plastic.

This kind of intervention is not universally supported and there is significant consumer resentment. Some point out how during rainy periods the paper bags become wet and grocery items can rip through the bags. Some cities allow exclusions, such as for plastic bags without handles that can be used to pack items like fish and meat purchased in wet markets.

Bag Tax

In some countries another type of intervention introduced is a charge for the use of supermarket plastic bags. In some cities within Metro Manila, consumers are required to pay for each plastic shopping bag at larger supermarkets to discourage people from taking excessive numbers of plastic bags and, as a corollary, to encourage people to provide their own reusable fabric bags. Such a scheme has been introduced in many countries in the European Union and elsewhere.

However, to make implementation more streamlined, only larger supermarket chains (employing more than 50 persons) often have to charge the tax. Therefore, dry and wet markets and the small corner stores are often exempted.

Degradable Bags

Different types of "degradable plastic" bags are now available (Box). Compostable plastic bags are often made from farmed products such as cornstarch, which in the right conditions will break down into elements like carbon dioxide, water, and methane.

Box: Comparison of Bag Types, According to Material and Cost

Cost Comparison of Bag Types

- Normal plastic bags: *2 units*
- Degradable (where the matrix biodegrades leaving numerous small pieces of plastic): *4–5 units*
- Biodegradable/Oxodegradable (special additives in the plastic allow the plastic to fully biodegrade over a specified period): *7–10 units per bag*
- Compostable (made of organic material such as cornstarch and not really plastic as such and fully biodegradable): *about 21 units per bag*
- Paper bags: *5–8 units*

Source: Author.

Biodegradable bags, on the other hand, are generally best suited to composting and may contribute to methane emissions if sent to landfills. To meet international standards, bags need to compost within 12 weeks and fully biodegrade within 6 months. Biodegradable bags are not suited to recycling. These bags are appropriate for large cities where bag turnover is very high. If the bags are stored for protracted periods due to slow sales or distribution issues, the bags will start to biodegrade prior to use. Therefore, compostable plastic bags are considered appropriate only in larger municipalities at this time.

Degradable plastic bags break down primarily through the reaction of a chemical additive to oxygen, light, or heat and are also known as "oxodegradable" bags. These are best suited to landfill disposal, since these bags survive long enough to present a threat to animals if littered. These bags are the second generation of degradable plastics.

The first generation of plastics termed "degradable" solely involved the decomposition of the matrix holding the plastic molecules together. This means the plastic bag merely broke down into a large number of very small pieces of plastic, which will then take many decades to biodegrade.

However, this second generation termed "biodegradable" benefits from having chemical additives that can be used to ensure that the entire bag structure breaks down into the basic atomic components, such as carbon and oxygen, over a specified time period. This time period can be set to vary from a few weeks up to a number of years as required by the purchaser. The central government in Fiji, for example, has mandated that all plastic bags must be of the biodegradable type. This applies not only to shopping bags but also to all storage bags, such as for hot bread, etc.

Summary

The hierarchy of plastic bag minimization measures ranges from simple education to the complete banning of plastic bags. This can include taxes and biodegradable options.

The preferred approach for each municipality will depend on local issues and the level of concern about these bags. The middle ground is to legislate that all plastic bags be biodegradable using the second-generation chemistry, wherein the bags break down entirely into their prime elements and not a multitude of small plastic remnants. Alternatively, a bag tax could be applied.

This approach could also be supplemented by an information and education campaign, which could encourage the use of reusable fabric bags and minimize the use of plastic bags, even though they are degradable.

Information, Education, and Communication Plans

Issue

Solid waste management (SWM) planning must address sustainability issues and not just engineering interventions. An information, education, and communication (IEC) campaign is crucial in order to engage with the community and civil society to bring about a better understanding of key waste management issues. These include the environmental and health impacts of poor waste management, waste avoidance, waste minimization, reuse, recycling, household composting, and the increasing need in the future for waste segregation, especially of green waste.

Discussing the issues help promote better behavior and waste practices. Many IEC campaigns, though, are relatively short term and do not achieve engagement in a sustainable manner.

Interventions

Objectives

Setting clear goals ensure a successful IEC campaign. The objectives of any SWM IEC campaign are to do the following:

- Create awareness, understanding, and competency among the communities to minimize, recycle, and reuse the produced waste, as well as dispose of it correctly through their normal day-to-day life strategies at the local level.
- Introduce methods and procedures that enhance participation of the communities and service users.
- Explain the responsibility and role of the stakeholders (i.e., municipality, nongovernment organizations, schools, media, and civic leaders) in the management of waste.
- Involve the community members, men, women, youth, and children for effective management of waste.
- Achieve a sustainable community attitudinal change regarding SWM which takes more than a decade and is essentially generational.

Delivery Methods

A comprehensive campaign using different communications channels likewise increase awareness and amplifies the message. IEC campaigns can be done across the following:

- Projects (e.g., compost demonstrations)
- Posters
- Signboards
- Radio and/or television (use of television is usually more effective with children)
- Street theater
- Committee briefings (e.g., environmental groups)
- Community meetings
- Nongovernment organizations
- Civil society groups
- Municipal staff presentations at meetings
- Social media

Target Audience

IEC campaigns can be as broad or diverse as the community itself or can be directed specifically to a particular audience. IEC campaigns can target the following:

- Schools
- Universities
- Private companies (e.g., restaurants and private collection firms)
- Market stallholders
- Communities
- Individual households, especially homemakers and shoppers

Common Issues and Solutions in Information, Education, and Communication Campaigns

The following table lists some of the issues and solutions that IEC campaigns deal with:

Table 1: Common Issues and Solutions in Information, Education, and Communication Campaigns

SWM Concept	Issues and Solutions	Household and/or Neighborhood Actions	Municipal Actions
Waste avoidance	Buy in bulk and refill reusable containers; avoid toxic plastics and excess packaging, pressure packs, tiny service-size washing powder, etc.	Advise on refillable alternatives; encourage shops to refill containers; encourage cooperatives if repackaging has legislative limitations	Information, education, and communication campaign and support local companies, shops
Environmental management	Burning garbage causes air pollution and health risks Illegal disposal of garbage into drains, rivers, and vacant lots	Explain the environmental damage caused by open garbage fires Explain the environmental damage caused by uncontrolled garbage dumping	Ordinances Ordinances
Waste segregation	Essential if recycling and composting schemes are to be efficient, but costly to have the necessary different receptacles and collection services	Start at the neighborhood and household levels; possibly use neighborhood workers to collect compostables and recyclables with only one municipality pick-up service; or involve/formalize the informal sector	Legislation requires segregation
Waste minimization	Purchasing products with least amount of packaging, reusable glass rather than throw away non-closure plastics. Encourage cloth nappy laundering service	Educate on benefits of lower cost of collection and wasted materials and landfill space consumed.	Container deposits
Waste toxicity	Reduce toxicity of products purchased	Educate on alternatives to certain chemicals, e.g., natural toilet cleaners or LED lighting rather than compact fluorescent light globes	Legislation to ban or limit specific toxic chemicals
Reuse	Reusing containers, such as jars and bottles; provide a tire wall cutter to allow tires to be used for erosion control and home composting stacks without causing an insect and mosquito microbreeding hazard.	Educate on benefits of packaging reduction and other sources; set up cooperatives to allow bulk buying and refilling; install drinking water refill stations for PET water bottles at markets Establish cloth nappy reuse service possibly with hospital laundry services at lower cost than disposables	Legislation

continued on next page

Table 1 *continued*

SWM Concept	Issues and Solutions	Household and/or Neighborhood Actions	Municipal Actions
Recycling	Recycling containers, such as polyethylene containers and plastic bags for garbage containers or outdoors furniture, rot-proof decking, bollards, and road marker posts	Educate on benefits as per the above Call or market for better prices (e.g., plastics and glass) and obtain market access (e.g., for sale of tin cans); negotiate discounted sea freight for returning containers and lead acid battery export to the Republic of Korea or similar recycler	Support local companies
	Drop-off centers for selected items	Consider a centralized system for white goods, garden or green waste, hazardous waste, etc.	Support local companies
Composting	Determining the level at which composting should be done (household versus neighborhood)	Provide training on methods and equipment required; do market development for neighborhood products Consider starting at neighborhood level and then go to households; also consider vermiculture if climate is suitable; look at local insect control culture and on-site use of compost; otherwise, neighborhood or regional processing will be required	Establish sustainable markets for compost Concentrate on erosion control for government-level landscaping, followed by municipal gardens, poor soil areas for agriculture, and lastly domestic uses
Green waste	Deciding how to manage yard and tree clippings	Equip with chippers at neighborhood level as input to composting; chipping for mulch not composting is also an option	Consider ways to fund the chipper Collection volume reduction of typically 14 times will make mobile chipping affordable in municipal collection in some countries
Energy recovery	Need for fuel or combustion support for institutional or industrial users	Collect plastic bags, polyethylene, PET containers, and tires	Convey to hospital incinerators; tires and plastic to cement kilns; to furnaces for cold climate central heating for schools, etc. Support local companies, such as charcoal producers

PET = polyethylene terephthalate, SWM = solid waste management.

Source: Author.

Requirements

The full list of requirements for an IEC campaign have to be developed in consultation with training and education specialists, as well as participants from the municipality. In general, the requirements include the following:

- Primers (why bother segregating, recycling, etc.);
- Fact sheets (how to compost and what to look for when producing compost);
- Presentation material for specialists to "train the trainers," such as nongovernment organizations, neighborhood officials, and so on to roll out the program to the community; and
- Presentation material for the "trainers" to use in the actual training and education at future neighborhood meetings or household meetings, nongovernment organization meetings, etc.

There is plenty of literature and training materials available from multilateral donors and international nongovernment organizations that can be used.

However, the key message is that intermittent IEC programs do not achieve the sustainable engagement required. It must be done over decades and mainstreamed, for example, into school curricula at all levels.

Intermittent IEC programs do not achieve the sustainable engagement required. It must be done over decades.

Summary

A long-term IEC campaign is essential to support the sustainability aims of SWM planning. The campaign elements can address the entire life cycle of waste management, but they are traditionally focused on the waste minimization and recycling aspects. At times, it also tackles waste segregation, if appropriate, and litter.

Numerous IEC campaigns have failed because of the short-term nature of the intervention. It is essential that the campaign be a long-term, almost generational approach to ensure sustainable uptake by the community and stakeholders, leading to enhanced SWM outcomes.[7]

[7] ADB. 2016. *Integrated Solid Waste Management Plan: Buriram.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161031/integrated-solid-waste-management-plan-buriram; ADB. 2016. *Integrated Solid Waste Management Plan: Mahasarakham.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161031/integrated-solid-waste-management-plan-mahasarakham; ADB. 2016. *Integrated Solid Waste Management Plan: Mandalay City.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161130/integrated-solid-waste-management-plan-mandalay; ADB. 2016. *Integrated Solid Waste Management Plan: Quezon City.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20160930/integrated-solid-waste-management-plan-quezon-city; ADB. 2016. *Integrated Solid Waste Management Plan: Sorsogon City.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20160930/integrated-solid-waste-management-plan-sorsogon

Climate Change-Responsive Approach to Solid Waste Management

Issue

Greenhouse gas (GHG) emissions from waste management contribute significantly to global climate change issues.

Open dumping and landfilling are the third-largest source of anthropogenic methane (CH_4) emissions.[8] CH_4 emissions from the waste sector contribute to approximately 18% of the global anthropogenic CH_4 emissions.[9]

Interventions

To address this critical issue, the GHG balance along the waste management chain must be analyzed. The GHG balance can be estimated as the difference of emissions produced and emissions avoided in each process of the waste management chain.

A life cycle assessment (LCA) approach is suggested for selecting the most appropriate waste management method. LCA is a methodical approach for quantifying GHG emissions considering all phases of the waste management life cycle, such as transportation, operation (preprocessing and treatment), and disposal. It enables identification of issues of concern and possible policies for effective GHG emissions mitigation, considering the direct and indirect impacts associated with a specified waste management method.

All the waste management options emit greenhouse gases during waste transportation, operation, and waste degradation. The emissions mainly occur during two stages of waste management: (i) waste collection, processing, and transport; and, (ii) waste disposal (composting or landfilling).

Biodegradable wastes, in anaerobic conditions, generate methane, a powerful GHG that has nearly 25 times the global warming potential of carbon dioxide over a 100-year period

The following are the general steps in choosing a climate-friendly waste management method:

Step 1: Identification of waste source, its composition, and quantity

Identifying the waste source, its quantity, and type helps to understand the nature of waste and estimate its potential for generating emissions. GHG emissions are generated mainly from biodegradable wastes, such as food waste, vegetable waste, tree trimmings, human waste, manure, sewage sludge, and slaughterhouse waste. These biodegradable wastes, in anaerobic conditions, generate methane, a powerful GHG that has nearly 25 times the global warming potential (GWP) of carbon dioxide (CO_2) over a 100-year period. Nonbiodegradable wastes, such as metals, rubber, glass, ceramics, and construction site waste, do not result in GHG emissions.

[8] P. Forster et al. 2007. Changes in Atmospheric Constituents and in Radiative Forcing. In S. Solomon et al, eds. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK: Cambridge University Press.

[9] C. Scheutz, P. Kjeldsen, and E. Gent. 2009. Greenhouse Gases, Radiative Forcing, Global Warming Potential and Waste Management – An Introduction. *Waste Management & Research.* 27. pp. 716–723.

Step 2: Estimation of emissions generated during waste collection, processing, and transport

Putrescible wastes (food waste, animal waste, manure, night soil, etc.) degrade at a faster rate and can generate emissions even within few hours of its generation and collection in waste containers. Fossil fuel consumed during the waste collection operation is a significant contributor to GHG emissions. The larger the waste quantity and the longer the distance between the collection points and processing and/or disposal site, the higher the emissions. Use of electricity at waste segregation and material recovery plants is also a source of emissions. Other emission sources include lubricants and engine oils from such waste recovery plant operations.

Incineration generally contributes to the generation of climate-relevant emissions, such as CO_2 as well as nitrous oxide (N_2O), oxides of nitrogen (NO_x), oxides of sulfur (SO_x), ammonia (NH_3), and black carbon (soot). Thus, the energy consumption and emission generation must be estimated at each stage of the waste management method.

The estimations to be done at this stage are:

- self-degradation of biodegradable or putrescible wastes and aerobic or anaerobic options,
- fossil fuel use during waste transport,
- electricity use at waste segregation and material recovery plants, and
- inherent waste generation and related emissions at waste management facilities.

Step 3: Estimation of emissions generated during waste disposal

Each waste disposal option should be analyzed with respect to GHG emissions along with other considerations of waste composition, investment needed, and conformity with the local site and environmental safeguard requirements.

With composting, microorganisms consume the organic matter and release heat and CO_2. In anaerobic composting, such as in many home composting bins, CH_4 is emitted as well as nutrient-laden leachate. In combustion processes (waste-to-energy and incineration), both CO_2 and N_2O are released. N_2O has around 300 times the GWP of CO_2 but makes up only a small percentage of the total emissions.

Landfilling is the most common waste disposal practice and results in the release of CH_4 from the anaerobic decomposition of organic materials. It is also noted that the operation and maintenance of the waste disposal site consumes some energy, and thus contributes to emission generation.

Accordingly, the estimation of the following emissions can be done in each waste disposal options:

- Composting: $CO_2 + CH_4 + N_2O$ emissions if aerobic
- Biogas and/or landfill gas combustion: CO_2 emissions
- Waste incineration: $CO_2 + N_2O$ emissions
- Municipal solid waste landfilling: $CO_2 + CH_4$ emissions
- Emissions from operation and maintenance of the waste disposal site, including the use of fossil fuels and biogas and/or landfill gas leakage during regular plant operation and maintenance, etc.

Step 4: Estimation of avoided emissions during waste disposal

By choosing a combination of appropriate technologies, a significant amount of material and energy from wastes can be recovered, along with reducing the amount of waste sent for disposal in the landfill. Recovered materials and energy can be used to replace the production of the equivalent amount of materials and energy from raw materials and conventional processes. Therefore, the GHG emissions that would otherwise occur from extraction of raw materials and conventional processes can be reduced. Aluminum recycling is a particularly beneficial process as it can save significant quantums of energy and material involved in the aluminum-making process.

In the composting process, most of the carbon contained in the organic matter is retained in the compost (and soil after its application) and therefore not released into the atmosphere. The compost can be used as replacement for inorganic fertilizers. The GHG emissions associated with the energy-intensive inorganic fertilizer production are then reduced.

The alternative is anaerobic decomposition of green waste in the landfill or digester which will generate very large volumes of CH_4 (typically 0.22 cubic meters per kilogram of organic dry matter) that can be captured and used for energy generation.[10] In this way, emissions from burning of fossil fuels for equivalent energy generation are avoided.

In the combustion processes, all wastes are incinerated and either heat and/or electricity are produced. In this option, dumping of wastes in the landfill is avoided and thereby emissions of CH_4, the GHG with higher GWP, from the landfill is also avoided. Also, emissions from burning of fossil fuels for the equivalent energy generation are avoided.

With landfilling, CH_4 can be captured and either flared or burnt for energy recovery, thereby avoiding most CH_4 emissions.

[10] N. J. Imu and D. M. Samuel. 2004. Biogas Production Potential from Municipal Organic Wastes in Dhaka City, Bangladesh. *IJRET: International Journal of Research in Engineering and Technology.* 3 (1). pp. 453–460. http://esatjournals.net/ijret/2014v03/i01/IJRET20140301078.pdf

In some countries, the kitchen scraps and sewage effluent are sourced for sealed anaerobic digestion to produce CH_4 for power generation.

Thus, the following estimations can be made on avoided emissions from different waste disposal options:

- Energy recovered from incineration and avoided use of fossil fuels elsewhere in the energy system, conversion of CH_4 to lower volumes of CO_2 emissions
- Avoided emissions associated with producing materials from primary resources, particularly aluminum
- Avoided emissions associated with the use of any inorganic fertilizers
- Avoided CH_4 emissions by aerobic composting of green waste
- Amount of carbon sequestered during the landfill

Step 5: Selection of appropriate technology mix

Based on net GHG calculations, along with other parameters such as investment needed, capacity limitations, technology transfer, land availability, and conformity with the local site and environmental safeguard requirements, the appropriate waste disposal technology mix with the maximum net GHG reduction can be selected.

For example, a combination of waste segregation, composting, recycling, and engineered landfill will provide a sound approach for minimizing emissions at each stage, suitable for the local context and scenario, and the final quantity of waste sent to the landfill will be reduced substantially.

Summary

GHG emissions can occur at all phases of solid waste management. The appropriate response is to determine interventions that minimize these emissions during each of these phases and incorporate them into the overall solid waste management plan where possible.[11]

[11] ADB. 2016. *Integrated Solid Waste Management Plan: Quezon City.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20160930/integrated-solid-waste-management-plan-quezon-city; ADB. 2016. *Integrated Solid Waste Management Plan: Sorsogon City.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20160930/integrated-solid-waste-management-plan-sorsogon; ADB. 2016. *Integrated Solid Waste Management Plan: Mahasarakham.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161031/integrated-solid-waste-management-plan-mahasarakham; ADB. 2016. *Integrated Solid Waste Management Plan: Buriram.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161031/integrated-solid-waste-management-plan-buriram; ADB. 2016. *Integrated Solid Waste Management Plan: Mandalay City.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161130/integrated-solid-waste-management-plan-mandalay; ADB. 2017. *Climate Change Vulnerabilities and Mitigation Options in Solid Waste Management (The Philippines, Myanmar, and Thailand)*. Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20170228/climate-change-vulnerabilities-and-mitigation-options-solid-waste-management; ADB. 2017. *Possible Options and Practices for Reducing Greenhouse Gases in Solid Waste Management Sector.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20170228/options-and-practices-reducing-greenhouse-gases-solid-waste-management; ADB. 2017. *GHG Emission Reduction Potential and CDM Possibilities for Solid Waste Management in 5 CSCs.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20170228/ghg-emission-reduction-potential-solid-waste-management

Integrated Solid Waste Management Plan Implementation: Evaluation and Diagnosis

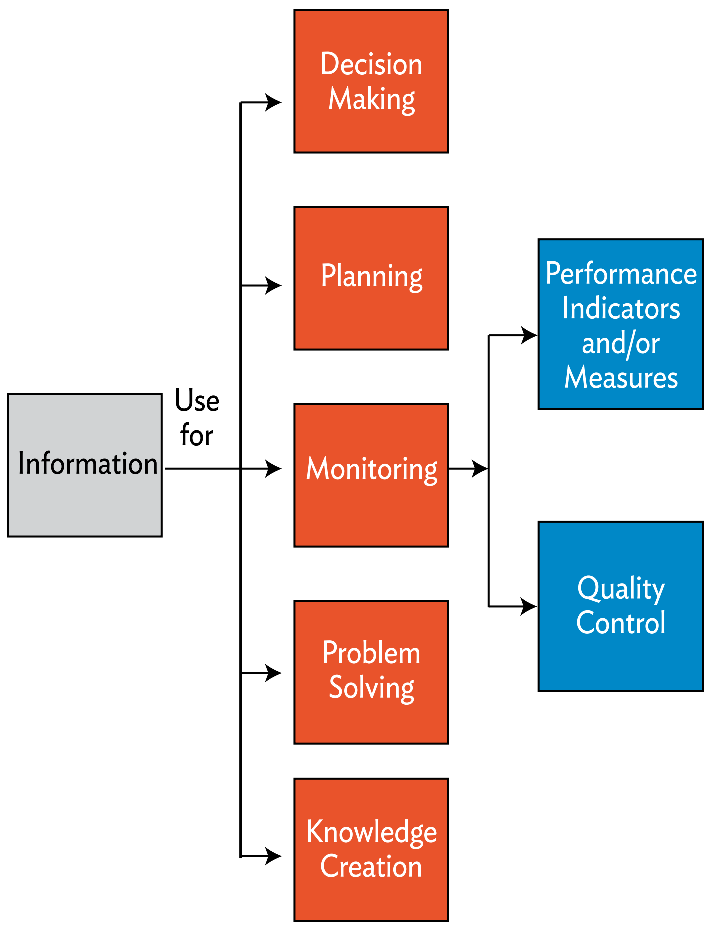
Issue

The process of implementing an integrated solid waste management (ISWM) plan must be monitored and regularly reviewed in order to identify weaknesses in the program and to identify actions to update the process (Figure 3).

First, the monitoring and evaluation of the solid waste management program needs to include detailed recording and assessments of the day-to-day operations. It is important to consider all costs incurred and what category they fall into. This is important to assess where resources need to be allocated, or, conversely, where program changes can be done to reduce costs.

Second, both qualitative and quantitative evaluations of the system need to be made. The success of the ISWM plan depends on records of the amount of solid waste collected, frequency of collections of both secondary and primary secondary waste points, cleanliness of the various parts of the systems, and general effectiveness of the program.

Figure 3: Information Flow and Actions



Source: Author.

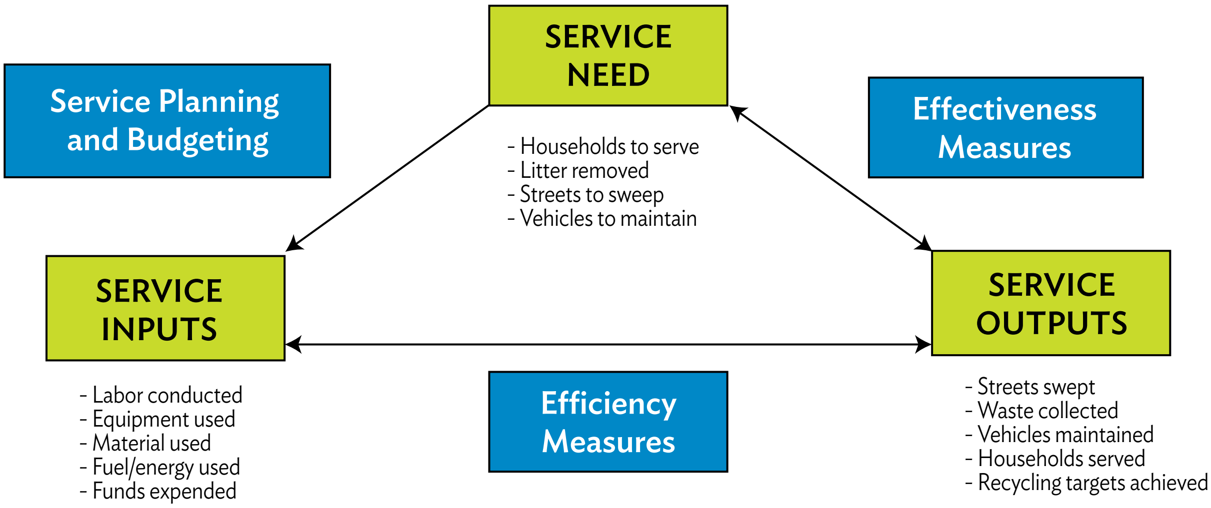
Interventions

Considering these issues, monitoring and evaluation spreadsheets are required and should include the monthly costs and evaluation of the following as a minimum:

- Landfill operations,
- Secondary system,
- Primary collection, and
- Primary storage.

The costs and evaluation information need to be recorded on a daily basis and turned over to the ISWM plan manager on a weekly basis. The manager should summarize the monthly information and prepare a report for the mayor or designated manager on a monthly basis.

Figure 4: Efficiency and Effectiveness Related to Planning and Budgeting



Source: Author.

The ISWM plan needs to be flexible and capable of modification and adjustment. Over time, plans need to take into account external influences such as availability of funding and resources and interaction with other areas of city activity and policy. The plan must also be strongly managed to ensure successful implementation.

Implementation of the ISWM plan should focus on both short-term actions and a longer (e.g., 10 years) period. The short-term action plan could be based on a 12-month period with two streams of activity, particularly the following:

- Short-term actions mean immediate actions which are required to ensure progress can be made during the first year of the strategy.
- Long-term actions require a thorough strategy that will involve a period of consensus building with the aim to bring firm proposals to politicians for full implementation of the ISWM plan.

Different reports are needed to summarize the results of the performance measurements. For general planning purposes and as a basis for updates of the ISWM plan, annual or biannual summary reports will be sufficient (Figure 4).

At the other end of the scale, routine management reports will be beneficial for upper-level ISWM plan managers on a weekly or monthly basis, while operational managers will need daily indication of the progress of general operations.

Implementation of the ISWM plan is likely to require the responsible authority to adapt its structure and resources to suit changing managerial requirements as ISWM projects are developed. Having developed the plan, the process of practical implementation must begin, and it is important that the city follow through a logical sequence of steps to ensure successful implementation.

Summary

Developing an ISWM plan demonstrates the need for collecting and utilizing information. These large amounts of data have to be processed into usable information to guide plan implementation.

The plan has to be flexible, since oftentimes there may be a need to adapt to changing circumstances and conditions, such as changes in the waste stream (e.g., through increased affluence), development of new technologies to treat and dispose of waste, or institutional changes.

Having a program to regularly review data can help increase the municipality's knowledge and understanding of the ISWM system through a process of interactive review, problem diagnosis, and development of remedial action programs. Waste audits of domestic customers can indicate whether recycling campaigns have had an effect or need a change in approach, among others.

Overall, data is critical and has to be collected during plan implementation on an ongoing basis, and the impacts need to be reviewed regularly.[12]

[12] ADB. 2016. *Integrated Solid Waste Management Plan: Quezon City.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20160930/integrated-solid-waste-management-plan-quezon-city; ADB. 2016. *Integrated Solid Waste Management Plan: Sorsogon City.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20160930/integrated-solid-waste-management-plan-sorsogon

Management of Specific Waste Types

Background

Landfills can be constructed over many years and to many standards. The categories below pertain to a suitably engineered landfill where solids, liquid leachate, and gases can be contained on-site or safely released. Less well-constructed facilities should only accept inert and acceptable wastes.

Waste entering a landfill may be categorized as the following, with some examples given:

- Acceptable wastes (general): general household and commercial waste;
- Acceptable wastes (but difficult) such as tires, mattresses, etc;
- Special wastes (sometimes acceptable): asbestos, liquid waste, etc; and
- Prohibited wastes such as radioactive waste.

General wastes and difficult wastes are always accepted, but the second category requires some special management. Special wastes may be acceptable based on quantities involved, actual waste characteristics, and so on, and is decided on a case-by-case basis. Prohibited wastes are never allowed into a landfill.

All loads must be inspected upon arrival at the site gate or any future transfer station in the collection system, with the waste type determined so as to guide whether it will be accepted or not.

Types of Wastes

Acceptable Wastes (General)

The following general wastes are accepted in a landfill:

- Domestic solid waste, as collected by city or private vehicles on a regular basis;
- Acceptable commercial and industrial waste regularly collected by contractors;
- Garden refuse (i.e., green waste or yard waste) that may or may not be collected separately to municipal waste; and
- Inert waste (i.e., construction and demolition debris including concrete, timber, masonry, bricks, etc.).

Difficult Wastes (But Always Acceptable)

These are wastes that are accepted at a landfill but require special treatment or diversion to ensure that the best compaction or disposal is achieved. Some wastes, such as car bodies, drums, and white goods, may be better recycled depending on operational preferences. This waste class does not include hazardous or dangerous wastes, but includes the following:

- Tires,
- Mattresses,
- White goods (fridges, freezers, or stoves),
- Vehicle bodies, and
- Drums.

The practice brief on Difficult Wastes (pp. 23–24) has more details.

Special Wastes (Sometimes Acceptable)

These are other wastes that may be accepted on-site but will have to be decided on a case-by-case basis. This may include some hazardous and dangerous wastes. Later sections provide more guidance on how to manage these materials:

- Asbestos;
- Medical waste, including “sharps;”
- Dead animals;
- Pathogenic wastes;
- Dry sludge, such as treatment plant sludge;
- Low-level radioactive waste;
- Liquid waste, including paints and thinners;
- Toxic substances, such as acids and biocides (pesticides and herbicides); and
- Contaminated soil.

Check the practice brief on Special Wastes for more details (pp. 25–28).

Sorting through different types of waste, including domestic solid waste.
Photo: Lester Ledesma for ADB.

A pile of green waste in Bangkok.
Photo: Apipong Lamsam.

Prohibited Wastes

Items that are always unacceptable in a landfill include:

- Hot loads, greater than 500°C in temperature;
- Pressure cylinders (e.g., condemned gas cylinders and fire extinguishers);
- Recyclables, except to the recycling area (e.g., green waste, bulk metals, or reusable demolition waste);
- Large volumes of liquid waste;
- Radioactive waste;
- Large containers which cannot be crushed; and
- Dangerous goods, such as reactive chemicals, explosives including unexploded bombs, and so on.

Dangerous wastes can affect your health or the environment. Some wastes appear to be safe when delivered to the landfill but when tipped can react with the air, water, or other wastes to form a dangerous material. Typical dangerous goods include the following:

- Chemical wastes which can react to form dangerous gases, liquids, or solids;
- Radioactive wastes (can come from hospitals, universities, research institutes, and private companies);
- Toxic liquid wastes like oils, pesticides, solvents, paints, etc.;
- Asbestos (may be very safe if correctly packaged, but dangerous if dry and powdery); and
- Medical wastes (may be safe if autoclaved or pretreated in some other manner, but very dangerous if contacting used sharps and syringes).

