Report on Environmentally Sound Technologies (ESTs) to be used in the implementation of ISWMP Maseru/Lesotho

Table of Contents

List of Figures

List of Tables

Introduction

The purpose of this document is to identify and list appropriate Environmentally Sound Technologies (ESTs) for all operational stages of the ISWMP of the City of Maseru, including source segregation, collection, transportation, sorting, treatment and disposal of different generated waste streams. This deliverable falls within **Activity 4-A: Identification and Selection of ESTs,** as stated in the Memorandum of Understanding concluded between the United Nations Environment Programme (UNEP) and the University of Cape Town (UCT) Environmental & Process Systems Engineering Research Group.

Furthermore, a basic techno-economic analysis of the identified appropriate technologies has been carried out, whilst drawing basic specifications of equipment and technologies in order to facilitate procurement. Price ranges for technologies have been given where appropriate. A useful manual for prices and availabilities of equipment via Southern African producers and retailers is given in the Buyers Guide & Directory of the Institute of Waste Management of Southern Africa. A digital copy of this manual is available under the following link:

http://www.iwmsa.co.za/index.php?catID=11&pageID=17&pageTitle=/Buyer's-Guide/

The report on ESTs has been developed based on the structure of actions as given by the ISWMP; the purpose here is to create an interface for the synchronisation of proposed technology related activities with all strategic planning steps given by the ISWMP. In the summary tableau given by Table 1, it is highlighted for which actions of the ISWMP ESTs have been identified.

Table 1: Summary Table – Identification of ESTs for ISWMP Actions

Action	Description	ESTs
1.1	Integration of Waste Prevention Measures	-
1.2	Introduction of Cleaner Production Measures	-
1.3	Implementation of a Source Separation System	V
1.4	At Source Value-Addition	V
2.1	Establishment of Ward-Specific and Material-Specific Collection Systems	V
2.2	Systematic Infrastructure and Route Planning	V
2.3	Optimisation of Collection Services Offered by MCC and Private Recyclers and the PPPUE	-
3.1	Creation of a Supportive Platform for Private Recycling Enterprises	-
3.2	Foster the Development of a Local Recycling Economy	V
3.3	Recognition and Support of Local Recycling Markets	-
3.4	Coordination of Local Recycling Activities	-
3.5	Develop Capacity to Work with Take-Back Levies	-
4.1	Adjustment and Integration of Planning Activities for Sanitary Landfill Site	V
4.2	Amendment of EIA	-
4.3	Capacity to Thermally Use Non-Recyclable Paper	V
5.1	Use of School Infrastructure as Awareness Creation Medium	-
5.2	Establishment of Waste Minimisation Clubs	-
5.3	Establishment of a Waste Information System (WIS)	V
5.4	Awareness Creation through Common Media	-
5.5	Review of this ISWMP on a Regular Basis	-

Environmentally Sound Technologies for Action 1.3 - Implementation of a Source Separation System

Short Introduction

Source separation essentially involves separating waste into classes of recyclables, biodegradables (or organics) and residual waste at the point of generation (e.g. at household level) to facilitate re-use, composting and recycling activities.

UNEP identifies separation of the organic fraction as a priority for developing countries as this typically is the largest category of MSW and thus represents the greatest reduction potential in wastes for disposal.

The second priority is to both support waste minimisation (see Actions 1.1 and 1.2) and maximise the recovery of recyclables, the latter preferably without separate collection by the municipal authority (UNEP-IETC, 1996).

The selection of an appropriate source separation system is of crucial importance, as it will affect any further downstream activity, and must therefore be integrated and adjusted with the design of the waste collection system (Action 2.1), as well as infrastructure and route planning (Action 2.2).

Source separation requires proper bins or bags for each waste fraction. The type and size of bag/bin for each type fraction and each waste generator (e.g. households, commerce and industry) needs to be determined based on the volumes of waste generated (information to be obtained from Action 5.3).

UNEP defines the following principles for the selection of set-out containers (http://www.unep.or.jp/Ietc/ESTdir/Pub/MSW/SP/SP3/SP3_2.asp):

- Choose containers made of local, recycled, or readily available materials.
- Choose containers which are easy to identify, either due to shape, colour, or special markings.
- Choose containers which are sturdy and/or easy to repair or replace.
- Consider identification of containers with generators by address or name or code number.
- Choose containers that are matched to the collection objectives.
- Choose containers that are appropriate to the terrain.

Summary of Technology Requirements

Area	Collection or managment system	Type	Size	Approx. Price per Unit [M]
Residential areas	Recyclables taken to schools	cloth bag		15.-
	Kerbside collection	clear/milky bag for recyclables		0.20 - 0.60
		black bag for		0.20 - 0.60

		residual waste		
		bins (where appropriate)	plastic 30-60 L	500.-
			steel or plastic 50 - 70 L	500.- - 2,000.-
	Bring/fetch system	clear/milky bag for recyclables		0.20 - 0.60
		black bag for residual waste		0.20 - 0.60
		shopping bags		no cost
Schools	Recyclables collected at schools	igloos	various	2,500.- -5,000.-
Commercial areas	Kerbside collection of recyclables	skips (where appropriate)	2m3 - 5m3	6,000.- - 8,000.-
		bins (where appropriate)	steel or plastic 50 - 70 L	300.-
		clear/milky bags		0.20 - 0.60
	Kerbside collection of residual/organic waste	skips	2m3 - 5m3	6,000.- - 8,000.-
		bins	steel or plastic 50 - 70 L	500.- - 2,000.-
		black bags		0.20 - 0.60
Industrial areas	Kerbside collection of recyclables	skips	2m3 - 30m3	6,000.- - 45,000.-
		bins	steel or plastic 50 - 70 L	500.- - 2,000.-
		clear/milky bags		0.20 - 0.60
	Kerbside collection of residual waste	skips	2m3 - 30m3	6,000.- - 45,000.-
		bins	steel or plastic 50 - 70 L	500.- - 2,000.-
		black bags		0.20 - 0.60
	Special collection of hazardous waste	hazardous waste containers	Material specific	Material specific

Technology Descriptions

The variables that impact the volume required for the storage of domestic wastes are:

- individual rate of waste generation
- number of individuals living in the premises, and
- frequency of collection.

Based on an average of six persons per family, the probable range required for storage in many economically developing countries is as given by Table 2 (Flintoff, 1984).

Table 2: Collection Frequencies

Collection Frequency	Minimum Volume (L)	Maximum Volume (L)
Daily	4	10
Twice/wk (maximum 4 days)	20	50

From the baseline study undertaken for Maseru, the average volumes of waste as given in Table 3 require storage based on a given collection frequency.

Table 3: Maseru Waste Collection Frequencies

Income level	Average household size	Collection Frequency	Average Volume of all waste (L)	Average Volume less recyclables (L)
Low	4.3	Daily	4.6	2.8
		Twice/wk (maximum 4 days)	18	11
		Once/wk	32	20
Middle	4.5	Daily	11	7.2
		Twice/wk (maximum 4 days)	45	29
		Once/wk	79	50
High	3.8	Daily	4.8	3.1
		Twice/wk (maximum 4 days)	19	13
		Once/wk	34	22

Bags

From the proposed ISWMP, four types of bags are identified for the separation and storage of recyclables and residual wastes. These are:

- Cloth bags for the transport of recyclables to school by school children
- Clear/milky bags for recyclables that are either collected at the kerb or taken to central collection points
- Black bags for residual waste

- Shopping bags for residual waste

Cloth bags have been selected as they are reusable and safe for children. The manufacture of these bags may also form part of a community based project.

Clear/milky bags for recyclables are selected so they can be distinguished from the black bags or shopping bags used to store residual waste. The clear/milky bag also allows the collector/recycler to ensure that the bags contain clean, dry recyclables only.

Disposable black bags or plastic bags supplied at supermarkets can be used for the storage and disposal of residual waste. There can be a cost constraint with black bags if the purchase of the bags are the responsibility of the household.

Bins (e.g. Wheely-bins, static bins)

In high income accessible areas the provision of bins for each household may be appropriate. According to UNEP (2006) the following types of bins are available and appropriate in most developing countries for residential areas:

- Plastic buckets (with lids), with capacities between 7 and 10 L, provide sufficient volume for the storage of domestic wastes generated by a family of six for daily collection.
- Plastic bins (with lids), with capacities between 30 and 60 L and equipped with handles, are suitable for a twice-per-week collection.
- Galvanised steel or plastic bins (with lids), with a capacity between 50 and 70 L, are necessary when collection is twice per week from high-income groups, or for daily collection from stores and commercial establishments. Bins of this size are more expensive than the smaller sizes because they are required to have a relatively long lifespan. Steel bins should be galvanised after manufacture and plastic bins should be made of high-density polyethylene (HDPE), or plastics of similar characteristics.

In other more densely populated poor areas, the roll out of standard bins may not be appropriate for the following reasons (UNEP, 2006):

- the challenges presented by organisation, distribution, maintenance, and replacement of the bins if they are supplied by the municipality;
- diversion of bins from their intended use (e.g., used for the storage of food or water); and
- loss of containers by theft and when residents move from one location to another.

In these areas larger bins (e.g. the 200L metal drum or the conventional steel (or plastic) bin with fitted lid of between 70 and 120 L) could possibly be utilised at collection points, although enclosures may be adequate.

The advantages of the 200 L drum are that it is cheap, readily available (being a waste product) and relatively portable. However, it typically does not have a lid, is heavy when full and is prone to rusting. Galvanised steel bins or plastic bins with lids are attractive in that they are hygienic and can improve collection efficiency. These bins are however very expensive and their roll out would require community cooperation.

Hybrid Bins (e.g. Multi-compartment bins)

Multi-compartment bins could be used to promote recycling in public areas (e.g. Maseru CBD). Here bins with one compartment for recyclables and one for residual waste are provided. Multi-compartment bins could also be provided at collection points, or the collection point separated into two areas one for residual waste bags and one for recyclables.

Igloos and recycling containers

Igloos have been proposed as storage containers for recyclables at schools under the pilot activity of the ISWMP. Igloos have the advantage that they are easily identifiable. They are also secure and can be fitted with a lock if necessary to prevent theft or vandalism. Igloos would be required for each different type of recyclable material to be collected (e.g. paper, glass, plastics etc.)

Skips

For larger commercial businesses, mini skips or jumbo bins of various sizes (from 2m3 to 5m3) should be provided for different waste types.

For industrial sites, mini bins/skips or large skips (ranging from 2m3 to 30m3 or larger) should be provided.

Hazardous waste containers (e.g. medical waste receptacles)

Special containers need to be provided for hazardous waste and will largely depend on the nature of the hazardous material.

References

Flintoff, F., 1984. Management of Solid Wastes in Developing Countries, WHO Regional Publications, South-East Asia Series No. 1, Second Edition, World Health Organization.

UNEP (2006) Solid Waste Management. Available from: http://www.unep.or.jp/Ietc/Publications/spc/Solid_Waste_Management/index.asp

Environmentally Sound Technologies for Action 1.4 - At Source Value-Addition

Short Introduction

This action covers all activities that fall under the “reuse” category of the waste minimisation hierarchy, where waste materials are reused or converted at source into other useful items. By managing these waste materials at source it not only decreases the need for new products but also lightens the load on down-stream collection and recycling/disposal activities.

Reuse is essentially any activity that lengthens the life of an item and is distinct from recycling where items are reprocessed into secondary raw materials to make new products. Many waste materials can be reused, e.g. plastic shopping bags, bottles and cans. But perhaps the largest potential for at source value-addition in the Maseru context comes from using the organic fraction of household waste as animal feed or for compost. This is because overall household waste is made up of a high percentage of kitchen scraps and other organic wastes that can be easily reused in this way.

Reuse can also be accomplished by:

- Take back levies (discussed in Action 3.5) where customers are offered a financial incentive to return packaging for reuse/recycling
- Purchasing durable goods
- Buying and selling in the used marketplace
- Borrowing or renting
- Donating used goods to charity
- Further benefits of reuse include:
- Energy and raw materials savings as reuse reduces the number of new products that need to be manufactured
- Reduced collection and disposal needs and costs
- Create new markets for materials
- Creatively refashioning used materials, maintenance, repair and refurbishment can also generate income and create employment opportunities
- Create opportunities for vocational training
- Cost savings for consumers as reusable products or reconditioned products are often more affordable than new products

Summary of Technology Requirements

Sector	Type	Approx. Price per Unit M
Composting	Domestic	< 800.-
	Commercial	Site specific
Composting accessories	Compost mate - for turning and aerating a relatively small-scale compost heap	150.-
	Tractor with mechanised turner for large scale "windrow" composting	200,000.-
Biogas Digesters	school/commercial (brick and mortar)	100,000.- (for two 20,000-litre digesters)
Commercial/industrial opportunities		set up and running costs vary, but activity should save costs
Craft applications		set up and running costs vary, but activity should be self-sustaining

Background - composting

Food waste and garden waste can be converted into a resource such as compost. Here composting is defined as:

- *the biological decomposition of biodegradable solid waste under controlled predominantly aerobic conditions to a state that is sufficiently stable for nuisance-free storage and handling and is satisfactorily matured for safe use in agriculture.*

In Maseru, it is thought that most kitchen waste is used as animal feed. However there may be opportunities to encourage small-scale composting on the level of the household or even community-based composting. Currently, compost is produced from the garden waste arising from the parks and gardens serviced by the MCC.

Compost technology can be separated into three stages:

- Pre-processing, where the organic wastes are prepared or processed to ensure that they are in a suitable form for composting
- Composting
- Preparation of compost for storage and sale, which may include upgrading.

The role of equipment or technology is to assist in ensuring optimum environmental conditions, particularly oxygen availability, for the microbes to successfully convert the waste into compost.

There are many benefits to composting, particularly in a developing country context. These are summarised by Hoornweg et al. (2000):

- Increases overall waste diversion from final disposal, especially since as much as 80% of the waste stream in low- and middle- income countries is compostable
- Enhances recycling and incineration operations by removing organic matter from the waste stream
- Produces a valuable soil amendment-integral to sustainable agriculture
- Promotes environmentally sound practices, such as the reduction of methane generation at landfills
- Enhances the effectiveness of fertilizer application
- Can reduce waste transportation requirements
- Flexible for implementation at different levels, from household efforts to large-scale centralized facilities
- Can be started with very little capital and operating costs
- The climate of many developing countries is optimum for composting
- Addresses significant health effects resulting from organic waste, such as reducing Dengue Fever
- Provides an excellent opportunity to improve a city's overall waste collection program
- Accommodates seasonal waste fluctuations, such as leaves and crop residue
- Can integrate existing informal sectors involved in the collection, separation and recycling of wastes

However, there are also a number of constraints to composting that must also be taken into account when selecting technologies (Hoornweg et al., 2000):

- Inadequate attention to the biological process requirements
- Over-emphasis placed on mechanized processes rather than labor intensive operations
- Lack of vision and marketing plans for the final compost product
- Poor feed stock which yields poor quality finished compost, for example heavy metal contamination
- Poor accounting practices which neglect that the economics of composting rely on externalities, such as reduced soil erosion, water contamination, climate change, and avoided disposal costs
- Difficulties in securing finances since the revenue generated from the sale of compost will rarely cover processing, transportation and application costs
- ”Subsidies” may be required to maintain programs; these reflect the benefits that accrue beyond local governments, and avoided disposal costs are not adequately addressed
- Sensible preoccupation by municipal authorities to first concentrate on providing adequate waste collection
- Inadequate pathogen and weed seed suppression

- Nuisance potential, such as odours and rats
- Poor marketing experiences
- Poor integration with the agricultural community
- Perverse incentives such as fertilizer subsidies or over-emphasis on capital intensive projects
- Land requirements are often minimal, but can be a constraint

Technology description - composting

Domestic composting technologies (e.g. compost bin, "tyre" compost bin, can-o-worms)

Backyard composting (or in-vessel composting) involves the use of bins of size varying with the amount of waste produced by a household and also to some extent with the size of the family. Residents of the house can dump in their wastes in the compost bins and turn the pile over a few times once in 2-3 days and within a few weeks time the compost should be ready. Since, there are gardens in almost each house in Maseru, following this practise would make sense because the residents of that house can use that compost for application in their household gardens and enhance the soil quality. Also this would result in waste segregation at source and almost 100 percent recycling of the kitchen and garden waste.

Desirable attributes in the home composter:

- It should have two drums of appropriate size, so that when one drum is filled and the compost is getting prepared, the household can use the other drum to dump the waste.
- It should sit higher than the ground-level to avoid attracting pests and rodents.
- It is better if it has a mechanism to mix and aerate the mixture which can be operated from the outside so that the people operating the drum don't have to open the drum and mix it as that would expose them to unpleasant smells of rotten waste.
- Door(s) for easy entry of waste and exit of compost.
- The composter should preferably be made from recycled materials.
- It should have a proper exit for excess water.

Larger scale composting technologies (e.g. heaps)

Compost systems for larger scale operations can be classed as "windrow" or "in-vessel".

Windrow composting involves dumping the biodegradable waste on an area in the form of windrows. Windrow systems can be mechanised to a considerable extent and may even be partially enclosed. Windrow system may be static, where aeration is accomplished without disturbing the windrow, or turned, where aeration is achieved by tearing down and rebuilding the windrow. Windrow composting involves the following principal steps (UNEP-IETC, 2006):

- incorporation of a bulking agent into the waste if an agent is required (e.g., biosolids),
- construction of the windrow and aeration arrangement,

- composting,
- screening of the composted mixture to remove reusable bulking agent and/or to meet specifications,
- curing, and
- storage.

Due to the availability of unskilled labourers in Maseru, manual turning may be a more appropriate approach than mechanised turning, which requires expensive machinery. If manual turning is to be employed, the operations are limited to a smaller scale than that achievable with mechanisation.

Mechanical turning can be achieved by machines specifically designed to turn windrowed compost material or standard earth moving equipment.

The economics of in-vessel systems in a developing country is less favourable than those for windrow composting because of the high labour, manufacturing and operational costs of the specialised reactors required for this purpose.

Background - Biogas Digesters

Biogas is a low cost form of energy derived from renewable resources: animal dung, human waste and organic materials, including kitchen and garden waste. A biogas digester – in which the biogas is produced – also provides an on-site water-borne sanitation system, as well as an integrated organic kitchen and garden waste recycling opportunity.

Biogas digesters are airtight containers in which water, organic wastes, animal wastes and/or faeces are acted upon by anaerobic bacteria i.e. those bacteria that thrive in the absence of oxygen (Agama, 2007). Biogas is formed by bacterial action on the organic matter to produce a mixture of methane and carbon dioxide. One m3 of this biogas will provide a cooking time of approximately 2 hours or 1.5 kWh electrical output. The second useful product is digested slurry.

The advantages of biogas technology are as follows (Agama, 2007):

- Biogas can make an important contribution to the protection and improvement of natural resources and environment
- Slurry, a residue from the process, is a high-grade fertilizer that can replace expensive mineral fertilizers.
- The technology is ideal for effective and productive management of livestock wastes.
- The technology provides an efficient wet sanitary system that enhances effective waste product disposal.
- It provides an integrated system for waste treatment, energy and fertiliser production.
- The use of biogas enables rural women to save time for productive agriculture, leisure and family care and welfare.
- Use of biogas technology improves the standard of living and can directly contribute to economic and social development of a country.
- Biogas systems result in halving of waste solid collection volumes and frequency and landfill disposal costs.

- A biogas digester can be locally produced or built, and locally operated.
- The technology has the potential to permanently employ many thousands of people should its potential be reached in the country.

Technology description - Biogas Digesters

Biogas digesters differ mainly in the types of materials used. The main types are fibreglass, plastic or brick and mortar. The fibreglass and plastic types are specifically for use by small households while the brick and mortar unit is more appropriate for larger systems, such as at schools and clinics.

If properly designed, installed and utilized the pay back period of a biodigester is less than 4 years on average, whereas the main structure can easily last for more than 20 years. Maintenance of biogas digesters is low in cost.

Background - Commercial/industrial re-use and recycling opportunities

There are many re-use and recycling opportunities in the commercial and industrial sector. However, some analysis of individual waste streams is required to determine alternate uses and to begin to identify specific opportunities.

Waste tyres are an example of a commercial/industrial re-use and recycling opportunity that is applicable to Maseru.

Waste tyres may be used for erosion control, where scrap tires are banded together and partially or completely buried on unstable slopes. Tyres used in this way with other stabilization materials to reinforce unstable slopes provides both an economical and effective solution. Furthermore, construction costs may be reduced by 50 to 75% of the lowest cost alternative such as rock, wire-mesh/stone matting, or concrete protection.

Tyres can also be recycled into items such as rubber mats, pipe lining, floor tiles, road surface additives, dustbins etc. In addition, crumb rubber can be mixed with concrete for the purpose of construction of sidewalks. Benefits of adding crumb rubber in concrete include reductions in thermal expansion, along with reductions in drying shrinkage and brittleness.

Plastic wastes are another stream that represents a possible commercial/industrial recycling opportunity. Soft-drink bottles can be transformed into polyester carpets and dry-cleaning bags, whereas bottle lids can become irrigation pipes. Soft plastic can be recycled into products such as black bags and other mixed plastic waste can be used to make road signs, fencing and outdoor furniture.

Background - Craft applications

Besides the large scale commercial opportunities for recycling, there are many opportunities for small businesses or individuals to make saleable craft items from recyclables or refurbish used items.

Set up costs will vary depending on the activity, but can certainly be self-sustaining.

References

Agama (2007) Biogas Technology: delivering Ecological Sanitation and Renewable Energy. Available online at http://www.agama.co.za/dmdocuments/AGAMA_Energy_biogas_digester_infosheet.pdf

Hoornweg, D., Thomas, L. and Otten, L. (2000) Composting and its applicability in developing countries. World Bank Working Paper Series 8 - Urban Waste Management, Urban Development Division, The World Bank, Washington D.C.

Environmentally Sound Technologies for Action 2.1 - Establishment of Ward-Specific and Material Specific Collection Systems

Short Introduction

As the wards within the city of Maseru are very different with regards to income structures, road access and waste management infrastructure in place, it is not possible to design a one-size-fits-all waste collection service. It is therefore proposed that waste collection systems be designed according to the specific requirements of each ward, with the collection systems aiming to achieve the following overall aims:

- maximise the amount of waste being diverted from informal disposal activities,
- minimise the contamination of the three separately collected fractions (see Action 1.3), and
- maximise the integration of existing infrastructures and resources.

In order to do so, the MCC must ensure that there is sufficient planning capacity in place for designing and allocating appropriate options to different wards. Such systems may include one or more of the following elements:

- Decentralised waste collection depots (bucket shops)
- Integration of informal collectors/waste pickers
- ‘Bring’ systems with commodity exchange (e.g. food or fuel tokens)
- Waste collection services by truck

Summary of Technology Requirements

Sector	Type	Approx. Price per Unit [M]
Small Collection Vehicles	Wheel barrow	700.-
	Other	<5,000.-
Large Collection Vehicles	Light Commercial Trucks	700,000.-
	Pickup trucks (Bakkie)	80,000.- - 250,000.-
	Compactor Trucks	800,000.-
	Container Trucks	900,000.-
	Tractor+Trailer System (Container)	300,000.-
Collection point	Skip (Container)	15,000.-
	Bin	300.-
	Fencing incl. Gates and Locks	10,000.-

Background

In the case of Maseru, it became apparent that a special emphasis needs to be put on the selection of appropriate collection vehicles depending on the area serviced. As some areas do have very limited accessibility in terms of road infrastructure, collection by a large compactor truck is not a viable option, and other alternatives such as small muscle-powered vehicles need to be considered. Furthermore, communities strive to standardise their collection vehicles assuming that similarity will result in cost-efficient operation and maintenance. This standardisation has resulted in the exclusion of large areas of cities from collection service. Vehicle design standards based on the requirements of the middle- and high-income areas rarely are suited to the needs and conditions of low-income areas.

The following points give principles for the selection of appropriate transportation vehicles: (http://www.unep.or.jp/Ietc/ESTdir/Pub/MSW/SP/SP3/SP3_2.asp):

- Select vehicles which use the minimum amount of energy and technical complexity necessary to collect the targeted materials efficiently
- Choose locally made equipment, traditional vehicle design, and local expertise whenever possible
- Select equipment that can be locally serviced and repaired, and for which parts are available locally
- Choose muscle- and animal-powered or light mechanical vehicles in crowded or hilly areas or informal settlements in developing countries.
- Choose non-compactor trucks, wagons, dump trucks, or vans where population is dispersed, or waste is already dense. These trucks are lighter, more fuel-efficient, and easier to maintain.
- Consider the advantages of hybrid systems where appropriate: satellite muscle-, electric-,or propane-powered small vehicles feeding a larger slow-moving or stationary compactor truck or container.
- Consider compactor trucks in industrialized urban areas where roads are paved, collection routes serve many generators, and waste is not dense or too wet.

Technology Descriptions

Small-scale collection and muscle-powered vehicles

In Maseru, a number of small-scale and muscle-powered vehicles are already in service. Private recyclers buy valuables from waste pickers who transport their materials in trolleys and carts. Furthermore, the Seapoint-Thibella community employs workers to transport waste bags from households to collection points in wheel barrows. It is suggested that existing local small-scale transport vehicles should systematically be considered in the design of Maseru's waste collection system.

Figure 1: Small-scale waste collection by cart - China

Other types of small-scale collection vehicles are muscle-powered carts, relatively small rickshaws pulled, pushed, or pedalled by people, bicycles, electric or propane-powered vehicles, or animals. Such systems are inexpensive and easy to build and maintain, compared with other vehicles.

Figure 2: Small-scale waste collection by tricycle – South America

As demonstrated for the case of Seapoint-Thibella, small-scale primary collection may be coupled with transfer to central collection points These collection points are small fenced-off areas fitted with gates and locks for security purposes, designed for the storage of wastes materials until picked-up from larger collection vehicles. The direct transfer from small-scale primary collection into larger vehicles at the edge of the neighbourhood is another alternative.

Figure 3: Waste Collection Point in Maseru/Lesotho

Pickup Trucks (Bakkies)

A pickup truck (or Bakkie - Southern Africa) is a light motor vehicle with an open- or closed-top rear cargo area. Features of a pickup truck are usually:

- a separate cabin
- rear load area or compartment

Instead of a well-type bed (short rigid sides) with an opening rear gate, some pickups have a flat tray back (i.e. flatbed). Others may have a specialty body mounted behind the cabin. Typical payloads vary between 500kg up to 2,500kg. (http://en.wikipedia.org/wiki/Pickup_truck)

Figure 4: Example of Pickup Truck (Bakkie)

For the area Seapoint-Thibella in Maseru, a community based system is being developed, organising owners of pickup trucks in a time-schedule for waste transportation from central collection points to the landfill site. Such a system has the advantage of using already existing and privately owned vehicles for the transportation of wastes, resulting in significantly reduced capital investment.

Light commercial trucks

Although they are primarily designed for the transport of construction materials, light commercial trucks are widely used for the collection of wastes from communal sites. The body of the truck is usually made of steel, with a flat platform equipped with hinged sides and tail-boards about 40 to 60 cm high. The volume of the truck is usually about 5 to 6 m3 and is suitable to carry high-density materials such as bricks and aggregates.

One of the major disadvantages of the vehicle is that it is rarely able to carry its rated payload of solid wastes. Even high-density wastes piled on the vehicle would be unlikely to exceed 4t. Common practice is to modify the design in order to increase volumetric capacity and ease of loading. Common modifications include:

- Extend height of sideboards

- Reduction of height of chassis by using wheels of smaller diameter
- Use of full forward control (cab-over engine) to increase space on the chassis for the body
- Extension of rear overhang
- Use of a long wheelbase

By include such design changes, loading capacity can be extended to up to $8m^3$. The advantages of this type of truck are its relatively low capital costs, it is sturdy and easily obtainable, it has good ground clearance, and it performs well on rough roads.

Compactor Vehicles

Compactor vehicles are mainly used in industrialised countries, their main advantage being the increased loading capacity through the compaction of collected waste. Typical designs of compactor vehicles include:

- Front loaders, generally used to service commercial and industrial businesses using large waste containers.
- Rear loaders, commonly used to service residential areas.
- Side loaders, designed to pickup smaller containers than front- and rear loaders.
- Pneumatic collection vehicles, fitted with a crane and tube incl. mouthpiece, used to suck-up waste from underground waste containers.
- Grapple trucks, designed for collection of bulky waste.

Compactor vehicles are not commonly used for waste collection in developing countries for the following reasons:

- In most developing countries, the initial density of wastes for collection are similar to that of compacted wastes from industrialised countries.
- The compaction mechanism imposes a need for additional maintenance facilities, and substantially increases fuel consumption.
- The capital cost of a compactor vehicle is significantly greater than that of a conventional truck.

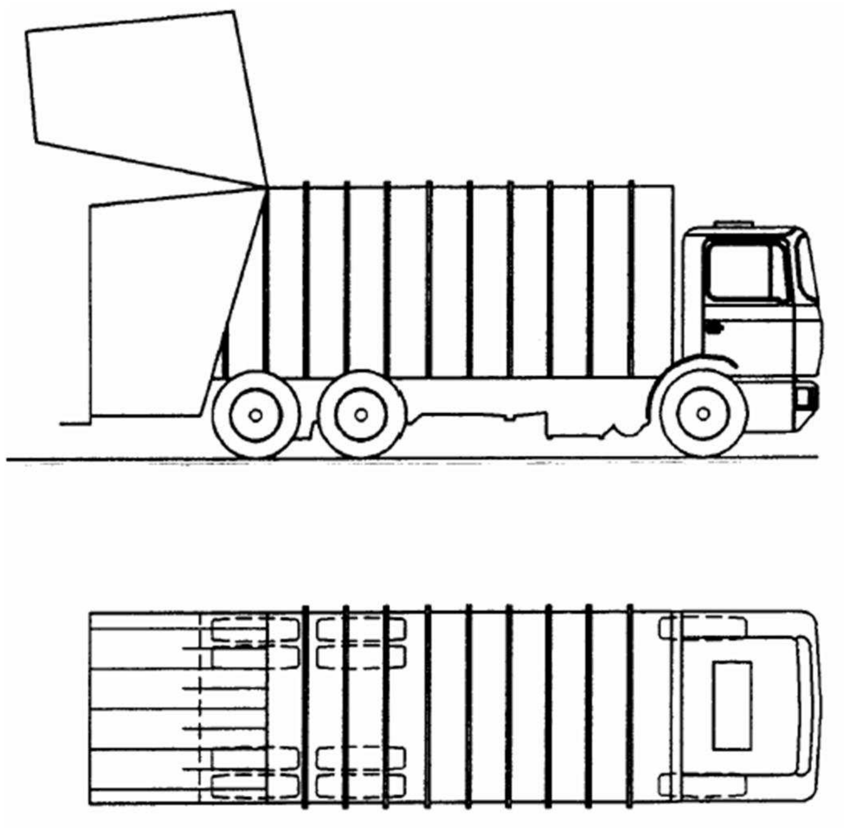


Figure 5: Compactor Truck – Rear Loader

The most common design for compactor vehicles is the rear loader, which would most likely be the design found in a developing country. They are designed with an opening at the rear, allowing a waste collector to throw waste bags or empty waste bins. They are often fitted with a lifting mechanism to automatically empty large carts called toters without the operator having to lift the waste by hand. Another popular system for the rear loader is a rear load container specially built to fit a groove in the truck. The rear loader usually compacts the waste with a sweep-and-slide system. Typical specifications of rear loaders are as follows:

- Volumes between 14 - 30 m^3
- Chassis design from 2 to 4 axis
- Degree of compaction is variable and is adjusted according to max. payload and density of waste

Container Vehicles

A number of waste collection vehicles exist for the handling of different waste containers larger than general household bins. In the context of Maseru, these include the handling of waste skips and recycling igloos.

Appropriate vehicle designs for the handling of waste skips include container-hoists, with typical volumes ranging from 2-15m^3. Container-hoists generally use a standard commercial chassis in the range of 5 to 10t equipped with two hydraulically-operated arms for “lifting” the skips on and off the vehicle. The containers can be tipped to discharge their contents while in position on the vehicle. The container-hoist is a viable alternative to tractor-trailer units i.a. because it has a lower operational expenditure and is faster. On the other hand, the capital cost of a container vehicle is about twice that of an agricultural tractor, and the payload of container-hoists are considerably smaller.

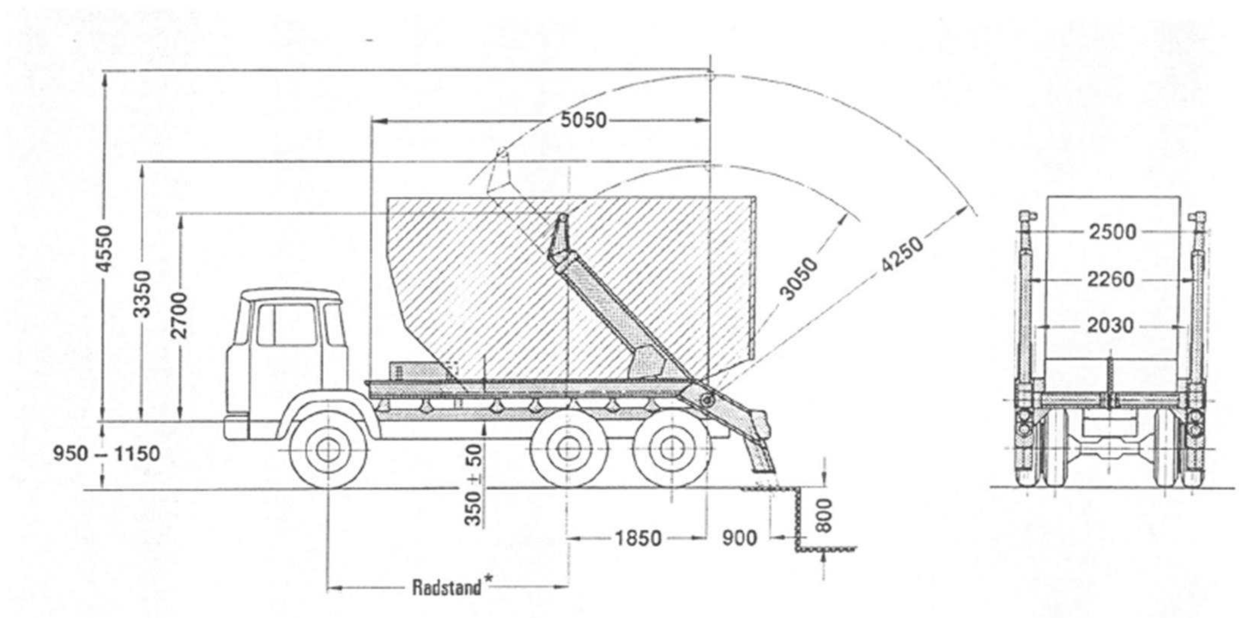


Figure 6: Container Vehicle with Hydraulic Arms for Lifting

Larger trucks are used to handle containers with volumes up to 6-40m^3. They are fitted with a cable- or chain-lift for “rolling” the container on and off the vehicle. The truck design can include a crane arm for the lifting and emptying of e.g. igloo-containers used for the collection of recyclables.