There are many other dangerous goods that can be delivered to a landfill. Site staff must exercise extreme caution when dealing with these wastes.

Summary

All loads of waste entering a processing facility or a landfill must be inspected. The waste can then be categorized according to the four standard categories described.

Based on the category adopted, any special processing or handling requirements can be identified and implemented.

Finally, if prohibited loads are discovered, the waste can be directed to an appropriate facility away from the landfill or processing center. The chapter on Landfill Operations (pp. 79–102) has more details.

Difficult Wastes

Background

Difficult wastes refer to types of trash that are always allowed to be tipped at the landfill but require special treatment to ensure that the best compaction or disposal is achieved. This class does not include hazardous or dangerous wastes, or special wastes.

Types of Wastes

Tires

Tires are a major problem at landfills as they are impossible to compact and provide homes for rats. After several weeks or months, tires "float" to the top of the landfill and pierce through the cover. Tires should be collected in a special area and shredded before they are tipped.

Alternatively, the tires may be useful as scour protection around the external bund of the waste mound or used to make home composting stacks. Darwin City Council in Australia devised a tire wall cutter blade to remove side walls, allowing tires to be used (connected) for slope establishment erosion control, on foreshores, and for home compost stacks (without retaining water which promotes mosquito breeding).

Another option is to sell the tires to cement manufacturers as refuse-derived fuel for burning in the cement kiln or to turn them into fuel at pyrolysis plants.

Mattresses

Mattresses are also hard to compact and are difficult to break up. When found in loads, they should be pushed to the toe of the landfill face and covered.

White Goods

Old or disposed kitchen appliances are commonly referred to as white goods. When a refrigerator, freezer, or stove is received in a landfill, it should be degassed first before it is tipped on the

Tires and a mattress, both considered difficult wastes, disposed at a landfill. Photos: AECOM (*Top*), Author (*Bottom*).

working face. It should also be carefully crushed to ensure that it is as small as possible.

Preferably, these larger items should be stored in the recycling compound and sold to a metal recycler after degassing.

Vehicle Bodies

Car and truck bodies should be collected for sale to metal recyclers. If car parts or bodies are tipped, they must be carefully crushed. Operators must take extra care as there may be petrol left in the tank, which could catch fire. Oil and fuel should be removed before delivery to the site.

If car bodies are collected and stored on-site for later recycling, they must not be stacked more than three units high. Some countries have access to a mobile car crusher plant to process stockpiles for shipping to recyclers.

Drums

Drums of any size must not be accepted if they are sealed or if they contain any liquid. If a sealed drum is found on the tipping face, it must be removed and the site supervisor notified. They will arrange for the contents to be tested and disposed safely.

Opened drums or large containers of any sort must be crushed before being covered, but should always be recycled, if at all possible.

White goods, vehicle bodies, and drums can trap landfill gas and cause a dangerous explosion, unless well compacted. In any case, they should always preferentially be recycled.

Chemical containers should be triple-rinsed at a sealed concrete evaporation pad before disposal.

Summary

All loads of waste entering a processing facility or a landfill must be inspected. The waste can then be categorized according to the four standard categories described.

Based on the category adopted, any special processing or handling requirements can be identified and implemented.

Finally, if prohibited loads are discovered, the waste can be directed to an appropriate facility away from the landfill or processing center. More details are in the chapter on Landfill Operations (pp. 79–102).

Special Wastes

Background

Special wastes include materials that may be accepted in a landfill but require special consideration on a case-by-case basis.

The management of these wastes may be covered by local legislation and ordinances or national standards and codes as appropriate. These wastes are allowed into a landfill on a case-by-case basis. The quality of the sealed impoundment of the landfill is also an important factor in deciding what waste types might be accepted.

Highly putrescible waste should be covered immediately.

Types of Wastes

Asbestos

The area where asbestos is deposited has to be identified with the date of deposit, quantity, whether fibrous or bonded, origin, name of contractor, and accurate location (global positioning system or GPS coordinates and level above mean sea level of the top and bottom of the deposit).

Asbestos is safe provided that it is bagged or wrapped in sealed plastic of heavy gauge and not allowed to escape from the bags in a dry state. It is always safer to keep the asbestos package material wet as an added safety precaution.

Ideally, asbestos should be managed under local legislation or using suitable international standards such as the Australian Code of Practice for the Safe Removal of Asbestos.

Dead Animals and Obnoxious Wastes

Animal and obnoxious wastes, which include rotting food produce or other condemned foodstuff, should be tipped in front of the landfill face and covered immediately.

Animal and obnoxious wastes should not be placed on the base or liner of the landfill.

Nontoxic Liquid Wastes

Disposal of large quantities of any liquid wastes and soluble chemical wastes is not permitted. This may encourage the generation of excessive leachate.

It is acceptable to allow up to 5% of the total landfill waste stream to be liquid in low to moderate rainfall climates. This is because refuse usually has a moisture content of 15%–50% in dry climates and is not saturated until the moisture content reaches more than 70%. Leachate will not flow until the refuse reaches saturation.

However, even with the moderately low rainfall conditions experienced in some regions, liquid waste should not be accepted in large quantities until the landfill mound is well established and experience is derived on leachate generation rates and refuse moisture content. Limiting the liquid waste to a maximum of 5% of the refuse volume is appropriate for low toxicity waste, such as grease trap pump-outs. Preferably, grease trap wastes should be transported in tanks to a wastewater treatment plant along with septic tank pump-outs. In Hong Kong, China, for example, grease trap wastes are processed and recycled into ingredients for biodiesel. Some jurisdictions require solids such as sawdust or fine sand to be added to the liquid waste until it achieves a "spadeable" consistency before it may be deposited to a site of an engineered sealed landfill. Lesser-quality landfills do not accept any liquid wastes.

Paint and solvent wastes are considered as highly toxic.
Photo: AECOM.

Toxic Liquid Wastes

Toxic liquid wastes must be recorded for type, source, and quantity at the front end of the landfill operation. If there is any doubt about the actual content of the load, it should be emptied into a separate bulk tank for subsequent inspection and, if deemed necessary, chemical testing.

Similar to nontoxic liquid wastes, mixing with sawdust or a similar absorbent to produce a "spadeable" consistency is preferred to limit mobility.

In general, the approach for this type of special waste is to pretreat the waste prior to placing in trenches within the landfill. These trenches are cut into a purposely installed clay cell in the landfill, and these are located at the head of the landfill mound to maximize the distance to the leachate interception system.

The waste will then be covered and entombed in a dedicated trench. The trench is sealed prior to the entry of any stormwater. At least 600 millimeters (mm) of low permeability clay or clay–lime mix should be underneath and around the trench.

The size of the trenches cannot be determined until there are reliable data on liquid waste generation volumes. They should be sized to accept up to 6 months worth of production of the component waste streams. This will allow the liquid to isolate from surface scum and bottom sludge and to allow evaporation to occur.

An alternative is to store the waste for eventual export to countries which can provide higher-technology solutions. The disadvantages to accessing this higher treatment standard is cost and violation of the general aim that people who produce the waste should manage it themselves and not export their potential problem. Another issue is that the style of treatment proposed for the landfill is essentially what happens to most cities' waste in many developed countries in any case.

The following are possible waste streams and treatment methods:

Oily Wastewater

The best option is to recycle the oil from the emulsions and suspension. A recovery plant may be available in the jurisdiction. Centrifugal oil separators or a triple interceptor trap might be best used to pretreat the emulsion or mixed oil and water to allow evaporation of most of the liquid. The bilge water incinerators at ports are a better disposal route if available.

These wastewaters generally have a high biochemical oxygen demand, high salinity, a waste oil or oil emulsion fraction, and potential contaminants such as radiator antirust fluids and heavy metals. These wastes usually come from petrol stations. Because of the potential toxicity, the volume should be limited to 1% of the refuse volume (compared with the general nontoxic liquid waste such as grease trap wastes that can be up to 5% of the waste stream).

Phenolic and Emulsified or Concentrated Oil Waste

This includes wastewaters contaminated with degreasers and decarbonizers, emulsified oils such as machine and cutting

Solvent containers and highly volatile liquid waste.

oils, and other products from the metal fabrication industry and tanker washouts. Where possible, the phenolics should be oxidized using potassium permanganate. The treatment and disposal method is the same as for oily wastes.

Acid, Alkali, and Metal Wastes

These wastes are derived from metal plating works, metal finishers, and the paint manufacturing industry.

Wastes should be neutralized where possible by blending acidic and alkaline wastes. This may require the construction of holding lagoons for the various waste stream components.

The blended product is then treated in the same way as the oily waste by chemical fixation using cement products. The disposal method is also the same, involving landfilling the solidified waste capsules and, where possible, evaporating the remaining liquid waste fraction.

If evaporation is unsuccessful, the liquid can be added to the landfill mound provided that the 1% rule is observed.

Paint, Pesticide, and Solvent Wastes

These include all pesticide, fungicide, and herbicide wastes, plus solvents such as methyl ethyl ketone derivatives. Sources include manufacturing processes for the nominated waste types, laboratories, and other heavy industries.

This type of waste is generally regarded as the most toxic waste stream and requires fixation with cement material.

Because organics do not fix strongly into the cement matrix (unlike metals, which are strongly fixed and become effectively immobile), the resulting cement capsules should be placed in a dedicated disposal trench as monofill. The trench into clay should then be sealed prior to the entry of any stormwater. And as previously described, at least 600 mm of low permeability clay or clay–lime mix should be underneath and around the trench or an artificial liner as part of the main cell.

The trench should be constructed within the landfill cell, and should be located at head of the landfill mound to maximize the distance to groundwater. Where poorer soils are present and good clay of permeability of 10-9 meters per second cannot be sourced, then a 1.5 mm high-density polyethylene sheet should be used beneath the local cohesive soil fill and in covering the trench before backfill. Some acids and strong alkalis should be checked against the chemical resistance of the plastic liner chosen. Lacquer thinner is highly combustible and should be disposed in an appropriately designed evaporation pan.

Pathogenic and Medical Wastes

These wastes typically do not make up a large fraction of the overall waste volume from medical facilities; nonetheless, these are dangerous.

Various local medical facilities, such a hospitals and medical clinics, have inadequate facilities to correctly handle all their special waste. This has been confirmed by medical wastes appearing in waste dumps in some communities.

The best solution is to require medical waste incinerators at such institutions. They should be away from the public, and ash residual should be safely disposed together with the refuse. The general requirements for an incinerator are that the temperature should be over 1,200°C and have a residence time of 2 seconds.

However, because of local cost constraints, a dedicated disposal area at some sites for medical and other special wastes may have to suffice. This is preferred over requiring individual medical facilities to bury their own waste within their compounds as these burial pits will not have the leachate control systems provided at an engineered landfill.

An alternative is autoclaving the hospital waste either at source or centrally at the solid waste management site.

The only residual concern is that the collection and handling of the medical waste must be dedicated and safe, and mediwaste is not comingled with other domestic or commercial waste. The main issue of concern is sharps, such as needles, scalpels, etc.

A double-lined waste containment with bentonite geocomposite overlain by clay should be set aside for medical waste and backfilled around containers with lime until full, whereupon it is covered with plastic or a geosynthetic clay liner and 600 mm of clay—and another site constructed. The location (GPS coordinates and level at the base and top) should be recorded and kept at the landfill and the municipal office.

Batteries

Lead acid batteries are recyclable and should not be allowed into the landfill.

If the local recycling market fails, then batteries should be drained of the acid prior to placing in the mound. However, this is a waste of the lead contained in the plates and should only be used as a last resort.

Local recycling of lead acid batteries can cause injury and death and should not be attempted. Placing batteries complete with acid on pallets and shrink-wrapping is all that is required to ship them to specialist recyclers (e.g., in the Republic of Korea) and other similar outfits for a very attractive price. Shipments from Australia and other countries are regularly dispatched and, thus, additional cargo like these batteries may be negotiated and sent in order to be safely recycled.

Dry cell batteries should be accepted without any special precautions being required, unless the quantities become significant.

Summary

All loads of waste entering a processing facility or a landfill must be inspected. The waste can then be categorized according to the standard categories described.

Based on the security of the landfill liner system concerned and the category adopted, any special processing or handling requirements should be identified and implemented.

Finally, if prohibited loads are discovered, the waste can be directed to an appropriate facility away from the landfill or processing center. More details are in the chapter on Landfill Operations (pp. 79–102).

Waste Containers and Collection

Issue

In developing countries, the cost of waste collection services is typically far greater than the cost of processing and disposal. Furthermore, the collection service has direct contact with the households and community. It should, therefore, have a standard that reflects the municipality's commitment to solid waste management.

In terms of haulage systems, identifying goals, objectives, and constraints can help guide the planning process. Issues that should be considered include the following:

- **Level of service:** What level of services is required to meet the community's needs?
- **Roles of the public and private sectors:** Is there a policy preference regarding the roles of the public and private sectors in providing collection services for wastes and recyclables?
- **Waste reduction goals:** What are the community's waste reduction goals and what strategies are necessary or helpful in achieving those goals?
- **System funding:** What preferences or constraints are attached to available funding mechanisms?
- **Labor contracts:** Are there any conditions in existing contracts that would affect the types of collection equipment or operations that can be considered for use?

Segregation placards posted on the waste collection fleet in Quezon City, Philippines.

Interventions

To decide what containers are required, waste segregation and collection must be addressed in parallel. If the goal is to sustainably segregate the waste, then some downstream benefit must be realized and supported by the community. Segregation takes time and costs money for the household due to additional bags or bins required. Many schemes have failed because the community does not see any benefit in waste segregation. In some cases, even the following incidents are usually sighted or experienced:

- Segregated waste is remixed in the haulage truck or at the landfill;
- No decrease in waste management charges or taxes, although this may be expected as a result of waste being recovered because of segregation efforts; and
- No environmental improvement with demonstrably less litter, or uncollected waste still apparent in the community.

Waste segregation should only be required if the municipality is fully committed to the requisite costs, education, and waste-handling requirements, and if it can demonstrate some net benefit overall.

Door-to-door Collection and Community Bins

There are two approaches to the collection of waste from residences and commercial producers. This primary waste collection process depends on either door-to-door collection or community bins are proposed. The former is usually about twice the cost of community bins.

Variety of bin types available.

Moreover, for door-to-door collection, there are many options ranging from plastic bags to hard containers. Hard containers are generally better (albeit more expensive) as they minimize odor emissions and spillages, as well as prevent animals from accessing and spreading the waste.

For community-based collection, a container-based approach is adopted. Dumping waste directly onto the footpath, road, or vacant lots is considered inappropriate. The actual size, mix, and location of the community bins are determined after a detailed public consultation campaign is conducted. Collecting hard green waste may be an exception in this intervention, but ultimately this should also be in receptacles or bunkers for processing.

Pushcarts

For areas that are very difficult to access, additional pushcarts may be purchased.

Modern pushcart.

Modern pushcarts can have up to 600 liters of capacity and are fitted with a tipping mechanism to facilitate easy emptying into hook-lift bins.

Alternatively, compactor trucks can be fitted with lifting arms to lift the pushcarts directly into the compactor and so the primary dumping location can be avoided for these areas. These carts can also be rigidly attached to a motorcycle.

Three-Wheeler Vehicles

In most cities, there are usually a number of streets and alleyways that are too narrow and uneven to allow access even by small compactor trucks.

Three-wheeler tipping vehicle.

A number of three-wheeled vehicles, or equivalent, capable of carrying 200 kilograms (kg) or more of waste can be utilized for such situations. These vehicles can collect waste door to door from households and carry the full load to hook-lift or skip bins acting as a limited number of secondary dumping areas.

Skip Bins

Skip bins can be used for community-based collection systems. These have the advantage of optional wheels so the bins can be moved more easily to the truck for emptying, unlike hook-lift bins.

Skip bin with lid.

The main advantage compared with hook-lift bins is that the waste is compacted prior to hauling. Its main disadvantage is that they must be limited in size, only about 4 or 5 cubic meters because of bin weight-lifting limits.

It is common to have multiple bins in one location if a lot of waste is generated locally.

Front lift compactor trucks are fitted with lifting arms to empty the skip bins into the compactor truck.

Rear lift compactor trucks can lift up to 1,100-liter skips on wheels. These can be narrow in size and placed on slabs over drains at the roadside so as to not impede traffic in constricted areas.

Depending upon the street sizes and other access constraints, it is usually necessary not only to have a range of compactor truck sizes to facilitate access to the narrower streets, but also to provide large compactors to maximize overall collection efficiency in the wider and more easily accessible roads. Single rear axle rear lifter compactor vehicles (approximately 8 cubic meters) are less wearing of poorer-quality gravel streets and more maneuverable than their larger counterparts.

Hook-lift Bins

Hook-lift bins can vary between a minimum of 5 cubic meters and 30 cubic meters. These can be low side bins equipped with rear-entry doors to allow walk-in and drive-in access to the bin. Experience confirms that unless these bins have easy access, people will merely dump the waste by the side.

Hook-lift bins can be located next to access steps at the roadside to allow access using smaller hatches in the lids. This will help youngsters to safely dispose small bags of domestic waste.

This type of waste collection bins also has its disadvantages. First, the bins are usually hauled away based on a standard collection schedule, regardless of whether the bins are partially or completely full. Second, the haulage process does not provide any compaction, making the overall haulage efficiency low. Third, the bins are often uncovered, letting the rain enter into the bins forming leachate; or, in dry weather the wind can blow out plastics and paper, resulting in excessive litter.

Tip Trucks

In addition to compactor trucks or hook-lift vehicles, it is usually necessary to have at least one tip truck for general collections and local cleanups.

Transfer Stations

If the haulage distance from the center of the city to the processing or disposal site is more than 20 kilometers one way, then installing a transfer station should be considered. Such stations can vary from being very simple installations where a large articulated tipping vehicle accepts waste from local body trucks to facilities where waste can be placed into a series of bins or tubes for haulage to the processing or disposal site.

Compactor truck lifting a skip bin.

Small tipping truck.

Planning the waste containers and collection fleet must be done in concert with any decisions on waste segregation

If the municipality considers private scavenging as an important benefit to waste minimization and for livelihoods, then an open pit transfer station is the better choice. This can accommodate small vehicles, as well as residents who self-haul waste with open trucks and trailers.

The waste in a transfer station is deposited into a shallow concrete pit, which is routinely track-rolled by a light bulldozer before pushing waste to the end where a chute drops it into transfer trailers to haul to a landfill. The track rolling and fall into the truck body allows reasonable compaction (about 400 kg per cubic meter) and the trailer top closes to prevent loss of load in transit. Such a form of station could segregate waste at the gatehouse as well as allow scavenging of tipped waste by locals before compaction and final transfer. This may retain advantages in some communities when compactor trucks collect curbside.

A full economic analysis is required to review and/or confirm the desirability of providing a transfer station in each municipality.

Summary

Planning the waste containers and collection fleet must be done in concert with any decisions on waste segregation.

Door-to-door collection is typically the preferred model, but it is usually at least twice as expensive as utilizing community bins.

A wide range of household bins and community bin types are available. For household door-to-door collections, hard bins are preferred as these minimize litter and waste spreading by animals.

For community-based bin collections, skip bins are more efficient than hook-lift bins. Planning for any new waste collection system should not include direct dumping on footpaths or roads for subsequent loading into haulage vehicles. If a nearby transfer station is used, the cost differential decreases.

A range of vehicle sizes is usually required to allow access to the narrower streets, but also to maximize the overall collection efficiency.[1]

1 ADB. 2016. *Integrated Solid Waste Management Plan: Buriram.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161031/integrated-solid-waste-management-plan-buriram; ADB. 2016. *Integrated Solid Waste Management Plan: Mahasarakham.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161031/integrated-solid-waste-management-plan-mahasarakham; ADB. 2016. *Integrated Solid Waste Management Plan: Mandalay City.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161130/integrated-solid-waste-management-plan-mandalay; ADB. 2016. *Integrated Solid Waste Management Plan: Quezon City.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20160930/integrated-solid-waste-management-plan-quezon-city; AECOM and ADB. 2016. *Integrated Solid Waste Management Plan: Sorsogon City.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20160930/integrated-solid-waste-management-plan-sorsogon

Recycling

Issue

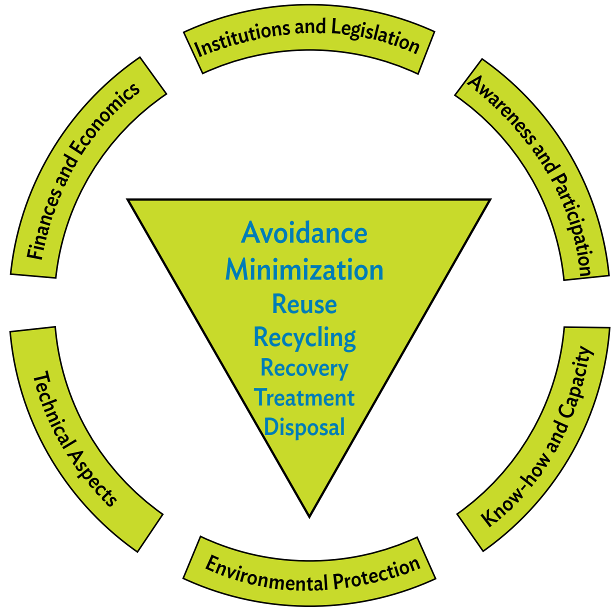
Recycling is a form of resource recovery that allows materials recovered to be used in a form similar to its original purpose, such as recycling paper for use again as paper or cardboard (Figure 5).

Local governments should advocate recycling as it diverts a considerable amount of useful materials present in the waste stream from being disposed of in landfills while at the same time providing livelihoods.

In terms of the local effort required, they must likewise ensure that they are complying with the requirements specified in legislation, such as achieving a certain percentage of recycling.

Recycling, however, cannot be the global solution to waste management, since there will always be some residuals. Recyclables have to be market driven to be sustainable.

Figure 5: Waste Management Hierarchy



Source: Author.

Waste pickers or scavengers.

Background

Recycling programs are always constrained by the makeup of the waste being processed. Generally, most of the higher-value recyclables, such as metals, glass, and paper, are already removed to a significant degree by domestic reuse, scavengers, and agents.

In poorer countries, most building materials and timber are removed by households for fuel. The two remaining categories of most interest are the organics, consisting of food scraps as well as green waste, and plastics consisting of plastic bags, containers, and beverage bottles.

Table 2 presents the aggregated results of many audits of waste entering landfills and demonstrates the likely makeup of the typical municipal waste stream, in terms of percentage of total waste stream mass:

Table 2: Typical Composition of Landfill Waste by Type and Amount

Waste Type	Country					
	Afghanistan	Cambodia	Pakistan	Philippines	Timor-Leste	Viet Nam
Food waste	13%–22%	19%–23%	10%–15%	9%–19%	12%	15%–35%
Green waste	10%–21%	31%–40%	20%–25%	40%–54%	33%	15%–38%
Paper and cardboard	1%–8%	2%–6%	4%–8%	4%–8%	22%	3%–8%
Plastic	11%–15%	3%–15%	15%–18%	15%–17%	18%	9%–16%
Textiles	–	1%–4%	1%– 4%	1%–3%	2%	0.1%–0.9%
Glass	2%–3%	1%–8%	1%–3%	1%–3%	2%	0.4%–5.0%
Metal	0.02%–0.95%	0.6%–8%	1%–5%	2%–3%	1%	0.3%–1.5%
Wood		–	0.5%–2%	0%–2%	0%	0.5%–3%
Soil and dirt	5%–11%	10%–30%	15%–25%	10%–15%	28%	10%–15%
Miscellaneous	4%–12%	2%–8%	2%–10%	7%–14%	2%–10%	2%–12%

- = no data.

Note: As different countries have different waste classification systems, figures in the table do not necessarily add up to 100%.

Source: Author.

Interventions

Composting

Composting is described in detail in a separate practice brief. However, for green waste (which accounts for up to half of the total waste stream in wet climates), the common approach to recycling is to separate it and then chip it. These green waste chips can be used for composting when mixed with high-nutrient sludge, such as from a sewage treatment plant. They can also be used on parks and gardens or given to the local community. In most cases, introducing a recycling or diversion program for green waste has the largest possible impact on the quantum of waste being recycled.

Aerobic composting (using abundant oxygenation) can be achieved in small- to large-scale facilities and is relatively quick to process. Nuisances and odors are also relatively reduced.

Anaerobic composting (in the absence of oxygen), on the other hand, takes far longer and produces objectionable odors, contaminating leachate and releases methane (a high strength greenhouse gas and flammable gas) into the atmosphere. Most domestic composting becomes anaerobic if the compost pile is not frequently mixed.

In some cultures, it is not usual to have a yard with soil or compost piles–like in Tonga, because of centipede prevalence and in Timor-Leste, where a bare swept house surrounding is considered good housekeeping. Solutions must match social and customary practices to succeed. Centralized composting facilities can overcome such constraints by supplying compost to local government, farmers, and landscapers, provided that external funding is available and ongoing and that product quality consistently meets requirements.

Introducing a recycling or diversion program for green waste has the largest possible impact on the quantum of waste being recycled

Lead-Acid Battery Recycling

There are also specialist roles in recycling, such as for automotive lead-acid battery recycling. Unskilled operations to recover lead usually result in gross pollution and disabling illness. The dispatch of whole batteries shrink-wrapped on pallets to recyclers in the Republic of Korea is simple and profitable. There are established agents shipping the batteries to the Republic of Korea from other countries, which might easily pick up additional loads from Asian countries en route.

Plastic Bag Recycling and Processing

There is very little opportunity for recycling plastic bags apart from burning as a fuel source or bringing in shredding equipment and molds to make plastic items such as posts, decking, chairs, and seats. However, given that most plastic bags are soiled in terms of either inorganic soil or organic material attachment, the overall environmental cost associated with having to clean and dry these bags, not to mention the higher labor content, would make such a scheme generally unattractive at the present time. There are some exceptions in Viet Nam and Thailand, but generally recycling of plastic bags is not economic.

Chipped plastic bottles.

High technology waste recovery with segregated waste.

The plastic bags can be used as a fuel source in refuse-derived fuels or waste-to-energy facilities and hospital incinerators or laundries, cement kilns, and charcoal production where partial processing is sometimes required.[1]

Beverage containers can be recycled and are often chipped or crushed to increase their density, thereby making transport more efficient.

Polyethylene containers and bottles and polyethylene terephthalate "rocket bottom" bottles may be reprocessed into outdoor furniture, roadside markers, and rot-proof planks for waterside uses, and they burn cleanly (as do the polyethylene shopping bags) with a fuel value equal to diesel or natural gas. In some locations, free plastic chair molds are provided by beverage manufacturers for nongovernment organization to reuse their scrap bottles to make extruded plastic products.

Recycling Mechanization

There are three stages of development for centralized recycling. The most appropriate stage typically depends on community wealth, which impacts the waste characteristics and the level of segregation.

The first stage is fully manual (scavengers). It is possible to improve conditions with personal protective equipment, weather covers, forming collectives to get better prices, and so on. Larger municipalities with significant distances to the landfill may profitably operate a transfer station, allowing segregation at the gatehouse, plus potentially scavenging in a large open concrete pit before dozer track roll compacting and pushing into transfer trailers parked below the pit chute to cart to disposal. This retains the advantages of scavenger sorting in a safer and more controlled environment.

The second stage is partially mechanical with selected mixed waste such as for refuse-derived fuels or composting.

The final stage is mechanically separating and packaging segregated waste. These fully mechanized recycling facilities or materials recovery facilities will only work sustainably on fully segregated waste.

Role of Municipalities

It is important for the municipality to take a supporting role rather than the leading role in recycling programs. There are many cases of market distortion when the municipalities establish their own facilities in direct competition with private sector recyclers. Almost always, the municipality reduces its direct involvement in running materials recovery facilities over the long term, meaning that the suppressed private sector then has to return to the recycling sector.

A suitable potential role for the municipality is to provide the equipment such as mobile chippers or the land area for stockpiling of recyclables prior to baling and sale. They should leave the primary role of recycling with the private sector (or may lease the sites). The other potential key role of the municipality is implementing an information, education, and communication campaign to encourage community awareness on the need for recycling which would then support the private sector endeavors. The only need for intervention is if scavengers are paid an unfairly low price by agents.

[1] ADB. 2015. *Preparing the Urban Services Improvement Sector Project: Final Report.* Consultant's report. Manila (TA 8750). http://k-learn.adb.org/materials/20151201/ta-8750-tim-preparing-urban-services-improvement-sector-projectfinal-report

Summary

Recycling programs must reflect the local environment in terms of domestic diversion or scavenging, local major recycling markets and haulage distances involved, as well as the local makeup of the waste stream. The best recycling programs are those developed to suit local conditions.

Most high-value materials and useful reusable containers (domestic reuse) are usually recovered prior to the waste entering the landfill.

As disposable income increases, diversion domestically decreases. In a typical waste stream, the remaining focus for recycling is typically on plastics and organics, in particular green waste.[2]

Mobile chippers for green waste.

[2] ADB. 2016. *Integrated Solid Waste Management Plan: Buriram.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161031/integrated-solid-waste-management-plan-buriram; ADB. 2016. *Integrated Solid Waste Management Plan: Mahasarakham.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161031/integrated-solid-waste-management-plan-mahasarakham; ADB. 2016. *Integrated Solid Waste Management Plan: Mandalay City.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161130/integrated-solid-waste-management-plan-mandalay; ADB. 2016. *Integrated Solid Waste Management Plan: Quezon City.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20160930/integrated-solid-waste-management-plan-quezon-city; ADB. 2016. *Integrated Solid Waste Management Plan: Sorsogon City.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20160930/integrated-solid-waste-management-plan-sorsogon

Composting

Issue

Composting is the biological process in which organic matter is broken down into simpler compounds by the action of microorganisms. Compost is the product of decomposition of organic matter.

Organic waste can be composted aerobically (in the presence of oxygen and the desirable approach for most compost schemes) or anaerobically (in the absence of oxygen). Anaerobic compost can be highly odorous and is what effectively occurs in stable landfills.

It is a suitable soil conditioner, as differentiated from a fertilizer. Composting is often promoted as a suitable scheme for managing organic wastes, such as food scraps and green waste, which often represent half the total waste stream. However, composting has not been consistently successful in many developing and even developed countries, especially where food scraps are delivered to a centralized facility.

There has been renewed interest in composting lately. However, the focus is more on composting chipped green waste, rather than food and vegetable scraps.

Closed container fermentation for liquid fertilizer has been a recent trend for segregated food waste or commercial food processing waste in a number of developed countries.

Interventions

Not all organics can be composted: no meat, oils, fish, dairy products, and bones should be composted as they can attract flies and vermin, can have a very high oxygen demand to decompose, and are odorous.

For a compost scheme of any size, two items must be right for successful composting:

- Correct moisture content (40%–60%) and
- Correct carbon (old grass clippings, leaves, paper, etc.) to nitrogen (food scraps, green grass, manure, etc.) balance .

Composting can be done at three levels:

- Domestic or household scale;
- Neighborhood; and
- Centralized scheme.

Household composting

Domestic or household composting schemes are common throughout the world and are often done in conjunction with feeding scraps that cannot be used for domestic animals like chickens or dogs.