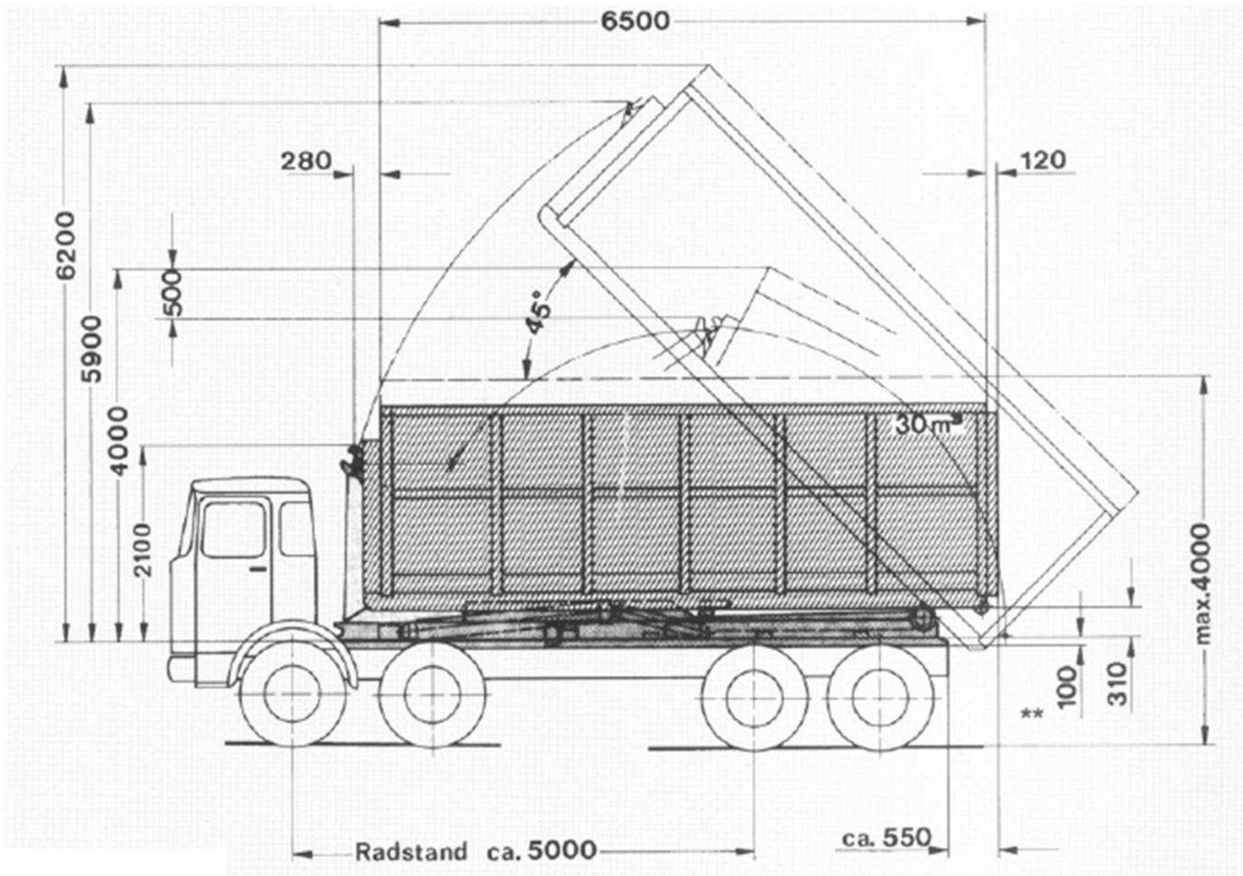


Figure 7: Container Vehicle for Larger Volumes (Roll-System)

Figure 8: Emptying of Igloo-Containers with On-Board Crane

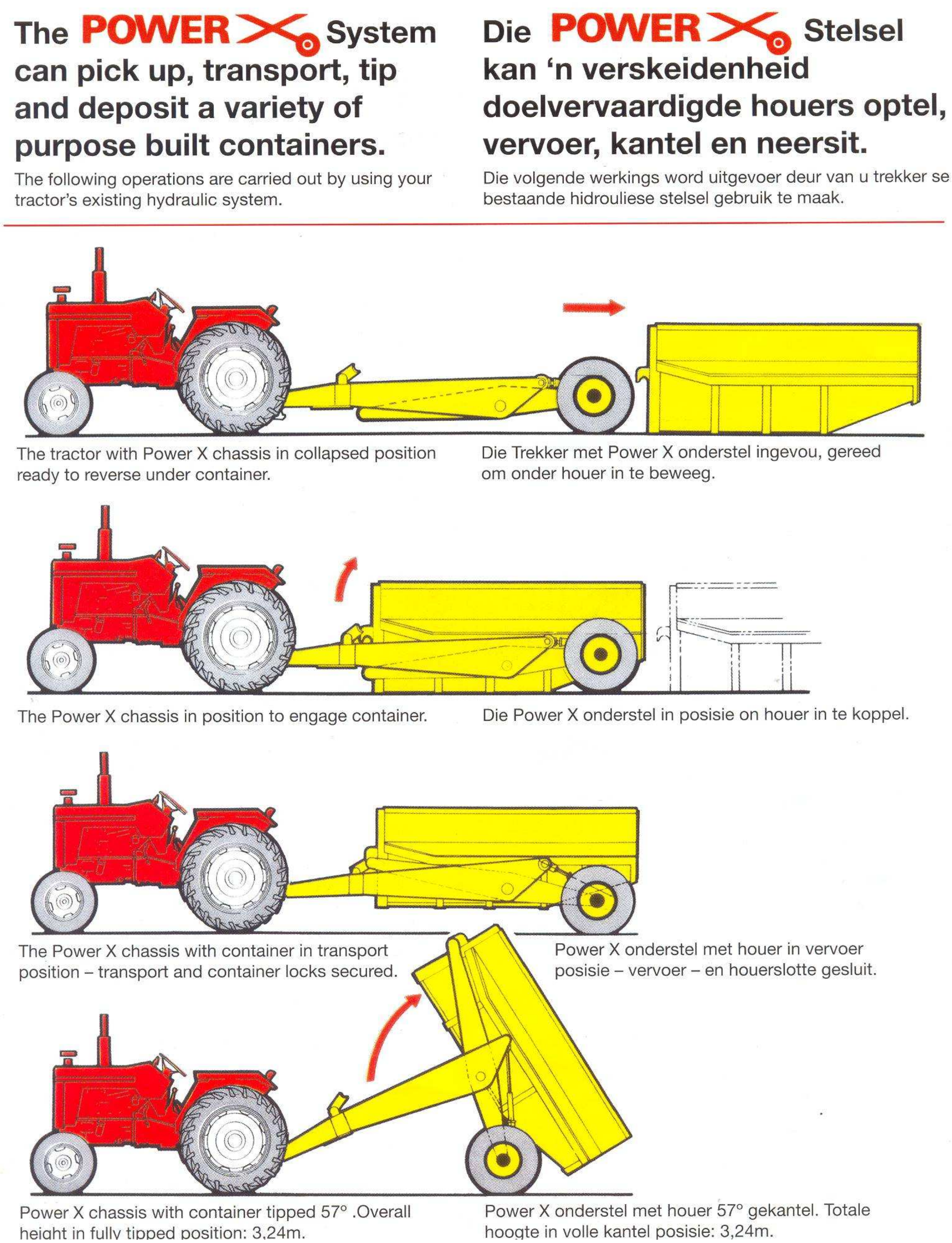


Figure 9: Example of Tractor Trailer System

References

IFA (2006): Entsorgungslogistik (ELO – Waste Management Logistics) – Skript zur Vorlesung, Institut für Aufbereitung Fester Abfallstoffe, RWTH Aachen University, Germany

UNEP-IETC (2006): International Source Book on Environmentally Sound Technologies (ESTs) for Municipal Solid Waste Management (MSWM), http://www.unep.or.jp/Ietc/ESTdir/Pub/MSW/index.asp

UNEP & WND (2007): Integrated Solid Waste Management Plan for Wuxi New District (Wuxi Municipality), Peoples' Republic of China

Environmentally Sound Technologies for Action 2.2 - Systematic Infrastructure and Route Planning

Short Introduction

The Department Health and Environment within MCC, in close collaboration with the MCC Department of Urban Planning (and with LSPP), should elaborate a waste collection infrastructure plan. Currently, certain wards are not serviced by the MCC as no appropriate access infrastructure exists. Furthermore, the location of waste collection centres as well as the regularity and timing of waste collection services by the MCC should systematically be addressed by both departments. Key staff needs to go on training and/or a consultant should be appointed to carry out this action.

Summary of Technology Requirements

Sector	Type	Approx. Prize per Unit [M]
Software	Route Planning Software	> 100,000.-
Hardware	PC+Printer	7,000.- - 10,000.-
	CB (Base station)	6,000.-
	CB (Truck Unit)	3,000.-
	Cell Phone	500.- - 5,000.-
Transfer Station	Transfer trailer (walking floor)	350,000.-
	truck tractor	500,000.-
	tractor/loader	300,000.-

Background

Under Action 2.2, basically three elements need to be considered in terms of environmentally sound technologies:

- General road infrastructure planning
- Waste management infrastructure planning
- Waste collection route planning

As the planning of general road infrastructure is a matter of civil engineering that lies at the core of the MCC Department of Urban Planning, informed by MCC Waste Management, this issue will not be dealt with in detail as it lies beyond the scope of this document. In this context, it should however be mentioned that a number of waste products available in Maseru can be used in the construction of road infrastructure such as builder's rubble and shredded car tyres. A concise document on the use of waste materials in road construction can be obtained from OECD: "Road Transport and Intermodal Linkages Research Programme - Recycling Strategies for Road Works" - http://www.oecdbookshop.org/oecd/display.asp?sf1=identifiers&st1=771997011P1.

With regards to the planning of waste management infrastructure, a number of methods and tools exist that can be helpful in successfully designing an efficient waste management system. The method that will be discussed in this context is the Graphical Determination of Centres of Generated Waste Mass, which is useful in the location of infrastructure such as transfer stations and landfill sites. Furthermore, the optimal layout of a transfer station will be discussed.

With regards to route planning, a variety of approaches exist, ranging from the manual elaboration of optimal routes based on hardcopy maps, to the more sophisticated route planning assisted by software applications. In this context, a number of route planning applications will be introduced. Furthermore, it has been raised by MCC that it is currently difficult to keep track of waste collection vehicles during daily operations. It is therefore suggested that waste collection vehicles are equipped with appropriate communication devices such as CBs (two-way radios) or cell phones, so that drivers can be contacted and located. However, these technologies will not be discussed in detail here.

Technology Descriptions

Graphical Determination of Centres of Generated Waste Mass

The purpose of this method is to graphically determine the location of the centre of generated waste mass in order to solve problems of the following types (IFA, 2006):

- Location of infrastructural elements such as transfer stations and landfill sites for the logistical optimisation of the waste management system
- Optimised allocation of collection areas (wards) to existing waste management infrastructure

The underlying reason here is to minimise transport expenditure as well as related costs and environmental impacts, and consists of a preliminary strategic step before engaging with actual operational route planning.

As a starting point, the following aspects should be considered:

- In each ward in Maseru, wastes are being collected according to a specific system, e.g. kerbside collection or bring system. Independently from the final destination of the wastes, transport distances covered for waste collection are considered a constant value within the waste collection system.
- The ward-specific centre of mass or population is considered the starting point for the transportation to the landfill site.
- Expenditures for transportation in various developed scenarios can be compared based on kms, time expenditure, CO_2 emissions, etc. and assist in deciding on a preferred option.
- Furthermore, the following elements are required:
- Map at a scale of minimum 1:50,000, preferably digitalised
- Statistical data on the study area, e.g. population and waste generation numbers
- In a first step, a central point is defined for each collection area (ward) which will be used as starting point for further calculations.

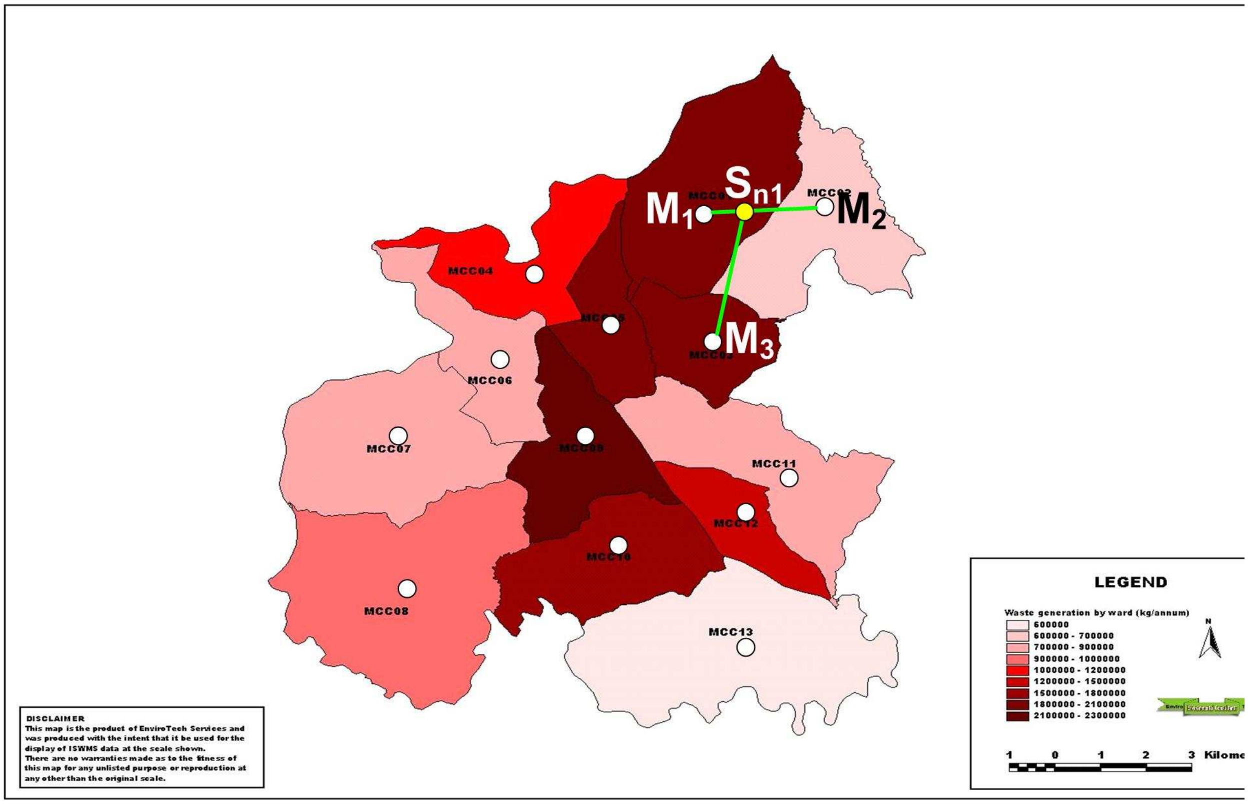


Figure 10: Calculation of Mass Centres in Study Area

Based on the following formula, the mass centre between 2 points is calculated:

$S_{n1}=1-M_1/(M_1+M_2)*100\%$

In the case of the example given in Figure 10,

$S_{n1}=1-195{,}000t/a / (195{,}000t/a+80{,}000t/a) *100\%=29\%$

The value of S_{n1} gives the distance between the 2 points in % from the perspective of point 2.

In the next step, the obtained point is connected with the next central point; for these 2 new points, a new mass centre S_n is calculated. In the same fashion, all points will be connected. The last mass centre will represent the total mass centre.

Layout of a Waste Transfer Station

The purpose of a transfer station is to transfer waste from waste collection vehicles to larger transport vehicles such as transport trucks or freight trains in order to optimise transportation expenditure and related system costs. This transfer of waste is frequently accompanied by some removal, separation, or handling of waste. In areas where wastes are not already dense, they may be compacted at a transfer station.

The construction and operation of waste transfer stations is however bound to additional costs that need to be outweighed by the system savings. Furthermore, there is extra time, labour, and energy needed for transferring waste from collection trucks to transfer trailers.

When planning the installation of a transfer station, the following points should be considered

(IFA, 2006):

- The payload of waste collection vehicles is smaller than the payload of transport vehicles (minimum factor 2)
- The personnel deployed on waste collection trucks is min. 1 driver/1 collector and is therefore higher than on transport vehicles.
- The capital bound in collection vehicles is by far higher than the capital bound in transport vehicles (ca. factor 2)
- Waste transfer requires technical equipment incl. locations, expenses for maintenance of operating points, and investments.
- For the transportation of waste over long distance, additional technical compaction might be required in order to achieve the maximum allowed capacity of transport vehicles.

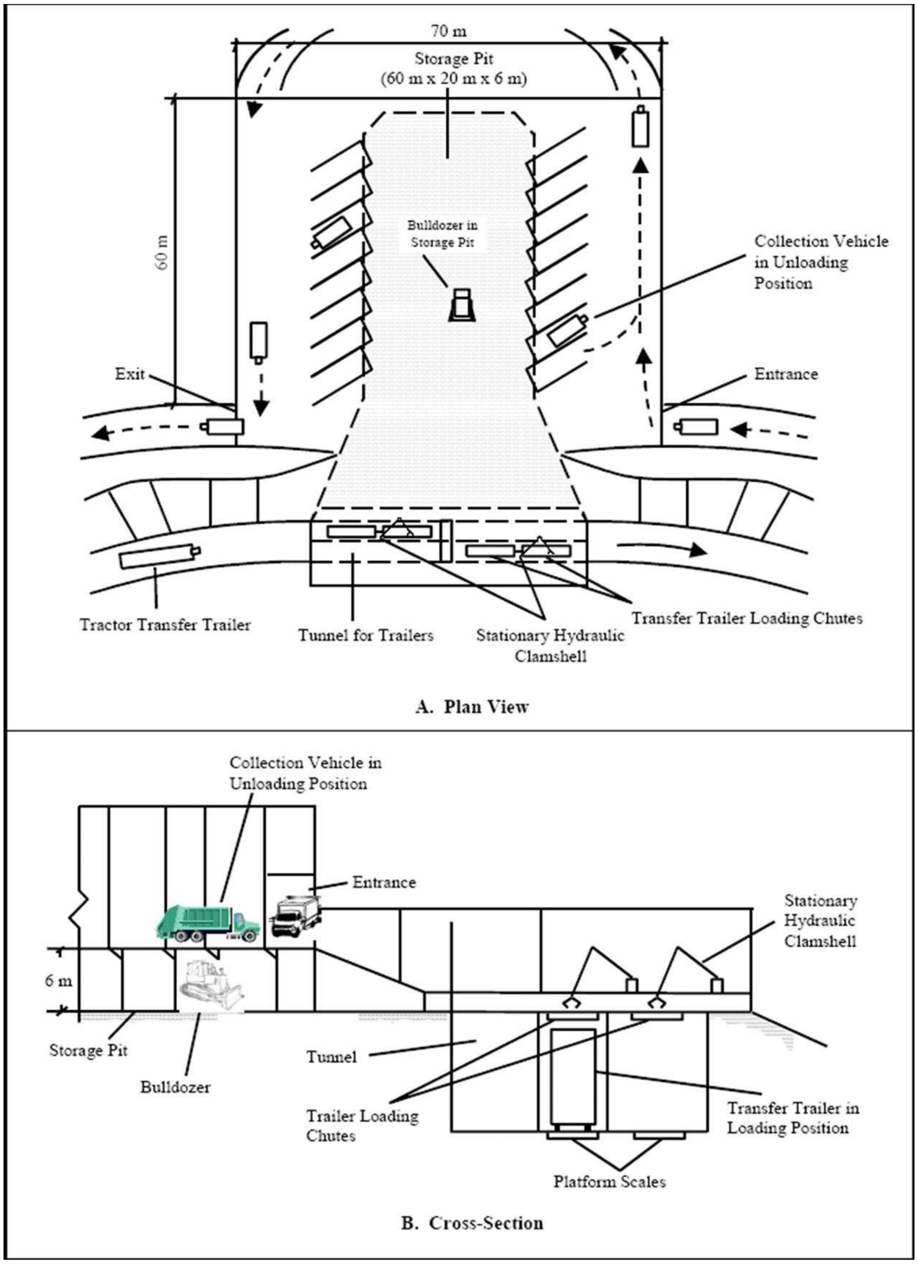


Figure 11: Typical Layout - Waste Transfer Station

In developing countries, some transfer stations are of the type depicted in Figure 11, but there are also unmechanized, local transfer points that serve the special needs of particular collection service areas. These local transfer points are discussed under ESTs for Action 2.1.

A number of truck types are currently used for transporting wastes from transfer points. At large transfer stations, large transfer trailers are used for bulk transport of compacted waste to more remote disposal facilities. These can be either open-top (usually a cover is required during waste transport) or enclosed.

Transfer station design in industrialized countries generally includes a tipping floor serviced by bulldozers for pushing waste into transfer trailers or a compactor blade for packing waste into trailers. Recyclables and special wastes are increasingly being sorted and processed at transfer stations. In the case of Maseru, the sorting and value-addition to recyclables is discussed under ESTs for Actions 3.1-3.4.

The following design and selection factors for transfer stations and transfer points are associated with sound practice (UNEP, 2006):

- Choose a transfer system that can accommodate the full range of collection vehicles already in use or planned (even when the long-term desire might be to phase out certain types).
- Site transfer stations and transfer points to minimize odour and noise and to allow waste to be accumulated, if necessary, prior to long-haul transport.
- Respect and abide by agreements with the neighbourhood in which a transfer point is sited.
- Select and design transfer systems that allow access to the waste for pre-processing and removal of recyclables, compostables, or problem materials, unless there is a compelling reason to do otherwise.
- For large-scale transfer stations, select locally made equipment, local designs, and local expertise whenever possible, supplemented if necessary by assistance from national or international experts.

In the case of Maseru, it has been suggested in a rejected EIA by Genesis Environmental Solutions for a new sanitary landfill site that a transfer station should be included to the City's waste management system. The necessity of a transfer station in Maseru is however highly questionable, as the new potential landfill site is located at 35km from the City centre. It is suggested to consider alternative scenario in order to take an informed decision on the viability of a design including a transfer station.

Route Planning Software

Route planning is an activity mainly performed by logistic companies for the planning, follow up, and quality securing of transports, collections and deliveries of goods and personnel. In the case of waste management, route planning can be used in order to improve efficiency of waste collection services by minimising transport distances and systematically organising the waste collection fleet and personnel.

One example for route planning software is RouteSmart by RouteSmart Technologies. In one software package, it offers solutions for a number of public work duties, incl. waste collection routing and street sweeping optimisation. It balances collection routes based on time, personnel/assets or volume parameters, and sequences stops in optimised travel order to minimise transport distances and meet time-of-service restrictions.(http://www.routesmart.com)

Another example for route planning software is Combitour from IVU Traffic Technologies. It is the leading system for waste handling logistics, used by more than eighty waste disposal companies. The system assists waste collection companies in optimising collection routes in terms of transport distances and collection times as operations become increasingly complex in competitive markets. (http://www.ivu.de/index.cfm?articleid=456&year=2004)

A comprehensive list of commercial vehicle routing software is given on the websites of the University of Karlsruhe (http://www.wior.uni-karlsruhe.de/bibliothek/Vehicle/com). Further information on route planning software can be found under the following URLs:

- http://www.isb-reinirkens.de/ISB-GIS-Entsorgung.html

- http://www.software-marktplatz.de/software-043015-1-1700-100-tpl-tourenplanung,-tourendisposition,-routenplanung,-leistungsbewertung-energiewirtschaft-versorgungswirtschaft.html
- http://www.tuvpt.de/fileadmin/pdf/Gueterverkehr/optimale_transporte-flyer.pdf

In the context of Maseru's ISWMP, it should be considered to integrate route planning software with other elements under a Waste Information System (see ESTs for Action 5.3 - Establishment of a Waste Information System).

References

Envirotech Services (2006): Baseline Assessment for the Development of an Integrated Solid Waste Management System (ISWMS) for Maseru City, prepared for NES, Maseru, Lesotho

IFA (2006): Entsorgungslogistik (ELO – Waste Management Logistics) – Skript zur Vorlesung, Institut für Aufbereitung Fester Abfallstoffe, RWTH Aachen University, Germany

UNEP-IETC (2006): International Source Book on Environmentally Sound Technologies (ESTs) for Municipal Solid Waste Management (MSWM), http://www.unep.or.jp/Ietc/ESTdir/Pub/MSW/index.asp

UNEP & WND (2007): Integrated Solid Waste Management Plan for Wuxi New District (Wuxi Municipality), Peoples' Republic of China

Environmentally Sound Technologies for Action 3.2 - Foster the Development of a Local Recycling Economy

Short Introduction

Recycling activities within Maseru are currently mainly constrained to the collection, pre-sorting and baling of recyclables, with the major value-adding processing steps being undertaken by companies in South Africa.

A healthy local recycling economy would focus on taking over some or all of the downstream, value-adding processing steps, thus supporting economic growth and job creation by selling value-added (intermediate) recycled products. The figure below illustrates the shift in the economy which would need to occur as an outcome of this action.

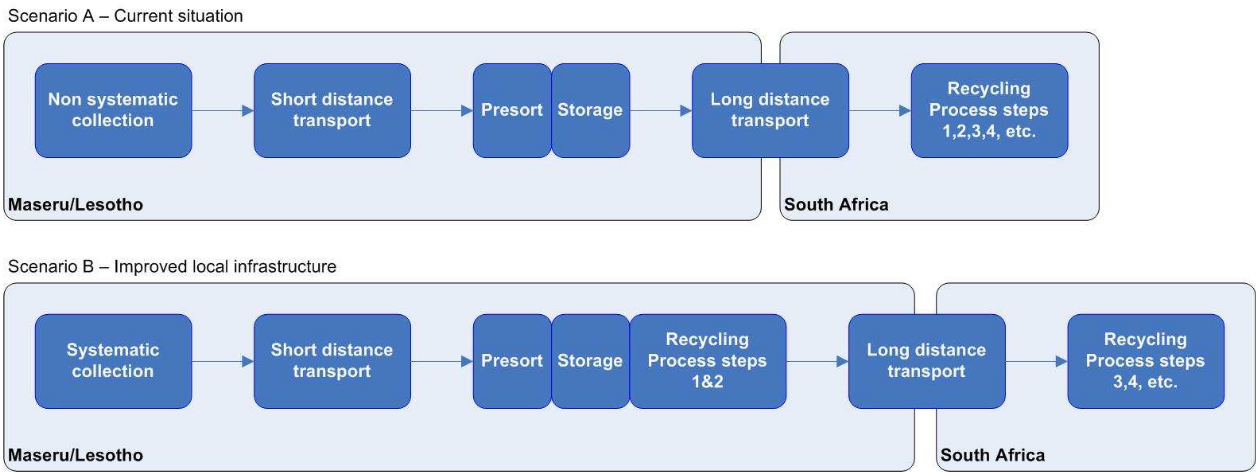


Figure 12: Local Recycling Infrastructure Maseru - 2 Scenarios

The recycling centre identified in Action 3.1 would assist in providing infrastructure for the local recycling economy, while Actions 3.3 (recognition and support of local recycling markets) and the proposed recycling forum of Action 3.4 would provide a healthy environment for collaboration surrounding the recycling economy.

Furthermore, a value add component for recyclables could be considered as part of the tender process for removal of wastes under the ISWMP.

Technology descriptions

The following are value-adding steps that may be appropriate in the Maseru context:

- Manual or Mechanical sorting of recyclables
- Cleaning
- Down-sizing (shredding)
- Baleing or Compacting

Manual Separation

Manual sorting will be required in Maseru to separate the collected mixed bag of recyclables into the various streams (i.e. paper, plastics, tins etc.). In general, labour-intensive low-tech processing, such as manual sorting, will be preferred over expensive high-tech processing.

Manual separation can further add value if, for example, bottle caps and rings are removed, labels are removed from tins/bottles.

Manual sorting can also be used to remove contaminants from the separated recyclables. In Maseru, the price obtained for baled recyclables is often lower than anticipated due to the prescence of contaminants. Recycling firms in South Africa receiving bales may even reject consignments if contaminants are present.

Equipment involved in manual separation of materials includes the following (UNEP):

- A sorting belt or table with workers stationed on one or both sides of the belt or table.
- Hoppers or other receptacles for receiving removed items positioned within easy reach of the sorters.

Mechanical Separation

Mechanical separation includes:

- size reduction
- screening
- air classification
- magnetic separation, and
- non-ferrous (e.g., aluminium) separation

In general, these processes are used to separate recyclables from a mixed MSW stream. Under the proposed ISWMP for Maseru, recyclables will be collected separately from residual MSW. As such, mechanical separation may not be required to the same degree. However, some mechanical separation processes may be appropriate to use with a mixed recyclables stream or to remove contaminants thereby increasing the value of the products transported to South Africa.

Size reduction

Different separated plastic streams could be shredded to increase their value and ease transportation. Glass fractions may also be ground down to facilitate the removal of labels and other contaminants.

Technologies that may be appropriate here include:

- Hammermills
- Shear shredders

In general, the shear shredder will result in a courser product.

Screening

Screening could be used to remove contaminants from a mixed stream or separated stream of recyclables if present.

Technologies appropriate for source-separated materials include:

- Vibratory flat bed screen
- Trommel screen

Air classification

Air classification is typically used to separate mixed shredded MSW into a light and heavy fraction. It is therefore not appropriate in the Maseru context. Newer pneumatic technology which selectively removes contaminants (e.g. from a plastics stream) may find application, but may also be too expensive. Manual sorting should rather be used.

Magnetic separation

Magnetic separation is a technically simple and relatively low cost process that could be used to segregate magnetic (i.e. ferrous) metal from the mixture of recyclables.

Magnetic separators are available in three configurations:

- magnetic head pulley
- drum, and
- magnetic belt.

Non-ferrous separation

It is felt that separation of aluminium and/or glass from a mixed recyclables stream can be easily achieved using manual separation. However the technology that could be applied here to separate these streams out is eddy current separators.

Cleaning

Under the ISWMP for Maseru, the aim is to collect clean, dry recyclables. However, if the collected recyclables, particularly plastics, are dirty, cleaning may be required. An ultrasonic cleaner is therefore proposed for this purpose.

Baleing or Compacting

To aid transportation of the separated recyclables streams, a baler is required. Balers are used for paper, cardboard, non-shredded plastics and cans. Other technologies for compacting include:

- biscuiter
- can densifier / flattener
- pelletiser (for plastics)
- Design of processing facilities

According to UNEP-DTIE (2006) the design of a successful processing facility should consider the following:

- Reliance upon proven technologies (appropriate to Maseru) and based on the fundamental principles of engineering and science
- Consideration should be given not only to the characteristics of the mixed recyclable materials, but also to the specifications of the recovered materials that are to be sold

- The recovered material qualities should be preserved or improved
- Processing flexibility to accommodate potential future changes in market conditions
- Recovery of the largest percentage of materials that is feasible given the conditions that apply in Maseru
- Accommodating the various types of vehicles that would deliver mixed recyclables to the facility, as well as the frequency of the deliveries
- Relying largely on manual labour where current automation technology is lacking, unproven or marginally effective
- Material storage, and
- Health and safety of workers and protection of the environment.

The table below summarises the technologies that can be used for the different recyclable streams in Maseru. Support processes necessary for transportation inside recycling facilities and storage are also listed in the table.