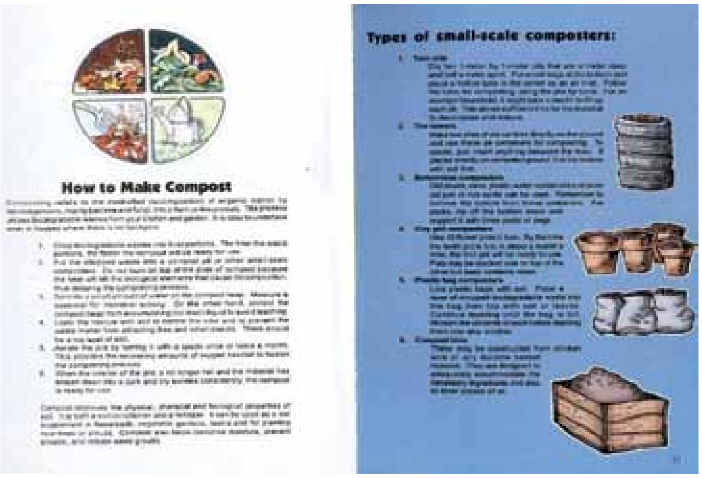
There are many types of home composting bins such as old tires stacked up, timber slats, open weave plastic bags, and slotted plastic bins (specially made).[3]

Domestic or home composting has an established operator and user and no legal liability issues unlike centralized systems. Obviously, this approach encourages waste segregation at source.

Home composting reduces potential odor problems later in the collection, haulage, and disposal stages. It also helps municipalities minimize initial and operating costs. However, composting does have the following issues:

- It requires educating households.
- It will not work with only small land allotments.

[3] United States Environmental Protection Agency. 1996. *The Consumer's Handbook for Reducing Solid Waste.* http://k-learn.adb.org/materials/20170228/consumers-handbook-reducing-solid-waste



Typical home composting guide.

Low-technology neighborhood composting system.

- It may require initial investment by the municipality where households will not or cannot fund the small start-up expenses required.
- Not all organic wastes can be composted.
- Rotating suspended bins have the best chance of aerobic composting in the home.
- Unless carefully operated, compost will become anaerobic (lacking oxygen) and emit methane and leachate, which in aggregate (for many households) can be detrimental to the environment. Many municipalities in developed countries and elsewhere provide plastic cylindrical bins and ignore these negatives in order to avoid the disposal costs.
- Stacked tires should have the sidewalls largely removed so as to avoid insect and stagnant water being a mosquito microbreeding site and should be suspended above ground level on a frame to admit airflow for ventilation of the composting pile.

Neighborhood Composting

If household compounds are too small, or control of associated insect or rodent pests needs a more structured processing area, neighborhood-scale systems are the next option. This involves collecting compostable material from households and taking it to a neighborhood scheme. The neighborhood will have to develop and market the system, noting that the issues are much the same as centralized schemes. The municipality may ideally provide a mobile chipper upon demand several times a year, preferably for no charge.

Many neighborhood schemes have failed, however, due to odor, poor compost quality, lack of compost demand and sales, and poor levels of segregation at the household.

Central Compost Facility

The last option is a large central compost facility, but organics must first be segregated from nonbiodegradable wastes. At-source (household) segregation is preferred but very unlikely to be 100% effective. Therefore, mechanical segregation using costly equipment (costly to buy and run) is required. A basic set of equipment for a small neighborhood scheme will cost in excess of $100,000, excluding loaders and buildings. Even if this mechanized segregation is efficient, it often still allows contamination of the compost feed with glass, sharps, metals, meat, fish, etc. For example, a single small battery can cause a large quantity of compost to exceed the very stringent heavy metal level standards for food production.

The main sustainability issue is usually the overall operating budget. A sustainable market must be found for the compost generated, and experience suggests this is often difficult as long-term demand is low. Farmers are unwilling to pay a sustainable price as they need to still apply artificial fertilizers to obtain the right nutrient content for crops. Compost alone will not achieve these nutrient levels. The best crop productivity outcome is a blend of fertilizers and compost, but this has to be economically attractive to the farmers and in most cases will require agricultural extension services and ongoing financial interventions.

The only sustainable centralized composting schemes are those which are either fully funded by private operators in carefully selected markets with secure segregated feedstock or external donors supporting operations on an ongoing basis or large public–private partnership (PPP) schemes where product quality is not critical as the PPP partners are using the compost on trees or other less sensitive crops.

An economic analysis taking into consideration the value of landfill airspace saved as a result of composting could be undertaken if considering such a composting scheme.

Green Waste

Green waste is garden waste, lawn clippings, and tree trimmings. It often makes up a much larger fraction of the total organic waste stream than food scraps and is suitable for composting.

Small-scale centralized composting system.

Portable green waste chipper.

Separate collection of green waste is common and it is usually chipped and used for

- compost (mixed with high-nutrient sludge) or trace elements and fertilizer;
- garden mulch;
- protection of initial placement over engineered linings, daily cover of active subcells, and establishing vegetative cover on final soil batters at landfills; or
- coarser woody material to improve road access in wet weather.

Both neighborhood and central composting schemes utilizing food scraps commonly fail unless there is a local sustainable demand for compost

Summary

Organic wastes such as food scraps or green waste can be composted. For food scraps, generally household-based composting or in-vessel processing for liquid fertilizer are the best approaches.

Both neighborhood and central composting schemes utilizing food scraps commonly fail unless there is a local sustainable demand for compost and the market is willing to pay a sufficient price to make the compost operation economic. Numerous neighborhood or centralized composting schemes utilizing food scraps have failed because of the lack of a suitable compost market in the long term. Even if the economics can be made to work, there is a history of ongoing contamination from centralized composting schemes that reduces buyers' interest in the product.

In many of the wetter climates, green waste is the dominant fraction of the total organic waste stream, compared with food scraps. Provided that green waste can be separated at source, it can then be chipped and composted or just mulched. Successful green waste composting schemes are usually coestablished with a sewage treatment plant where dried sewage sludge is mixed with the green waste to provide the correct nutrient balance in the compost.[4]

[4] ADB. 2016. *Integrated Solid Waste Management Plan: Quezon City.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20160930/integrated-solid-waste-management-plan-quezon-city; ADB. 2016. *Integrated Solid Waste Management Plan: Mandalay City.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161130/integrated-solid-waste-management-plan-mandalay; ADB. 2011. *Toward Sustainable Municipal Organic Waste Management in South Asia: A Guidebook for Policy Makers and Practitioners.* http://k-learn.adb.org/materials/20151201/ta-8750-tim-preparingurban-services-improvement-sector-project-final-report

Waste-to-Energy Emissions Management

Issue

Incineration is one of the waste treatment and waste-to-energy (WtE) technologies proposed in the Integrated Solid Waste Management Plan for Quezon City in the Philippines.[5] However, emissions from waste incineration have attracted significant public and civil society concerns.

Flue gas is the exhaust gas generated from the combustion process, which may contain pollutants like particulate matter, heavy metals, acidic gases, and dioxin. Dioxin has raised the most concern from the public due to its high toxicity. Therefore, extensive effort is required to minimize its emission.

For the case of the Philippines, one of the major hurdles in developing WtE plants is the Clean Air Act (RA 8749). It bans burning activities that emits poisonous and toxic fumes, and has set up stringent emission standards. Flue gas cleaning measures have to be implemented in order to meet the RA 8749 requirements.

International guidelines, such as the Environmental, Health, and Safety Guidelines produced by the International Finance Corporation and the Integrated Pollution Prevention and Control document produced by the European Commission, have suggested good international industry practices or best available techniques for flue gas cleaning. The international guidelines also state emission standards to regulate the pollutant emission in flue gases.

Interventions

The following provides background on emissions management options. Some major processes and industrial common practices for flue gas treatment are also included.

Acid Gas Removal

Acid gases (e.g., hydrochloric acid and sulfur dioxide) can be removed by adding alkaline materials. The abatement process can be categorized into dry, semidry, and wet sorption systems. Particulates in wet sorption systems are first wetted by contact with liquid droplets (e.g., water, lime slurry, and caustic soda solution) and are then impinged onto a collecting surface. Due to the better reaction conditions in the wet state, the chemical demand is usually lower than those of the dry and semidry processes, whereas in the dry or semidry type systems dry chemicals (usually lime or caustic soda) are introduced into reaction towers. The gaseous pollutants are removed by adsorption and chemical reactions. Chemicals and reaction products are then removed by a particle separation system. In semidry systems, slurry is introduced into a spray dryer.

Acid gas removal is a closed process with little potential for chemical exposure during normal operations. However, corrosion or oxidation of improperly maintained or operated plants may increase the risk of chemical exposure or fire within a facility.

Heavy Metals and Dioxin Removal

The minimization of dioxin requires a collective approach. As the temperature range favoring dioxin formation is 250°C–400°C, incineration processes should avoid this temperature range by having good burnout processes and rapid cooling of postcombustion gases. Therefore, the municipal solid wasted injected into the combustion chamber should maintain a flue gas temperature of 850°C and residence time of at least 2 seconds to achieve complete combustion and avoid formation of dioxins. For heavy metals, most are converted into nonvolatile oxides which are deposited with

[5] ADB. 2016. *Integrated Solid Waste Management Plan: Quezon City.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20160930/integrated-solid-waste-management-plan-quezon-city

fly ash. Using activated carbon and bag filters can further reduce heavy metal and dioxin contents in the flue gas.

Particulates Removal

Cyclones and bag filters are two common interventions for particulates removal. Cyclones separate particulates from the flue gas stream using centrifugal forces. A bag filter is an effective technology with a long track record. It is capable of maintaining mass collection efficiencies in excess of 99% down to a particle size of 0.1 micrometer, thus achieving low dust emissions.

Nitrogen Oxide Removal

Selective noncatalytic reduction and selective catalytic reduction are common practices in the removal of nitrogen oxides. Ammonia or urea are used as reducing agents and are injected into furnaces at high temperatures to remove nitrogen oxide in hot flue gas. For selective catalytic reduction, it involves the addition of ammonia at lower temperatures but in the presence of a catalyst. The flue will pass through a mesh of catalysts to increase the rate of reaction.

To ensure that emissions meet the requirements of international standards such as the Environmental, Health, and Safety Guidelines, they should be monitored by a continuous emissions monitoring system. The following are appropriate requirements:

- Sulfur oxides, nitrogen oxides, carbon dioxide, oxygen, and hydrogen chloride are measured at chimney and induced draft fan outlets.
- Sulfur oxides, nitrogen oxides, and carbon dioxide are measured using the infrared principle.
- Oxygen is measured using zirconia cells.
- Hydrogen chloride is measured using the gas filter correlation infrared-based principle.
- The gas temperature and the pressure are also analyzed continuously to regulate the dosing of sorbents.

Summary

To address ongoing public concerns with WtE facilities, managing emissions is paramount. Local governments considering a WtE incinerator should apply various emission control interventions as suggested by international guidelines to meet stringent standards.

The public likewise needs to be advised that emissions can be minimized if the WtE facilities are well managed.

Waste Pretreatment Required for Waste-to-Energy Incinerators

Background

The primary goal of municipal solid waste (MSW) incineration is to reduce volume and mass and make the waste chemically inert in a nonpolluting combustion process without the need of additional fuel. This process also enables recovery of energy, minerals, and metals from the waste stream.

By using appropriate waste preparation and combustion conditions, an efficient combustion process can be reached, thus achieving the primary goals.

Waste Preparation Process

A key parameter in MSW combustion is the energy content or the lower calorific value or lower heating value in megajoules per kilogram. To ensure autothermic combustion of the waste, the lower heating value should not be below 7 megajoules per kilogram on average over a year.

In developing countries, the lower heating value of unsorted MSW often is below this threshold due to a dominant organic content with high moisture. Also, a significant level of inert waste fractions, such as ash or sand, could reduce the lower calorific value of MSW.

Therefore, despite the pretreatment process not being necessary for moving grate incinerators, sorting the waste can increase the efficiency of combustion or reduce air pollutant emissions. Fluidized bed incinerators are an example of incinerators that require pretreatment to improve the combustion efficiency. Tables 3 and 4 show different types of waste sorting technologies and the impacts of removing certain MSW fractions to the incineration process.

After being weighed by the weighbridges and throughout pretreatment (if any) at the incineration plant, the MSW will then be unloaded to the waste storage bunker at the

Table 3: Different Types of Waste Sorting Technologies

Technologies	Description
Size separation	Involves separation of mixture of materials into portions by means of one or more screening surfaces, which are used as go or no-go gauges. Typical equipment include vibrating, trommel, and disc screens.
Density and/or mass separation	Separates materials based on their densities and aerodynamic characteristics. It has been applied to municipal solid waste on two major components: (i) the light fraction, composed primarily of paper, plastics, and organics; and (ii) the heavy fraction, which contains metals, wood, and other relatively dense inorganic materials. A typical example is light or heavy pneumatic separators.
Magnetic and electrostatic separation	Sorts out wastes based on their electrostatic charge and magnetic permeability of materials. In particular, magnetic separation is used to separate ferrous and nonferrous materials, while electrostatic separation can be utilized to separate plastics from paper, based on the differing surface charge characteristics of the two materials.
Optical sorting	Recyclables, especially plastics, are separated into the appropriate type of recyclables by using optical sensors.

Source: Author.

Table 4: Impacts of Removing Certain Municipal Solid Waste Fractions on the Incineration Process

Fraction Removed	Prime Impacts on Remaining Waste
Glass, metals, ash, and minerals from construction and demolition waste	Increased calorific value Decreased quantity of slag and recoverable metals
Paper, cardboard and plastic	Decreased calorific value Decreased chlorine loads (e.g., from polyvinyl chloride) in emissions
Organic waste from kitchen and garden	Decreased moisture loads Increased calorific value
Bulky wastes	Reduced effort for shredding waste
Hazardous waste (e.g., batteries and electronics)	Reduced effort to remove toxic volatile heavy metals from air emissions (e.g., mercury) Reduced concentration of toxic pollutants in slag and fly ash (e.g., cadmium, lead, and zinc)

Source: Author.

unloading platform. As mentioned earlier, since the MSW of most developing countries has a high organic content and high moisture content, the temperature of the combustion chamber could be lowered as a result and could degrade the combustion performance. Hence, the MSW received at the incineration plant should, in most cases, be kept in the waste bunker for about 3–7 days to drain away some of the leachate and excess moisture. As such, the bunker should be designed with sufficient capacity to at least store a few days of MSW. It should also be covered, protecting against additional moisture entering due to rain.

Summary

MSW in developing countries has a relatively high organic content and can have a high moisture content.

Preconditioning and operational amendments can still allow MSW to be incinerated and generate electricity successfully.

Refuse-Derived Fuels

Issue

There is significant community interest in reducing the quantity of municipal solid waste (MSW) going to disposal. One method of doing this is to process the MSW into cofired fuel for the use of industrial processes, such as refuse-derived fuels (RDF) for cement kilns.

However, there are a number of mitigating factors against the widespread adoption of processing waste into RDF and the option needs to be carefully examined before committing to this strategy.

Intervention

Compared with "as-received MSW," RDF is usually of higher calorific value (due to its increased content of paper, plastics, and stabilized organic waste), enabling higher efficiency of the waste-to-energy process. It is also easier for handling, storage, and transportation.

Due to its very high operating temperature (about 1,450°C) and energy-intensive nature, modern cement kilns can use RDF as cofired fuel without any modified processing system. Older kilns require extensive modification, however, to be configured to accept RDF. The fuels that are suitable for cement kilns should have at least 18.8 megajoules per kilogram of calorific value, lower than 30% of moisture content, and less than 1% of chloride and sulfur.

On the other hand, there are some key challenges in using RDF in cement kilns, including variation of input MSW characteristics, possibly high transportation cost, need for sophisticated sorting and control technology, seasonal limitations, and large storage requirements. For example, chlorine can weaken cement and increase the risk of corrosion of steel bars in reinforced concrete structures. MSW streams with a high proportion of polyvinyl chloride (a plastic with high chlorine content) could affect the quality of the cement produced.

Also, cement kilns using RDF as cofired fuel should be capable of mitigating air emission impacts. This is because chlorine in feedstock could potentially lead to the formation of acidic gases (e.g., hydrogen chloride and hydrogen fluoride) and dioxins.

Furthermore, many cement companies are implementing increasingly stringent specifications for acceptance of RDF as supplementary fuels. This is significantly reducing sales volumes, and some facilities are moving over to alternative fuels such as rice husks since RDF cannot consistently meet the new acceptance standards specified by the cement companies.

In Thailand, RDF recovery is only operational during the dry season.

Process Requirements

The manufacturing process of RDF usually includes screening, shredding, size reduction, size reduction, classification, separation, drying, densification, and storage. The following presents brief descriptions of each piece of major equipment:

Storage or Bunker

The storage or bunker can be separated for the fresh MSW and for each product. The receiving bunker should be designed to have a capacity of 1–3 days.

Receiving Hopper

The fresh MSW or old waste mined from the landfill can be taken from the storage or bunker and dropped into the receiving hopper to start the process of RDF production.

Wrapping a bale of refuse-derived fuel.

Bales of refuse-derived fuel awaiting transport to cement kiln.

Preshredder

The preshredder is used to reduce waste to a size of less than 150 mm. It is also called the primary shredder, bag breaker, or bag opener.

Disc Screen

The disc screen unit applies a size separation process with the aim of removing smaller particles (mainly organic fraction of MSW) from the fresh MSW stream or old waste. The opening between each disc allows for smaller particles to drop down below the space and be transferred to other processes.

Air Classifier

The air classifier separates the MSW based mainly on content density. In this process, rising air jets are applied to the material stream. As a result, the light fractions are blown upward and the heavy fraction falls down below. The heavy fraction is usually rejected or nonbiodegradable materials which can then be sent to the landfill for final disposal.

Overband Magnet

The overband magnet uses a powerful magnet to remove metal from the waste stream and deliver it to a storage area where it can be collected for sale.

Manual Sorting

In essence, the manual sorting involves a long conveyor belt that has staff on both sides to collect or remove particular types of waste from the waste stream. For example, in the RDF stream, the staff can remove unwanted materials such as nonmetals, ceramic, and bones.

Fine Shredder

This machine cuts materials into small particle sizes by using rotating blades. The final sizing depends on the use of the product. Hence, it is important to design this system according to the requirements of the buyers.

RDF facilities can be economical at relatively small sizes upward of around 100 tons per day

Summary

On the surface, RDF appears to be a strong candidate for diverting waste from landfilling.

RDF facilities can be economical at relatively small sizes upward of around 100 tons per day, compared with a mass burn waste-to-energy facility which usually requires at least 500 tons per day to be economical.

However, recent concerns about emissions standards from kilns and also the chlorine impact on cement clinkers have resulted in cement companies often requiring RDF to meet quality standards in terms of RDF composition and quality. This has proved difficult to meet in a number of countries with the cement companies moving away from RDF to other alternative fuels such as rice husks.

Overall, RDF remains a possibility for productive waste diversion but must be carefully evaluated on a case-by-case basis.[6]

[6] ADB. 2016. *Buriram Prefeasibility Study: Refuse Derived Fuel Project.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161201/buriram-prefeasibility-study-refuse-derived-fuel-project; ADB. 2016. *Integrated Solid Waste Management Plan: Buriram.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161031/integrated-solid-waste-management-plan-buriram

Overview of Waste-to-Energy Options for Developing Countries

Background

There is significant interest in reducing the quantity of municipal solid waste (MSW) being disposed and a mounting demand for electricity supply, especially for developing countries. As a result, waste-to-energy (WtE) or energy-from-waste is gaining considerable attention. WtE is the process of generating energy in the form of electricity and/or heat from MSW and is in effect a form of energy recovery from MSW.

Most WtE processes produce electricity and/or heat directly through combustion, but they can also produce a combustible fuel commodity such as methane, methanol, ethanol, or synthetic fuels.

However, there are a number of mitigating factors (including public concerns over emissions referred to in a previous article in this chapter on Waste-to-Energy Emissions Management) against the widespread adoption of WtE, and the option needs to be carefully examined before committing to this strategy.

Interventions

The pros of WtE plants and associated electricity generation are the proven technology, electricity sale benefits (government contracted via a concession agreement that could provide regular income), little to no pretreatment in the case of moving grate incinerators (see practice brief on Waste Pretreatment Required for Waste-to-Energy Incinerators), able to meet high environmental performance standards if designed and operated properly, and a smaller footprint required than for landfilling.

The cons of WtE plants are the long lead time to build the plant, high capital expenditure and operating costs, difficulty locating the facility due to public concerns, and a large capacity requirement (normally a minimum of 250–300 tons per day of waste throughput to be economical).

A range of technologies are available for each of the thermal treatment processes. The following are those that have been reviewed for the purpose of this comparative assessment:

- Moving grate incineration,
- Fluidized bed incineration,
- Rotary kiln incineration,
- Gasification,
- Plasma gasification, and
- Pyrolysis (conventional pyrolysis).

Moving Grate Incineration

This is an incineration system equipped with an inclined moving grate system which keeps the waste moving through the furnace during the combustion process. It is one of the most widely used MSW incineration technologies worldwide with an extensive commercial track record. The moving grate system has a high operating efficiency regardless of the composition, calorific value, and moisture content of the MSW. Therefore, the MSW feedstock does not require extensive pretreatment before undergoing the incineration process (if any) is not required to be extensive.

Fluidized Bed Incineration

This is an alternative design to a conventional combustion system in which the moving grate is replaced by a floating bed of granular materials, such as sand, which can withstand high temperatures. There are two main types: bubbling and circulating beds.

Pretreatment of MSW is required for this system, usually by shredding, drying, and pelletizing. The process efficiency may also be improved by co-combusting waste with other homogeneous, high-calorific materials such as coal or woodchip.

Rotary Kiln Incineration

This system provides good mixing and stoking of wastes, along with a high level of control of waste residence time, thereby resulting in more complete combustion. A significant advantage of a rotary kiln is that no waste preprocessing is required and that it is able to handle both liquids and solids. It is commonly used to treat hazardous wastes, including high-energy liquids. However, it has higher maintenance requirements than moving grate systems and capacity is restricted by limitations in drum size. Energy recovery efficiency is also lower as heat is lost through the metal shell of the rotating drum.

Gasification

This refers to incomplete oxidation of organic compounds and conversion of combustible waste to syngas or producer gas at temperatures in the range of 500°C–1,800°C. Syngas comprises carbon monoxide, hydrogen, methane, carbon dioxide, water, nitrogen, argon, solid carbon, and contaminated substances such as tar, particulate, chloride, alkali metals, and sulfide.

The amount of air pollution substrates, particularly dioxins and furans, emitted from gasification is typically reported to be less than from mass burn incineration. Furthermore, although the types of air pollution control devices may be similar, they are smaller than for incineration. Gasification provides higher efficiencies and energy recovery rates along with lower investment cost than incineration. Therefore, gasification technology has a good potential to treat MSW in the future because of easy handling and burning of syngas, efficient conversion, low air pollution substrates, and the capability to scale down the technology. However, the current gasification plants in operation have a much lower unit and plant capacity than the moving grate incineration plants for mixed MSW treatment with their plant capacity generally ranging from 100 tons to 450 tons per day, respectively.

Plasma Gasification

This is a more recent advent in waste treatment technology. It entails the chemical decomposition of waste in a low-oxygen environment, utilizing a high-temperature plasma torch. The temperature of the plasma arc typically ranges from 2,700°C to 4,400°C. However, instances of temperatures up to 10,000°C have been reported. Plasma gasification plants have a comparatively low capacity range (between 20 tons and 500 tons per day), and high capital expenditure and operating costs. At present, it has not been widely adopted for MSW treatment.

Pyrolysis

This is an anaerobic indirect heat process in which organic waste is decomposed to produce oil, carbonaceous char, and combustible gases. These by-products are used as a fuel source and are burned to generate heat. Since oxygen is not required in the pyrolysis process, the volume of flue gas generated is lower than in the incineration and gasification processes. Unlike incineration and gasification systems, which are self-sustaining and use oxygen for waste combustion, an external heat source is required to drive the pyrolysis reaction. Relatively low temperatures (in the range of 400°C–800°C) are required for pyrolysis. Pre-preparation of the MSW is also required.

Moving grate incineration is believed overall to be the preferred option for developing countries

Pyrolysis is not yet widely used as a treatment technology for MSW and information available for review is limited as many projects are still in the pilot stage. Challenges include low energy production (due to the amount of energy required to power the process), difficulties in process optimization, and safety concerns.

Technical Feasibility

When evaluating the WtE technologies, moving grate incineration is believed overall to be the preferred option for developing countries for the following reasons:

(i) **Flexibility in waste composition.** Moving grate incineration possesses a high level of flexibility to deal with variations in solid waste quality and composition. It also does not require extensive preprocessing of MSW (if any) in contrast to other systems (apart from rotary kiln incinerators) that require pretreatment of MSW for higher efficiency. Moving grate incineration is also flexible in terms of treatment capacity, with effective facility sizes ranging from 20 tons to 4,000 tons per day.

(ii) **Electricity production efficiency.** For conventional incineration systems (i.e., moving grate, fluidized bed, and rotary kiln), energy in the MSW is recovered through a near complete waste burning process and the heat energy is then diverted to waste heat boilers to generate steam for electricity generation using steam turbines. Although this process can result in greater heat loss as the energy is exchanged between the various systems, the electricity production is still considered to be acceptable to moderately efficient.

(iii) **Reliability and track record.** Broadly speaking, the greatest operational reliability at present is provided by moving grate incineration. This is by far the most widely used technology for both energy recovery from MSW as well as incineration without energy recovery. They have been proven to be robust and easy to maintain in comparison to other technologies.

(iv) **Land requirements and system complexity.** Although moving grate incineration has a large footprint, each process unit has a large treatment capacity, requiring a smaller number of units to be installed for large throughput. In contrast, other technologies have a relatively smaller footprint, but each unit has limited treatment capacity, requiring a larger number of units to be installed for large throughput. As such, for large volumes of MSW throughput, moving grate incineration can provide an optimal combination of land requirement and treatment capacity.

(v) **Capital and operating costs.** In terms of cost efficiency, moving grate incineration is usually the go-to option, as it has large treatment capacity (reducing the number of treatment units required), relative operational simplicity, widespread application, and low pretreatment requirement (if any).

(vi) **Air emission.** Comparing with direct combustion technologies (i.e., rotary kiln and fluidized bed), moving grate produces the lowest volume of flue gas. Although the flue gas emissions may contain various pollutants, application of appropriate air pollution control technologies can mitigate the pollution and meet the international emission standards.

Economics

WtE plants normally need to be designed and constructed for relatively large waste throughput. Facilities need to sell the electricity generated and, in most cases, charge a gate fee for the waste being incinerated to be economical. The facilities are usually provided through a public–private partnership or similar arrangement, and the concession is usually more than 25 years to allow capital cost recovery by the operator.

Summary

There are many options and issues to be considered for WtE facilities. Some processes are more efficient than others, others require more waste pretreatment, others need large quantities of waste to be economic, and yet others are effectively only emerging technologies with few full-scale functioning facilities.

Municipalities therefore should be very cautious of being influenced by marketing materials associated with WtE facilities and should retain experienced WtE independent consultants to guide their decisions.[7]

[7] ADB. 2016. *Quezon City Prefeasibility Study: Conventional Waste-to-Energy Project*. Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161201/quezon-city-prefeasibility-study-conventional-waste-energy-project; ADB. 2016. *Integrated Solid Waste Management Plan: Quezon City*. Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20160930/integrated-solid-waste-management-plan-quezon-city

Siting Guidelines

Background

There are many guidelines available for selecting a landfill site. However, many contain criteria which are very onerous and restrictive, and are more appropriate for very large cities in a developed country context. In fact, such guidelines would rule out many acceptable sites.

The proposed criteria have been developed in conjunction with many international landfill design criteria as base documents. These provide some generic background and also local specifics.

The following criteria are pragmatic but will still provide adequate socioenvironmental protection with a suitable landfill design and standard of operation.

Interventions

Basic Site Selection Criteria

The following criteria are the basic issues that need to be addressed when siting a landfill:

(i) The site selected must be consistent with the overall land use and development plan of the municipality.
(ii) The site should be large enough to accommodate the community's wastes for a long period.
(iii) The site must be accessible from major roadways or thoroughfares, with strong pavements for trucks.
(iv) The site should have an adequate quantity of suitable earth cover material that is easily handled and compacted.
(v) The site must be chosen with regard for the sensitivities of the community's residents.
(vi) The site must be located in an area where the landfill's operation will not detrimentally affect environmentally sensitive resources such as aquifer, groundwater reservoir, watershed area, ecologically sensitive area, etc.
(vii) The site should be distant from airport landing and takeoff paths.
(viii) The site chosen should facilitate developing a landfill that will satisfy budgetary constraints, including site development, operation for many years, closure, postclosure care, and possible remediation costs.

Detailed Site Selection Criteria

In addition to such general requirements, the following criteria should be followed:

(i) The site should be large enough to accommodate the community's wastes for a minimum period of 20 years, including allowance for areas such as buffer areas, recycling, equipment sheds, cover material stockpiles, buildings, internal access roads, compost processing area, etc.
(ii) Preferably, a site accessible within 30 minutes of travel time from the central business district is sought. At travel distances greater than 30 minutes, for collection operations to be economic, investment in either large capacity collection vehicles (5 tons per load or greater) or transfer stations with large capacity vehicles (20 tons or greater) is necessary. If transfer stations are required, the landfill should be accessible within 2 hours of travel time (one-way) by transfer trucks from the transfer station.
(iii) The site should be accessible from a competent paved public road which has an adequate width, slope, visibility, and construction to accommodate the projected truck traffic. To minimize landfill development costs, the requirement for new access road construction generally should be less than 10 kilometers (km) for large landfills serving metropolitan areas and less than 3 km for small landfills serving secondary cities.

(iv) The site should have a gently sloped topography, amenable to development of a landfill by the ramp method. Steeper slopes are acceptable, provided that the landfill design can accommodate these slopes and still yield a suitable site life. Flat sites mean leachate management can be difficult.

(v) Groundwater's seasonal high level should be at least 1.5 meters (m) below the proposed base of any cell excavation. An absolute minimum clearance of 1 m of relatively impermeable soils above the groundwater's seasonal high level should exist (preferably less than 10^{-9} m per second permeability when undisturbed). If these criteria are not met, use of impermeable clay and/or plastic liners may be required to protect groundwater quality.

(vi) Availability on-site of suitable soil cover material to meet the needs for daily, intermediate, and final cover, as well as bund construction must be ensured. The best soils are clayey silts which provide good cover in both wet and dry weather periods. Too little clay increases permeability so that water can enter the waste mound. Too much clay can result in trafficability issues in wet weather and cracking in dry periods. For purposes of siting, at least 10% of the final landfill volume should be assumed to be cover material. Well-run landfills are closer to 25% cover material content, but 10% is the bare minimum allowed.

(vii) There are no private or public drinking, irrigation, or livestock water supply wells within 500 m down-gradient of the landfill boundaries, unless alternative water supply sources are readily and economically available. (Three bores as a minimum can show direction of groundwater flow if not evident on the surface.)