Table 4: Typical design considerations and processing alternatives for facilities that process source-separated feedstocks (UNEP-IETC, 2006)

Collection Category	Basic Feedstock	Tipping Floor	Sorting Conveyer (or room)	Interim Storage	Preparation for Shipping	Finished Product Storage
Paper and cardboard	Newspapers, office paper, cardboard, some coated grades	Hand pick contaminants	Hand pick contaminants	Accumulated in bins or bunkers before being selectively conveyed to baler	Baler	In stacks or bales on processing floor or stacked in transport vehicle
			Infeed Conveyer	**Screen**	**Dynamic/Pneumatic Separator**	
Commingled containers	Tin, bi-metal and aluminium cans; plastic and glass containers; contaminants	Hand pick contaminants	Hand pick contaminants; Magnetic separator for ferrous	Broken glass recovered as undersize mixed-colour fraction	Separate aluminium and plastic from glass	
	Sort Method	**Bale**	**Biscuit**	**Shred**	**Air Classify**	**Store**
Ferrous (bi-metal)	Manual and/or magnetic separation of tin cans and bi-metal if required	With baler	With can densifier	With can shredder	n/a	Convey shredded cans to outside transport vehicle, or bales or biscuits in stacks on processing floor, outdoors or in a transport vehicle
Ferrous (tin cans)	Manual and/or magnetic separation of tin cans and bi-metal (if required)	With baler	With can densifier	With can shredder	To remove labels	shredded cans to outside transport vehicle, or bales or biscuits in stacks on processing floor, out-doors, or in a transport vehicle
		Flatten	**Transfer**	**Bale**	**Biscuit**	**Store**
Aluminium	Eddy current apparatus separates aluminium from non-metals	With can flattener	Pneumatically convey to outside transport vehicle	With baler	Compress in a densifier	On process-ing floor, outdoors, or in a transport vehicle
			Interim Storage	**Perforate**	**Bale**	**Store**
Plastic (PET)	Pneumatic and/or manual sort of PET		In overhead hoppers	Drop from overhead hopper or pneumatically convey to perforator	Mechanically or pneumatically from perforator to baler	On processing floor or outdoors in transport vehicles

				Granulate	**Bale**	**Store**
Plastic (HDPE)	Manual sort of HDPE		In overhead hoppers	Drop from overhead hopper or pneumatically convey to granulator	Mechanically or pneumatically convey to baler	Granulated in boxes on processing floor before loading into transport vehicle, baled in stacks on processing floor or outdoors in transport vehicles
				Crush	**Upgrade**	**Store**
Glass	Hand sort or optical automatic sort by colour			With glass crusher	Remove paper labels, metal lids, and other contaminants by screen and/or air classifier	In bunkers for loading by front-end loader, or in overhead bins for selectively conveying to transport vehicles
					Bale	**Store**
Plastic (HDPE and PET)	Manual sort of each type of resin				Mechanically or pneumatically convey to baler	In bunkers for loading by front-end loader, or in overhead bins for selectively conveying to transport vehicles

Environmentally Sound Technologies for Action 4.1 - Adjustment and Integration of Planning Activities for Sanitary Landfill Site

Short Introduction

The Department Health and Environment within MCC, in close collaboration with the MCC Department of Urban Planning (and with LSPP), should elaborate a waste collection infrastructure plan. Currently, certain wards are not serviced by the MCC as no appropriate access infrastructure exists. Furthermore, the location of waste collection centres as well as the regularity and timing of waste collection services by the MCC should systematically be addressed by both departments. Key staff needs to go on training and/or a consultant should be appointed to carry out this action.

Summary of Technology Requirements

Sector	Type	Approx. Prize per Unit [M]
Development	Site Access	4,000,000.-
	Site Amenities & Services	2,800,000.-
	Cell Construction (incl. liner)	10,000,000.-
	Leachate Management System	2,500,000.-
	Gas Management System	800,000.-
	Caping System	13,500,000.-
Operation	Chain Bull-dozer	2,500,000.-
	Front-end Loader	2,000,000.-

Background

The aim of environmentally sound landfilling is to avoid both short and long term impacts or any degradation of the environment in which the landfill is located, and more specifically to prevent pollution of surface and groundwater. The threat that current waste dumping activities pose to Maseru's groundwater reserves is unacceptable, and it is therefore recommended that a sanitary landfill site is built.

A sanitary landfill site is an engineered facility for the controlled disposal of municipal solid waste. Its design has the purpose is to minimize potential hazards for public health and the environment by including a number technical barriers around the landfill body. A typical landfill site setup consists of a number of cells in which waste is systematically placed. Its base is usually lined to prevent leakage of leachate into the ground- and surface water.

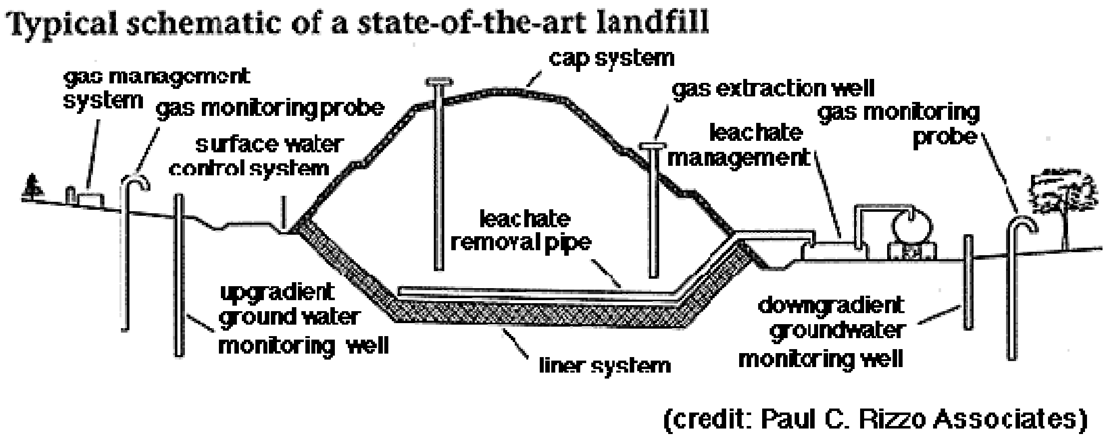


Figure 13: Typical Design of a State-of-the-Art Landfill

In the design phase of a new landfill site, the following points should be considered:

- Compliance with local zoning and land-use criteria
- Accessibility by waste collection and transportation vehicles
- Protection of surface and ground water reservoirs
- Capture and/or control of landfill gas emissions
- Location in proximity to earth cover material
- Not located in environmentally sensitive areas
- Comprise enough land and internal capacity to allow for expansion and buffer zone from neighbouring properties
- Approved by the local regulatory authorities and accepted by the public

A sanitary landfill site is highly capital intensive venture, and should therefore be designed to operate for a period of more than ten years. Furthermore, operational costs should be bearable by the community it is intended for, and the organization that owns or operates it.

Development of a New Landfill Site

The development of a new landfill site is a regulated process (at least in South Africa) that interacts with the national regulating authority at different stages. The development process depicted in Figure 14 has been adapted from the South African Minimium Requirements for Waste Disposal by Landfill (DWAF, 1998), and gives the different steps required for the selection, design, operation, closing and monitoring of a sanitary landfill site.

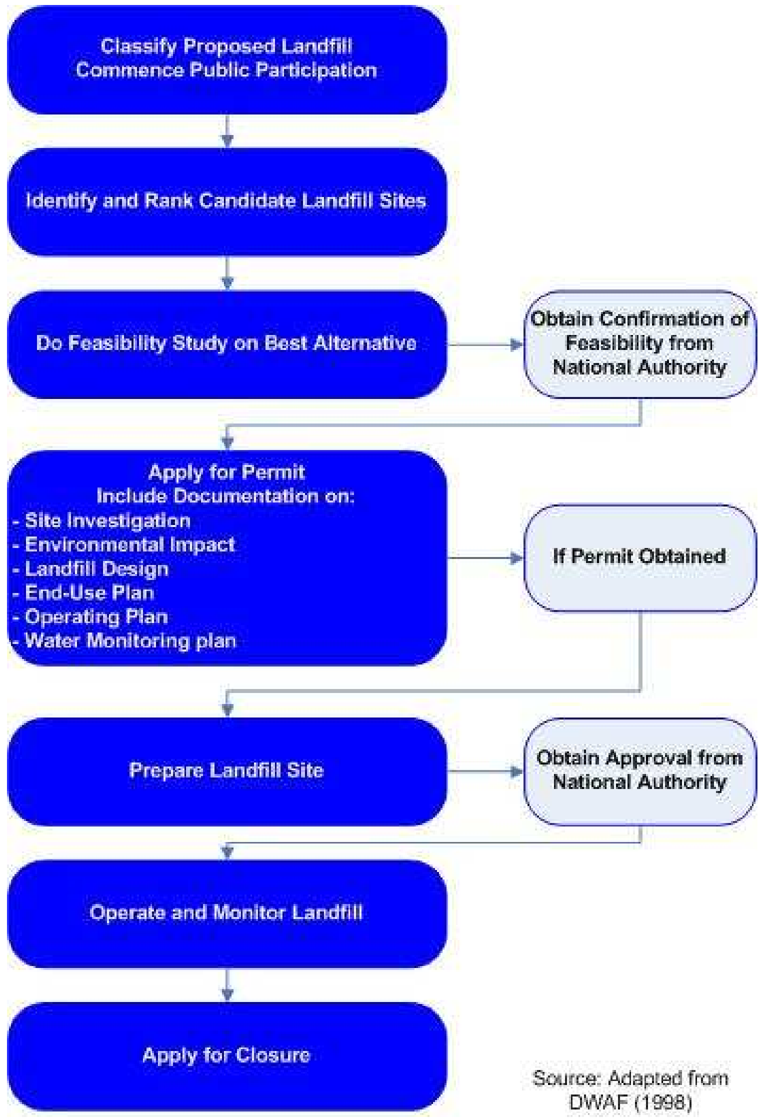


Figure 14: Flow-Chart for the Development of a New Landfill Site

The development of a new sanitary landfill site is a lengthy process, and responsible parties are advised to thoroughly conceptualise the development process before taking concrete action. Development activities for the new sanitary landfill site at Tsoeneng are currently underway, and a consulting company has been commissioned by NES to review and amend and EIA that has been rejected in its current form.

Classes of Landfill Sites

Waste generated in Maseru is either of general (G) or hazardous (H) type. Although waste disposal by landfill is not regulated in Lesotho yet, the South African Minimum Requirements on Waste Disposal by Landfill give a good basis on the technical necessities for disposing of different waste types in an environmentally sound fashion.

According to DWAF (1998), hazardous waste is the waste that has the potential, even in low concentrations to have a significant adverse effect on public health and the environment because of its inherent toxicological, chemical and physical characteristics. Hazardous wastes are rated as follows:

- Hazard Rating 1 - Extreme Hazard
- Hazard Rating 2 - High Hazard
- Hazard Rating 3 - Moderate Hazard
- Hazard Rating 4 - Low Hazard

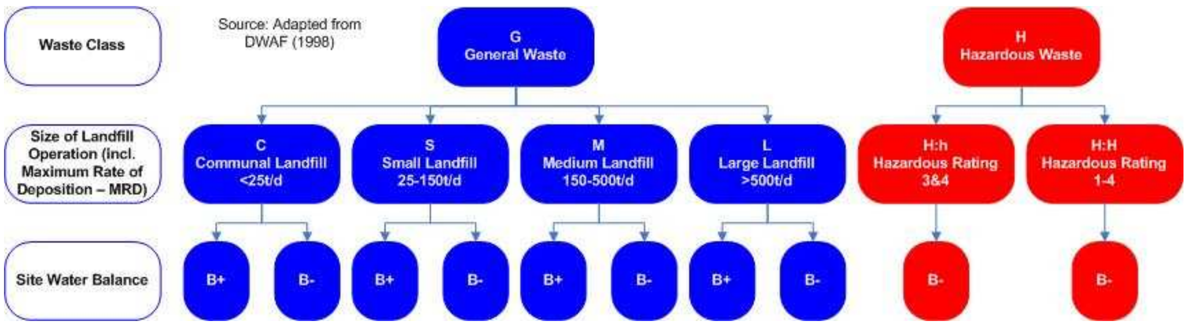


Figure 15: Landfill Classification - Source: Adapted from Minimum Requirements, DWAF (1998)

It is estimated by the MCC that the new landfill site should have a lifespan of minimum 20 years. In the rejected EIA proposed by Genesis Environment Solutions (2005), the Maximum Rate of Deposition has been calculated based on the formula given under section "calculation methods" (MRD=249.35 t/d). According to their findings, the proposed landfill should be classified as size medium. It is however suggested that the MRD is calculated based on the waste generation and management projections proposed in the ISWMP. For this purpose, the formula would no longer be applicable, as a number of detailed and non-exponential waste generation and management patterns have been assumed.

According to Genesis Environment Solutions, the Climatic Water Balance (see Formula under "Calculation Methods") is negative, which means that no significant leachate will be produced by the landfill (B-).

Technology Descriptions

The technical design and operation of a landfill site must prevent emissions from the landfill body to the environment. According to specific impact categories, the following elements need to be considered:

- **Prevention of Liquid Emissions:** A main threat related to the final storage of waste materials in a landfill is the production of leachate which could pollute surface- and groundwater. Therefore, an appropriate physical separation, i.e. liner system, needs to be installed, complemented by an effective drainage system.
- **Prevention of Solid Emissions and Odour Control:** On the other hand, waste, dust and odour emissions from the landfill body often enhanced through wind need to be controlled via regular covering to isolate the waste from the environment. Sufficient cover material should be available in proximity to the landfill site.
- **Prevention/Control of Gaseous Emissions:** The decomposition of organic materials in the landfill body leads to the production of landfill gas that is mainly composed of CO_2 and CH_4. Both components are active greenhouse gases which contribute to global warming. Furthermore, CH_4 is flammable, and poses a hazard especially to people working on the landfill site. Although it is an aim of the ISWMP to divert as much of organic waste as possible from landfilling and therefore reduce the potential of

uncontrolled gaseous emissions and stabilise the landfill body, it should be considered to integrate measures for the end-of-pipe capture of landfill gas at the design stage. In a subsequent operational stage, the captured gas could either be flared or used for energy recovery.

Technical Resources for Environmentally Sound Landfill Development

Infrastructure and Road Access

Depending on the size and the location of the landfill site, a number of infrastructural and logistical elements need to be implemented. If the site is located in an area without adequate road access, appropriate road infrastructure needs to be put in place so that waste collection and transport vehicles are able to enter the landfill site. Furthermore, access control should be provided for every type and size of landfill sites. It is especially for larger landfill sites that services such as water, sewerage, electricity, telephones, security, weighbridges, and site offices need to be put in place.

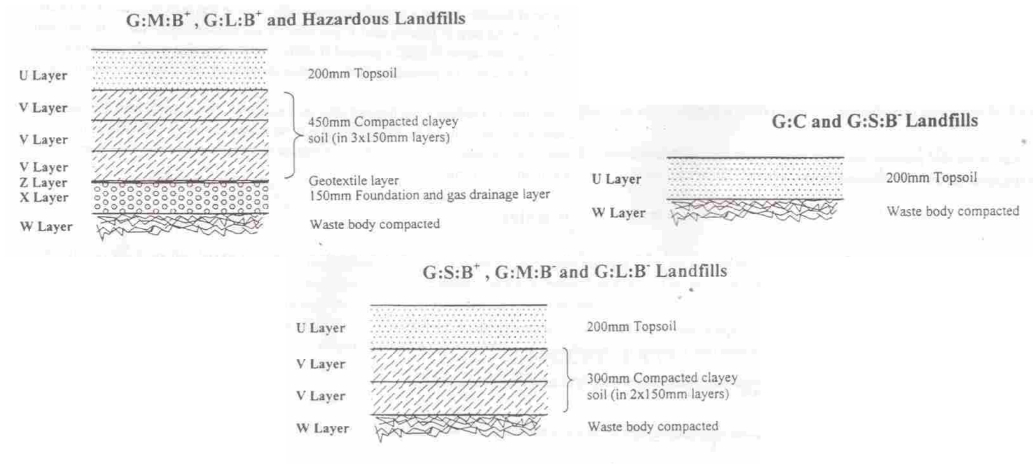
Liner and Capping Design

The requirements for the liner and capping design will depend on the type of landfill site as defined in section "landfill types". The different elements required for the construction of the liner and capping systems are defined as follows:

- Layer: Protection layer consisting of soil, gravel, rubble or other similar material material.
- A Layer: Leachate collection layer.
- B Layer: Compacted clay liner layer.
- C Layer: Layer of geotextile.
- D Layer: Leakage detection and collection layer.
- E Layer: Cushion layer of sand.
- F Layer: Geomembrane or flexible membrane liner.
- G Layer: Preparation layer consisting of a compacted layer of reworked in-situ soil.

Liner Designs

Cover or Capping Designs



Leachate Management System

Leachate produced by the landfill body will eventually accumulate, and poses a risk to the environmen by potentially leaking through the liner system unless it is removed by a leachate collection system.

The design of leachate management systems basically consists of a perforated piping system situated above the liner in order to collect the leachate, and a tank for the storage of the collected leachate. In a subsequent processing step, the leachate must be removed from the tank and treated or disposed of. Options for the environmentally sound management of leachate include:

- Discharge to a wastewater treatment plant
- On-site treatment followed by discharge to sewerage or surface water depending on the quality of the treated leachate
- Recirculation back into the landfill

All of these options generally require a pumping system. They require considerable maintenance due to the corrosive nature of the leachate.

Landfill Gas Management System

For every size and type of landfill operation, there should at least be a monitoring system in place in order to determine whether dangerous amounts of gas are being released. There are basically two types of landfill gas management systems, which are called passive and active landfill gas collection systems.

The advantage of passive systems is that they rely on the natural pressure of the landfill gas for the collection via buried vertical perforated pipes; such a system can therefore be realised at comparatively low costs. Once collected, the gas can either be vented or flared at the surface.

The design of active collection systems is based on a buried network of pipes coupled to pumps in order to capture the gas. The landfill gas can subsequently be processed and used for process heat or electricity generation. The advantage of active systems is that they realise higher gas yield than passive systems. Disadvantages are however the hazard bound to the pressurised capture of a potentially explosive gas, and relatively high costs.

In order to make the capturing of landfill gas an economically viable operation, the following conditions should be given:

- Sufficient methane generation

- Capital availability for gas processing
- Local demand for natural gas or means for transportation
- Relatively high market price for natural gas

Resources for Environmentally Sound Landfill Operation

The environmentally sound operation of a landfill site should aim at two basic principles:

- **Waste Compaction:** By compacting the deposited waste with heavy machinery, hollows in the waste body are minimised, which prevents the rapid infiltration of leachate, reduces the risk of fire, and increases site life through the achievement of higher waste densities.
- **Covering of Waste on a Daily Basis:** The regular covering of deposited waste with soil or other suitable materials (i.e. builder's rubble) is mainly aimed at reducing odour emissions, although it also reduces fire hazard and waste outflow.

In order to secure the environmentally sound operation of the landfill site according to the above mentioned principles, the following points need to be considered:

- **Equipment:** In order to secure the proper disposal of wastes on the landfill site, appropriate equipment needs to be available. Larger sites would require a combination of landfill compactors, bulldozers, front-end loaders and trucks in order to support appropriate operation of the site. Smaller sites would require less of the above mentioned equipment.
- **Staff:** According to the Minimum Requirements, landfill operation is carried out under the supervision of one responsible person. Furthermore, sufficiently qualified staff and back-up are required are required to ensure that the activities related to landfill operation are carried out properly.
- **Methods for Landfilling:** Sanitary landfills consist of elements referred to as cells which are built buy spreading and compacting solid waste into layers within a confined area. On a regular basis, the compacted waste is covered with a thin, continuous and compacted layer of soil. A series of adjoining cells at the same elevation constitute a lift. Typical heights of cells vary between 2 and 4 meters. The minimum width of the cell or minimum width of the working face depends upon the type of equipment used. Usually, a cell is about 2 to 2.5 times the width of the blade used for building the cell.

Additional Information

Selection of a Landfill Site

The selection of a landfill site requires decision makers to choose an appropriate site based on a number of considerations. A precondition for a successful selection is the presence of a number of potential candidate sites.

- **Economic considerations:** Early economic consideration regarding a potential site should include elements such as transportation distances from waste generation sources, site size, land availability and access.

- **Environmental considerations:** These considerations consist of elements having potential impacts on the environment, especially those related to local surface and groundwater reserves.
- **Public acceptance considerations:** These considerations include potential impacts of the landfill site on public health and safety, quality of life, local land and property values. Especially the early involvement of the directly affected population is of special importance, as this will help to accelerate the approval process significantly by clarifying potential misconceptions in the early stages of the development process.

Design of a Landfill Site

Depending on the outcome of the site selection process, a landfill site needs to be design in order to guarantee its main purpose, which is the prevention/control of solid, liquid and gaseous emissions from the landfill body into the environment. The matrix given in Table 2 can assist in identifying the different environmental impacts of a landfill site. As the selection of the site is based on criteria broader than just geohydrological aspects, substantial additional engineering might be required in order to secure the landfill body.

Table 5: Environmental Impact Matrix

Actions or Results of Landfilling	Blowing Dust, Odour & Air Quality	Landfill Gas Emissions	Noise During Operation	Additional Traffic on Roads	Litter	Leachate Production & Water Pollution	Salvagers	Etc.
Agriculture								
Recreation								
Residential Areas								
Surface Water								
Ground Water								
Archeological Site								
Indigeneous Forest								
Industrial Development								
Global Climate								
Etc.								

Closing of a Landfill Site

The closing of a landfill site must be authorized by the responsible authority. The closure of the landfill site will includes the application of final cover, drainage maintenance and leachate management, and the implementation of an end-use plan, e.g. recreational uses such as parks.

Monitoring

Monitoring is a control mechanism present at all stages of the development of a landfill site, incl. site preparation, liner installation, operation, rehabilitation, and after-closure. Furthermore, impacts on the environment are controlled by water and gas monitoring.

Calculation Methods

Maximum Rate of Deposition (MRD) at a Landfill Site

$MRD = IRD(1+d)^t$

MRD = Maximum rate of deposition in t/d during the final year of operation

IRD = Initial rate of deposition in t/d and would either be measured or estimated from appropriate information

d = the expected (constant) annual increase in the rate of deposition and would usually be based on the anticipated population growth rate

t = the period or planned life of the site expressed in years.

Climatic Water Balance

The Climatic Water Balance gives an indication on whether a significant amount of water will be produced or not, and is calculated as follows:

$B = R-E$

B = Climatic Water Balance, R = Rainfall, E = Soil Evaporation

Landfill Site Life

The volume of the waste V_r is calculated from the total volume as follows:

$V_r = (1-R)V_t$

R = Average ration of cover to total airspace, usually 1:5

V_t = Total volume of airspace of the site

The total mass of the waste Mr is calculated as follows:

$M_r = \gamma V_r$

Γ = Average density of compacted waste

The total mass of waste Mr is related to the initial rate of deposition (IRD) and the average annual growth rates as follows:

$M_r = IRD/l \,.\, [(1+l)^n -1]$

l = Average growth rate per year

n = time period or life of the site in years

For the purpose of calculating the expected site lifetime, the equation is rewritten in a more convenient form as follows:

$n = \log[M_r l/IRD + 1]/\log(1+l)$

References

DWAF (1998): Minimum requirements for Waste Disposal by Landfill, Second Edition, Department of Water Affairs and Forestry, Pretoria, Republic of South Africa

Genesis Environment Solutions (2005): Environmental Impact Statement for Tsoeneng Sanitary Landfill and Waste Management in Maseru, prepared for NES, Maseru, Lesotho

UNEP-IETC (2006): International Source Book on Environmentally Sound Technologies (ESTs) for Municipal Solid Waste Management (MSWM), http://www.unep.or.jp/Ietc/ESTdir/Pub/MSW/index.asp

UNEP & WND (2007): Integrated Solid Waste Management Plan for Wuxi New District (Wuxi Municipality), Peoples' Republic of China

Environmentally Sound Technologies for Action 4.3 - Capacity to Thermally Use Non-Recyclable Paper

Short Introduction

This action is concerned with creating capacity in Maseru to energetically use the stream of waste paper that remains after all reuse and recycling opportunities have been exhausted.

A process has been developed by the Appropriate Technology Section (ATS) to make paper briquettes for thermal use as a substitute for charcoal or biomass. As well as diverting paper waste from landfill, these waste paper briquettes fill the increasing need for an alternative fuel source in Maseru.

Summary of Technology Requirements

Sector	Type	Approx. Price per Unit [M]
Paper briquette press	1 x briquette	80.-
	2 x briquette	140.-
	4 x briquette	220.-

Technology Descriptions

The process developed by the ATS involves the following steps:

- Waste paper is soaked in water
- The resulting pulp is placed in a simple press
- Water is squeezed from the “briquette”

The paper briquette press is shown in the following figures:

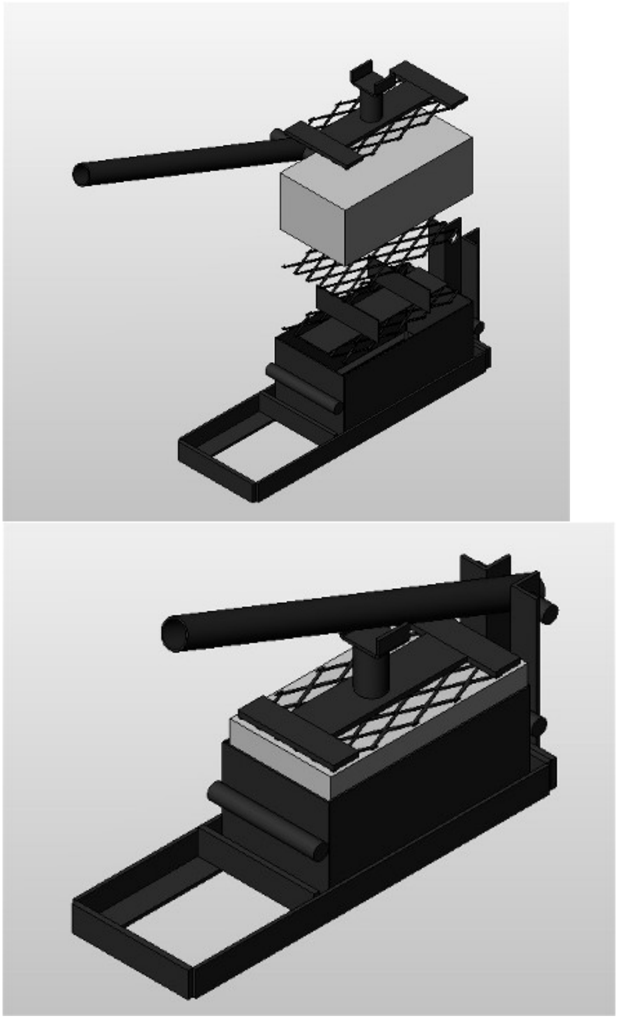


Figure 16: Paper Briquette Press

The briquette press has the following features:

- It is straightforward to manufacture and assemble
- It is easy to use
- It is robust and does not require maintenance
- If used properly, it can make briquettes that are comparable in characteristics to charcoal briquettes
- It is easily movable and lightweight

Environmentally Sound Technologies for Action 5.3 - Establishment of a Waste Information System

Short Introduction

Crucial to effective waste management is up to date and accurate knowledge on waste quantities generated, as well as their final fate. A WIS is a tool that enables the gathering, storing and interrogation of waste data. Besides the technical realisation of such a system, the legal perspective is of paramount importance; data will often not be obtained if the reporting of such data is not compulsory by law. Development of an appropriate system should be supported.

Summary of Technology Requirements

Sector	Type	Approx. Prize per Unit [M]
Software	Database Application	>3,000.-
	Analysis and Modelling Tool	>3,000.-
	Billing System	>5,000.-
	GIS	>15,000.-
	Route Planning Software	>100,000.-
Hardware	PC+Printer	7,000.- - 15,000.-

Background

The purpose of a WIS is to render activities in the waste management sector more efficient by enabling the systematic gathering, storing and interrogation of waste data. There is no single definition of a Waste Information Systems, and system configurations can vary widely in size and type. There are WIS for entire countries, states/provinces or municipalities. Furthermore, a WIS can be realised in form of a simple hardcopy filing system up to a highly complex IT system coupled to Enterprise Resource Planning (ERP) and Geographic Information Systems (GIS).

A WIS needs to be tailored to the requirements of the customer. In the case of the Maseru City Council, the current level of data gathering regarding waste information and IT infrastructure in the public administration sector needs to be identified prior to system design. Furthermore, it needs to be clarified for which purposes the WIS will be used by MCC.

The functionalities of a WIS can include:

- Data storage
- Data analysis and modelling
- Geographic information management
- Route planning and fleet management
- Customer billing

Whereby the functionalities mentioned here above can be provided separately by a number of (IT) tools or methods as stand-alone solutions, there is the option of combining up to all of these components into one integrated WIS.

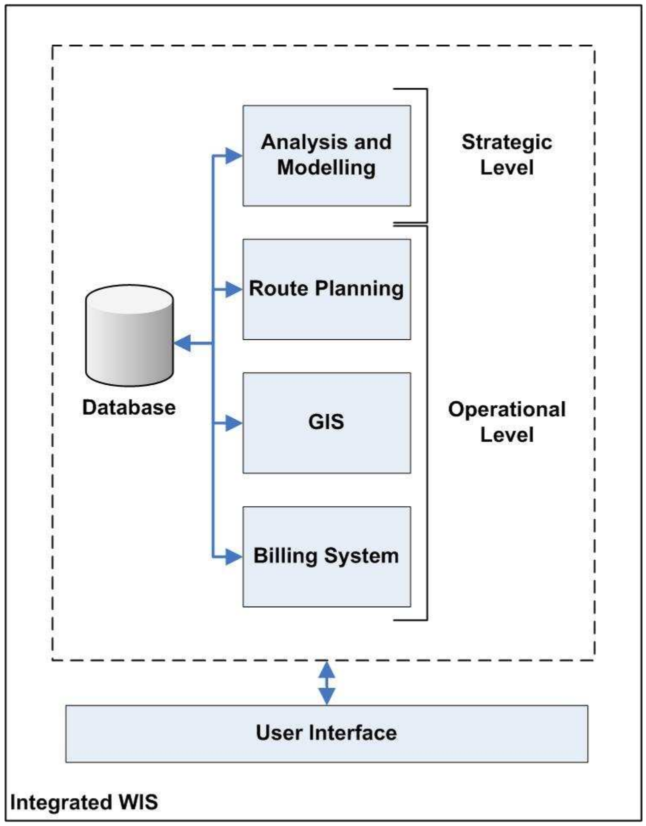


Figure 17: Example of an Integrated Waste Information System

Advantages of an integrated WIS are:

- Centralised storage and sharing of all waste management related data,
- Detailed planning and monitoring of waste management activities on the operational and strategic level, and
- Management of work order data and billing processes.

However, the disadvantages of an integrated WIS are as follows:

- Complex and customised IT solution
- High implementation, operation and maintenance expenditures
- Intensive and ongoing training of system administrators and users

As a rule of thumb, a WIS should be realised as simply and efficiently as possible. Furthermore, Maseru's WIS design should integrate proposed components within other actions in the ISWMP, use existing (IT) tools in other public administration departments, and allow upgrade and interfacing to further system components at a later stage.

Technology Descriptions

Database Applications

A database is a logical collection of interrelated information, managed and stored as a unit, usually on some form of mass-storage system such as magnetic tape or disk.

In the IT world, there exists a variety of database applications, ranging from spreadsheet applications such as MS Excel for the management of a rather restraint number of information, up to industrial scale database applications such as Oracle, suitable for the management of extensive data sets.

In the case of Maseru, the order of magnitude of waste information that needs to be collected and stored in a database application must be estimated in order to make an informed decision on the type of database system to be used.

Examples of database applications:

- MS Excel and MS Access
- Open Source: MySQL
- Industrial Scale: Oracle, IBM DB2, IBM Informix

Analysis and Modelling Tools

Analysis and modelling tools help to understand, interrogate and analyse activities in the waste management sector on a strategic level. Typical functionalities include the representation and analysis of generated waste amounts according to generators and final fates, and assist in the identification and projection of trends affecting the waste sector.

Within the framework of the development of the ISWMP for Maseru, the technical consulting team based at UCT/Cape Town developed a customised and comprehensive waste management model representing the different generated waste amounts on a detailed level according to source and sinks in Maseru. A functionality for scenario development and trend analyses has been included, taking into account the different interventions described in the ISWMP. Furthermore, a financial model has been developed based on an interface to the waste generation model, allowing the precise calculation of expenditure and income streams from a systems perspective.

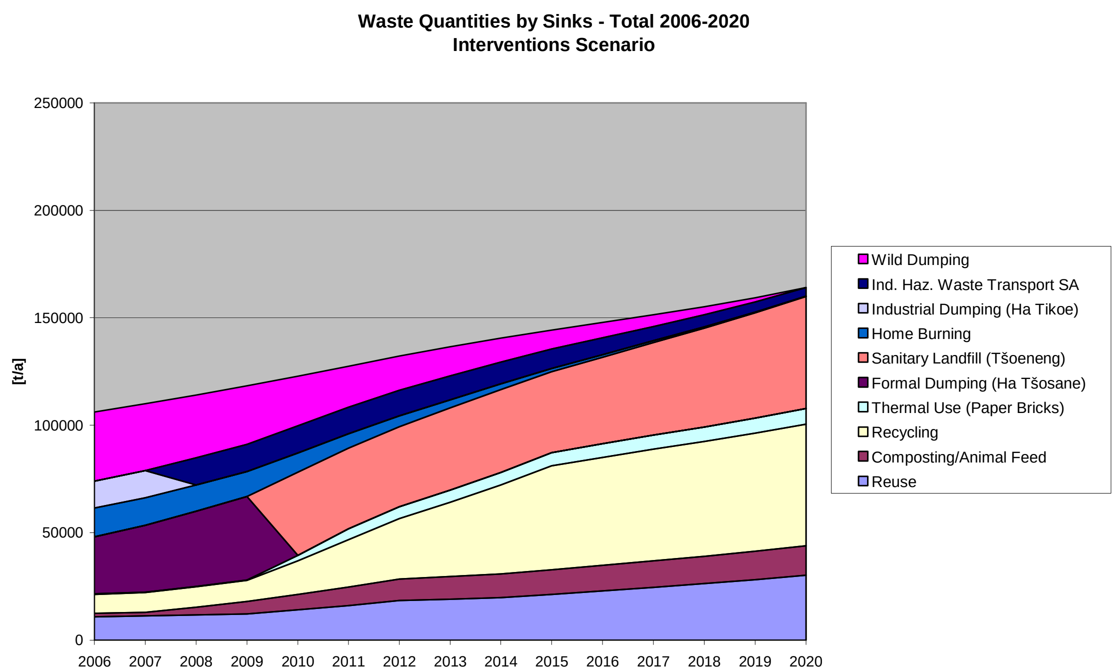


Figure 18: UCT Waste Sector Analysis and Modelling Tool – Customised for MCC

An off-the-shelve software solution is SWPlan - Solid Waste Management Planning Software. It handles the entire solid waste flow from generator to final disposal, including management approaches such as waste reduction, recycling, composting, and landfilling. It analyses amounts and types of wastes, calculates capital and operating costs, and considers revenues from i.a. recyclables.

http://www.scisoftware.com/products/solid_waste_overview/solid_waste_overview.html

Billing Systems

The two main features of billing systems are generally the management of customer information and invoicing. The latter needs furthermore to comply with country specific legal requirements (e.g. VAT). In the case of the waste management sector, a billing system can be employed in order to manage a database of households and commercial/industrial outlets that need to be serviced, and track payments of waste collection fees, which are a special challenge in the context of Maseru.