(viii) No environmentally significant wetlands of important biodiversity or reproductive value are present within the potential area of the landfill cell development. No known environmentally rare or endangered species breeding areas or protected living areas are present within the site boundaries.

(ix) No significant environmentally sensitive areas are within 500 m of the landfill cell development area.

(x) Preferably, prevailing winds do not blow toward habituated areas from the landfill.

(xi) No major electrical transmission lines or other infrastructure (i.e., gas, sewer, telecoms, or water lines) are crossing the landfill cell development area.

(xii) There are no underlying underground mines which could be adversely affected by surface activities of landfilling.

(xiii) No residential development within 250 m from the perimeter of the proposed landfill cell development.

(xiv) There is no perennial stream within 200 m down-gradient of the proposed landfill cell development, unless diversion is economically and environmentally feasible to protect the stream from potential contamination.

(xv) No significant seismic risk exists within the region of the landfill which could cause destruction of berms, drains, or other civil works, or require unnecessarily costly engineering measures.

(xvi) No fault lines or significantly fractured geologic structure are present within 500 m of the perimeter of the proposed landfill.

(xvii) The site must not be within 3 km of a turbojet airport and 1.5 km of a piston-type airport.

(xviii) The site must not be within a floodplain subject to 10-year floods.

(xix) No major valley features are present on the site which cannot be readily diverted to prevent stormwater external to the site entering the waste mound.

(xx) Siting should be avoided within 1 km of sociopolitically sensitive sites where public acceptance might be unlikely (i.e., memorial sites, churches, mosques, or schools) and access roads that would pass by such culturally sensitive sites.

There should be no residential development within 250 meters from the perimeter of the proposed landfill cell development

Community Engagement

The technical and engineering aspects of landfill siting are relatively straightforward. However, the assessment of potential landfill sites will need to consider the concerns of the host community. This will allow information sharing and early identification of issues of interest that can be considered in the site screening process.

Once initial meetings with the local community have been undertaken and the landfill development has been discussed and supported, a program of community participation should be continued for subsequent phases of the project. Effective engagement practices help identify potential issues, impacts, opportunities, options, and solutions for improvement and facilitate more efficient decision making. This may be part of an environmental impact study or assessment and social impact assessment, especially for larger proposed facilities. The benefits of planned and well implemented engagement include:

- enabling the community to be better informed and encouraging local pride and active citizenship;
- reducing the amount of misunderstanding and

misinformation with clear communication and very early engagement of the community;
- enabling all groups to have a better understanding of community and local needs;
- enabling greater commitment to and ownership of decision making by the community;
- building mutual understanding and ownership of problems and solutions;
- supporting more efficient and effective decisions, as actual community needs can be identified and community knowledge used throughout the business phases;
- supporting behavioral and attitudinal change in all groups; and
- enabling industry to be a good neighbor by building trust and confidence through its openness and transparency and by listening and responding to community needs.

Summary

There are numerous international guidelines for siting landfills. Many are too restrictive and would rule out suitable sites for a small or midsize city in the developing context. The guidelines presented here are pragmatic and generally suitable for siting a small to midsize facility. For very large facilities, more detailed assessments are essential.[1]

[1] The practice brief on Geotechnical Assessments (pp. 52–54) provides fieldwork requirements.

Geotechnical Assessments

Background

A geotechnical study is required for any controlled landfill if it is to be a large permanent facility.

The scope of works specified is to adequately define the geotechnical conditions to allow the landfill design to proceed, in particular the liner requirements. This will include all works required to achieve this description.

It should be noted that for very large landfills, the scope of works may have to be extended.

Interventions

Fieldwork

The following steps should be followed in the fieldwork process:

(i) Develop a grid of nine pits over the proposed base area:
- Locate the test pits on a grid of 3x3 pits giving a grid of nine pits equally spread over the site.
- Three of these nine pits (main pits) will be logged in detail, as specified below.
- The remaining six pits will be used to determine the soil profile, but the holes will not be logged in detail.

(ii) Conduct in situ infiltration tests on the surface of the clay or silty clay layer using the double-ring infiltrometer method. This should be done at three sites near the test pits where the pits are fully logged.

(iii) Excavate nine test pits to a depth of at least 4 meters (m). If the pit collapses due to unconsolidated and/or saturated ground conditions, then the pit should be logged to the maximum practical depth. Depths of pit wall collapse should be noted.

(iv) For each of the three main pits:
- Log and classify the soil types encountered and the strata depth according to the Unified Soil Classification system, including usual parameters such as color and stiffness.
- Pay particular attention to identifying the presence, type, depth, and thickness of any impermeable layers, such as clay or clayey bands.
- Note features such as the presence of tree roots or other structure that may alter the gross permeability of the soil strata.
- Determine the standing water level in each of these three main pits, if standing water is encountered. If the water level is slow in stabilizing, the pit should be left open until a stable water level can be determined.
- Undertake the usual field tests to confirm the soil classifications, such as stiffness.

(v) For the remaining six pits:
- Measure the depth from the surface to the top of any impermeable layers, such as clay or clayey bands, or any permeable layers such as sand or gravel.
- Measure the thickness of the soil band(s).
- There is no need for formal soil logging or sampling required in these six supplementary pits. They are just to identify any clay or highly permeable layers.

(vi) Backfill pits immediately upon completion of the site work. Also, compact and level them back to sensibly meet with the natural surface profile. The only reason for keeping a pit open would be while waiting for the water level in the pit to stabilize.

(vii) Drill one hole to a depth of at least 10 m at the center of the site:
- Using a suitable drill rig, drill to a depth of at least 10 m or until the groundwater is reached.

- Log and classify the soil types encountered and the strata depth according to the Unified Soil Classification system, including usual parameters such as color and stiffness.
- Pay particular attention to identifying the presence, type, depth, and thickness of any impermeable layers, such as clay or clayey bands.
- Determine the standing water level in the drill hole. If the water level is slow in stabilizing, the pit should be left open until a stable water level can be determined.
- Undertake the usual field tests to confirm the soil classifications, such as stiffness.
- Insert three bores with piezometers to monitor water table depth over the wet and dry seasons and to allow determination of groundwater flow. These pits might be clear of the landfill footprint to become permanent water quality monitoring bores. The basic chemical constituents of the water can be monitored for 12 months to give background levels should regulations require such measures.

Sampling and Testing

Sampling

An undisturbed sample should be collected from a representative soil layer in each of three main pits spread over the site area. These pits should be selected so as to best represent the variations, if any, in stratigraphy over the entire site.

Sufficient additional sample volume should be collected of the clay or low permeability layer from the three pits selected earlier for laboratory analysis of the liquid limit, shrinkage and plasticity index, and Emerson pin test for dispersivity.

Laboratory Testing

The three undisturbed clay samples should be tested for permeability in an oedometer test rig.

The three disturbed samples from the same pits should be subjected to laboratory analysis for the liquid limit, linear shrinkage and plasticity index, and Emerson pin test for dispersivity.

Fieldwork Reporting

The fieldwork report should include the following:

- A short site report describing the site activities, staff, and equipment used;
- Soils logs of the three main pits describing the features required above, printed at one log per A4 page;
- Plots from the in situ infiltrometer tests and calculated infiltration rates; and
- A table of the general soil profile in the six supplementary pits.

Laboratory Results Reporting

The laboratory results should be detailed, providing basic interpretation of soil properties, and including the results of

- liquid limit, linear shrinkage and plasticity index, Emerson pin tests;
- permeability testing in an oedometer test rig; and
- any other laboratory tests considered essential to adequately describe the soil profiles.

Double-Ring Infiltrometer Field Test

The infiltration rate is the velocity or speed at which water enters into the soil. It is usually measured by the depth of the water layer that can enter the soil in unit of time (e.g., millimeters per day, etc.). An infiltration rate of 15 mm per hour means that a water layer of 15 mm on the soil surface will take 1 hour to infiltrate.

In dry soil, water infiltrates rapidly. This is called the initial infiltration rate and is dependent on the sorptivity of the soil. As more water replaces the air in the soil pores, the water from the soil surface infiltrates more slowly and eventually reaches a steady rate. This is called the saturated soil infiltration rate.

The infiltration rate depends on soil texture (the size of the soil particles) and soil structure (the arrangement of the soil particles and tortuosity of the void flow path). It is a useful way of categorizing soils in terms of their ability to transmit water vertically. The most common method to measure the infiltration rate is by a field test using the double-ring infiltrometer.

Table 5 shows the typical infiltration rates for various soil types:

Table 5: Infiltration Rates for Different Soil Types

Soil Type	Basic Infiltration Rate (mm/hour)
Sand	30+
Sandy loam	20–30
Loam	10–20
Clay loam	5–10
Clay	1–5

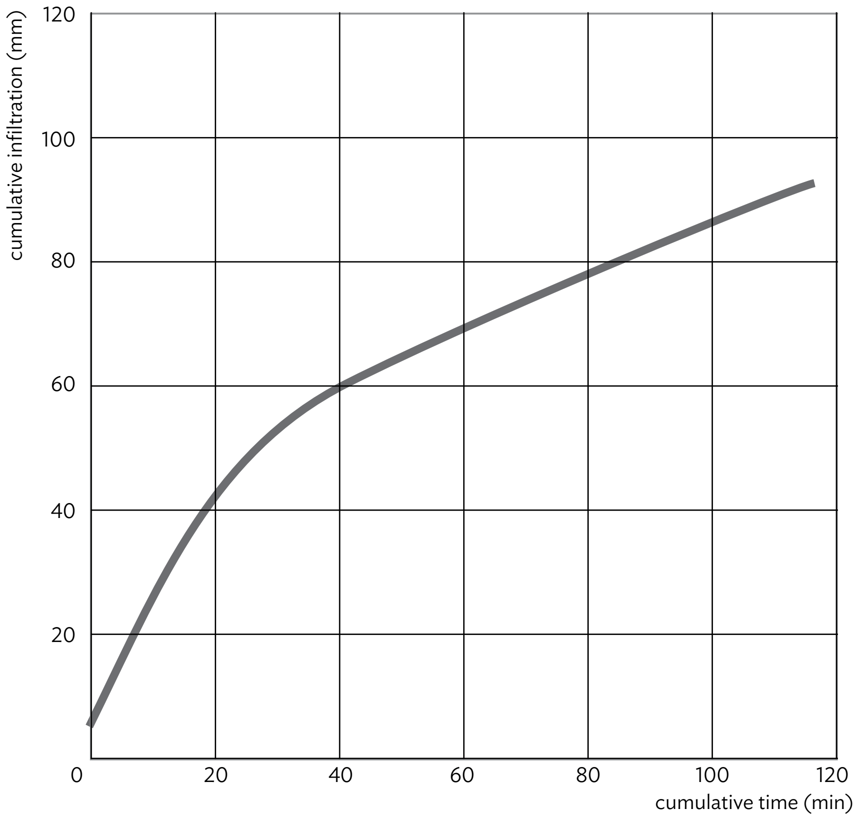
mm = millimeters.

Source: Author.

A double-ring infiltrometer of 30 centimeters (cm) in diameter and 60 cm diameter should be used for this investigation:

(i) Hammer the 30 cm diameter ring at least 15 cm into the soil. Use the timber to protect the ring from

Figure 6: Typical Plot of Cumulative Infiltration versus Time



Source: Author.

damage during hammering. Keep the side of the ring vertical and drive the measuring rod into the soil so that approximately 12 cm is left above the ground.

(ii) Hammer the 60 cm ring into the soil or construct an earth bund around the 30 cm ring to the same height as the ring and place the hessian inside the infiltrometer to protect the soil surface when pouring in the water.

(iii) Start the test by pouring water into the ring until the depth is approximately 70–100 mm. At the same time, add water to the space between the two rings or the ring and the bund to the same depth. Do this quickly.

(iv) Record the clock time when the test begins and note the water level on the measuring rod.

(v) After 1–2 minutes, record the drop in water level in the inner ring on the measuring rod and add water to bring the level back to approximately the original level at the start of the test. Record the water level. Maintain the water level outside the ring similar to that inside.

(vi) Continue the test until the drop in water level is the same over the same time interval. Take readings frequently (e.g., every 1–2 minutes) at the beginning of the test, but extend the interval between readings as the time goes on (e.g., every 20–30 minutes).

The basic infiltration rate should be determined from plotting the infiltration rate to see when it has stabilized. Once the values of the infiltration rate are constant, the basic infiltration rate has been reached. Figure 6 shows a typical infiltration plot.

Summary

This overview of typical geotechnical assessments required for small to midsize landfills is based on a mixture of test pits as well as borelogs. Some on-site testing is required with regard to permeability and recording soil profiles. Appropriate laboratory testing procedures have also been described.

The overall aim is to understand the site hydrogeology so appropriate lining systems and other leachate interventions can be developed.

Appropriate Standard for a Waste Disposal Facility

Issue

Most countries have their own standards for waste disposal facilities, usually related to the tonnage received at the facility. In many cases, this requires the provision of either lagoons for storing leachate or provision of a full leachate treatment plant. Leachate treatment plants are inappropriate and/or challenging for all but a few landfills, being both capital intensive and requiring large operating budgets and high-level skills. In summary, these plants are rarely operated correctly and a better approach (with or without lagoons) is to minimize the leachate generated and reuse it on site, rather than to treat and discharge.

Similar issues such as lining requirements should be considered in the light of not only best available technology but the best available technology economically achievable. Most landfills fail not because of the design or construction issues, but because of poor operation as a result of the higher cost of operations required for the overly complex landfill facility. A more sustainable approach is described in the following.

Interventions

The selection of the design and operational standard for the disposal facility should be based on the options listed in Table 6. This includes four options ranging from uncontrolled open dumping to a fully engineered sanitary landfill.

The first option of open dumping is essentially what is happening at many uncontrolled dumpsites at present, or even somewhat worse, and this cannot be supported in the future.

The second option is a controlled dump, but this still does not have waste compaction and soil covering, leading to significant ongoing environmental impacts. This option also should not be supported.

The third option of a controlled landfill has most of the environmental and operational benefits of the final option (a fully engineered sanitary landfill) but without the technical complexities of leachate treatment plants, for example, and the social dislocation of banning all waste pickers from the site. The controlled landfill option can be upgraded with scale-appropriate additional interventions for leachate and gas management, but not burdened with the additional constraints of the full sanitary landfill option, which are undesirable for almost all small to midsize facilities.

The fourth and most complex option is a fully engineered sanitary landfill. In addition to the requirements of a controlled landfill (the third level of complexity), this option compulsorily includes (i) a leachate treatment plant; (ii) mechanized material recovery facilities; (iii) mandated removal of all waste pickers from the active deposition site; and (iv) full gas control and venting, flaring, or use.

This combination is considered too expensive, and far too complex, for small to midsize municipalities to operate sustainably, without ongoing external technical support or funding. Also, the additional operating costs for items like the leachate treatment plant are significant but yield little or no environmental gain at this scale given their demonstrated unreliability. Furthermore, the required removal of all waste scavenging from the site could have significant social impacts and increase airspace consumption.

Given that there is little difference in cost or operational complexity between a controlled dump and a controlled landfill, but that a controlled landfill has significantly better environmental benefits, a controlled landfill is the most appropriate disposal system for most small to midsize municipalities.

Table 6: Waste Disposal Facility Options

Type	Characteristics	Advantages	Disadvantages
Open dump	Poorly sited Unknown capacity No cell planning Little or no site preparation No leachate management No gas management Occasional or no cover soil No waste compaction No fence Waste burning No record keeping Uncontrolled waste picking No groundwater monitoring	Easy access Low initial cost Low operating cost Aerobic decomposition Access to waste pickers Materials recovery	High environmental impacts Unsightly Groundwater contamination Surface water contamination High risk of explosion, fire, greenhouse gases Vectors/disease transmission Reduced lifetime of dumpsite Inefficient use of landfill area Breeds vermin, rodents, flies No record of landfill content Air pollution High health risk to waste pickers, especially children
Controlled dump	Sited with regard to hydro-geology Planned cell development Grading, drainage in site preparation Partial leachate management No waste covering No compaction Fence Basic record keeping Uncontrolled waste picking Waste burning No gas management No groundwater monitoring	Moderate environmental impacts Permits long term planning Improved stormwater control Less risk of leachate release Controlled access and use Access to waste pickers Materials recovery	Moderate environmental impacts Groundwater contamination Surface water contamination Moderate risk of explosion or fire due to gas Vectors/disease transmission Reduced lifetime of dumpsite Inefficient use of landfill area Breeds vermin, rodents, flies No record of landfill content Air pollution High health risk to waste pickers, especially children
Controlled landfill	Sited with regard to hydro-geology Planned cell development Grading, drainage in site preparation Improved leachate and surface water management, including provision of a low-permeability basal liner (can be compacted clay and not necessarily an artificial liner) Regular (not usually daily) cover Waste compaction Fence Basic record keeping Controlled waste picking Gas management provisions Monitoring of groundwater	Low environmental impacts Permits long term planning Improved stormwater control Reduced risk of leachate release Controlled access and use Reduced risk to waste pickers Materials recovery Waste is covered by soil Efficient use of landfill area Reduced breeding of vermin, rodents, flies Extended lifetime of landfill site	Still reduced environmental impacts Still limited potential for groundwater contamination Still limited potential for surface water contamination Still low risk of explosion, fire due to gas Still reduced risk of vectors/disease transmission Little or no record of landfill content Some air pollution Some health risk to waste pickers, no children allowed
Sanitary landfill	Site based on environmental risk assessment Planned cell development Extensive site preparation Full leachate and surface water management Full gas management Daily and final cover Daily waste compaction Fence and gate Record waste volume, type, source No waste picking	Minimized environmental risk Permits long-term planning Improved stormwater control Minimized risk of leachate release Reduced risk from gas Vector control Improved aesthetics Extended lifetime Controlled access and use Eliminate risk to waste pickers	High initial cost High operating costs Longer development time Slower waste decomposition unless bioreactor operation used Minimized risk of vectors/disease transmission Minimized risk of vermin, rodents, flies Displacement of waste pickers Loss of recyclable resources Optimum use of landfill site

Source: Adapted from United Nations Environment Programme. 2002. *Municipal Solid Waste Management*.

Summary

As noted, most countries have their own landfill development criteria which will have to be considered during the formulation of the design specifics. However, it is strongly recommended that the criteria listed earlier for controlled landfills form the basis of these deliberations, as this will usually provide the best balance between capital and operating costs versus environmental protection achieved.

In all cases, the reinjection of leachate into the landfill mass will bring waste and voids between waste particles up to the "field moisture content" absorbing much of the excess leachate. This also promotes biological activity by maximizing anaerobic decomposition of the waste, known as the "bioreactor" landfill operation. The transition from aerobic conditions to the production of full-strength leachate can take up to 6 years in any case. This approach also uses the voids and absorptive capacity of waste in the mound to act as a de facto wet weather storage. Once dry weather returns, excess leachate can be drained from the mound and irrigated.

One recent innovation is a plastic membrane-covered pond with air blown beneath the partly suspended cover to achieve evaporation on all but days of 100% humidity while excluding rainfall. This could be utilized if the absorptive and storage capacity of the waste is exceeded in protracted wet periods.

Dumpsite Remediation

Issue

Many municipal waste dumps are either poorly designed, poorly operated or both. This is usually blamed on funding shortcomings by municipality staff, but significant improvements are possible through a more structured approach to design and operation.

Most dumpsites are operated on the generic concept of cut-and-fill, meaning waste is placed in shallow excavated pits which are possibly lined and then filled to establish a shallow mound often with an almost flat top surface. Municipalities often believe their disposal site is then full to capacity and after placing a thin soil cover on top of the mound the site is suitably closed. Such a design is very wasteful of landfill space and also maximizes the environmental risks given the likely quantity of leachate then generated.

Dumpsite too flat and not covered with soil.

Leachate is predominantly the liquid formed when rainwater or runoff water enters the landfill mound, infiltrates through the waste, and becomes contaminated. Leachate is generally regarded as the primary environmental issue associated with waste disposal facilities, given that it has a high concentration of organic and inorganic pollutants and can contaminate water bodies. Most other issues such as rodents, birds, odor, and windblown litter are largely managed by the processes recommended in this section.

Large leachate discharge from an open dump.

Interventions

The contemporary approach to remediating midsize municipal dumpsites is to adopt a controlled landfill approach as per the categories listed in the preceding practice brief (Appropriate Standard for a Waste Disposal Facility). The categories range from open dumping through to engineered sanitary landfills. This approach recognizes that environmental returns rapidly diminish after the basic management systems are in place, so for small to midsize cities, it is best to use a controlled

A well-run controlled landfill.

Retrofitting a perimeter leachate collector when remediating an open dump.

landfill standard with stormwater diversion, daily or weekly compaction, shaping and soil cover application, perimeter leachate collection pipes and pump station, and leachate reinjection or irrigation systems, but without a leachate treatment plant or leachate discharge (where achievable in a given climate). The practice brief on Controlled Landfill Sizing and Design Guidelines (pp. 61–66) provides more information.

These remediation interventions are usually sufficient, provided that the existing dumpsite is not in a sensitive environmental location such as near a community water supply or on deep gravel soils. In these cases, the dumpsite may have to be relocated entirely (more information on siting are in the section on Siting Guidelines pp. 49–51).

Steps required for remediating dumpsites as controlled landfills include levelling and compacting existing garbage heaps, and construction of drainage canals and ditches. However, the most critical issue is that the slopes at the site should be maximized (steepened) to minimize rainfall infiltration and therefore leachate generation. The overall approach to leachate management must be to minimize the quantity formed, rather than to accept large volumes as inevitable and then provide expensive and often poorly operated leachate treatment facilities prior to discharge of the liquid. Leachate prevention not treatment is the priority.

External batters should be at a slope of 1:2.5 (vertical to horizontal) as such a slope allows soil cover to still be applied by conventional equipment and, when properly constructed, is stable (even in significant earthquake events) at heights of 50 meters or more (assuming the local natural soils have sufficient bearing capacity). This is generally the case except in areas of deep weak alluvial silts or clays in floodplains, for example.

The most critical issue is slopes at the site should be steepened to minimize rainfall infiltration and therefore leachate generation

The working areas on top of the mound should never be flat as is unfortunately often the case. A minimum slope of 5% should be adopted at all locations on the site. Flatter slopes allow rainwater to infiltrate and they also facilitate the formation of local depressions due to differential settlement within the waste. These depressions maximize leachate formation and must be avoided by appropriate mound sloping.

In terms of site development efficiency, the common belief is that waste mounds higher than approximately 5 meters are unstable. Many well-run controlled landfills have waste at heights exceeding 40 m or 50 m and therefore are very efficient in terms of site utilization and development cost returns.

The existing landfill may not be lined to modern standards, but if the ingress of rainwater is prevented, there will be no driving force (water head) to force leachate out. Therefore, a cover and grading of the finished landfill profile will go a long way to prevent leachate emissions.

Small leachate pumping station.

This combination of maximizing slopes throughout the site, regular application of soil cover material, and cover maintenance will minimize leachate generation and reduce or obviate the need for leachate treatment plants and offsite discharges in many cases.[2]

Leachate should be collected in a network of pipes retrofitted around the waste mound base and directed into a pump station from where leachate is irrigated in dry weather on previously worked areas to encourage grass growth or used for dust suppression.

In periods of rainfall when irrigation may cause contaminated runoff, leachate should be pumped to the top of the waste mound and reinjected under the soil cover. The leachate will then be absorbed by the drier waste material in the upper levels and also retained in the waste pore space. When the upper layers of waste become saturated with the reinjected leachate, the leachate will percolate down through the mound to again reach the leachate interception pipe work. This leachate percolation accelerates biological activity within the upper waste mound and accelerates stabilization processes as a side benefit. Early in the landfill operation, there will be insufficient waste mass to accept reinjection and so a balancing storage or spray irrigation area may be needed in the interim. Full-strength leachate can take up to 6 years to appear as anoxic conditions in the landfill finally cause anaerobic bacteria to break down the waste.

Summary

Remediated dumpsites should have steep sides, sloping profiled top surfaces, and regular applications of soil cover to maximize site efficiency as well as to minimize leachate generation. Collected leachate should be irrigated or reinjected depending on the season, not treated and discharged. There is usually no need for a leachate treatment plant if the site is well operated.

Landfills are stable with these 1:2.5 external slopes for heights of many tens of meters which maximizes site efficiency and site life. This approach is suitable for both remediating and extending the life of old “flat” dumpsites or a new greenfield controlled landfill development.

2 ADB. 2017. *Landfill Operations Manual.* Consultant’s report. Manila (TA 8566). http://k-learn.adb.org/materials/20170301/sample-landfill-operations-manual

Controlled Landfill Sizing and Design Guidelines

Background

Most countries will have a series of design criteria and standards that need to be applied locally. However, in some cases, these requirements may be considered inappropriate and the following presents some guidance on appropriate standards of landfill design for small to midsize cities in developing countries.

Sample of a concept landfill design schematics.

Interventions

Landfill Size Required

As part of the site selection process, a landfill volume and footprint spreadsheet should be developed and utilized. This simple spreadsheet would allow the municipality to input the volume of waste being transported per day to the site and then, by manipulating the length and width of the landfill mound, the capacity of the site (both volumetrically and in terms of years of life) can be determined.

A further enhancement is that various depths of excavation under the landfill footprint can be inputted which allows the quantity of cover material, and therefore the percentage of cover available, to be determined. This is critical where soil is not available on-site and would have to be imported at significant cost. For smaller and less sensitive operations, a 10% cover component allowance of total airspace would be sufficient.

Alternatively, if there is ample soil available on the overall site at no appreciable cost, the base of the landfill should be designed to minimize earthworks (and therefore costs) but still satisfy the need for the various slope constraints. Cover soils would then just be excavated as needed from outside the landfill footprint.

General Layout

A site layout then must be developed and will principally be driven by the footprint of the actual waste mound and how it relates to essential site infrastructure, such as how external stormwater will be diverted or permanent and intermediate access roads installed.

Daily volume delivered, vehicle numbers, and turning circles will dictate the size of the active tipping face. Modules of about a week of tipping will make up the subcell and modules of months will make up the cell size, building in modules to fill the available airspace while preserving gradients the trucks can manage and areas on the tipping crest large enough to maneuver the vehicles servicing the site as well as compacting and spreading the waste.

The site layout must account for the ultimate mound footprint, leachate pond(s), any mandated buffers, buildings, perimeter access roads, recycling areas and storage pens, green waste processing or composting areas, cover stockpiles, vehicle parking and maintenance areas, groundwater monitoring wells, stormwater diversion drains, leachate pump stations and power substations and/or generator housing(s), weighbridge

Master drainage to keep stormwater runoff out of the landfill mounds.

and entrance office (if weighbridge is to be provided), perimeter fencing, and so on. (The excavation depths required to win cover must not violate the vertical separation distances between the base of the landfill and the groundwater table level.)

Access roads will need to be incorporated and progressively relocated as the landfill mound changes in shape and height during its life. Road slope should be less than 10% for truck access, but short lengths up to 15% are acceptable. The roads must be wide enough to allow two vehicles to pass through even for one-way roads, in case one vehicle breaks down or becomes bogged. If the roads can be made one-way running in a continuous circuit to the exit, this is better for safety. Recycled concrete, brick, and stone can be used for temporary road surfacing extracted from the arriving trucks and municipal works salvage.

Master Drainage

Leachate is potentially one of the main environmental impacts from a landfill. The site layout and landfilling operation, therefore, must be designed to minimize contact of surfaces to runoff and percolating rainwater mixing with the waste, as well as to maximize the vertical separation of the waste above the groundwater table.

Positioning of the waste mound on the site must ensure that it is not located within a major drainage valley, especially one with a large catchment external to the site. If this is unavoidable, then the landfill can only be developed if the stormwater flows within the valley feature can be diverted around the landfill mound. This is often appropriate if the soil that needs to be excavated to provide the diversion channels can be stockpiled for use as cover material within the mound. However, if the valley feature is particularly steep, the only solution is to place a sealed jointed pipe or culvert running underneath the landfill. This is very much the last resort as enclosed drains under a landfill are a potential major hazard for both seepage and gas buildup. In summary, unless the stormwater can be readily diverted around the ultimate waste mound, a new site should be investigated.[3]

Landfill Geometry

Many landfills in developing countries are excavated on the cut-and-fill method where a hole is constructed and is then filled up with waste and then covered at essentially the natural ground level. This is a poor design as it does not maximize the airspace available from the site preparation and as such any intervention works like liners, soil treatment, and leachate drainage systems are underutilized. Such a flat design also maximizes the surface area of the waste mound and therefore rainwater infiltration and leachate generation problems. It is essential, if the landfill is built as a pyramid, to minimize rainwater infiltration and also maximize the utilization of the costly base liner preparations.

In terms of impacts upon the landfill design, site slopes should at all times (i) be kept as steep as possible to maximize landfill airspace, but (ii) be sufficiently flat to allow the soil to be able to remain on the slope and also to avoid any waste slips.

The adopted external slope is 1:2.5 (vertical to horizontal), which over time will reduce to a slope of 1:3. This is an internationally accepted slope for landfills even in earthquake-prone areas.

If the landfill is to be higher than 10 meters, a horizontal bench should be installed at 10-meter vertical intervals around the exterior faces of the mound. These benches are traditionally made sufficiently wide to allow vehicle access, which assists in managing drainage, soil cover, and vegetation growth during operation. The bench should slope one way at 5% away from the landfill mound so water falling on the batter above will run off the bench and not be trapped between the bench and the batter, potentially resulting in excess rainwater infiltration.

The general issues and sequence involved are presented in Table 7.

[3] See practice brief Stormwater Runoff Management in the following chapter (pp. 79–80).