An example of a billing system is the Pastel Accounting Suite by Softline, targeting a large variety of businesses in terms of nature and size. Interestingly, Pastel is a software product by a South African company launched in 1989. It complies with SA regulations, and includes functionalities for the management of the customer database, quotations, invoices, purchase orders and inventories. (http://www.pastel.co.za)

Another example of a billing system is SAP for Utilities by SAP. It is a high-end IT-solution for managing a broad range of activities within the utilities sector, including solutions for billing and customer relationship management. (http://www.sap.com/industries/utilities/index.epx)

Geographic Information Systems

A Geographic information system (GIS) is an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information. (http://www.fws.gov/data/IMADS/glossary.htm)

For the purpose of designing a WIS for Maseru, it should be borne in mind that GIS software is only one tool amongst others required. It should be verified whether GIS software exists in other departments of the MCC which could be shared or interfaced. If not, it should be verified whether GIS software meets the specific needs for which it is required prior to purchase.

An example of GIS software is ESRI's ArcGIS. It is a complete system for authoring, serving, and using geographic information. It is an integrated collection of GIS software products for building and deploying a complete GIS according to specific customer requirements. The basic desktop software allows for maintenance of a personal geo-database of clients, cadasta, addresses, roads, depots, imagery, etc., and includes mapping, inquiry and analysis functions.

An extensive list of GIS software is given on the website of the University of Florida (http://www.geoplan.ufl.edu/software.html).

Route Planning Software

See ESTs for Action 2.2 - Systematic Infrastructure and Route Planning.

Examples of Waste Information Systems

Solid Waste Information System - State of California, USA

http://www.ciwmb.ca.gov/SWIS/

The Solid Waste Information System (SWIS) database contains information on solid waste facilities, operations, and disposal sites throughout the State of California. The types of facilities found in this database include landfills, transfer stations, material recovery facilities, composting sites, transformation facilities, waste tire sites, and closed disposal sites.

For each facility, the database contains information about location, owner, operator, facility type, regulatory and operational status, authorized waste types, local enforcement agency and inspection and enforcement records.

The data in the facility database is continuously updated and the downloadable data file is updated on a regular basis several times per week.

National Waste Information System - South Africa

http://wis.octoplus.co.za/?menu=1

The South African Waste Information System (SAWIS) developed by DEAT in 2005, is a system used by government and industry to capture routine data on the tonnages of waste generated, recycled and disposed of in South Africa on a monthly and annual basis.

Local Waste Information System - City of Cape Town, South Africa

http://www.capetown.gov.za/iwmp/pdf/Chapter11WasteInformationSystem.pdf

Currently, the Waste Department of the City of Cape Town has no comprehensive database or overlying integrated management information system in place to produce reliable data and management information. The Waste Department has decided to proceed with the acquisition of a WIS that best meets its future planning and management requirements.

The WIS is to include weighbridge software and should ideally interface with the City's new SAP information and business solution (which has the facility to include a waste module). The elements of the WIS considered to be necessary for the City's requirements include the following:

- Development of an effective operating, planning and financial management tool
- Easy interrogation and provision of meaningful management information for effective decision-making
- Interface with City's SAP information and business solution
- Effective provision of data required for maintenance of Provincial and National WIS systems
- Good accessibility of information and output in format required by waste management staff
- Incorporation of data verification and quality control systems
- Interface for weighbridge data
- Functionalities for analyses, incl. GIS component, optimisation of collection beats, staff information, details of plant, depots and waste departments facilities

- Record existing information required for the management of waste reduction, collection and disposal
- Monitoring of progress and effectiveness of strategies adopted in IWMP

BELUGA - Integrated WIS, City of Hamburg, Germany

http://www.sapinfo.net/public/en/printout.php4/article/Article-1002763edf388185889/en

An example of an integrated WIS is the BELUGA system developed by ÖKODATA for the waste management department of the City of Hamburg/Germany. The goal of the BELUGA system is to integrate the processing of commercial, technical and logistic data. The system includes mySAP Utilities for Waste Management from SAP, which is used to manage all work order data and billing processes, Combitour by IVU traffic technologies for logistic planning and fleet management, and ESRI’s GIS software for geographic database management and analysis.

Appendix A – Sustainability Assessment of Technologies Framework

1 ESTs for ISWM

Environmentally sound technologies (ESTs) for integrated solid waste management (ISWM) cover all the five stages of ISWM, viz.: waste collection, sorting and material recovery, transportation, treatment and resource recovery and final disposal. At each stage of ISWM, various technological measures are to be identified and implemented for efficient and effective ISWM. Table B-1 indicates important technological measures for each stage of ISWM.

Table B-1 Technological Measures for ISWM (Non-hazardous waste)

Stages in ISWM Chain	Activities
Collection	Segregation at Source – type, size and location of different bags/bins and collection points Transportation – type, size and O&M of collection vehicles for mixed, segregated and hazardous waste
Transfer Station	Sorting & material recovery – layout of facility and equipment for sorting, compacting and/or baling Transportation – type, size and O&M of vehicles for transporting compacted waste for treatment/disposal
Treatment	Thermal treatment plant with resource recovery (waste to energy) – layout, equipment and O&M Biological treatment plant with resource recovery (compost/biogas/ethanol) – layout, equipment and O&M Hazardous waste treatment plant – layout, equipment and O&M Residual waste – transportation to disposal site
Final Disposal	Sanitary landfill – layout, equipment and O&M Controlled landfill for hazardous waste – layout, equipment and O&M

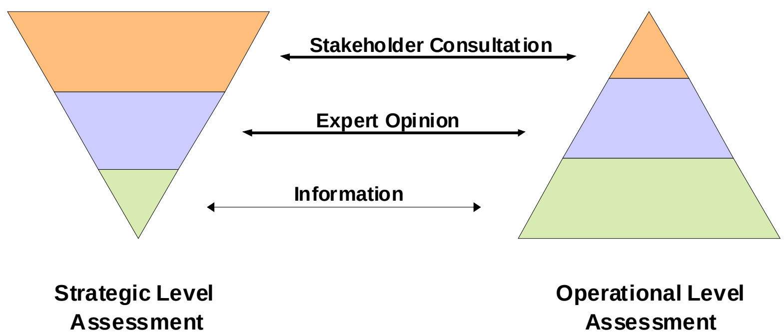
To identify appropriate technologies under each technological measure, a set of criteria is to be developed. This should cover technological, economic, social and environmental aspects of the technologies. Based on the criteria, technologies are identified and ranked to assist decision-makers to make a final selection of appropriate technologies. UNEP has developed a framework, Sustainability Assessment of Technologies (SAT) Framework, to identify and rank ESTs.

2 Sustainability Assessment of Technologies (SAT) Framework

This framework works at strategic level as well as operational level. At strategic level, the choice is made among competing technical solutions, such as thermal treatment versus biological treatment. While at operational level choice is made among competing technological choices for that technical solution, such as type, size and operations for thermal treatment plant, if thermal treatment is chosen at strategic level as one of the technical solutions for waste treatment. SAT assists decision makers both ways, to make operational level decision based on the strategic level decision or vice versa, if enough information is not available to take strategic level decision at first place:

It is important to note that the decision at the strategic level is *the* critical factor in the subsequent identification of candidate technology system options. These system options will then undergo assessment at the operational level.

Figure B-1 Tools used in Strategic and Operational Level of SAT



As shown in the figure above, the tools used in SAT (stakeholder consultation, expert opinion and information) at the strategic and operational levels vary in terms of their sequence and extent of application.

To identify appropriate ESTs for WND ISWM Plan, strategic decisions are already taken regarding segregation of organic waste from other waste at source, transfer stations with sorting facility for material recovery for recycling, thermal treatment for waste to energy and biological treatment of organic waste to produce compost/biogas/ethanol. Sanitary landfill facility is available with Wuxi Municipality. Similarly, hazardous waste collection, treatment and disposal facility is also available with Wuxi Municipality. Therefore, SAT Framework, could be used to assist decision-makers to select appropriate ESTs for source segregation, collection and transportation of waste, transfer stations with material recovery facility and thermal and biological treatment system. In WND, there is one thermal treatment system which is being expanded. However, SAT Framework may assist to identify the important technical, economic, social and environmental aspects of existing thermal treatment plant which are required to be improved.

2.1 Identifying technology system options through SAT Framework

Based on the problem definition, situation analysis and the outcomes of strategic level assessment, a basket of potential technology systems should be identified, which will be subjected to further rigorous three-tiered assessment. This initial exercise too, must be done with the help of expert opinion. Reference can be made to available technology fact-sheets, case studies and other available information resources such as UNEP's ESTIS or other environmental technology databases.

Depending upon the specific situation and needs, the stakeholder group may like to adopt the proposed set of generic and/or sector specific criteria without any changes. As noted earlier, in some situation-specific cases, it may be essential to revisit the generic set of criteria, and modify or add some specific criteria.

2.2 Screening tier (*tier 1*)

At this stage, the short-listed system options first undergo screening using criteria in tier 1. The tier 1 criteria yield only an objective Yes/No type answer and hence, those options that do not qualify one or all the conditions, then get automatically eliminated. For example, one of the criteria in tier 1 relates to a very basic requirement - legal compliance. In case a technology system can not ensure legal compliance, then it would get eliminated at this point itself. This assessment can be done by a suitable stakeholder group with / without the help of expert opinion.

2.3 Scoping tier (*tier 2*)

Short-listed system options from the tier 1 then go through the comprehensive scoping assessment (tier 2) that is more of qualitative in nature (low / medium / high). During this stage of SAT, the stakeholders are required to assess the various technology system options vis-à-vis the generic and customized criteria and indicators using any of the listed computational methods (preferably the simple weighted sum method) by following the steps as described below:

It is important to note here, that the scoping exercise lends an advantage in narrowing the decision range of scores, for a particular criterion in the detailed assessment level. For instance if low / medium / high scores are assigned on a basis of a scale of 0-10, then a selection of 'medium' score would scope the scores between 4 and 6. This allows a better sensitivity analysis to be carried out.

2.4 Weighted sum method

As one of the simplest methodologies for assessing alternatives, the weighted sum technique has been widely and effectively used in various applications.

The Weighted Sum Method is a quantitative method for screening and ranking available technology options against the recommended criteria. This method provides a means of quantifying and emphasising the important criteria over the others. This methodology is described in detail in subsequent sections, with relevant examples.

In situations where alternatives cannot be objectively assessed with ease and need a subjective or expert opinion based approach, weighted sum technique could pose some hurdles in decision making. In such cases one can resort to other and more complex techniques under what is collectively known as 'Multi Criteria Decision Making' Approaches.

One such technique, the Analytical Hierarchy Process (AHP), is explained in the next section.

2.5 Analytic Hierarchy Process

Multi Criteria Decision Making (MCDM) is often a challenging process and different techniques have been tried out till date.

While making decisions involving a variety of tangible and intangible strategic goals, managing conflicting stakeholders, or selecting from among dozens of alternative technology options, the Analytical Hierarchy Process (AHP) can help managers and developers combine all of this information and make informed decisions.

One of the reasons for AHP's popularity is that it derives (presents) preference information from (to) the decision-makers in a manner that they find easy to understand.

AHP is a systematic and structured procedure to construct and represent the elements of a problem in a hierarchy format. The basic rationale of AHP is organized by breaking down of the problem into smaller constituent parts at different levels. Decision-makers are guided through a series of pairwise comparison judgments to reveal the relative impact, or priority of the elements (*e.g.*, criteria, alternatives) in the hierarchy. These judgments in turn are transformed to ratio-scale numbers representing relative weights of the elements at a certain level of the hierarchy, as well as globally.

The hierarchy in AHP is often constructed from the top (goals from the management standpoint, *e.g.*, environmentally-sound development), through intermediate levels (criteria on which subsequent levels depend, *e.g*., physical, chemical, biological, and socioeconomic criteria) to the lowest level (usually a set of alternatives, possible actions). AHP allows the combination of group judgments by taking the geometric mean of single judgments.

One of the software applications that uses the AHP technique to carry out MCDM is 'Expert Choice' (available at http://www.expertchoice.com).

Expert Choice provides an interface that guides the stakeholder group through the process of:

- Structuring decision into objectives and alternatives
- Measuring objectives and alternatives using pair-wise comparisons
- Synthesizing objective and subjective inputs to arrive at a prioritized list of alternatives thus eliminating the need for complicated mathematical / numerical calculations
- Incorporating sensitivity analysis and expert opinions to overcome subjectivity
- Reporting decisions with a documentation mechanism
- Allowing participatory assessment by stakeholders

2.6 Assigning weights against each criterion

While a basket of generic as well as sector specific SAT criteria has been proposed in the new methodology, not all may be of equal importance in the process of decision making. Depending on the specific situation, conditions and priorities some criteria become more important than others for that particular case. Weighted sum method captures such a scenario by assigning weights to different criteria in accordance with their relative importance in the given context.

Let us consider a simplified example of a solid waste management project where technology system options are being assessed against the criteria such as costs (capital plus operating and maintenance costs), space requirement, energy consumption (and hence greenhouse gas or GHG emissions), and acceptance by affected communities. Different stakeholder groups may have different opinions about the relative importance of each of the criteria. For the concerned government agency overseeing the project, costs and space requirement may be of prime importance, while neighbouring communities may place emphasis on the "acceptance" of the technology system. Environment groups / NGOs may be more concerned about aspects such as energy consumption and GHG/pollutant emissions. How does one assign the weights to different criteria in such a case?

Firstly, the moderator can go round the table and try to build consensus for arrange the set of criteria in **order of priority** (rather than straight away assigning the weights). Once the relative importance of the criteria is established, the group can then move to assigning weights for each criterion.

There is no standard formula for assigning weights to criteria – rather, it is to be done within a group setting with a participatory flavour. The group may decide weights on a scale of 0-10 or 0-100; there is no hard and fast rule concerning this.

In such situations however, "*groupthink*" can occur. For example, the eccentric views of charismatic or even outspoken speakers can get undue prominence as the group seeks to make a decision by consensus, thus leading to poor decision making. Techniques like the Delphi Method can be applied in such situations to reach a properly thought-through consensus among stakeholders. **Box B-1** describes the Delphi method for consensus building which may be used in this exercise.

Box B-1: Delphi Method for Consensus Building

The Delphi Method works through a number of cycles of discussion and argument, managed by a facilitator who controls the process, and manages the flow and consolidation of information. Following are the steps for consensus building using Delphi:

1. Clearly define the problem to be solved (in our case, assign weights to the criteria)
2. Appoint a facilitator or chairperson with the skills and integrity needed to manage the process properly and impartially (the rest of this process assumes you are this person)
3. Select a panel of stakeholder with the depth and breadth of knowledge, and proven good judgment needed for effective analysis of the problem
4. Get individual panel members to brainstorm about the problem from their point of view and provide feedback to the facilitator, anonymously
5. Facilitator consolidates the individual responses, and resubmits these to the panel.
6. Now resubmit this summary information to the group and get new responses. Some individuals may change their mind and may decide to go with the majority. In other cases, those who are not with the group decision may provide some new information which may influence the group decision in the next round.
7. This process continues until a consensus on alternatives has been reached. (For instance, 70% participants may agree that social acceptability is the most important criteria and should be assigned a weight of 7 on a scale of 0-10).

2.7 Preparing the weighted sum matrix for the selected options using the relevant criteria

Once the weights have been assigned for each criteria, each available technology option is to be rated against each criterion using a scale (say) of 0 to 10 (0 for low and 10 for high). Again, there is no golden rule in this regard.

In the criteria table provided in **Table B-2**, the responses (scores) for tier 2 criteria are in the form of the "High / Medium / Low". It is essential to change this qualitative information to numbers. For this, the group may agree to some guidelines such as for "low" assign a score between 0-4, while for "medium" it could be between 4-7 and 8-10 for "high". This also has to be decided through a group consensus.

Finally, the rating of each option for a particular criterion is multiplied by the weight of the criterion. An option's overall rating is the sum of the products of rating times the weight of the criterion.

A matrix of criteria vis-à-vis available technology options using the weighted sum method as described above can be prepared. A template for developing such a matrix is shown below in **Table B-2**.