Table 7: Steps for Controlled Landfill Sizing and Design

Item	How	Steps Required and Parameter Range Guidance	Comments
Prepare population and waste generation projections	Develop a spreadsheet	Minimum 20-year projection required. If more precise rates are not available, adopt a waste generation rate of: • 0.15 kilograms per day (kg/day) for rural areas • 0.25–0.6 kg/day for towns/small cities • 0.4–1.0 kg/day for larger cities Percent waste collected in serviced area: often 60%–90%; default of 70% if more precise rates are not available. Recycling from primary disposal locations and by waste haulers: default of 5%; increases over time with increasing community wealth and more packaging being purchased. Recycling at landfill: default of 5%; increases depending on site programs such as green waste recovery and chipping, or food waste in-vessel composting. Waste density in landfill: • 300 kilograms per cubic meter (kg/m^3) with no compaction • 500 kg/m^3 minimum with bulldozer • 650 kg/m^3 minimum with specialized landfill compactor • Higher densities may be achieved against firmer and rock foundations of up to 750–1,000 kg/m^3 Percent soil cover: minimum 10%, up to 25% for high standard of operation; default of 10%. Ignore the loss of airspace due to any batter slope intermediate benches required as this is very minor compared with ultimate landfill volumes.	Agree serviced area and collection and target recycling methods and efficiencies first. For example, the solid waste management (SWM) plan must be completed for aspects such as recycling focus proposed, considering centralized composting, materials recovery facilities, etc. as these impact on landfill layout planning. Use defaults as last resort.
Concept sizing of landfill footprint	Use spreadsheet	Use target of 10% cover material allowance for determining required excavation depth. Excavation depths will also be influenced by other factors such as the base slope requirements and connecting with leachate drains for future cells. (The ultimate landfill shape must de designed initially to ensure leachate drains can be connected from stage to stage.) The initial stages have to occasionally be excavated much deeper than required for cover winning reasons so later stages can connect into the “back end” of the first stage leachate drains. It is the total cover needs of the ultimate landfill that set the excavation depths overall. Alternatively, if there is ample soil available on site at no appreciable cost, the base of the landfill should be designed to minimize earthworks while still satisfying the need for the various slope constraints and allow the efficient construction of the leachate evaporation lagoon below the toe of the ultimate landfill.	Ensure excavation depth does not violate groundwater separation requirements.
Apply landfill footprint to available site and prepare preliminary site layout	Have a large format plan showing existing site features such as water courses, hills, rock outcrops, neighbors, access roads, etc. High-resolution maps with contours of 1 meter or smaller interval.	Select site using landfill siting guidelines. If the site has supported waste disposal previously, then determine old waste pile depths and location so that the old waste areas can be remediated and/or incorporated into the landfill design and layout. It may be necessary to allow for temporary stockpile areas to extinguish any burning waste as this cannot be done with the burning waste in place. Stormwater master drainage is a key issue in deciding the site layout if external water catchments cannot be diverted by drains or bunds. Staging plans can be completed later. Unused areas must be diverted to clean runoff and intermediate cell covers also designed to shed clean water away from the leachate collection system. If lined areas are constructed for ease of operation, then leachate drains should have disconnected sections and bunds have drain cuts through them to divert clean water until a cell is activated for waste placement. Allow for future expansions in the layout if it is a long-term facility. Issues like avoiding the need to move buildings or major roads must be considered. It is best to work backwards from the ultimate site capacity to the earlier stages.	Workshop the layout and design concept with the SWM working group and SWM committee.

continued on next page

Table 7 *continued*

Item	How	Steps Required and Parameter Range Guidance	Comments
		Allow for initial infrastructure such as cover stockpiles being close to the specific landfill stage where it will be needed. Often the cover is placed where future stages will be developed. Allow for buildings, huts, generator sheds, recycling compounds, equipment sheds and parking, etc. Allow space for future infrastructure even if not proposed for immediate installation, such as a weighbridge. (If private contracts for waste haulage or landfill operation are to be considered, then a weighbridge is essential for close contract management, though less critical for very small landfills.) There will need to be a special thick pavement to allow landfill compactors to travel from the workface to their storage/servicing building as these compactors will destroy normal road pavements. Determine if site buffers are mandated and allow for these. Recycling and cover soil stockpiles can go into buffer areas as they are not odorous, unless composting is proposed. Allow space for the leachate pumping station and rising mains to avoid damage or relocation as the landfill develops. Ensure permanent and temporary roads are incorporated. One-way perimeter and temporary internal roads are always preferred for safety reasons.	
Understand local hydrogeology	Site visit, observe local road cuttings, and eventually undertake soils tests for larger-capacity landfills	Visit the site to observe soil types. Look for local road or other cuttings to see soil profile. Use geology maps if available. Talk with neighbors if they have water wells to get soil profiles. Also, determine depth to water table at this time. Landfills can be built in any soil, but highly permeable noncohesive soils are poor for liners and soil cover, though better than nothing if no other sites are available. Commence water quality monitoring for at least 12 months before cells become active to determine baseline water quality, especially nitrates and metals etc. which may be naturally occurring. Commission soils tests and drilling program for larger landfills.[a]	Confirm if soils are generally suitable for easy excavation (no rock) or have some clay content preferably. Depth to water table is critical in some locations.
Leachate collection system	Landfill tonnage required	Use slotted 200-millimeter (mm) high-density polyethylene (HDPE) plastic pipe located in a nominal 600 mm square gravel drain for all landfills greater than 20 tons per day. Use a gravel drain for smaller landfills. Avoid polyvinyl chloride (PVC) pipes which crack easily under plant load. Use fusion-welded or flanged pipe joints to allow future extension of drains or electrofusion coupler pipes to connect future active cells to existing pipes. Place leachate collection drains less than 50 meters apart. Base lateral slope toward leachate pipe (minimum of 5% leachate pipe slope; desirable minimum of 2% although 1% would be acceptable, if steeper slopes are hard to achieve) without becoming a major constraint. Note that the pipes are surrounded by gravel, so any flow can exit into the gravel and reenter if there is a local blockage. Decide if the stages need more than one valley feature for the leachate drain location. Submersible pump (with standby for larger installations) needs to be explosion-proof because of methane potential.	A solid wall pipe is still required at small landfills to convey leachate from the gravel drain into the leachate pond.

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Table 7 *continued*

Item	How	Steps Required and Parameter Range Guidance	Comments
Prepare basal lining strategy	Soil tests	Determine if local soils are sufficiently impermeable in situ, such as natural clays, which will usually be adequate as a liner. For very small landfills (less than 20 tons per day), provided that here are no nearby groundwater users and the soil is a fine silt or better (some clay or structure), then lime mixing in the top 150 mm may be sufficient assuming that the environment is not sensitive (many neighbors drinking groundwater, etc.). Bentonite powder can also be mixed in with poorer clays to provide impermeable liners. Note sodium bentonite reacts with limestone and replaces its structure with calcium bentonite which is far less waterproof. For a midsize landfill, or a small landfill in permeable soils, either a compacted clay liner or an artificial liner may be required if no clay is available locally, depending on the local environmental sensitivity (local groundwater users, depth to water table, soil profile, etc.). Large landfills (greater than 500 tons per day) will most certainly require proper liners using reworked clay, HDPE, or geosynthetic clay liners (GCL). Note again that sodium bentonite (GCL sealant) reacts with limestone and will need clay or HDPE barrier to prevent calcium bentonite forming and greatly reduces the efficacy of the liner. Salty water near the liner also needs special bentonite formation and prehydration to function effectively. Consult with suppliers.	Big landfills may require an environmental impact statement (EIS) to be prepared which may dictate the type of basal lining required.
Landfill gas management	Use options list above	Determine legal obligations under local legislation on whether gas has to be collected, can be vented, has to be flared, or has to be reused. Standard design options: Passive release (no specific interventions) can be just to use cracks in the cover clay. Passive vent systems (6-meter-high stacks at the mound crown, fed by a gas blanket system). Flaring requires power eductor fans and specialist flare systems costing \$350,000 approximately plus piping. Productive reuse for high-speed gas turbine power generation or heating such as for optimum wastewater treatment requires vertical wells to be installed. Can be done once landfill cells are completed or during operation. Realistically needs more than 500 tons per day of waste to be economic.	
Refine landfill mound design	Soil types, site topography	The basic design should be refined based on site and soil details. For example, if there is a significantly sloping base or valley feature, then airspace volumes will have to be recalculated by preparing sections by computer-aided design or similar packages. Large landfills, require specialized site-specific investigations and design. Then, aspects such as drainage design and general layouts need to be updated to see if they still suit the proposed staging plans.	Refined landfill concept design ready for detailed design.
Macrodrainage and hydraulics	Above activity outputs	Ensure major natural drains are diverted around the waste mound in advance of mound stages being impacted. Ensure the diversion works can be integrated into the staging plan to use the material excavated for the drain as cover material. Check whether the drain needs protection such as riprap. Determine if a pipe or culvert has to go under the mound. This should be a last resort because of possible blockages resulting in local flooding. Near-vertical drains can be constructed on batters or steep walls at the sides of the landfill allowing for easy incremental extension and reconnection of intermediate drains as the fill rises in the footprint. If the site is flood-prone (on a floodplain), determine flood height for a 1-in-10-year event and install appropriate perimeter earthen bunds.	Keeping stormwater completely separate from the waste mound and leachate systems is critical to a successful landfill operation.

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Table 7 *continued*

Item	How	Steps Required and Parameter Range Guidance	Comments
Prepare final layout	Utilize all the above activities	Finalize site layout using the revised landfill mound sizing. Include final sizes for all immediate buildings and storage area needs. Aspects such as internal road widths and maximum grades as well as macrodrainage should be finalized. Allow for possible future needs such as additional buildings, more recycling areas, weighbridge and guardhouse, leachate pumping stations, gas flare site, etc. If resident self-haul is anticipated, design a transfer area to dump to skips which can transfer to the working face to keep residents and vehicles away from the heavy plant. This can also be a safe scavenging location if such activity is continued. Determine sizes and language(s) for major direction signs external to and inside the facility. Entry gate sign should have tipping categories and charges which can be changed as rates vary.	
Prepare costings	Final design plan and layout	Prepare a quantity estimate for all materials and equipment. Obtain prices from recent local contracts where possible or use published rates if needed. If capital funds are unavailable, allow for renting equipment such as a bulldozer (Drott bucket), tipper, and front end loader on a regular basis.	Obtain SWM committee agreement to the funds required.

Source: Author.

Summary

A structured approach to landfill design can result in significant cost savings while still achieving a suitable level of environmental protection.

By looking at the ultimate layout of the site, any conflicts can be avoided during landfill development and operation, thereby making the site far more efficient and workable. This approach also ensures that a suitable overall site development plan evolves.

Any design must comply with local requirements but the criteria and approach discussed should be adopted wherever possible.[4]

Many landfills in developing countries are excavated on the cut-and-fill method, a poor design as it does not maximize the airspace available from the site preparation

[4] More background details are in: Siting Guidelines (pp. 49–51), Geotechnical Assessments (pp. 52–54), and Appropriate Standard for a Waste Disposal Facility (pp. 55–57).

Life Extension and Reprofiling

Issue

Many landfills in developing countries are excavated on the cut-and-fill method where a hole is excavated, filled up with waste, and then covered at essentially the natural ground level or slightly above.

This is a poor design as it does not maximize the airspace available from the site preparation and as any underlying intervention works such as liners, soil treatment, and leachate drainage systems are underutilized. Also, this does not maximize the landfill life.

Such a "flat top" design also maximizes the flatter portion of the waste mound and therefore maximizes rainwater infiltration and leachate generation problems.

In some countries, the landfill heights are actually specified. In Thailand, for example, it is "a maximum of four lifts." This means the total landfill height including the lifts below grade is a maximum of 10 meters (m).


Completed section of landfill too shallow and flat.

Interventions

Landfill Geometry

It is essential if the landfill is built as a pyramid to help shed and minimize rainwater infiltration and also maximize the utilization of the expensive base preparations.

In terms of impacts upon the landfill design, site slopes should at all times (i) be kept as steep as possible to maximize landfill airspace, but (ii) be sufficiently flat to allow the soil cover to be able to remain stable on the slope and also to avoid any waste slips in the filled material.

The adopted external slope is 1:2.5 (vertical to horizontal) which will decrease to a slope of 1:3 with settlement over time. This is an internationally accepted slope for landfills even in earthquake-prone areas.


A high landfill with many lifts and benches as well as good steep external batter slopes.

If the landfill is to be higher than 10 m, a horizontal bench should be installed at 10 m vertical intervals around the exterior faces of the mound. These benches are traditionally made sufficiently wide to allow vehicle access, which assists in managing drainage, soil cover, and vegetation growth during operation.

The bench should slope at 5 degrees away from the landfill mound so water falling on the batter above will run across and off the bench and not be trapped between the bench and the batter, potentially resulting in excess rainwater infiltration.

The approach of having a series of separate cells with permanent roadway access in between is unsuitable. This greatly reduces the overall site airspace capacity for no benefit, as suitable access to the entire site can be achieved by introducing roads onto the landfill benching as well as utilizing the access roads, which are progressively relocated as new tipping faces are opened. The entire landfill site should be integrated into one mound, wherever possible, to maximize airspace and landfill life as well as to minimize any areas of flat slope that will facilitate greater rainfall infiltration and therefore leachate generation.

The landfill previously serving New York is 90 m high and many landfills are more than 40 m high. At the recommended slope, or even sometimes steeper at 1:2, these landfills have survived major earthquakes and typhoon conditions, provided that they are operated in accordance with standard operating procedures.[5]

Summary

By adopting this higher and steeper approach to landfill design, significant cost savings will result over the life of the landfill, as well as improving the level of environmental protection.

There are numerous examples of high landfills throughout the world including in earthquake-prone areas and those receiving typhoon-like rainfall events. Limiting the height of landfills to a small number of lifts is uneconomic and results in extra environmental issues.

The only time when landfill stability becomes an issue is when fresh waste is being placed over an old landfill or where an artificial liner has been placed at a steep grade on top of some geographical feature or an old landfill cell. In these cases, more detailed stability assessments are appropriate. Laboratory friction tests and suitable anchorages can address such design issues successfully. When bonding new to old, as with earthen embankments, the lifts should be keyed into the existing face by cutting back into each existing face with a dozer blade as a minimum treatment.[6]

[5] ADB. 2017. *Landfill Operations Manual.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20170301/sample-landfill-operations-manual

[6] More details are in the practice brief on Controlled Landfill Sizing and Design Guidelines (pp. 61–66).

Lining Systems

Issue

Liners are provided at landfills to prevent leachate from flowing downwards (permeating) into the soils and the groundwater underneath. Typically, they are designed for a permeability of 10^{-9} meters per second or less, which is essentially impermeable.

The liners can be artificial such as plastic liners (typically high-density polyethylene [HDPE]), special clay liners (geosynthetic clay liners [GCL] using sodium bentonite), chemically amended soils (lime or bentonite treated), or reworking and then compacting local clays.

Plastic liners are often specified in national guidelines or codes, but in reality these plastic liners often do not perform as they should, indicating that a more robust system is appropriate.

In monsoonal or wet climates, plastic welding is extremely difficult and many consequent patches add to potential leakage. HDPE less than 1.5 millimeters (mm) is prone to punctures and a 2 mm sheet is extremely hard to handle. The plastic liner will, by default, direct leachate to any hole in the liner, concentrating leakage at that point, rather than diffusing it as with clay liners or GCL. The melting point of the liner (melt flow index) is also critical in joining sheets from differing manufacturers and the choice of extrusion welding rods, if a full weld is physically impossible.

An exception is when the natural local soils under the waste mound are deep bands of low-permeability clays providing a liner by default.

Clay liner installation.

Interventions

Lime- or Bentonite-Stabilized Soils

For small landfills and those landfills located in nonsensitive socioenvironmental areas, an option is to use bentonite- or lime-stabilized soils by adding lime and mixing into the top 150 mm of the soil. This will reduce the permeability at low cost and, depending on the soil type, may achieve very low permeability. Although most soils can be lime stabilized, some soils are more easily stabilized than others.

Bentonite powder can also be rotary-hoed or mixed thoroughly into the local soil to provide a swelling reaction when wet-up and to improve the waterproofing of marginal soils. Tests are required to determine the optimum percentage to add.

With soil stabilization by lime, clay soils (clay content greater than 10%) are chemically changed into a natural cement structure of calcium silicates or aluminates. When lime products are added to raise the pH of the soil above 11.5, clays become a gel. Soils containing less than 10% clay will need a source of silicates and aluminates (pozzolans) to build the

High-density polyethylene liner installation and high-density polyethylene liner damage.

"bridges" between soil particles for the natural cement to form. A source for these pozzolans is fly ash, a by-product of the coal-burning power industry. Sufficient fly ash to bring the pozzolan (clay) content above 10% is needed. It should be noted that early waste decomposition in landfills goes through an acidic stage until oxygen is depleted, with some possible reaction with carbonates.

Lime stabilization is usually reserved for smaller landfills.

In Situ Clay Liner

Developing clay liners involves progressively covering the landfill base with a 600 mm thick clay liner placed in 3 x 200 mm thick uniform layers compacted to 95% of standard compaction (achieves 95% of the possible maximum dry density for the clay). The soil should be placed at a moisture content of at least 3% above optimum and compacted using a sheep's foot roller, peg leg, or similar compactor which utilizes a "kneading" action to achieve the nominated density.

It is estimated that between 90% and 95% compaction will achieve the desired permeability of less than 10^{-9} meters per second. The resultant very low permeability and consistency of the clay soil liner are the important factors rather than density.

The liner should be placed in sections and progressively covered to prevent the formation of desiccation cracks. To control moisture loss and cracking of the in-place clay liner, it should be covered with mulch or waste (e.g., composted or shredded green waste) immediately after placement. Clay used in the liner construction should have a minimum liquid limit of 50 and a minimum plasticity index of 20. One of the reasons for a 600 mm layer is the top half is potentially affected by cracking and is partly "sacrificial."

Clay liners have the advantage of being at least partially self-repairing if pierced or accidently driven over with landfill tracked equipment, and finally clay cannot burn. However, clay may be unavailable locally and can be expensive to haul and work.

Artificial Liners

Where clay is unavailable, or at large landfills where hazardous waste quantities could be received in significant quantities, alternative lining may be mandated to protect groundwater resources such as a 1.5–2 mm thick HDPE plastic liner or a GCL containing bentonite.

In developing countries, HDPE liners have often suffered, either due to fire as they are readily combustible or heavy vehicle traffic track damage, especially if driving over angular particles that perforate the liner. In fact, many landfills in developing countries using HDPE or similar liners demonstrate extensive liner damage, making the liner ineffective.

Furthermore, the liners have to be heat welded to join the sheets, and there are many cases where this heat welding has proved ineffective and where rewelding has caused mechanical stress cracks along seams.

For landfill capping on slopes, the extensibility of linear low-density polyethylene is preferred to HDPE.

The GCL (two layers of needle-punched polyester either side of typically 5 mm thickness of sodium bentonite and stitched together like a quilt) does not have to be joined using either thermal or solvent processes and merely has to be overlapped. A bentonite paste primer is used for overlap sheets and some manufacturers have a primer strip incorporated at sheet edges. The other advantage of a GCL, in situations where installation and subsequent operational care may be suboptimal, is that it is partially self-repairing. For example, a hole up to 50 mm in diameter will be self-repaired by the bentonite swelling and moving between the two geotextiles forming the GCL sandwich and plugging up the puncture.

However, GCL requires careful placement and, to be effective, requires application of a consistent depth (minimum 300 mm) of load-bearing material such as gravel, soil, or selected waste. This must be done when the sheet is dry as the wet bentonite can extrude sideways like modeling clay under point load, leaving just two permeable sheets of fabric as the water seal. Wet sheets must be replaced if this occurs before the confining cover is added.

Another trap is contact with limestone as the calcium can replace the sodium bonded to the bentonite and the calcium bentonite has far poorer waterproof characteristics. A plastic or clay barrier between GCL and limestone will be required.

Salty groundwater can also negatively affect the performance of sodium bentonite. Where there is a risk of this contact with saline groundwater or springs in excavated batters, the GCL needs to be ordered with chemical additives and sometimes prehydrated with fresh water following the placement of confining fill.

There are grades of bentonite raw material. Some manufacturers add a polymer to the bentonite which swells upon hydration to make the product pass its "swell index" and to resist water by "prestressing" the surrounding bentonite. Such amended lower quality products should be avoided where pure bentonite can be obtained economically.

Summary

Clay is robust and can withstand damage from fire and limited piercing, as well as tracked vehicle damage. However, it must be kept moist to avoid drying and cracking, prior to waste being placed on top of the liner. Composted or shredded green waste is an ideal protective layer and is alkaline, encouraging the waste to achieve anaerobic decomposition more quickly as aerobic decomposition is acidic.

HDPE does not satisfy these real-world requirements in lower-technology and high rainfall areas. GCL also is less robust than clay, with some technical precautions required.

Overall, clay may not achieve the absolute impermeability possible with perfectly installed and maintained HDPE, but in the real world, clay is a better option given its far greater resilience where clay is available locally.[7]

[7] ADB. 2017. *Landfill Operations Manual.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20170301/sample-landfill-operations-manual

Overview of Leachate Management

Issue

Leachate is one, if not the biggest, environmental issue at a controlled landfill and is traditionally managed by treating it in a leachate treatment plant and then discharged.

Almost all of these leachate treatment plants in a developing country environment are not performing correctly, if being operated at all. A comprehensive leachate treatment plant will include elements such as balancing storage, pH correction, anaerobic treatment, aerobic treatment, and possibly disinfecting and then sludge management. If the correct facilities are installed and operated correctly, the cost can be very high, especially for a small to midsize municipality. For example, at the landfill serving the greater Suva area in Fiji, which received about 230 tons of waste per day, electricity costs for the leachate treatment plant aerators alone exceed $6,000 a month. A leachate irrigation and reinjection pumping system would consume about 10% of this amount.

Frequently, the result is that the leachate treatment plant is bypassed, and untreated leachate is discharged to the receiving water environment with the potential for significant environmental harm.

Different features of a low-technology leachate treatment plant.

Interventions

In accordance with the contemporary approach for small to midsize landfills in the developing country context, it is recommended to adopt an operational procedure that minimizes leachate generation (common to all size operations) and includes the leachate either reinjected or irrigated at the site, obviating the need for a leachate treatment plant. Thus, the approach is to minimize the volume being created and to reuse on site, rather than adopting an end-of-pipe approach which accepts large volumes of leachate generated unnecessarily and then having to manage these large volumes in an expensive treatment plant.

The following are the basics of the recommended management strategy:

- Reduce the volume of leachate generated by using filling, compaction, shaping, and covering procedures which severely inhibit direct rainfall entry to the waste mound. Only the active tipping face should be subject to rainfall inflow (Controlled Landfill Sizing and Design Guidelines [pp. 61–66]).
- Further reduce the volume of leachate generated by intercepting and bypassing all upstream surface water catchment areas around the fill area utilizing surface drainage channels or bunds (Stormwater Runoff Management, [pp. 79–80]).
- Eliminate seepage of leachate from beneath the site by installing a compacted clay liner where the in situ soil is

too permeable to construct the liner. If the soil or nearby borrow pit soil is unacceptable for liner construction, an artificial high-density polyethylene (HDPE) or geosynthetic clay liner (GCL) geomembrane will need to be provided (Lining Systems [pp. 69–71]).

- Eliminate lateral escape of leachate through the toe of the refuse mound by grading the base of the cell to the central area and intercepting this flow in leachate interceptor or collector drains.
- Progressively pump leachate from leachate pumping station wells and recycle it through the waste by means of "dry wells" or temporary open trenches in the capping layer after sufficient closed cells have been constructed or by irrigating previously worked areas or future landfill areas in dry weather. This effectively utilizes the storage capacity of the landfill waste pore space as wet weather storage (waste has a field moisture content below which it can accept fluids). This means leachate does not have to be irrigated in wet weather, possibly resulting in contaminated stormwater runoff.
- Monitor the groundwater quality hydrogeologically upslope and downslope of the site.

With the many years that should be associated with each stage of the development of the final landform, there is ample time available to modify the system if required, and monitoring programs will be sufficient to detect problems on-site before they become a potential problem for downstream surface water or groundwater users. Full-strength leachate takes about 6 years to develop and this also gives time to monitor accumulation rates for leachate.

Summary

Many countries still require full leachate treatment plants for small to midsize facilities. Experience strongly indicates that these treatment plants are rarely constructed according to the design requirements and even less often operated correctly to achieve the required discharge standards. The United States Environmental Protection Agency's HELP model or similar models can predict leachate yields using climate records for rainfall and evaporation as the landfill develops. Should the climate and/or local regulations require treatment, simpler batch type precast treatment plants utilizing contact media, which rely on timers rather than computer panels, are more reliable.

Note that any mandated balance pond can passively treat water through detention as with sewage effluent and should be covered to prevent rainwater ingress. However, the preferred approach should always be to use the void space and absorptive capacity of the waste to act as a type of wet weather storage and, in parallel, to convert the mound into a bioreactor to accelerate decomposition. This progressively adds to usable airspace available at the landfill.

This preferred approach greatly reduces the need for expensive leachate treatment plants and the likely discharge of only partially, if at all, treated leachate which can result in significant local environmental harm.[8]

[8] See the following practice briefs Leachate Collection Systems and Lagoon Issues, and Leachate Treatment Plants.

Leachate Collection Systems and Lagoon Issues

Issue

Leachate is one, if not the biggest, environmental issue at a controlled landfill and is traditionally managed by treating in a leachate treatment plant (often incorporating a lagoon system) and then discharged.

Assuming that the recommended approach for aggressively minimizing leachate production is adopted, there is (depending on climate and mass balance) reduced or no need for leachate lagoons.

These lagoons are often expected to satisfy two conflicting roles. One is to provide treatment of leachate prior to discharge, in which case the lagoon should be full to maximize the surface area and treatment capacity. However, the lagoons are often also expected to act as storage facilities, in which case the lagoon should generally be empty to maximize the storage available.

In any case, the use of lagoons in wet climates inevitably results in lagoons filling with rainwater diluting the leachate and creating a major disposal and treatment issue.

Interventions

Leachate Collection Network

Even with good landfill design and implementation, some leachate will form, and it needs to be managed and not allowed to saturate the entire waste mound. This is particularly so at early stages when little landfilled mass is present.

The leachate collection system typically consists of a network of perforated plastic polyethylene pipes, with a minimum of 200 millimeters (mm) in diameter and a high crush strength wall thickness placed within a gravel bed on top of the landfill liner.

The lateral slope of the landfill base bringing leachate across the landfill base to the leachate collection pipes should be constructed at a minimum 5% fall. Leachate pipes should be installed at a minimum slope of 1%–2% and configured such that no part of the landfill is more than 50 meters (m) from a leachate collector pipe.

However, it is preferable to have the leachate pipes at separations of only 20 m (i) to provide some redundancy in case leachate pipes block or are damaged and (ii) to minimize the head of leachate impounded in the waste mound (and thereby minimize the driving head for leakage).

The perforations, slots, or holes in the leachate pipes need to be small enough so that the encasement stones do not enter the pipes, and only part of the circumference of the pipe should be perforated. The pipe is laid so that the perforations are on the bottom of the pipe at about 120 degrees coverage. This arrangement minimizes the inflow of soil and dirt and other foreign objects into the pipes, which may result in blockages. The gravel bed may be protected from clogging by adding an encircling geotextile liner, but this invites the risk of slimes forming during the early acidic decomposition stage blocking the geofabric. A woven geofabric with larger pore sizes is preferable to a needle-punched geofabric.

One design response is to run a lateral drain pipe to the top edge of the site so water can be flushed back down the drain. It should also be understood that local blockages will merely force liquid out into the surrounding gravel to flow past the blockage and back into downstream slots. There is support for allowing smaller fine soil particles into the drains and flushing them occasionally and pumping away until a natural grading occurs around the gravel drains. Using a finer sand over the surrounding gravel also helps this approach.

Generally, the leachate gravel drain should be a minimum of 600 mm square in cross section with the 200 mm diameter slotted leachate pipe placed centrally. Some designs utilize

Uncovered leachate lagoon and landfill cells full after rain event.

just a gravel drain for collection, but this is not accessible for maintenance without exhumation.

Usually, the gravel drain ends up significantly wider than 600 mm at the base as the drain sits on the liner in the shallow vee of the valley. Therefore, the edges settle to the angle of repose, meaning additional gravel has to be applied to the top of the drain profile to achieve a final depth of 600 mm for the gravel.

Leachate Lagoons

As noted, leachate lagoons are often installed at landfills as they are commonly mandated by local legislation. Superficially, this seems an appropriate response to intercept the leachate, but, particularly in areas of medium to high rainfall or areas susceptible to typhoon activity, these lagoons often fill with stormwater. The resulting impounded diluted leachate then has to be managed and is often simply allowed to overflow the lagoon and discharge.

A new approach is to fit a flexible roof to the storage to intercept any rainfall falling on the lagoon. This can be partly supported so that air can flow under the cover to continue evaporation (can be fan forced).

In the idealized contemporary approach to leachate management, little or no treatment or storage lagoon capacity is required. Leachate is simply intercepted in a drainage network as described and directed into a leachate pumping station from where it is either irrigated to encourage grass growth on previously worked areas or onto stones to maximize evaporation area, used to suppress dust, or reinjected at the head of the mound into unsaturated accumulated waste in wet periods.

There is no need to provide large volumes of balancing storage or a lagoon as this is provided within the pore space of the waste within the mound (in an established landfill) and the absorptive capacity of the waste. In the wet season when irrigation is not possible, the leachate level within the mound may rise along with an increase in the moisture content of the waste in the upper levels. This can drive leakage from any weak points in the liner system, so a good liner is needed for such an approach. In dry periods, this reinjected leachate is drawn out and irrigated such that the mound moisture content decreases, as does the leachate level.

Summary

Even with the idealized contemporary approach to landfill design which aggressively minimizes leachate generation, leachate will still form at the base of the mound. This leachate can be directed to the external pump station by providing appropriate grades on the base of the landfill as well as including a suitably designed interception pipe network.

Many countries still require full leachate treatment plants for small to midsize facilities. Quite often, the treatment facility includes lagoons. These are used to perform two conflicting ideals and generally do not perform well on either requirement. In many climates, lagoons merely fill with stormwater, generating a large volume of dilute leachate requiring additional management. The idealized contemporary approach is to utilize the waste pore space and reduced moisture content of the upper levels of the landfill to act as the buffer storage, and to divert stormwater from all but the active tipping face, thereby remaining disconnected from major rain events (Leachate Treatment Plants [pp. 76–78] and Overview of Leachate Management [pp. 72–73]).

Leachate Treatment Plants

Issue

Leachate is the contaminated liquid that forms when water percolates though solid waste. The generation of leachate can be from surface runoff, precipitation, groundwater, and liquid from degradation of the solid waste. Although a well-designed landfill will minimize leachate generation, it cannot be completely avoided.

In some cases, local legislation may mandate the provision of a leachate treatment plant. Hence, landfill designers and operators should have at least a basic knowledge of how to treat this kind of wastewater.

Background

When waste is first deposited, there is air (with oxygen) entrapped with the waste. When it is sealed off by further waste or capping cells, the oxygen is depleted by the high biochemical oxygen demand (BOD) and chemical oxygen demand (COD) of the waste deposited (i.e., aerobic decomposition) and slowly becomes anoxic, then anaerobic.

Aerobic bacteria slowly die off, but this stage can take up to 6 years during which anaerobic bacteria increase in numbers and subsequently methanogenic bacteria start to break down the remaining BOD and COD.

The initial acidic aerobic or anoxic stage is when slime production is greater (and can block any filter membranes), and it also produces odorous gases such as cadaverine and putrescine. The mass-to-gas conversion is far more efficient in the subsequent anaerobic conditions and can reduce waste volume by up to 30%, gaining airspace due to settlement. This is why most modern landfills try to accelerate the start-up of anaerobic decomposition following the bioreactor philosophy by reinjecting leachate at the top of the waste mound.

Initially, leachate in a new landfill is primarily diluted waste products and can have a very high oxygen demand which can overload an aerobic treatment plant. The operating landfill eventually reaches a stable anaerobic state and the waste strength drops. Building a leachate treatment plant early in the process lifetime also makes it difficult to maintain sufficient “food” to the treatment plant.

Intervention

Leachate characteristics vary depending on the type of solid waste placed into the landfill, age of the landfill, precipitation amount, and solid waste composition. Typically, leachate is characterized by a high level of COD, BOD, ammonia nitrogen as well as other ions (calcium, magnesium, sodium, chloride, and sulfate). The typical composition of landfill leachate from new and mature landfills is presented in Table 8.

Table 8 should be treated merely as an example of leachate characteristics. Leachate is highly variable in quality, and it is almost impossible to predict leachate characteristics. If necessary, the leachate information from a nearby landfill accepting a similar kind of solid waste should be taken into consideration. However, it is not a guarantee that leachate characteristics will be identical.

Many leachate treatment plants have failed to perform due to the design data not matching the actual leachate characteristics. Therefore, the designer of a leachate treatment system should take a very conservative approach when adopting design data.

Some key factors must be considered before selecting the leachate treatment plants process, including whether the effluent will be discharged (or reused), effluent standards

Table 8: Composition of Landfill Leachate

Constituent	Value (mg/L)		
	Operating Landfill		Mature Landfill
	Range	Typical	(>10 years old)
BOD_5	2,000–30,000	10,000	100–200
COD	3,000–60,000	18,000	100–500
Total suspended solids	200–2,000	500	100–400
Organic nitrogen	10–800	200	80–120
Ammonia nitrogen	10–800	200	20–40
Nitrate	5–40	25	5–10
Total phosphorus	5–100	30	5–10
Alkalinity as $CaCO_3$	1,000–10,000	3,000	200–1,000
pH	4.5–7.5	6	6.6–7.5
Calcium	200–3,000	1,000	100–400
Magnesium	50–1,500	250	50–200
Potassium	200–1,000	300	50–400
Sodium	200–2,500	500	100–200
Chloride	200–3,000	500	100–400
Sulfate	50–1,000	60	20–200

BOD_5 = 5-day biochemical oxygen demand, $CaCO_3$ = calcium carbonate, COD = chemical oxygen demand.

Source: G. Tchobanoglous, H. Theisen, and S. Vigil. 1993. *Integrated Solid Waste Management: Engineering Principles and Management Issues.* New York and London: McGraw-Hill International Edition.

required, investment cost, operation and maintenance (O&M) cost, and the requirement and availability of skilled labor. Usually, the discharge standard is not achievable with just biological treatment processes (e.g., aerobic treatment such as trickling filter and aerated lagoon, and anaerobic treatment such as upflow anaerobic sludge blanket).

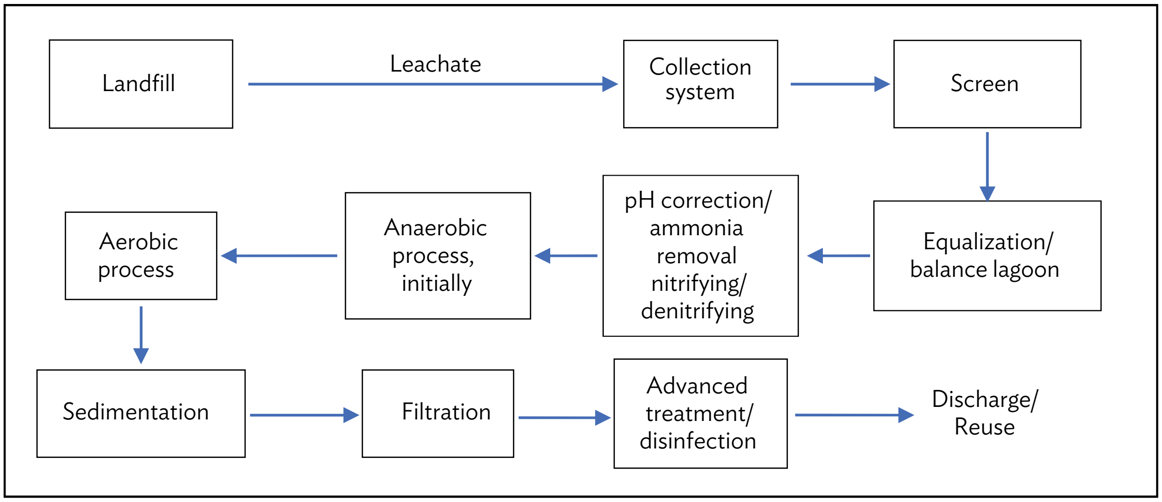
Physical–chemical treatment processes (e.g., coagulation–flocculation, pH control and aeration/ammonia stripping, activated carbon adsorption, and reverse osmosis) are often required as a large fraction of COD in the leachate is comprised of hard to treat COD. Low BOD–COD ratio, high ions, and total dissolved solids also make it even more difficult to apply chemical treatment processes or any biological treatment process. This may well be a reason to reject some liquid waste in certain landfill operations.

Figure 7 displays the general treatment process to be considered for a sophisticated leachate treatment system.

The objectives of each unit process are as follows:

- **Collection system:** to remove leachate such as to minimize the driving head on any leakage paths through the liner.
- **Screen:** to remove large objects and solids that may get into the collection channels or pipes.
- **Equalization lagoon or tank:** to equalize and balance the seasonal variations in incoming flow and provide continuous feed to the following processes.
- **Ammonia removal or pH correction:** to remove ammonia nitrogen from leachate since ammonia prevents chemical precipitation and can inhibit anaerobic bacteria activity. This could be ammonia stripping or an aeration process. It also corrects the pH for later biological processes.
- **Anaerobic process:** to remove strong (generally >2,000 milligrams per liter) biologically degradable materials, but the process may not produce a significant amount of biogas as there are often inhibiting substances. Once

Figure 7: Treatment Process for a Sophisticated Leachate Treatment System



Source: Author.

anaerobic digestion is fully established in the landfill, this process will have minimal BOD reduction effect if there is little infiltration flushing out partially degraded leachate from the waste mound.

- **Aerobic process:** to remove biologically degradable materials (intermittent for nitrifying and denitrifying wastewater) and achieve low BOD.
- **Sedimentation:** to remove settable solids and bacterial flocs, thus decreasing the suspended solids.
- Filtration: to further remove suspended solids prior to any advanced treatment system.
- **Advanced treatment:** to remove residual COD, color, total dissolved solids, and ions. Examples of this process are membrane filtration (ultrafiltration or nanofiltration or reverse osmosis, adsorption using activated carbon), ion exchange, chemical oxidation, etc.
- **Irrigation and spraying:** to reduce leachate by evaporation and to oxidize the wastewater. Partially or untreated leachate may be reinjected back into the waste mass (bioreactor landfill) to bring waste up to field moisture content and maximize wetted area for microbial decomposition.

Some plants, such as the common coconut palm, are very tolerant of high salt loads and can transpire 150 liters per tree when mature. Some grasses are also very salt tolerant and testing of treated effluent should be undertaken to expand disposal options.

Summary

Typically, the investment and O&M costs for this kind of treatment plant are so high that the effluent unit price exceeds the raw water supply cost. Therefore, it is more appropriate to reuse the effluent in the landfill operation process, for example, for truck or facility washing, dust suppression, irrigation of controlled landscaped areas, or, more effectively, in a bioreactor landfill by reinjecting into the waste mass to maximize anaerobic activity in waste breakdown. The plant operators need to have a sound knowledge of the principles of each unit process to be able to operate and maintain the system properly. This can be overcome by seeking private sector technical input, but obviously this potentially increases O&M costs.

There are not many leachate treatment plants operating correctly in the developing country context because of the high O&M costs and a lack of local operator skills. The preferred approach is always to absolutely minimize leachate generation through proper landfill design and operation, reject difficult-to-treat wastes especially excessive liquid wastes, and adopt recirculation and irrigation of untreated leachate through the landfill mass wherever possible (Overview of Leachate Management [pp.72–73] and Leachate Collection Systems and Lagoon Issues [pp.74–75]).

Stormwater Runoff Management

Issue

Leachate is potentially one of the main environmental impacts from a landfill. The site layout and landfilling operation therefore must be designed to minimize the contact of surface water runoff and percolating rainwater with the waste, as well as to maximize the vertical separation of the waste above the groundwater table.

The drainage systems must therefore ensure that the rainwater falling external to the site is diverted around the landfill mound and also the rainfall within the site, wherever practicable, does not come into contact with waste or mix with leachate.

Failure of either of these will result in excessive leachate generation and escalated environmental management concerns and the potential for harm.

Concrete perimeter stormwater drain.

Interventions

The site's waste mound should not be located within a major drainage valley, especially one with a large catchment external to the site. If this is unavoidable, then the landfill can only be developed if the stormwater flows within the valley feature which can be diverted around the landfill mound.

This is often feasible if the soil that needs to be excavated to provide the diversion channels can be stockpiled for use as cover material within the mound.

However, if the valley feature is particularly steep, the only solution is to place a pipe or culvert running underneath the landfill. This is very much the last resort as enclosed drains under a landfill are a potential major hazard. This is because the pipes are often damaged during landfill operations or with settlement and can therefore block, resulting in flooding both of the entire landfill site and perhaps of neighboring properties.

These damaged pipes can then allow floodwater to enter into the waste mound forming excess leachate. This leachate can then permeate back through the damaged pipes during drier periods allowing leachate to escape the site.

In summary, unless the stormwater can be readily diverted around the ultimate waste mound, a new site should be investigated.

If the local soils are friable, the diversion drains will need to be protected against erosion at entry and exit as well as inverts by using vegetation, rock riprap, concreting, or other means.

Floodplain Areas

The other extreme is when the landfill site is within the floodplain of a river or stream. Generally, a landfill should not be located on land which is inundated by a 1-in-10-year flood event. If this is unavoidable, then the entire perimeter of the waste mound, and preferably the landfill site, should be protected by an earth bund of sufficient height to prevent inundation of the site by floodwater. This should be a last resort as it will create significant costs for the construction and maintenance of the perimeter bund and will also cause ongoing maintenance issues with water being trapped in the site following local direct rainfall or snowfall.

If the landfill is a small operation and there are no buildings or other infrastructure on the site, an alternative approach is to merely ensure that the waste mound is completely surrounded by soil bunds up to the 1-in-10-year flood level. The soil mounds can protect the landfill against inundation. However, an all-weather access road constructed above this flood level will also be required to allow the landfill to be operated during flood events. In many cases, the cost of this elevated access road and significant site bunding will be prohibitively high. Nevertheless, the key message is that it is possible to develop a satisfactory landfill on a floodplain, provided there is sufficient commitment to installing the necessary engineering interventions.

A landfill should not be located on land which is inundated by a 1-in-10-year flood event

Summary

Managing stormwater is a key aspect of good landfill design and operation. If stormwater is not managed correctly, it can come into contact with the waste and result in large volumes of dilute leachate forming. These large volumes will overload any leachate management system, thereby potentially resulting in environmental harm.

The key element is the separation of uncontaminated stormwater flows from leachate at all times.

Landfill Gas Management

Issue

In addition to leachate management, landfill gas management is a critical component of controlled landfill design.

Gases found in landfills are composed mainly of carbon dioxide and methane, and minor amounts of ammonia, carbon monoxide, hydrogen, hydrogen sulfide, nitrogen, and oxygen, as well as many other trace constituents. In the early stages where aerobic bacteria still survive, gases such as putrescine and cadaverine as well as acid slimes can be produced. This is one reason the acceleration into anaerobic decomposition by recirculation leachate is desirable. During peak periods of anaerobic decomposition, the landfill gas reaches methane concentrations of about 50%.

Landfills are the third-largest source of anthropogenic methane in the United States. According to the United States Environmental Protection Agency, landfill gas comprises 17.7% of all methane emissions in the country. There are no reliable data relating to the context of developing countries, although this is expected to be lower but still significant.

Organic matter such as food scraps is a significant contributor, as is unprocessed green waste. Lower-income countries tend to have greater numbers of domestic animals and less waste produce, thereby contributing less to gas generation. Asian diets, which are potentially high in fats, tend to generate more gas.

Landfills accepting organic waste as part of the municipal stream continue to generate gas for up to 20 years after closure.

Interventions

Safety

Concerns about explosions due to landfill gas buildup are unfounded if the landfill is operated correctly. Landfill explosions only occur where there is a void which fills with

Landfills are the third-largest source of anthropogenic methane in the United States

landfill gas and mixes with air in the explosive range of 5%–15%. Internationally, explosions have occurred as a result of gas leaking into nearby fault lines or cracks in clays, into underground sewers, or into old vehicle bodies or water tanks and the like that have incorporated into the waste mound and are not crushed or cut up. (Such items should be recycled in any case.)

Provided that the landfill is operated correctly with regard to avoiding void formation, passive release is safe, directed through the uppermost layers to the atmosphere, even if less than ideal environmentally.

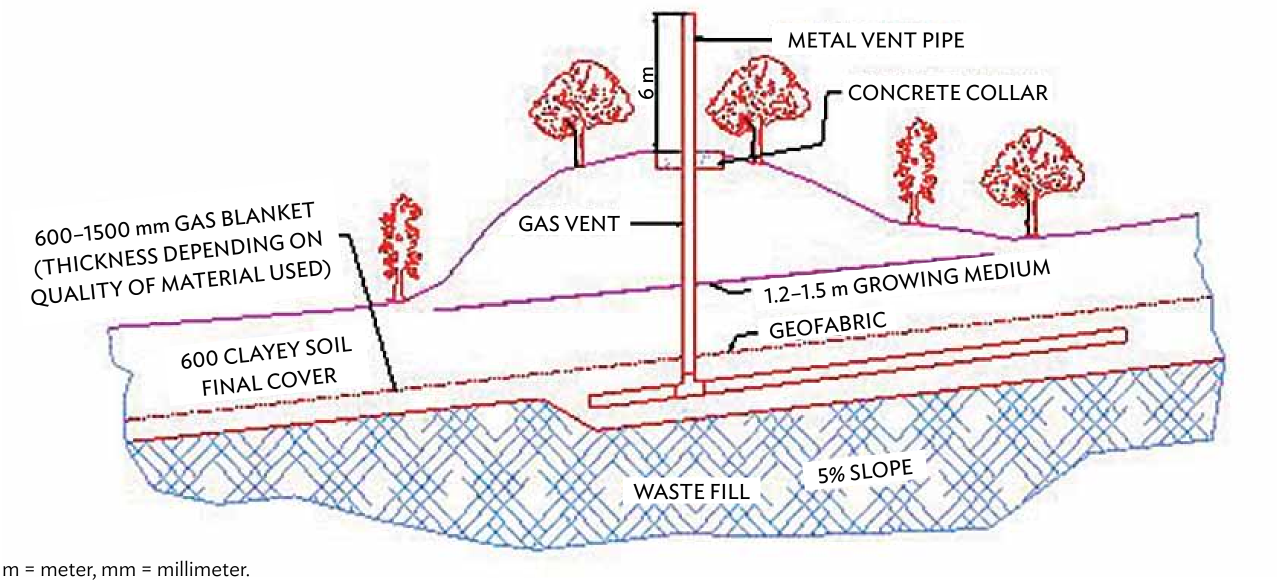
Interception Options

There are many options for landfill gas management.

Passive release through the final 600-millimeter (mm) thick final cover is safe, but the methane will contribute to greenhouse gas emissions (Figure 8). This is all that should be provided at the smaller landfills (in the order of less than 100 tons of waste received per day) unless future legislation requires all landfill gas to be collected and flared or the municipality wishes to oxidize the methane using a flare system for environmental reasons (as a global community contribution).

Note that if trees are intended to be placed on the remediated landfill cap, methane under the liner cap can fill soil voids and poison the tree root zone. Gravel or geofabric "wick" drains to discrete discharge points may be needed to support plantings after closure.

Figure 8: Local Gas Blanket Intercepter



m = meter, mm = millimeter.

Source: Author.

The next option at the present time for larger landfills is placing a gravel blanket under the top third of the final clay cap. The required thickness depends on the material used (Table 9).

Table 9: Required Thickness for Different Materials of Gravel Blanket

Material	Nominal Grading (mm)	Blanket Thickness (mm)
Crushed rock	20	300
Granulated tires	10–20	450
Shredded tires	100	600
Broken tiles, bricks, cobbles, gravel, etc.	10–100	450
Concrete, bricks, tiles, gravel, etc.	10–200	600
Rubble, bricks, concrete, tiles, etc.	10–450	1,000

mm = millimeter.

Source: Author.

A number of 6-meter (m) long vent pipes should then be installed at the top of the landfill to release the gas from the blanket. The collected gas will, therefore, not significantly penetrate into the cover material, which can lead to vegetation dying off. This is the main advantage of the passive venting system.

At a later time, an extraction system be can be connected to the vent network and fan, from which the gas harvested can be flared if desired or required. A typical flaring system costs in the order of $350,000 and needs a power supply or diesel motor to energize the vacuum pumps.

Theoretically, 1 million tons of active landfill waste emit enough landfill gas to produce 0.7 megawatts of electricity

The ultimate solution is to install 150–200 mm diameter slotted pipes in vertical circular wells 1 m in diameter filled with gravel, at about 25–50 m centers. The wells only penetrate into the top two-thirds of the waste mound, so these are not installed until the landfill is well into development. These are then connected into a manifold and the gas either flared or reused productively for power generation.

Theoretically, 1 million tons of active landfill waste emit enough landfill gas to produce either 0.7 megawatts (MW) of electricity or 216 million British thermal units of heat. Because waste effectively produces landfill gas for approximately 20 years, this means that 50,000 tons of waste per year is required to maintain gas production equivalent to a 1 million ton active landfill. This gives a ratio of approximately 120 tons of mixed waste a day, which is theoretically capable of producing 0.5 MW of electricity.

In reality, however, unless the landfill is very well sealed, is well operated, has the correct moisture content profile through the mound, and is not subject to significant organic waste

Installation of landfill gas pipes.

Landfill gas field.

diversion, the actual amount of electricity produced will be substantially less than this "theoretical maximum." In fact, a general rule of thumb is that a municipal landfill receiving anything less than 500 tons of waste a day, and with significant organic content, will not attract commercial interest in providing power generation facilities.

It is also important to understand the gas production curve (the yield gradually decreases over time) in order to fully address the economics.

Costs vary greatly, but internal combustion engines smaller than 1 MW typically cost $2,300/kilowatt (kW) to install with annual operation and maintenance costs of $210/kW, and engines larger than 800 kW typically cost $1,700/kW to install with annual operation and maintenance costs of $180/kW. Revenue depends on electricity buyback rates that are specific to local electric utilities. Until recently, gas turbines were inefficient for small-scale power production. However, with the advent of high-speed alternators, this has become the preferred direct method to generate power from biogas.

Summary

Since any one or a combination of all of the described treatments and controls can be implemented at a later date without detrimental effects, there is no need to make a final decision on landfill gas management matters in the initial design phase.

If gas reuse becomes more economic or mandatory in the future, vertical wells can be retrofitted into the mound to maximize gas recovery rates for commercial activity or methane destruction by flaring.

Layout and Cell Development

Issue

It is critical that waste is not just dumped anywhere on the site. Every load must be placed according to the site development plan and within the part of the cell constructed for that day's waste.

Therefore, the landfill cell infrastructure development must be done ahead of waste delivery with all operational elements completed and available, in all weather conditions.

Cell staging over the landfill life.

Interventions

Site Layout

A suitable site layout must be developed and will principally be driven by the footprint of the actual waste mound and how it relates to essential site infrastructure, such as how external stormwater can be diverted and access roads can be installed.

The site layout must account for the ultimate mound footprint, leachate pond(s), any mandated buffers, buildings, perimeter access roads, recycling areas, cover stockpiles, vehicle parking and maintenance areas, groundwater monitoring wells, stormwater diversion drains, weighbridge and entrance office (if a weighbridge is to be provided), generator buildings and fuel tanks, perimeter fencing, and so on. (The excavation depths required to win cover must not violate the vertical separation distances between the base of the landfill and the groundwater table level.)


Cell base preparation.

Normal road drainage should be provided for the perimeter access roads which should be gravel sealed. The main entrance road into the landfill and up to the buildings should be bitumen sealed as this is in a permanent location. Access to the landfill by landfill compactor vehicles requires a specialized strong pavement to carry the vehicles regular passage. Active tipping face layouts need to feature turning circles suited to

Internal access road.

maneuvering all fleet vehicles used on-site and in the numbers arriving to avoid queues. One-way circulation from entry to exit should also be addressed as well as resident self-haul transfer station skip bins or similar to prevent small vehicles and residents on foot from accessing the active tipping face.

Cell Development

Each cell must be set out carefully to optimize the operation of the site. For each cell, several things need to be carefully considered:

- Access for the collection trucks and commercial trucks, for the life of the cell particularly temporary all-weather pavements and gradients less than 10%;
- Access prevention for the general public to the tipping face via a transfer operation or scavenging area at the site;
- Access for the tipping of cover material;
- Stormwater drainage so that water does not enter the waste and no ponds are formed, hence access roads can remain open;
- The slope on the top of the cell and sufficient area for vehicles to reverse and drive out without unacceptable queuing;
- Where the next cell is to be built, and connecting it to the leachate collection system, and removing it from the stormwater diversion system as it is commissioned;
- The length of the cell and adequate area for plant and trucks to operate;
- Haul distances for cover material;
- The amount of waste to be put in the cell; and
- Leachate collection.

Survey

Before filling of any cell is started, the area must be surveyed to allow monitoring of the amount of airspace used. The area required for each phase of the cell should be at least enough to allow for 1 month of tipping. It is useful if the grid used for GPS coordinates and levels remains the same over the operating life. This allows for more accurate calculation of layer thicknesses and airspace changes.

Installation of Liner

The liner (clay or otherwise) must be installed ahead of waste placement, but should also not be placed too far ahead to avoid the liner becoming damaged by weather or traffic, or dry out (if a clay liner) (Lining Systems [pp. 69–71]).

Stormwater Runoff Management

Stormwater runoff at all landfills is one of two types: clean or dirty.

Clean stormwater is water running over undisturbed areas of the site, such as areas of the site still not cleared, previously worked areas that have been covered with soil and fully revegetated, hardstand areas such as parking areas, and building roofs.

Dirty stormwater is rainwater runoff from active dumping cells, previously worked areas of the site that have not been fully revegetated as yet, cleared areas of the site awaiting development as waste cells, and dirt access roads.

The aim is to keep the two types of stormwater separated at all times, as clean stormwater should be directed straight off the site without treatment of any sort. Dirty stormwater is usually allowed to also flow off the site untreated, but future permits may require it to be directed through a settling pond to collect the first flush runoff (about 10 mm of runoff) or a silt trap prior to flowing off the site.

Placing stormwater main collectors at the perimeter batters of the landfill allows for sequential connection of runoff drains from intermediate cappings and will save relaying costs for pipework. Shallow (bedded in sand) or surface-mounted high-density polyethylene Victaulic-coupled pipes can be salvaged and relocated as the mound rises higher.

Neither type of stormwater should ever be mixed with leachate (Stormwater Runoff Management [pp. 79–80]).

Construction Staging and Placement

Clean stormwater diversion drains or bunds must always be constructed upslope of the active cell to stop rainwater runoff entering the cell. This is to minimize the volume of water contacting the exposed waste prior to covering.

The area should be stripped of all topsoil, which must be stockpiled for use later in rehabilitating the site, usually as the top layer of the final cover. The stockpile should be placed in an area that has been marked on the site management plan.

If site material is to be used for cover, the cell area should be dug out to the finished depth, so that it drains to the leachate system or a drainage sump, and a pump should be installed to pump all water out of the cell to the leachate system. The spoil should be stockpiled near the cell for use as daily cover and the access roads constructed to minimize haul distances.

If the new cell is to be built on top of the older cells, any areas of excess cover should be stripped and stockpiled for daily cover use. Stripping off old cover layers should only be performed on areas about to receive waste and not left exposed. This allows better movement of landfill gas through the waste mound and also reduces the quantity of cover material required.

Leachate Collection

The leachate collection system should be installed and inspected by the supervisor or nominee before placement of any waste in the cell. Inside the cell, the floor must be uniformly graded and all water that contacts waste must be collected and directed to the leachate system. A vertical precast circular manhole is a good option for the pumps, as it can be set on a strong sealed concrete base at the lowest point of the landfill and successive ring segments added as required.

All stages of landfill development and site utilization must be planned and timed to match the airspace requirements of the incoming waste loads

Access Roads

First, the access road should be constructed to the start (head or top) of the cell. The road should approach the current tipping area by going over previously covered waste or native soil. It should not require vehicles to drive over uncompacted and uncovered waste in normal operation.

Access roads will need to be incorporated and progressively relocated as the landfill mound changes in shape and height during its life. Road slope should be less than 10% but with short lengths up to 15% being acceptable. The roads must be wide enough to allow two vehicles to pass even on one-way roads, in case one vehicle breaks down or becomes bogged. If the roads can be made one-way, this is better for safety. The speed limit on all areas of the site should be restricted typically to 20 kilometers per hour and slower at the tipping face.

The road should be planned so that, as the cell grows, the access road can be extended. The access road should be about 8 m wide (6 m for one-way traffic) and drainage constructed so that the road does not become boggy.

The access road should be constructed to the cover stockpiles. The road, which should be 6 m wide, should preferably be apart from the cell access road to help reduce traffic problems.

Recycled and recovered crushed concrete and brick waste can form these roads, supplemented as required for the climate. Larger shredded wood waste can be useful.

Summary

All stages of landfill development and site utilization must be planned and timed to match the airspace requirements of the incoming waste loads.

Once the general site layout has been agreed, the staging plans and site development staging must be implemented in an integrated manner.[1]

[1] ADB. 2017. *Landfill Operations Manual.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20170301/sample-landfill-operations-manual

Overview of Cell Operation

Issue

Most landfills fail due to poor operation rather than poor design. Still, even a very poorly designed landfill can be made to operate relatively effectively, provided certain guidelines and fundamental objective criteria are followed.

Interventions

Sequence of Filling

The sequence of filling chosen should satisfy the following key issues:

(i) Place waste fill progressively from the top or "head" of the catchment toward the eventual final outlet.
(ii) Allow the progressive shedding of surface water as the landforms are built and eventually merge.
(iii) Allow the ready diversion of external catchments around the various stages of filling.

Staged Filling Sequence

The staged filling sequence should be detailed in the site development plans and kept in the site manager's office.

It should be noted that as each stage reaches its "final" shape, it will be covered and the "external" perimeter slopes mulched and/or grassed to allow direct shedding of surface water into the adjoining catchments (Figure 9).

If there is going to be a long time frame involved before the temporary slopes are amalgamated, these slopes should also be mulched and/or grassed to control erosion and siltation.

The cover depth should be increased to 300 millimeters (mm) for intermediate slopes. Intermediate slopes are those not covered on a daily basis, for up to 6 months, but will eventually be covered with more waste.

When truckloads of waste are tipped at the landfill, the best method of spreading is to "eat" the sides from the pile, not push front on

The method of construction recommended for the development of soil berms up the interior slopes of each stage uses excessive soil, but this material will be recovered as fill and it will eventually be placed against these batters.

Spreading Waste

When truckloads of waste are tipped at the landfill, the best method of spreading is to "eat" the sides from the pile, not push front on. To try and push the whole of the load will not give good compaction and consumes a lot of fuel.

The dozer blade should have waste about half way across and the waste pushed up and across the face in layers less than 600 mm thick.

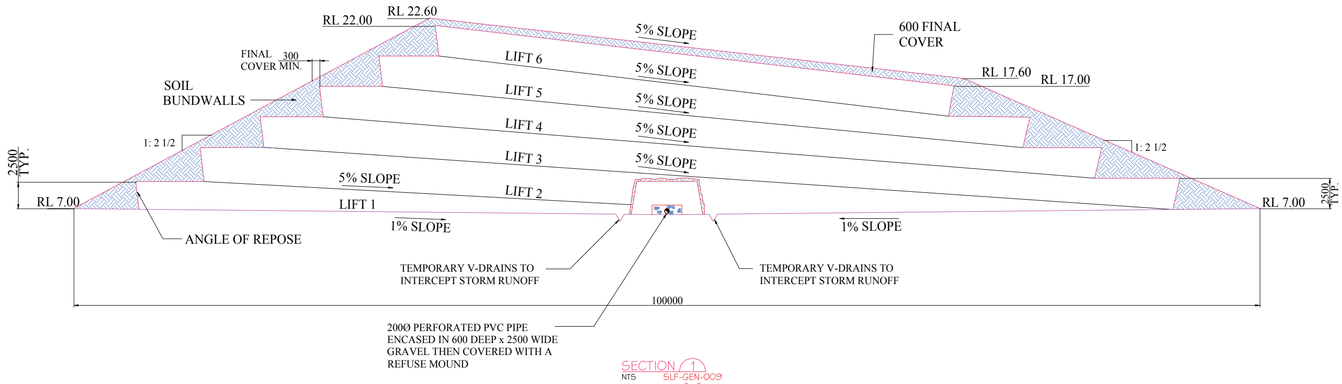
Daily Cover

At the end of each day, the tipping face must be covered.

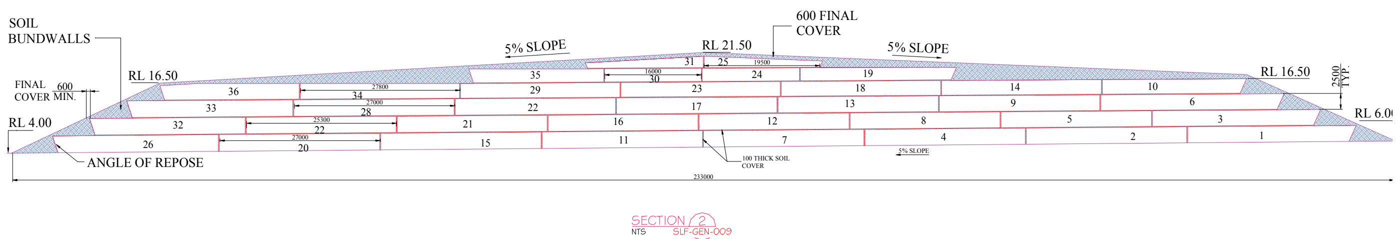
To make covering easier, the face must be fully compacted and as smooth as possible. Unevenly compacted waste surfaces use extra soil to provide the minimum thickness of cover.

Cover material, which is delivered to the cell site, should be tipped near the top of the tipping face and, if available, a dozer should be used to spread out the material as soon as the face

Figure 9: Cross Section through Stage 1 (top) and Cross Section through Final Landfill (bottom)



CROSS SECTION THROUGH STAGE 1



CROSS SECTION THROUGH FINAL LANDFILL

Source: Author.

reaches final height. A compactor is not efficient at spreading cover.

The daily cover thickness should be 150 mm and should be spread and compacted with about 3–4 passes.

The best cover material is sandy clay since this seals the top to stop rainwater getting into the waste, and yet will not dry and crack in hot weather. Daily cover will admit some rain in any case, so compost or shredded green waste is an option which allows ready transmission or repumped leachate from higher cells in a bioreactor landfill operation. Pure clays interfere with reinjection efficiency and methane gas harvesting.

Effective Use of Equipment

All equipment must be properly inspected each day and serviced when required. All problems with equipment must be reported to the site supervisor. In particular, one problem to avoid is overcompaction. This only consumes more fuel and people's time.

To efficiently use equipment, follow these guidelines:

- Waste is spread in layers less than 600 mm thick.
- Each layer should be given 3–6 passes. The best compaction is five passes.
- Each lift should be between 2 m and 3 m high.

Applying soil cover material.

- Compactors give higher compaction than bulldozers.
- Big heaps of waste should not be pushed as they eat away at the sides of heaps.
- If there is not much waste arriving at the face, equipment should be parked and compacting should be discontinued.
- Compactors are not efficient at spreading or excavating cover.
- Bulldozers should be used for spreading cover.

Compacting waste using bulldozers.

- A Drott or four-way dozer blade can be useful to move large objects during operations.
- The width of the face should be kept to the minimum necessary to avoid queuing of tipping vehicles.
- Two faces may be necessary to allow organized waste pickers. One option is to utilize a self-haul and small truck tipping transfer pit to one side of the landfill active face. Compactor trucks access the tipping face as well as compaction plant and dozers, but public and small vehicles tip in a transfer pit or series of skip bins which would keep scavengers away from reversing heavy plant. The skips can be lifted by hook truck or large front loader with quick hitch for transfer to the tipping face.
- To get better compaction waste should be tipped at the bottom of the face and pushed up and across the face.
- Cover material should be tipped at the top of the face.

Summary

Landfill operation is not difficult provided that certain guidelines and operating procedures are followed. If they are, the life of the landfill is maximized, operating costs minimized, and socio-environmental benefits will be achieved.[2]

[2] ADB. 2017. *Landfill Operations Manual.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20170301/sample-landfill-operations-manual

Waste Compaction

Issue

It is critical that waste is not just dumped anywhere on the site. Every load must be placed according to the site development plan and within the part of the subcell constructed for that day's waste.

The waste must then be placed at the designated tipping face and pushed, compacted, and then covered in the most efficient manner. At many landfills, waste is not managed effectively or efficiently, thereby costing valuable airspace and consuming additional fuel.

Interventions

When waste arrives at the landfill, it is only lightly compacted (loose in trays typically 140–250 kilograms per cubic meter [kg/m^3]). In compactor trucks, waste can be compacted typically up to 450 kg/m^3. In transfer trailers, waste can be compacted to around 300–400 kg/m^3. If the waste is dumped in the cell and is not carefully compacted, it can take up to 2–3 times the volume of well-compacted waste. Poorly compacted waste causes many other problems including more litter, more odor, more vermin problems, extra leachate, damage to vehicles because the roads are not as smooth, and drainage problems.

In addition, the site will continue settling for many years making it difficult to keep the final landform. Also, the site will be difficult to develop for other uses.

To achieve the optimum compaction, there are a number of things to consider:

(i) The most important point for good compaction is the thickness of each layer of waste. If the layers are thicker than 0.6 m, it does not matter how many times the waste is compacted, the density will not get any better.

(ii) The second most important point for good compaction is the number of passes made over the waste. Each layer should receive a minimum of three passes. For the best compaction, five passes are required. If more than five or six passes are made, the density will not be increased.

(iii) The type of plant used for compaction will also affect compaction. If possible, a purpose-built waste compactor should be used. If a bulldozer is used, the layers should be kept thin and the face steeper than for a compactor.

(iv) The width of the face should be kept as small as possible. The width required will depend on how many vehicles are at the tipping face. For an efficient operation, vehicles should not be kept waiting to tip. The width of each face for each cell will need to be judged when the landfill starts. However, as a general guide, a 25 m face should be more than adequate. The tipping face should not be wider than 25 m. Each lift should be 2–3 m high.

(v) All waste should be tipped at the bottom of the face and pushed up and across. This pushing uphill helps to compact the waste further. Pushing waste down or over the face does not achieve the compaction essential to the efficient running of the operation.

(vi) If a tracked bulldozer is being used to compact waste, the tipping face should be kept at a slope of 1:3. This high slope will help the tracks to break up and cut the waste as the dozer climbs up the face.

(vii) If a compactor is being used to compact the waste, the tipping face should be kept relatively flat at 1:8 or 1:10. The compactor does not need a steep slope to break up the waste as the teeth on the wheels are designed to do this. The much heavier weight of the compactor is best at compacting waste if the slope of

Compacting waste using a landfill compactor on a flat area.

the face is fairly low. Compactors should not operate on faces steeper than 1:4.

(viii) The top of each cell should drain away from the tipping face, either to one side or toward the start of the cell (minimum slope 5%).

(ix) Determining the level of compaction achieved is possible using a truck and weighbridge. The placed and compacted waste is reexcavated from the landfill working face into a preweighed empty tipper and weighed. This gives the mass of the excavated waste. Sand is used to fill the truck completely to a known volume and weighed. The sand is used to fill the excavated hole and the partially full truck is then reweighed, which gives the hole volume from the portion of sand consumed. The density is then calculated. Typically 600 kg/m^3 is a minimum target and 750 kg/m^3 is good performance on firmer surfaces for urban waste streams. Up to 1,000 kg/m^3 is possible in ideal circumstances.

Summary

All stages of landfill development and site utilization must be planned and timed to match the airspace requirements of the incoming waste loads.

Efficient use of equipment and achieving the required compaction effort is critical for numerous operational reasons, including maximizing airspace, managing leachate, facilitating access road construction, and minimizing cover material requirements.[3]

[3] ADB. 2017. *Landfill Operations Manual.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20170301/sample-landfill-operations-manual

Litter Management

Issue

Litter on-site can result in safety concerns as well as the obvious aesthetic and environmental impacts.

Excessive litter also indicates to the site users that the landfill operators are not committed to achieving a high standard of operations and this reflects poorly on the municipality.

In addition, off-site litter reflects badly on the operator and municipality, as well as presenting potential socio-environmental impacts.

Interventions

Litter control is required on all areas of the site.

Litter is best controlled by source reduction, achieved by proper placement of waste, correct working and compaction, and then covering with soil as per the specified frequency in the site license conditions.

Tipping Area Litter Fences

Movable litter fences should be positioned on the downwind side of the tipping face about 50 m from the edge of the tipping face. They should form a curve in the horizontal plane, slope inward and have no gaps.

The length of the fence (usually chain wire) depends on the size of the tipping face, but should be wide enough to allow for changes in wind direction. The litter fence should be cleaned every second day, or daily in windy weather.

Boundary Fence

The boundary fence will help stop trespassers and keep litter inside the site. The boundary fence (or outer litter fence) should be cleaned each week, or more frequently in windy weather. Where scavengers and pickers are allowed on the site, this work could be paid by volume or rotated between pickers for an agreed fee.

Litter control is required on all areas of the site

External stormwater drains washing litter off-site.

Where pickers exhume waste searching for recyclables and cause litter to be blown over the site, an agreement on cleaning up should also be reached with those pickers, or a dedicated litter-controlled picking area set aside at a distance from the active face.

Access Roads

Litter is often dropped from loads on the way to landfills and is sometimes dumped near the site by people arriving when the site is closed.

Litter fences.

Litter on access road to landfill.

The approach roads within 200 m of the site should be kept free of litter (or other distance as may be subsequently required by the site license). This will require litter collection by hand to be undertaken each week.

If a large amount of litter is found on any day, it should be reported to the site supervisor who will arrange for a special cleanup.

All staff should try to "catch" illegal dumpers and get them to pick up their waste and dispose of it legally. Often, waste left at the gates out-of-hours will contain envelopes and discarded mail addressed to the litterer.

If intercepted on-site and they refuse to clean up their litter, as much of the following information as possible should be collected and reported to the site supervisor:

- Name
- Address
- Vehicle registration number plate
- Vehicle type
- Vehicle color
- Date and time
- Type of material
- Amount of material

If possible, photographs should be taken of the vehicle and people dumping illegally.

Any material found on the access roads should be cleaned up each day before the site is closed.

General Site

Overall, litter in and around the site should be managed. This includes spilled liquid from engine changes or drum spills. This should be cleaned up with dry powder, such as sand or sawdust, in the first instance. Personal protective equipment should be worn, particularly if the liquid is of unknown chemicals.

Summary

Poor litter management reflects badly on the landfill operator and the municipality, as well as presenting a safety and socio-environmental impact. Appropriate interventions are easy to implement and inexpensive, but can garner significant public support and acknowledgment for an aesthetically improved facility.[4]

[4] ADB. 2017. *Landfill Operations Manual.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20170301/sample-landfill-operations-manual

Fire and Pest Management

Issue

Poorly run waste disposal sites are often identified by the presence of fire and/or excessive numbers of pests, disease vectors, and rodents.

Even a very poorly designed landfill can be made to operate effectively, provided certain guidelines and fundamental objective criteria are followed.

Interventions

Fire Control

Notification Procedure

As with any proper landfill, purposeful lighting of fires at the landfill should be banned, as should be smoking anywhere on the site, or at least at the active tipping face and near any flammable materials such as plastics stockpiles.

Fires usually occur because of chemical reactions from hazardous chemicals, autocombustion, or composting wastes in the landfill. The landfill gas supports ongoing burning, provided oxygen is present.

When smoke is found coming from the landfill, the site supervisor must be immediately notified. Under no circumstances is the fire to be put out by the operator if there is no other person present. The site supervisor will decide what action to take. If the fire is over a large area, the site supervisor will contact the fire brigade.

Firefighting Procedure

Unless the fire is in a discrete surface pile, such as tires, flooding the waste mound with water hoping to extinguish the fire must be avoided where the only evidence of burning is smoke emission at the surface. There is no guarantee that the fire is directly under the smoke emission, so applying water at the surface may not reach the source of the fire. In fact, this rarely succeeds and will only form large quantities of leachate.

The best method of putting out a deep fire is to open up the landfill and spread out the burning waste

Fire truck permanently stationed at a major landfill.

Major landfill fire being exposed for extinguishing.

Flies on equipment at a landfill and major bird control issue at a poorly run landfill.

The best method of putting out a deep fire is to open up the landfill and spread out the burning waste. Before the landfill fire is opened, the site water tanker should be brought to the area and checked to ensure it is in operating condition.

Operators must take extreme care when fighting fires with earthmoving equipment because exposing buried waste to oxygen may ignite more fires. All major plant equipment must have a fire extinguisher ready for use.

Any plant equipment in poor condition must not be used, especially if there are any oil leaks as the vehicle may catch fire. Or, if the plant is in need of service, it may break down putting at risk the operator and the equipment.

The waste mound should be opened near the smoking area and the dozer will then push the waste well away from the point of fire. The burning waste is spread out on the surrounding cover and either put out with the site water tanker or buried with cover material. When the fire is put out, the material should be reworked to ensure there are no hot spots before it is reburied.

Pest Control

On a poorly run site, there can be a number of pests including the following:

- Birds such as seagulls, ibis, and pigeons.
- Flies can be a major problem if the working face is not covered quickly.
- Rats live at nearly all landfills and can breed into large populations if not controlled.
- Feral cats, dogs, cattle, goats, and pigs are often found on landfills (country specific) and should be controlled, especially as the cats will prey on native animals and the dogs can form packs.
- Mosquitoes and other insect pests can use stagnant and water-filled containers to promote microbreeding and present a risk for dengue or malaria and other diseases.

The best method of control of all pests on a landfill is to operate the site properly. If the waste is properly compacted and quickly covered and the tipping face is covered each night, the pests find it difficult to feed and will go elsewhere. Where animal owners see the landfill as free grazing or do not control their pets, the animals should be impounded for a fine or sold to cover costs of removal. The boundary fence is a major control measure for larger animals and should be kept in good repair.

Well-compacted waste will make it difficult for rats to find cavities, and access to the waste is difficult if the cover is properly applied. Cover material and crushing containers should limit stagnant water for mosquito breeding. Uncontrolled feral dogs and cats can be shot or poisoned if other measures fail.

Many methods are used to control birds, including poison, scare guns, wires between high poles, nets, noise, eagles and hawks, and even whips. None are completely successful but can be of some use if birds are a major problem.

Rats are difficult to control and it is common to employ a contractor to lay poison to keep the population under control if numbers become excessive. Typically, the contractor comes each day that rubbish trucks deliver to the site. If the landfill accepts a lot of solid waste and little kitchen waste, baiting may only be required twice a week. Regular compaction will kill rodents at the active face.

Summary

A well-run landfill will control fires and pests by default as part of the day-to-day operation, preventing either becoming a major problem.

Both issues do not require special interventions in most cases, provided that normal operations are ongoing, such as correct procedures for waste placement, profiling, compaction, and covering. Only in unusual situations is there a need for special interventions such as bird, mosquito, or fly control.

Fire control is critical at landfills and the appropriate methods of extinguishing deep fires must be observed for safety reasons.[5]

[5] ADB. 2017. *Landfill Operations Manual.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20170301/sample-landfill-operations-manual

Waste Pickers or Scavengers

Issue

Waste pickers or scavengers are common at many dumpsites in developing countries, and in some developed countries as well. Legislation in many countries bans this activity at engineered landfills. Instead, they specify that materials recovery facilities (MRFs) should be provided.

In reality, these MRFs fail at a disappointing frequency when trying to recover recyclables from a fully mixed waste stream. Most operate in series to remove individual materials and a breakdown in any component stops the whole facility, with incoming waste then stockpiled or stopped. High-technology components need significant skills to maintain. Greater success may be with human pickers on a conveyor belt, but this is generally where separate curbside recycling collections are undertaken. Unless the waste source is completely segregated, these facilities will struggle to operate successfully, which has been the usual experience to date. A better approach is to allow scavenging but to introduce structure to the process as well as livelihood and safety improvements.

One exception is fully presorted waste, such as processing only dry waste from a commercial area, which can be mechanically sorted for producing refuse-derived fuel (RDF), for example.

A better approach is to allow scavenging but to introduce structure to the process as well as livelihood and safety improvements

Interventions

Background

The approach depends largely on the throughput at a landfill. Larger landfills with dedicated landfill compactors and heavy dozers constantly driving forward and reversing, with limited visibility, and with compactor trucks reversing in to the tipping face do not want semitrained pedestrian scavengers darting in and out to reclaim certain items. An alternative, as adopted in Manila, is to form the scavengers into associations and allocate truckloads of waste to certain associations to avoid too many scavengers attempting to access the individual loads. Furthermore, the tipping face can be split into two areas such that scavengers have access to waste on one half the tipping face while the operating equipment is pushing, leveling, and compacting waste in the other half of the active tipping area. After an agreed delay, typically 20–30 minutes, the scavengers relocate from their previous location and move to the second area where fresh waste will have been deposited on the compacted waste. The heavy equipment then moves to the first tipping area to level and compact the waste piles which have just been picked over. This avoids most conflicts between waste pickers and heavy equipment on-site.

The compressed and ejected waste plug in a compactor truck is also harder to split apart to search for recyclables than loose loads in tippers or trailers.

Given that larger cities will most likely need to restrict scavenging at the active face, other strategies to allow scavenging may be needed. The practice brief on Recycling (Chapter 4) notes that much scavenging is done at home and at curbside, particularly where agents travel to neighborhoods to buy recyclables. It is also common for open truck collectors to sort materials in the rear of the truck to be dropped off at recycler depots along the road to the landfill. Collection in compactor vehicles stops this activity, but these fleets are needed to save on fuel costs in hauling waste to a more distant landfill site.

Dangers to waste pickers sorting waste.

A cooperative of scavengers picking waste.

Introduction

Scavenging schemes can be successful even in developed countries, such as the Revolve scheme in Canberra, Australia. In this type of scheme, a community group has a designated area of land set aside at the landfill for the receipt and sale of reusable items. Other cities establish “dump shops” at or near the landfill to sell recovered items. These schemes can be operated in a safe and sensible manner to avoid health risks and manage safety issues.

The alternative of a mechanized materials recovery facility is really only appropriate with segregated or selected waste. The likelihood of sustainable waste segregation is discussed elsewhere.[6]

The most common approach is to allow scavenging but to introduce some rules, such as not allowing entry by children, and to provide some training on the health risks involved, and so on.

There is a definite occupational health and safety exposure involved in these activities and some municipalities might find they have a “duty of care” to scavengers that might result in legal claims for compensation for exposure to risks—even those risks beyond the control of the operators at the landfill.

Accredited pickers will need training in safety and personal protective equipment will need to be issued, as well as some limitation set on the cost of or replacement of such equipment (which might also be “recycled”). Pickers will need to sign a waiver or form of acceptance of individual liability and conformance to the instructions given on-site. This would be a moral, if not a legislative, requirement.

Accreditation

The critical step is to ensure that all scavengers are accredited with the municipality and/or the landfill operator. This can be used to prevent children entering the site as well as to limit the number of scavengers on-site, to avoid arguments over waste load allocations and to allow plant operators a clear view of who they must interact with. In most cases, scavengers are required to wear an identifying permit.

Associations or Cooperatives

The advantages of establishing associations are that they can collectively scavenge a large mass of material for sale. This means they can sell in larger quantities to wholesalers rather than smaller operators and therefore achieve a higher price per unit than an individual scavenger could. These associations can also have averaging rules whereby each scavenger receives a certain set percentage of the total income. This can even be extended to provide for scavengers who are absent due to illness or other urgent need.

Each scavenger group is allowed about 20–30 minutes to pick on the dumped wastes for recyclables and other materials with value for them. Each association is given respective area(s) and schedules of waste-picking activities. Scavengers who are not members of these authorized associations are not allowed to scavenge at the disposal facility.

Personal Protective Equipment

It is common to provide protective equipment to the scavengers in terms of rubber boots, gloves, breathing masks, and even eye protection.

In reality, many scavengers will only wear the rubber boots, which already protects them from injury and perhaps infection if medical waste has been mixed through the municipal waste entering the site.

Processing Sheds

In some cases, covered areas are provided so that individuals can take their recovered material to an area protected from the elements while packaging and weighing their material ready for sale. These areas are also commonly used as rest areas and to take meals. Sanitary facilities need to be provided.

6 ADB. 2016. *Integrated Solid Waste Management Plan: Quezon City.* Consultant’s report. Manila (TA 8566). http://k-learn.adb.org/materials/20160930/integrated-solid-waste-management-plan-quezon-city; ADB. 2016. *Integrated Solid Waste Management Plan: Mandalay City.* Consultant’s report. Manila (TA 8566). http://k-learn.adb.org/materials/20161130/integrated-solid-waste-management-plan-mandalay

Covered area for waste pickers.

Self-Haul Transfer Skips at Landfill

Given that compactor loads are more difficult to scavenge, one alternative to keep pedestrians out of a busy active face is to allow small trucks and resident self-haul waste to be placed in a pit or in multiple skips alongside a raised parking berm. These loose loads can be readily scavenged and the materials stockpiled nearby with all activity occurring away from the heavy plant.

Transfer Stations within the City

Given that open truck collection allows for more scavenging at loading and en route to disposal sites, the lower load capacity of tippers can be somewhat offset by using a local transfer station and resident self-haul site. Waste segregation can be achieved at the gate by directing loads to various stockpiles, but the pickers may readily have access at this type of transfer pit. As an example, the transfer station for Whitehorse Council in Victoria, Australia (population 160,000) features a self-haul wide shallow concrete pit, which has a drop chute at its lower edge feeding into 70-cubic-meter transfer trailers. These are hauled to the landfill and ejected using "walking floor" conveyors built into the trailer.

After a suitable depth of waste is deposited in the shallow pit, a dozer track-rolls the waste and progressively pushes it into the chute dropping into open-topped transfer trailers. A lookout monitors residents' safety during dozer operations. This form of transfer retains the existing open-topped trucks and also employs accredited pickers for the small truck and resident self-haul waste. Medical or liquid waste is excluded and pickers' health and safety enhanced. The active landfill site is then free of pedestrian dangers.

Livelihood Training

In some cities, scavengers have been provided with livelihood training so they can cease scavenging activities. Surprisingly,

In some cities, scavengers have been provided with livelihood training so they can cease scavenging activities. Surprisingly, some of these have failed

some of these have failed with scavengers returning to their previous endeavors, for example at the Payatas landfill in Manila, Philippines. Some of the reasons given were the following:

- Scavengers can work the hours they wish to earn the money required for their current needs. For example, at the start of the school year, many scavengers work longer hours so they can provide for their children's academic requirements.
- Scavengers can wear old clothes to work and do not have to buy new clothes for employment opportunities off-site.
- Scavengers do not have to pay for transport to and from work and do not lose time traveling to and from work.
- Some advised that they actually make more money scavenging than they do in their new livelihood roles, such as in the building trades.
- Hence, while outsiders view scavenging as a type of employment that should be avoided, many scavengers have a very different interpretation. In many cases, they are accepting of their work even when they have been trained and supported in livelihoods programs.

Summary

Waste scavengers provide a very efficient method of recovering recyclables from mixed waste streams, certainly in the context of developing countries.

Scavengers' livelihoods can be significantly improved by forming associations or cooperatives at larger landfills (higher income is possible), requiring personal accreditation to keep children out of the sites, providing covered recovery areas, and providing personal protective equipment.

A number of livelihood schemes have been tried internationally to move scavengers off-site into other activities such as the building trades. Surprisingly, a number of these have failed and scavengers have returned to the landfill for reasons mentioned earlier. Waste scavenging is not restricted to developing countries and occurs in developed countries as well.[7]

[7] ADB. 2016. *Integrated Solid Waste Management Plan: Quezon City.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20160930/integrated-solid-waste-management-plan-quezon-city; ADB. 2016. *Integrated Solid Waste Management Plan: Mandalay City.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161130/integrated-solid-waste-management-plan-mandalay

Reporting and Complaints Register

Issue

A crucial part of correctly operating a landfill is to ensure that appropriate reporting is occurring and that these reports are passed on to the relevant managers. This provides an opportunity for managerial and external oversight.

Part of this reporting involves maintaining a complaints register which provides a third-party indicator as to whether the landfill operation is being accepted by the local community. It also may be a leading indicator of potential significant problems at the site.

Interventions

Daily Diary and Miscellaneous Report Sheets

The landfill diary must be completed each day before the site supervisor leaves the site (Figure 10). A typical diary form is presented in the Landfill Operations Manual together with all other forms mentioned.[8]

The incoming waste designation sheets, load analysis sheets, and incident record sheets should be collected at the end of each week or month. A summary report covering the number of loads, total volume of waste or fill received, and the number of incidents at the landfill should be prepared. The individual sheets and the weekly summaries should be filed and a copy sent to the manager.

The site supervisor should provide a monthly report to the manager on all aspects of the environmental management plan, including complaints and monitoring results. A summary of the operation of the landfill should be included.

Figure 10: Sample Daily Landfill Diary Entry Page

DAILY LANDFILL DIARY

Date: **Day:** **Shift:**

WEATHER
Temperature: Very Hot Hot Warm Cool Cold **Rainfall:** …………mm ……….. Time
Wind: Strong Light Still

RECEIVALS:	**SAFETY INSPECTIONS:**			**DEFECTS REPORTED:**
		Morning	**Afternoon**	
Cubic Metres/Tons ……..	**Roads**	☐	☐	
No. of Trucks …….	**Work Area**	☐	☐	
No. of Cars …….	**Signs**	☐	☐	
No. of Trailers …….	**Staff**	☐	☐	
	Amenities	☐	☐	

PLANT AND EQUIPMENT: List all major plant and equipment onsite including sub-contractors

Description	Unit No.	Hours Worked	Hours Idling	Breakdown/ Repairs	Comments
Compactor Dozer Payloader/excavator Truck Chipper/crusher Other (e.g. water truck)					

SUB-CONTRACTORS: List name of sub-contractors, crew size and work area

Name	Hours Worked	Comments/Work Performed

VISITORS: List any visitors

Name and Organization	Purpose of Visit	Sponsor

TRAINING: List employees undertaking training

INDUSTRIAL, SAFETY & ENVIRONMENTAL: List any industrial concerns, accidents, improvement notices issued on safety or environmental grounds. List verbal instructions given to workers.

OTHER COMMENTS: List any EMP Monitoring undertaken, prohibited wastes received, OH&S issues, etc.

…………………………… …………………………… ……………………………
Name **Signature** **Title**

Source: Author.

[8] ADB. 2017. *Landfill Operations Manual.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20170301/sample-landfill-operations-manual

Complaints Register

The complaints register serves two purposes:

(i) It identifies problems unseen or neglected by the landfill staff and will ensure that this problem is recognized and action is taken if appropriate.

(ii) It enables the public to maintain an ongoing relationship with the landfill operator and enables them to have their concerns formally documented and recorded.

The complaints register applies to many aspects of the landfill operation including noise, odor, dust, mud, visual impacts, litter, water quality, and so on.

The landfill staff will keep a record of all complaints made about the landfill. Generally, the gatekeeper receives the initial complaint, if it is by phone (landline or mobile) directly to the landfill, or the site supervisor if it is a written complaint. Telephone complaints direct to the city offices must be recorded and passed on to the site supervisor immediately.

The site supervisor will deal with all complaints and organize the appropriate action to be taken, assess the level of urgency, and check if the complaint is valid. The site supervisor is also responsible for informing the party who complains by letter of the outcome of their complaint, with a copy in the monthly report to the client manager.

Operating License Reporting Requirements

The external reporting requirements will be taken from the site license. They must be strictly followed or the operator (contractor) can be fined.

In general, the city is required to report on at least the following issues:

- Annual quantity of different waste types accepted;
- Annual quantity of different waste types rejected;
- Annual quantity of different waste types recycled;
- Half-yearly evaluation of the overall site performance, including monitoring results, complaints handling, remaining airspace, etc. The review should involve all landfill staff and include a group section on possible environmental improvements. An external component should include feedback from neighbors and discussions with environmental agencies, etc.;
- Possible annual overview audit by external auditor;
- Possible yearly comprehensive external audit results; and
- Environmental improvement plan update, including training requirements, amendments to the policy statement, etc.

Summary

Reporting requirements provide not only the history of the landfill operation but, with the complaints register, also some indication as to whether the landfill may be subject to increasing social pressure in the future.

Environmental Monitoring and Management Plans

Issue

The purpose of an environmental monitoring and management plan (EMMP) is to outline the methods used and actions necessary for the municipal landfill to comply with environmental regulations. The EMMP should be read in conjunction with the Landfill Operations Manual.

The EMMP addresses the various stages of landfill development, including predevelopment of the site, construction, operation, and decommissioning and rehabilitation.

Interventions

A typical EMMP chapter list follows based on the Sample Environmental Monitoring and Management Plan:[9]

(i) Introduction
(ii) Waste Acceptance Criteria
(iii) Compaction
(iv) Cover
(v) Vegetation
(vi) Dust Control
(vii) Mud Control
(viii) Pest Control
(ix) Litter Control
(x) Fire Control
(xi) Noise Control
(xii) Visual Control
(xiii) Odor Control
(xiv) Complaints Register
(xv) Landfill Gas Control
(xvi) Stormwater Management
(xvii) Leachate Control
(xviii) Post Closure Management Plan
(xix) Environmental Monitoring and Management Plan – Summary Table

For each item, the activities required are summarized in the final chapter (Table 10).

Table 10: Sample Activity and Corresponding Action in an Environmental Monitoring and Management Plan

Element	Policy	Performance Objective	Monitoring	Corrective Action
Dust Control	To prevent excessive dust from being generated on the site.	1. Dust levels are not to be excessive (compared with neighboring site activities) at the boundary of the site. 2. Dust levels within the site will satisfy the required safety and health levels.	1. Daily visual appraisal of dust generation via inspection by site supervisor.	Water the source of the dust, such as internal unsealed roads or dry compost piles. Moisten any dust- producing substances (e.g., fly ash, builders rubble) prior to delivery Minimize the disturbed areas by only clearing vegetation when required Accelerate revegetation of completed batters

Source: Author.

[9] ADB. 2017. *Landfill Environmental Monitoring and Management Plan.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20170301/sample-landfill-environmental-monitoring-and-management-plan

The local environmental legislation and associated landfill license or permit conditions will obviously have to be incorporated into the sample EMMP, such as the groundwater monitoring parameters and frequency of monitoring required.

The sample EMMP does have industry standard recommendations together with a layered approach to water monitoring to minimize compliance costs but still ensures confidence that any emissions are being detected.

Summary

An EMMP should be prepared for all landfills, even for small facilities though greatly simplified. The EMMP can be used not only to guide operations but also as a training document for new staff so they are aware of the scope and extent of the landfill's environmental obligations.

Private Sector Participation: Packaging Options

Issue

The main challenge in packaging private sector participation in solid waste management (SWM) is striking the right balance between efficiency gains from private sector involvement and costs.

Expanding private sector involvement in the collection aspects is traditionally the most promising opportunity in the first instance, and this has been adopted in many cities within developing countries. In more established markets, a variety of waste-to-energy and landfill developments have been successful. It is critical, however, to consider the length of contracts for private sector participation success. Short contracts of 1–2 years' duration are insufficient to allow the investor enough time to recover their capital expenditure exposure.

Traditionally, a mix of nongovernment organizations, informal players, or commercial companies undertake recycling activities, so there is little opportunity for involvement of the private sector in traditional recycling, unless at a very large scale, such as development of a mechanized materials recovery facility. The impacts of such schemes on informal recyclers' livelihoods also have to be considered.

Regarding landfill operation, the private sector may not be attracted because of the low potential for innovative technological or management solutions that will make the private sector price cheaper than the city operating cost. However, if a new landfill is to be constructed, private sector involvement in the design and construction or even the design, build, and operation may be commercially attractive to both parties.

The most important factor to attract the private sector is to set a policy framework with the "polluter pays" principle evident so that residents know "waste management costs money" and residents must expect to pay for this service.

The most important factor to attract the private sector is to set a policy framework with the "polluter pays" principle

Interventions

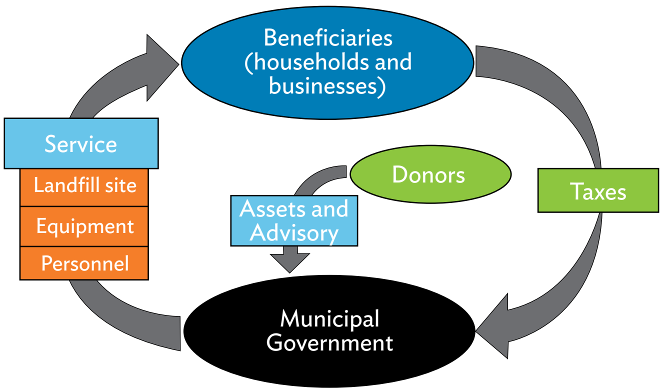
A key aspect that must be presented to the community is that private sector participation does not normally lead to lower up-front fees or prices. The key factor is the "value for money" assessment wherein the service quality improves, while the cost increases but does not increase as much (to reach the better level of service) if the old cost structure were simply extrapolated. The cost per ton of waste collected reduces but the overall cost increases for example.

Modality Options for Private Sector Participation

The typical public-based structure for SWM is presented in Figure 11.

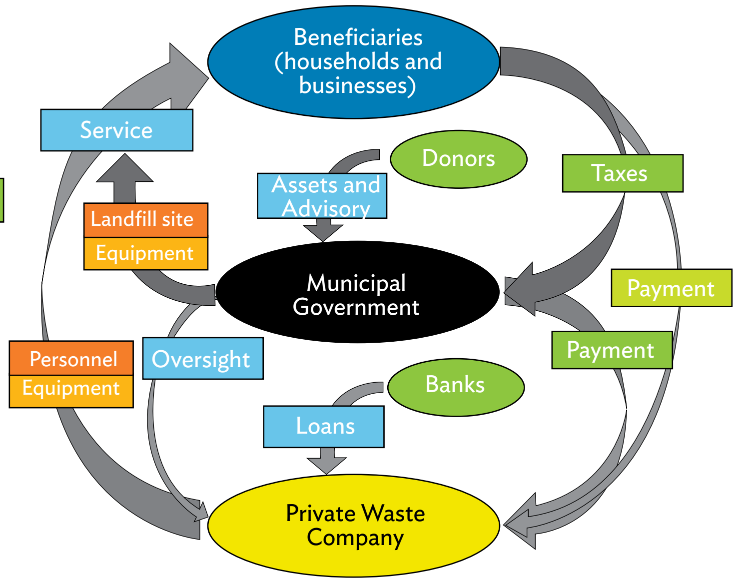
There are a large number of options for private sector involvement in SWM (Figure 12). These range from very simple short-term service contracts to complete privatization and asset sales. The options will vary depending on numerous factors, such as the ownership of the equipment or the disposal site, such as a possible fleet of collection equipment including expensive compaction vehicles, risk allocation, access to skills and technology, and so on.

Figure 11: Municipality-Led Institutional Model for Solid Waste Management



Source: Author.

Figure 12: Public–Private Institutional Model for Solid Waste Management



Source: Author.

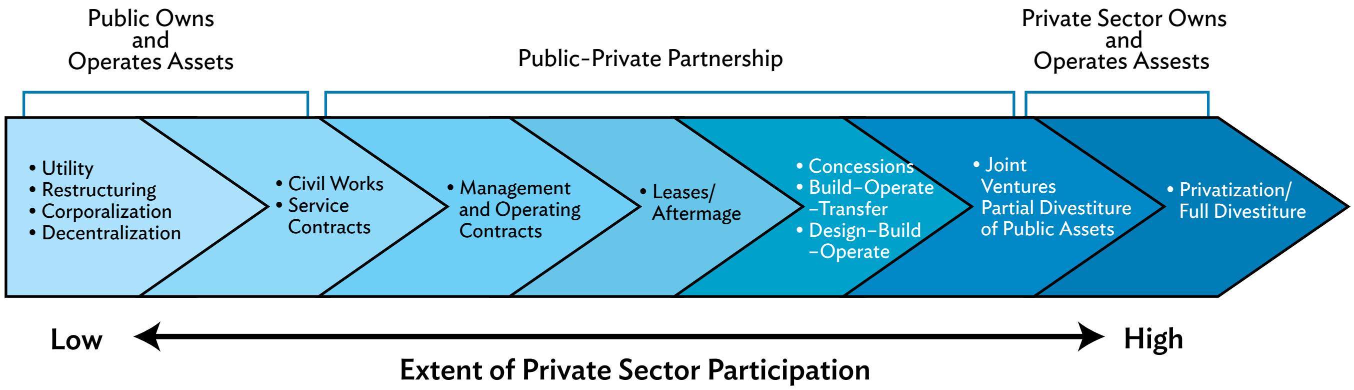
Seven of the common options are presented in the following. However, there are many more suboptions available, often relating to who finances the infrastructure in the partnership. The roles of the public and private sectors vary between the models, as does—critically—the allocation of project risks.

- **Service contract:** The public sector sources goods and services from private sector.
- **Management or operation and maintenance contract:** The contractor maintains and operates public infrastructure to provide services to specified performance requirements. The contractor is paid a regular service fee (e.g., quarterly) by the government, and payments are abated to the extent that contractual performance standards are not met.
- **Lease:** The contractor maintains and operates public infrastructure, pays rental payment to the public sector, and receives payment directly from customers.
- **Design–build–operate (DBO):** The contractor designs, builds, and operates, and/or maintains public infrastructure to specified performance levels. The facility is publicly financed. The contractor is paid a regular service fee (e.g., quarterly) to cover operating costs, and payments are abated to the extent that contractual performance standards are not met. Design deficiencies must be rectified by the contractor at own cost.
- **Build–operate–transfer, build–own–operate, build–own–operate–transfer, design–build–finance–operate, and design–construct–manage–finance:** These are similar to DBO, except that the contractor also finances the public infrastructure. The contractor may receive payment from the government and/or users.
- **Concession:** The contractor designs, constructs, finances, operates, and maintains a specialist piece of public infrastructure to provide public services, usually directly to users, and receives payments from the users. The contract may also provide for the contractor to pay penalty payments to the government where contractual performance conditions are not met.
- **Divestiture:** All or a significant amount of the government's interest in a public infrastructure is transferred to the private sector.

These may be explained by the spectrum in Figure 13 and the summary in Table 11.

Short-term contracts may require utilizing client-owned plant to attract bids from operators who otherwise might not recover costs. It can also involve sale of plant to an operator. The contracts need careful structuring to gain a fair price for plant sale, or alternatively to ensure adequate servicing of plant to maximize its service life. Targets for airspace consumption (compaction densities) as well as limiting acceptance of clean fill and volume of intermediate cover layers needs attention. The quality and coverage of collections need to be carefully stipulated as higher compactive effort and thorough street cleansing equate to higher plant and staff costs for the operator. Both long- and short-term contracts can contain bonuses (and penalties) for performance.

Figure 13: Spectrum of Private Sector Participation in Infrastructure and Development Projects



Source: J. Delmon. 2010. *Understanding Options for Public–Private Partnerships in Infrastructure.* Washington, DC: World Bank.

Table 11: Types of Private Sector Participation and Main Benefits

Types of Private Sector Involvement	Key Features and Benefits
Service contracts	• Contractor to carry out particular assignment(s) and receive fees from the public sector. • Promotes competition when contracts are bid. • Contracts can be retendered every 1–5 years. • If contract fails, risk is relatively low. • With the relatively short contract duration, if problems occur, it can easily be retendered. • Relatively easy/simple contractual form. • Potential starting point for private sector participation. • Can increase utility's focus on core business. • Potential for efficiency gains in the area covered by the contract.
Management or O&M contracts	• Contractor to manage a range of activities and receive fees from the public sector. • Promotes competition when contracts are bid. • Contracts can be retendered every 3–7 years. • Can improve service while retaining public ownership. • Potential first step to concession contract and as transitional arrangements for introducing the private sector into managing infrastructure. • Potential for setting performance standards (with incentives to improve and achieve standards). • Reduced risks to government and contractor. • Can revert to in-house management or contract, may be retendered if problems arise.
Lease	• Contractor to manage a range of activities, pay rents to the public sector, and receive fees from the customers. • Promotes competition when contracts are bid. • Contracts can be retendered every 8–15 years. • Can improve service while retaining public ownership. • Collection risk passed to contractor. • Potential first step to concession contract and as transitional arrangements for introducing the private sector into managing infrastructure. • Potential for setting performance standards (with incentives to improve and achieve standards), but contractor will require assurances over tariffs and compensations.
DBO	• The public sector owns and finances the construction of new assets, while the contractor designs, constructs, and operates to meet certain performance standards. • Promotes competition when contracts are bid. • Contracts can be retendered every 10–20 years. • Can improve service while retaining public ownership. • Contractor assumes full responsibility for construction and operation. • Potentially large improvements in operating efficiency. • Limited (if any) financing risks on the capital to the contractor as a sum will be paid to the contractor for the design and build, and an operating fee for the operation.

continued on next page

Table 11 *continued*

Types of Private Sector Involvement	Key Features and Benefits
BOT, BOO, BOOT, DBFO & DCMF	• Takes over management of design, construction, and operation from the government, but contract term must be long enough to allow return on capital (typically 15–30 years). • Usually for new projects. • Promotes competition when contracts are bid. • Contractor finances, owns, and undertakes construction during the contracted period, after which the facility is transferred back to the public sector. • Mobilizes private finance, which relieves government of the need to fund or raise capital for the investment. This addresses the funding shortfall. • By inserting certain performance standards, potentially large improvements in operating efficiency. • Full private sector incentives across utility. • Attractive to private financial institutions. • Contracts are relatively complex, which need parity in negotiating strength to achieve fair outcome. • There is no revenue stream from the outset, so the contractor assumes a lot of risks. Often, contractors require some form of assurances/guarantees from the public sector.
Concession	• Takes over management of design, construction, and operation from the government, but concession term must be long enough to allow return on capital (typically 15–30 years). • Could be granted for both new and existing projects. • For the case of existing projects, contractor takes risk for the project condition. • Promotes competition when contracts are bid. • Contractor finances, owns, and undertakes construction during the contracted period, after which the facility is transferred back to the public sector. • Mobilizes private finance, which relieves government of the need to fund or raise capital for the investment. This addresses the funding shortfall. • By inserting certain performance standards, potentially large improvements in operating efficiency. • Contractor receives payment from general public/customers. • Full private sector incentives across utility. • Attractive to private financial institutions. • Contracts are relatively complex, which need parity in negotiating strength to achieve fair outcome. • In the context of common law, concession is comparable to BOT.
Divesture	• A fast option for improving solid waste management, but substantial effort required if reversal of divesture is needed. • Mobilizes private finance, which relieves government of the need to fund or raise capital for the investment. This addresses the funding shortfall. • Private sector assumes full responsibility for operations. • Potentially large improvements in operating efficiency of utility. • Private company would have clear incentives to achieve full cost recovery. • Could be successful where there is a good track record of private ownership. • Needs strong regulatory oversight.

BOO = build–own–operate, BOOT = build–own–operate–transfer, BOT = build–operate–transfer, DBFO = design–build–finance–operate, DBO = design–build–operate, DCMF = design–construct–manage–finance, O&M = operation and maintenance.

Source: Author.

Summary

Increased private sector involvement in SWM is a global trend, including in developing countries. This is because private sector involvement allows municipalities to concentrate on their core business, which is not collecting, processing, and disposing waste, or accessing external funding and technology, and reallocating risk. However, one of the common reasons is externalizing municipal capital commitments by contracting their private sector partner to provide the funding.

If the city is interested in seeking greater private sector involvement, it can be sought on a noncommitment basis. This means that the city can seek tenders for one or more components of their waste management services and compare the offers. In any case, it is likely that the collection, recycling, and disposal aspects will be undertaken under different arrangements, contractual or otherwise.

Public–Private Partnerships in the Solid Waste Sector: Can They Succeed?

Issue

In countries such as Myanmar, there is no national governing law for public–private partnerships (PPPs) and so the national government does not have the legislative power to approve local government-level PPPs. As a result, each city must manage its PPP program on its own. Other countries have similarly difficult legal environments for implementing PPP activities, making this a common concern. In effect, the government is not actively looking into how to enable private sector participation.

Given the urgent need to improve municipal solid waste management (SWM) services, the two largest cities (Yangon and Mandalay) in Myanmar, for example, tendered a number of SWM projects, but none of the subject projects have yet commenced.

The following discussion provides some likely reasons for the poor results to date. The irony of the flaws in the Myanmar solid waste tendering processes is that they may have easily been avoided; since they essentially replicated the seeds of other numerous failed Southeast Asian city PPP tenders over the last 2 decades.

Interventions

Project output must be carefully defined.
Any analysis of value for money focuses on client government expectations of what it will gain from a PPP, particularly when (as typical for SWM) a utility service is in need of start-up or major upgrading. In the solid waste sector, service enhancement is usually critical, so detailed performance measures need to be defined. Failure to meet contractual targets should trigger a meaningful level of liquidated damages and/or payment abatements. These are often summarized in the supporting key performance indicators and then detailed in the associated contract terms.

The government, not the private proponent, should provide the initial draft of contract documents.
Governments should provide detailed draft PPP contracts for bidders as they best reflect the nature of the business deal that the government is proposing. Well-run bidding processes ensure that bidders are comfortable with the proposed contract documentation structure by engaging in prebid dialogue resulting in amendments if suggested by one or more bidders and accepted by the government.

Have a prequalification or shortlisting stage.
A reasonable general rule to benefit both government and bidders is that some minimum criteria should be met for qualification. Otherwise, highly qualified bidders may be put off by the risk that they could lose to a politically connected firm with insufficient industry experience.

For waste-to-energy contracts, indicate rules for electricity and tipping fee revenues.
In a situation where no rules for electricity and tipping fee revenues have been put in place, bidders sometimes have to negotiate their own revenue sources. With no tipping fee on offer, these bidders were also required to negotiate an electricity tariff that by definition would be materially higher than other fuel source tariffs. Not surprisingly, electricity utilities declined the tariff levels proposed. Had governments commissioned a well-researched financial projection in advance of bidding, this would have been averted.

Summary

International experience suggests that particularly when governments are initiating PPPs in a new sector, extensive government-side project preparation helps attract committed bids from appropriately experienced and qualified companies and streamlines the bid award and final negotiation process.

Furthermore, as the business deal is made clear to all parties from an early stage, financial close and implementation of projects become more efficient and predictable.

CONTRACT
ISSUES

Public–Private Partnership Contracts in the Philippines

Issue

Public–private partnerships (PPPs) in the local government unit or municipality sector in the Philippines have been subject to repeated studies and marketing by donor agencies in recent years.[1] However, many studies generally gloss over the difficult issues to be dealt with when creating bankable commercial PPP structures underpinned by major municipality general fund payment obligations. Since the greater majority of municipal PPP projects implemented to date do not involve municipalities incurring major liabilities, this is very much an issue for future planning, not historical study or accrued liability accounting. Other countries have similar PPP packaging issues.[2]

PPP projects in the solid waste disposal sector raise the clear potential that private sector investors rather than municipalities could undertake funding of capital costs.[3] Compensation requires a municipality's contractual commitment to long-term annual appropriation of investment tariffs and tipping fees to compensate developer investment over and above operation and maintenance costs. This may not always be understood at the beginning of project development cycles as project proponents may accentuate ancillary by-product revenues such as electricity sales and/or refuse-derived fuel returns for supplying cement kiln operators, while avoiding the fundamental point that long-term municipality tipping fee tariff obligations remain major revenue sources without which project economics are usually not viable.[4,5] It is also important for the municipality to understand its performance obligations.

PPP projects in the solid waste disposal sector raise the clear potential that private sector investors rather than municipalities could undertake funding of capital costs

The general obligation pledge of a municipality for its tipping fee tariff obligations under a long-term PPP contract is relatively untested legally and commercially from both the investor and the limited recourse lender perspectives. The following discussion takes the vantage point of investors and lenders and their access to municipal revenues and rights to such revenues particularly vis-à-vis existing municipality lenders.

1 ADB. 2016. *Philippines: Public–Private Partnerships by Local Government Units*. Manila. http://k-learn.adb.org/materials/20161101/philippines-public-private-partnerships-local-government-units

2 ADB. 2016. *Integrated Solid Waste Management Plan: Sorsogon City.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20160930/integrated-solid-waste-management-plan-sorsogon; ADB. 2016. *Sorsogon Prefeasibility Study: New Buenavista Landfill Design Build Operate Contract.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161201/sorsogon-prefeasibility-study-new-buenavista-landfill-design-build-operate; ADB. 2016. *Sorsogon City Solid Waste Action Plan: Term Sheet and Bid Parameters.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161231/sorsogon-city-solid-waste-action-plan-term-sheet-and-bid-parameters

4 In Metro Manila, the Metro Manila Development Authority (MMDA) waste disposal fees may be used to reduce or eliminate tipping fees but are not yet legally binding obligations, nor can MMDA credit risk be considered bankable.

5 ADB. 2016. *Quezon City Prefeasibility Study: Conventional Waste-to-Energy Project.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161201/quezon-city-prefeasibility-study-conventional-waste-energy-project; ADB. 2016. *Integrated Solid Waste Management Plan: Quezon City.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20160930/integrated-solid-waste-management-plan-quezon-city; ADB. 2016. *Quezon City Solid Waste Action Plan: Term Sheet and Bid Parameters.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161231/quezon-city-solid-waste-action-plan-term-sheet-and-bid-parameters

The discussion is intended to raise these issues but not anticipate the final opinions of stakeholders and their respective legal counsel.

Interventions

Claim Position with Regard to Municipality Debt

Under international standards, tipping fees are ordinarily viewed as a municipal operations expense and consequently regarded as senior in rank to all other nonoperating expenses including debt. In the Philippines, for example, domestic bank municipality lending documents typically do not reference PPP contractual obligations as a liability class, but this right should therefore be pursued, so it is not automatically clear whether they rank senior, pari passu, or junior to bank debt in the drafting of PPP contractual documentation.

In cases where municipality debt is outstanding at the time of PPP contract signing, the position of private sector investors of a PPP would be weakened by the effective bank lender collateralization of all or part of internal revenue allotments (IRA) (revenue sharing) under virtually all loan documentation. This represents a particularly strong security right for government financial institutions in the Philippines (Land Bank and Development Bank of the Philippines) which have sole rights to act as IRA depositories and can make automatic deductions from local government unit accounts to pay debt service.

Ensure Net Internal Revenue Allotment Sufficiency vis-à-vis Operating Expenses

In the Philippines, the implementing rules and regulations of a municipality or of a local government unit provide municipalities with the right to pledge IRAs to meet "contractual obligations" including PPP contract obligations. This is not subject to the 20% IRA restriction applicable for debt. It allows project investors and project lenders some latitude on design of security structures over a municipality's IRA, but municipalities need to ensure that these are acceptable to future municipality lenders. All parties must ensure that net IRA after PPP obligations and municipality debt repayment is projected to be sufficient to meet operating expenses.

Summary

Similar conditions are present in other countries, so this issue must be addressed when packaging PPP opportunities regionally.

Finding Bankable Solutions for Public–Private Partnership Termination Fees

Background

Under international standard public–private partnership (PPP) contracts, a municipality termination fee obligation is triggered by a government contractual default. The definition of government contractual default under a PPP contract is not standardized but can be expected to include (i) payment default by the municipality and (ii) failure of the municipality to honor material provisions of the PPP contract. In some cases, central government actions (outside the municipality's control) may also be construed as contract default. These events are classified as contingent liabilities of the municipality.

The termination fee formula is the total of all the outstanding principal, interest, and certain future dividends. This quantum can be very large and very possibly well in excess of the municipality's operational reserves. Full payment is due on demand with a 2- to 3-month grace period at most under typical PPP contracts.

The potential for central government guarantees for the municipality's termination fee obligations is allowed for in the Philippines' Build–Operate–Transfer (BOT) Law Implementing Rules and Regulations.[6] However, there is little, if any, precedent of any such guarantees being issued over the last 2 decades. It would take a major policy change for the government (or an executive branch decision for an exception) to effect such guarantees.[7]

In Myanmar, the PPP legal structure is scant and the termination fee issue is not directly addressed. The PPP system in Thailand is so complex that proponents generally try to develop work-arounds to avoid having to develop their projects under the present PPP requirements.[8]

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6 Article 13.3(b) of the BOT Law Implementing Rules and Regulations provides for "credit enhancements (which) may include, but are not limited to government guarantees on the performance or obligation of the Agency/LGU (municipality) under its contract with Project Proponent." This remote option would only be open to local government units (municipalities) that seek project approval under the BOT Law (not under local government unit code authorization).

7 State-owned enterprise guarantees would not usually be regarded as being creditworthy unless central government support for the state-owned enterprise was provided.

8 ADB. 2016. *Integrated Solid Waste Management Plan: Mandalay City.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161130/integrated-solid-waste-management-plan-mandalay; ADB.2016. *Mandalay Prefeasibility Study: Chan Aye Thar Zan Waste Collection.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161201/mandalay-prefeasibility-study-chan-aye-thar-zan-waste-collection; ADB. 2016. *Mandalay Solid Waste Action Plan: Term Sheet and Bid Parameters.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161231/mandalay-solid-waste-action-plan-term-sheet-and-bid-parameters; ADB. 2016. *Integrated Solid Waste Management Plan: Buriram.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161031/integrated-solid-waste-management-plan-buriram; ADB. 2016. *Buriram Prefeasibility Study: Refuse Derived Fuel Project.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161201/buriram-prefeasibility-study-refuse-derived-fuel-project; ADB. 2016. *Buriram Solid Waste Action Plan: Term Sheet and Bid Parameters.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161130/buriram-solid-waste-action-plan-term-sheet-and-bid-parameters

While it will always prove challenging to ensure that municipality obligations to meet termination fees are bankable, the following could provide the basis for a bankable credit structure.[9]

Interventions

The municipality could agree to specific debt limitation restrictions so as to ensure estimated available future legal borrowing capacity is sufficient to meet the full contingent liability.
Risks:

(i) The municipality may not be able to raise sufficient debt from the market at the time when the termination fee becomes due.
(ii) Without a known tenor, average life, and interest rate, it is not possible to know what exact amount of debt would fall within the debt service limitations of the relevant Local Government Code (or equivalent), such as the Philippines' limit of 20% of annual revenue.

Advance commitments made by project or other lenders to provide debt to municipalities.
Risks:

(i) Such commitments would have to be short term in nature and run the risk of not being renewed or carrying substantially increased costs upon renewal.
(ii) Most lender terms cannot be negotiated in advance, which may make it easy for a lender to require a municipality to grant difficult off-market terms.

Summary

Given that no precedents exist in the Philippines at least, there are no assurances that these or other solutions may be accepted by key PPP stakeholder counterparts. Should no agreed bankable solution for termination fee issues emerge, there may be a need to abandon developer funding alternatives in favor of cheaper and easier municipality funding solutions.

For example, under a design–build–operate structure, it is still possible to transfer most commercial risks to the private sector even when a municipality acts as project funder.

[9] ADB. 2016. *Quezon City Prefeasibility Study: Conventional Waste-to-Energy Project.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161201/quezon-city-prefeasibility-study-conventional-waste-energy-project; ADB. 2016. *Integrated Solid Waste Management Plan: Quezon City.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20160930/integrated-solid-waste-management-plan-quezon-city; ADB. 2016. *Quezon City Solid Waste Action Plan: Term Sheet and Bid Parameters.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161231/quezon-city-solid-waste-action-plan-term-sheet-and-bid-parameters; ADB. 2016. *Integrated Solid Waste Management Plan: Sorsogon City.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20160930/integrated-solid-waste-management-plan-sorsogon; ADB. 2016. *Sorsogon Prefeasibility Study: New Buenavista Landfill Design Build Operate Contract.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161201/sorsogon-prefeasibility-study-new-buenavista-landfill-design-build-operate; ADB. 2016. *Sorsogon City Solid Waste Action Plan: Term Sheet and Bid Parameters.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161231/sorsogon-city-solid-waste-action-plan-term-sheet-and-bid-parameters

Public–Private Partnership Project Stakeholders: Understanding Potential Internal Conflicts

Issue

Typically, public–private partnership (PPP) projects are long-term investments. Returns are derived from the successful development, financing, construction, and operation of the project. Key parties to a PPP project are off-takers, sponsors (equity), lenders (debt), contractors, feedstock suppliers, and operators.

When parties have more than one role in a PPP project, there is an inherent conflict of interest (e.g., an engineering procurement construction or engineering procurement construction (EPC) contractor who is also a sponsor or shareholder).

Early identification and effective management of such conflicts is key to a successful PPP project.

Interventions

From the equity holder or shareholder's perspective, the project is to be developed, financed, constructed, and operated cost-efficiently and cost-effectively. The equity holder's returns are derived from the project, which is a long-term investment. Hence, the project must be designed and constructed on time and on budget to achieve expected returns for the equity holder or shareholder from a construction perspective. It must be operated in line with projections ideally to ensure these returns.

In addition, the equity holder continues to have "skin in the game" with respect to the project after construction. The project needs to be operated and maintained efficiently and effectively to achieve the expected returns and benefits to long-term stakeholders, including the municipality.

One measure to minimize conflict is to employ equity lock-ins, or restrictions against entire or partial sale or transfer of shareholding interests for a certain period

On the other hand, the EPC contractor's perspective is about ensuring the project is designed and constructed in accordance with the EPC contract. The EPC contractor's aim is to execute the contract on time (or earlier), but not necessarily on budget (project cost), unless it is a fixed price EPC contract. The EPC contractor's returns are derived from the EPC contract and it is therefore in the contractor's interest to maximize returns. This is a short-term focus. Once the EPC contract is completed (including defects warranty period expired), the contractor's role has ended and the contractor has no further "skin in the game" with respect to the project.

The operation and maintenance (O&M) operator's perspective is to operate the plant in accordance with the terms of the O&M agreement, meet the operating key performance indicator and within budget, and maximize payments and bonus while minimizing "penalty" deductions. Compared to the EPC contractor, the O&M operator's interest is longer term and is somewhat more aligned with that of the equity holder or shareholder.

However, it is becoming increasingly common for EPC contractors or O&M operators to be shareholders. Typically, the EPC contractor or O&M operator will have a minor equity or shareholding in a project, typically 10%–20%.

When this occurs, a potential conflict situation arises, as they have dual and conflicting interests in the project—as a contractor or operator and as a shareholder. It is therefore important for not only the majority shareholder but also the lenders to avoid or minimize the conflict.

One common measure is to have the contractor or operator represented by different personnel with different reporting lines, divisions, and affiliates from those of the contractor or operator shareholder, particularly in contract negotiations and also management meetings. Another measure is to employ equity lock-ins—restrictions against entire or partial sale or transfer of shareholding interests for a certain period. Other measures include negotiating robust, arms-length contracts with the contractor or operator, as well as a shareholders' agreement.

Summary

Shareholders, especially the government municipality, need to manage this risk through (i) appropriate risk allocation in the EPC contract (e.g., claims, variations, force majeure, defaults or termination, and dispute resolution); and (ii) appropriate safeguards in the consortium or shareholders' agreement (e.g., board representation, voting, veto rights, and sale and transfer moratorium).

It is critical to identify and address these inherent conflict issues early when negotiating these agreements.[10]

[10] ADB. 2016. *Quezon City Solid Waste Action Plan: Term Sheet and Bid Parameters.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161231/quezon-city-solid-waste-action-plan-term-sheet-and-bid-parameters; ADB. 2016. *Sorsogon City Solid Waste Action Plan: Term Sheet and Bid Parameters*. Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161231/sorsogon-city-solid-waste-action-plan-term-sheet-and-bid-parameters; ADB. 2016. *Buriram Solid Waste Action Plan: Term Sheet and Bid Parameters.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161130/buriram-solid-waste-action-plan-term-sheet-and-bid-parameters; ADB. 2016. *Mahasarakham Solid Waste Action Plan: Term Sheet and Bid Parameters.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161130/mahasarakham-solid-waste-action-plan-term-sheet-and-bid-parameters; ADB. 2016. *Mandalay Solid Waste Action Plan: Term Sheet and Bid Parameters.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161231/mandalay-solid-waste-action-plan-term-sheet-and-bid-parameters

American Society for Testing and Materials. *The History of ASTM International.* https://www.astm.org/ABOUT/history_book.html

Asian Development Bank (ADB). 2011. *Toward Sustainable Municipal Organic Waste Management in South Asia: A Guidebook for Policy Makers and Practitioners.* http://klearn.adb.org/materials/20151201/ta-8750-tim-preparingurban-servicesimprovement-sector-project-final-report

————. 2015. *Preparing the Urban Services Improvement Sector Project.* Consultant's report. Manila (TA 8750). http://k-learn.adb.org/materials/20151201/ta-8750-tim-preparing-urban-services-improvement-sector-project-final-report

————. 2016. *Buriram Prefeasibility Study: Refuse Derived Fuel Project.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161201/buriram-prefeasibility-study-refuse-derived-fuel-project

————. 2016. *Buriram Solid Waste Action Plan: Term Sheet and Bid Parameters.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161130/buriram-solid-waste-action-plan-term-sheet-and-bid-parameters

————. 2016. *Integrated Solid Waste Management Plan: Buriram.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161031/integrated-solid-waste-management-plan-buriram

————. 2016. *Integrated Solid Waste Management Plan: Mahasarakham.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161031/integrated-solid-waste-management-plan-mahasarakham

————. 2016. *Integrated Solid Waste Management Plan: Mandalay.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161130/integrated-solid-waste-management-plan-mandalay

————. 2016. *Integrated Solid Waste Management Plan: Quezon City.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20160930/integrated-solid-waste-management-plan-quezon-city

————. 2016. *Integrated Solid Waste Management Plan: Sorsogon City.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20160930/integrated-solid-waste-management-plan-sorsogon

————. 2016. *Mahasarakham Solid Waste Action Plan: Term Sheet and Bid Parameters.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161130/mahasarakham-solid-waste-action-plan-term-sheet-and-bid-parameters

————. 2016. *Mandalay Prefeasibility Study: Chan Aye Thar Zan Waste Collection.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161201/mandalay-prefeasibility-study-chan-aye-thar-zan-waste-collection

————. 2016. *Mandalay Solid Waste Action Plan: Term Sheet and Bid Parameters.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161231/mandalay-solid-waste-action-plan-term-sheet-and-bid-parameters

————. 2016. *Philippines: Public–Private Partnerships by Local Government Units.* Manila. http://k-learn.adb.org/materials/20161101/philippines-public-privatepartnerships-local-government-units

————. 2016. *Quezon City Prefeasibility Study: Conventional Waste-to-Energy Project.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161201/quezon-city-prefeasibility-study-conventional-waste-energy-project

————. 2016. *Quezon City Solid Waste Action Plan: Term Sheet and Bid Parameters.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161231/quezon-city-solid-waste-action-plan-term-sheet-and-bid-parameters

————. 2016. *Sorsogon City Solid Waste Action Plan: Term Sheet and Bid Parameters.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161231/sorsogon-city-solid-waste-action-plan-term-sheet-and-bid-parameters

————. 2016. *Sorsogon Prefeasibility Study: New Buenavista Landfill Design Build Operate Contract.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20161201/sorsogon-prefeasibility-study-new-buenavista-landfill-design-build-operate

————. 2017. *Climate Change Vulnerabilities and Mitigation Options in Solid Waste Management (The Philippines, Myanmar, and Thailand).* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20170228/climate-change-vulnerabilities-and-mitigation-options-solid-waste-management

————. 2017. *GHG Emission Reduction Potential and CDM Possibilities for Solid Waste Management in 5 CSCs.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20170228/ghg-emission-reduction-potential-solid-waste-management

————. 2017. *Landfill Environmental Monitoring and Management Plan.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20170301/sample-landfill-environmental-monitoring-and-management-plan

————. 2017. *Landfill Operations Manual.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20170301/sample-landfill-operations-manual

————. 2017. *Possible Options and Practices for Reducing Greenhouse Gases in Solid Waste Management Sector.* Consultant's report. Manila (TA 8566). http://k-learn.adb.org/materials/20170228/options-and-practices-reducing-greenhouse-gases-solid-waste-management

P. Forster et al. 2007. Changes in Atmospheric Constituents and in Radiative Forcing. In S. Solomon et al, eds. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK: Cambridge University Press.

N. J. Imu and D. M. Samuel. 2004. Biogas Production Potential from Municipal Organic Wastes in Dhaka City, Bangladesh. *IJRET: International Journal of Research in Engineering and Technology.* 3 (1). pp. 453–460. http://esatjournals.net/ijret/2014v03/i01/IJRET20140301078.pdf

C. Scheutz, P. Kjeldsen, and E. Gent. 2009. Greenhouse Gases, Radiative Forcing, Global Warming Potential and Waste Management – An Introduction. *Waste Management & Research.* 27. pp. 716–723.

United States Environmental Protection Agency. 1996. *The Consumer's Handbook for Reducing Solid Waste.* http://k-learn.adb.org/materials/20170228/consumers-handbook-reducing-solid-waste

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