Table B-2 Template for computation using the weighted sum matrix method

Criteria	Weight	Tech System A		Tech System B		Tech System C		Tech System D		Tech System E	
		Score	Weight x Score	Score	Weight x Score	Score	Weight x Score	Score	Weight x Score	Score	Weight x Score
Criteria 1	W1	A1	W1xA 1								
Criteria 2	W2	A2	W2xA 2								
Criteria 3	W3	A3	W3xA 3								
Criteria 4	W4	A4	W4xA 4								
TOTAL											

Acores can be assigned on the basis of a predecided scale. Actual information on a particular criterion could be qualitative or quantitative and will have to be converted to a score on the basis of the sale assumed.

Note: It is critical here to decide consistent descriptor definition for the scores. That is, whether a higher or a lower score is better and desirable for qualification.

In most cases, the weighted sum method can provide satisfactory results. It is recommended that Expert Choice be used for more complicated and/or high value decisions. Expertise in the use of the software is also a prerequisite, in addition to the licensing fees. **Section 4** provides an illustration of the application of the new methodology, where a detailed illustration of the weighted sum method is also included.

2.8 Detailed Assessment Tier (*Tier 3*)

As an outcome of the scoping exercise, a number of non-feasible or unqualified EST options would be eliminated and the options with the best overall ratings are thus selected for further detailed (tier 3) technical and economic feasibility. This level of assessment is rather situation-specific and the suggested criteria at this stage demand a lot more detailed and quantitative information to facilitate decision making. Using the information, the stakeholder group should once again prepare a new weighted sum matrix or revise the existing one. In some instances, it is possible that the rating of the technology systems may change due to the new scoring based on available information. As an outcome of this exercise, the group will get a number of technology system options ranked in the order of their scores – or in other words their performance vis-à-vis the principles of sustainability.

2.9 Sensitivity analysis

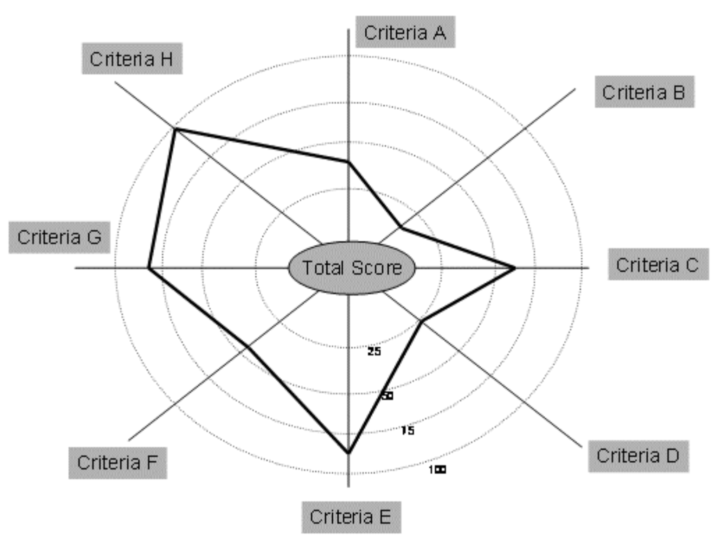
In the process of developing the weighted sum matrix, it can be seen that at times the difference between the total scores for some options may be very marginal. In other words, if the group decides to change the weights or scores for some of the criteria or technology options, then the ranking of the technologies can change accordingly. **During the group discussion therefore, it is essential to try various iterations to check the sensitivity of the matrix to such changes**. This can actually provide important insights as to how different criteria contribute in the final decision and thus help the group in making a rational and robust decision.

For conducting such sensitivity analysis, it is possible to develop a simple spreadsheet model, and try out various weights and scores to see how they influence the final scores and thus, the decisions.

2.10 Star diagram for presentation of outcomes

Another limitation of weighted sum matrix is that at the end of the process, users get an aggregated score for each technology option and it is not possible to see as to which were the dominating criteria amongst all. To overcome such a situation, it is recommended that the total scores for each technology options may be represented using a star diagram as shown below (**Figure B-1**):

Figure B-2: Star diagram for the presentation of outcomes



Such a diagram can illustrate the influence of various factors in the final scores. In some cases, for instance, the total score earned by a technology system may be the highest, but this could be due to the contribution of non-priority criteria This will require revisiting the weights and scores to ensure that the total scores are in accordance with the priorities defined by the stakeholder groups, and thus lead to a more rational and acceptable decision.

The illustration of SAT methodology application for solid waste management project in **Section 4** also shows the preparation of star diagram for all the assessed technology options.

2.11. Anticipatory Scenario building

When a stakeholder group undertakes a systematic SAT, it starts with a set of technology systems based on the current situation analysis. However, it may so happen that the selected "best" technology system choice made with the current set of information may be found to be inadequate or inappropriate in the future. This may happen due to changes in the situation, local requirements, legislations or even the new developments on technology front.

It is therefore recommended that once the group has completed one cycle of the SAT, before making a final decision, the same methodology be used to simulate certain future scenarios and ensure that the outcome of the current exercise is robust enough and can the suggested technology system can stand the test of time.

2.12 Implementation / monitoring

Once the decision is made, it would then form the basis for further steps such as detailed engineering design, tendering, actual construction and commissioning. It is also important to monitor and evaluate the technology system during its operational phase to ensure that it is meeting the desired objective vis-à-vis various criteria considered during the SAT process.

2.13 Feedback loop

The outcomes of the monitoring and evaluation should be reported to the stakeholder group – especially government agencies, planners and other decision makers. Such important information from implementation forms the basis for situational analysis for similar future projects, and hence can help in making better informed decisions.

3 Proposed criteria and indicators

The proposed criteria and indicators are tabulated in **Table B-3** together with some guidance notes. It must be emphasized here that the list of criteria and indicators is rather generic. It may or may not be necessary to use all the criteria during each assessment. Appropriate criteria can be selected by the users/ stakeholders as deemed most relevant to their own scenarios and contexts. **Table B-4** list sector-specific SAT criteria for municipal solid waste management in the same format.

Table B-3 Proposed Generic Criteria and Indicator System

Group Heading	Criteria	Indicators	Guidance Notes / Verification Requirements
Tier 1: Screening Criteria			
Compliance	**Compliance with Local Environmental Laws**	**Yes / No**	This is a very basic requirement and rather a simple check. The proposed technology system must ensure compliance with local as well as national legislation. Supporting information to make this decision can be found with technology fact sheets, expert opinions and information from vendors and expert opinion if necessary.
	Compliance with National Environmental Laws	**Yes / No**	
	Compliance with Multilateral Environmental Agreements (MEAs)	**Yes / No / Not Applicable**	Check if proposed technology system results in violation of MEAs. For instance, use of ozone depleting substances (ODS) can result in such a violation and hence must be avoided. This needs to be carefully scrutinized and it is necessary to rely on expert opinion for this, since this is rather a specialized area.
Other Requirements	**Meeting the objectives *(e.g. 3R, Remediation, Rehabilitation etc.)***	**Yes / No**	In view of the outcome of the strategic assessment, at times the objective of the technological intervention may not merely be legal compliance, but could be something more - say recycling, remediation etc. It is essential to ensure that the proposed technology meets this objective. Decision on this criterion can be made using information such as technology fact sheets, expert opinions and information from vendors.
Tier 2: Scoping Criteria			
Technical Suitability	**Compatibility with local Natural Conditions** **(Geographical, Climate)**	**Low / Medium / High / Not Applicable**	For the optimal performance of the technology, necessary to check the compatibility with the local natural conditions (*e.g. is the proposed*

Group Heading	Criteria	Indicators	Guidance Notes / Verification Requirements
			technology system suitable for geographical or climatic condition or not? Is it giving any secondary impacts such as groundwater contamination? Is it suitable for the topography?). To make this decision, refer to technology fact sheets, expert opinions and information from vendors. Depending on the extent of compatibility of the technology systems, one can rate them as Low Medium or High.
	Extent of local materials usage	**Low / Medium / High / Not Applicable**	In case of the technology intervention, preference should be given to the use of local material for both the cost as well as social reasons. Reference to vendor information and technology fact sheets, can help in making such a decision. Depending on the extent of local materials used, it is possible to can rate Low Medium or High.
	Availability of local expertise	**Low / Medium / High/ Not Applicable**	It would be essential to have the necessary local expertise for commissioning as well as operation and management of the new technology system. Depending on the expertise requirement vis-à-vis availability, one can rate Low Medium or High accordingly. Use vendor information and technology fact sheets, vis-à-vis available local expertise to make the decision on this criterion.
	Track record on performance	**Low / Medium / High / Not available**	Before making a decision about any technology system option, it is essential to check the track record of the technology as well as vendor. Technology fact sheets, market intelligence, site visits to similar installations can help in deciding on this aspect. Depending on the track record,

Group Heading	Criteria	Indicators	Guidance Notes / Verification Requirements
			one can assign a rating of Low, Medium or High accordingly.
	Compatibility with existing situation *(technology, management systems)*	**Low / Medium / High / Not Applicable**	In some cases, it is quite possible that the new technology system would build upon some existing system. As such, it is essential that the new system is compatible with the existing infrastructure/technology systems as well as the organization's management systems. It is possible to make this decision with the help of expert opinions supplemented by the technology fact sheets and vendor information. Depending on the level of the compatibility with the existing system, it is possible to assign the rating of Low, Medium or High for this criterion.
	Adaptability to future situations	**Low / Medium / High / Not Applicable**	In order to get the maximum benefit from the technology intervention, it is essential to check the flexibility or adaptability of the technology system for the future scenarios. This may, for instance, include the scale-up / expansion possibility or technology upgrade for improving efficiency in order to meet the changing needs. Ratings can be assigned for this criterion by referring to the technology fact sheets and expert opinions. It may also be essential to revisit situation analysis and undertake some simulation / scenario building exercises to be able to decide on this aspect. Depending on the adaptability with the future situations, can rate Low Medium or High.
	Process Stability	**Low / Medium / High**	The stability of the proposed technology systems during its operation phase is a very important consideration to get the desired results. The

Group Heading	Criteria	Indicators	Guidance Notes / Verification Requirements
			technology system must perform in a stable manner in the various scenarios / situations during the operation phase such as shock loads, sudden variations in process parameters etc. For making this decision, it is essential to rely on expert opinions and also by referring to the technology fact sheets, past similar case studies as well as vendor information. Based on the stability of the proposed technology system under different conditions, it is possible to rate the systems as Low, Medium or High against this criterion.
	Level of Automation / Sophistication	**Low / Medium / High**	Level of automation, sophistication for the proposed technology system can be assessed by referring to vendor information, technology fact sheets and expert opinions. Accordingly, it is possible to assign rating as Low, Medium or High against this criterion.

Group Heading	Criteria	Indicators	Guidance Notes / Verification Requirements
Environment, Health and Safety Risks	**Risk levels for workers**	**Low / Medium / High**	Before making the decision on the proposed technology system, it is essential to assess the potential environmental, health and safety risks to the workers, communities / beneficiaries as well as to the environment / biodiversity. Depending on the scale and sensitivity of the proposed technological interventions, it may be essential to conduct a full-fledged risk assessment exercise in some instances, while in other cases, this decision can simply be made by expert opinion supported by technology fact sheets, vendor information and expert opinions. Based on the potential risk levels, one can rate them as Low, Medium or High. *It is important to note that higher scores should be assigned for lower risks, while assigning the scores for the ratings during weighted sum matrix. This is different from many other criteria, where high rating corresponds to high scores.*
	Risk levels for communities / beneficiaries	**Low / Medium / High**	
	Risk to the environment e.g. to biodiversity	**Low / Medium / High**	
Environment: Resources and Emissions	**Resource Usage**		

Group Heading	Criteria	Indicators	Guidance Notes / Verification Requirements
	Space Requirement	**Low / Medium / High / Not Applicable**	Various aspects related to resource usage can be assessed by referring to vendor information, technology fact sheets and expert opinions. Accordingly, it is possible to assign rating as Low, Medium or High against this criterion. *It is important to note that higher scores should be assigned for lower space requirement, energy, water and raw material consumption while assigning the scores for the ratings during weighted sum matrix. This is different from many other criteria, where high rating corresponds to high scores.*
	Energy Consumption per unit	**Low / Medium / High / Not Applicable**	
	Extent of use of renewable energy	**Low / Medium / High / Not Applicable**	
	Extent of use of waste materials as input	**Low / Medium / High / Not Applicable**	
	Water Consumption	**Low / Medium / High / Not Applicable**	
	Raw Material Consumption	**Low / Medium / High / Not Applicable**	
	Resource Augmentation Capabilities	**Low / Medium / High / Not Applicable**	The proposed technology intervention may result in remediation or recovery/augmentation of resources as a side effect /additional benefit and must be considered in the making the decision regarding the technology system. For this decision, one can rely on expert opinions and also by referring to the technology fact sheets, past similar case studies as well as vendor

Group Heading	Criteria	Indicators	Guidance Notes / Verification Requirements
			information. Accordingly, it is possible to rate the systems as Low, Medium or High against this criterion.
	Emissions	**Low /Medium / High/ Not Applicable**	Various aspects related to emissions, odor, usage of hazardous materials can be assessed by referring to vendor information, technology fact sheets and expert opinions. Accordingly, it is possible to assign rating as Low, Medium or High against this criterion. *It is important to note that higher scores should be assigned for lower emissions, odour etc., while assigning the scores for the ratings during weighted sum matrix.*
	Odour	**Low / Medium / High**	
	Extent of use of Hazardous Materials	**Low / Medium / High**	
Economic / Financial Aspects	**Capital Investment**	**Low / Medium / High**	Various aspects related to costs and benefits can be assessed primarily by referring to vendor information, technology fact sheets and sometimes expert opinions. Accordingly, it is possible to assign rating as Low, Medium or High against this criterion. *It is important to note that higher scores should be assigned for lower costs (and higher benefits) while assigning the scores for the ratings during weighted sum matrix. This is different from many other criteria, where high rating corresponds to high scores.*
	Operation and Maintenance Costs	**Low / Medium / High**	

Group Heading	Criteria	Indicators	Guidance Notes / Verification Requirements
	Benefits (*Energy, fertilizer, reclaimed land, enhanced biodiversity*)	**Low / Medium / High / Not Applicable**	
Social / Cultural Aspects	**Acceptability**	**Low / Medium / High**	Criterion related to social aspects can be assessed by using information collated through relevant socio-economic survey, census data etc. In addition, it may be essential to refer to the vendor information and expert opinions. Accordingly, it is possible to assign rating as Low, Medium or High against these criteria. *It is important to note that higher scores should be assigned for lower extent of resettlement required while assigning the scores for the ratings during weighted sum matrix. This is different from many other criteria, where high rating corresponds to high scores.*
	Extent of necessary resettlement and rehabilitation of people	**Low / Medium / High / Not Applicable**	
	Income Generation Potential	**Low / Medium / High**	
Tier 3: Detailed Assessment Criteria			
Environment: Resources and Emissions	**Land/Space Requirement**	**Area of land occupied by installation of the technology (including surrounding buffer margins) vis-à-vis availability**	In this tier of assessment, detailed information is collected for the listed criteria for this level of assessment using information collected from vendors and technology fact sheets. It would be essential to resort to expert opinion to study and analyze the collected information and accordingly assign the ratings for each criterion.
	Energy Consumption		

Group Heading	Criteria	Indicators	Guidance Notes / Verification Requirements
	Fuel	**Type of Fuel** **Quantity per unit operating hours or unit output**	
	Electricity	**Quantity per unit operating hours or unit output**	
	Steam	**Quantity per unit operating hours or unit output**	
	Raw Materials Consumption	**Quantity per unit output or production**	
	Water Consumption	**Quantity per unit output or production**	
	Emissions	**Quantity per unit output or production**	
	Noise & Vibrations: Noise levels near installation during operation	**Intensity in Decibels**	
Economic / Financial Aspects			
	Capital Costs		
	O&M Costs		
	Benefits (*Energy, fertilizer, reclaimed land, enhanced biodiversity, Carbon credits*)	**Economic returns**	
	Economic Viability	NPV, IRR, C/B Ratio, Payback Period	

Table B-4 Proposed Sector Specific Criteria and Indicator System for Municipal Solid Waste Management

Group Heading	Criteria	Indicators	Guidance Notes
Tier 1: Screening Criteria			
Compliance			
	Compliance with local environmental laws	**Yes / No**	This is a very basic requirement and rather a simple check. The proposed technology system must ensure compliance with local as well as national legislation. Supporting information to make this decision can be found with technology fact sheets, expert opinions and information from vendors and expert opinion if necessary.
	Compliance with national environmental laws	**Yes / No**	
	Compliance with Multilateral Environmental Agreements (MEAs)	**Yes / No / Not Applicable**	Check if proposed technology system results in violation of MEAs. For instance, use of ozone depleting substances (ODS) can result in such a violation and hence must be avoided. This needs to be carefully scrutinized and it is necessary to rely on expert opinion for this, since this is rather a specialized area.
Other Requirements			
	Meeting the objectives *(e.g. 3R, remediation, rehabilitation etc.)*	**Yes / No**	In view of the outcome of the strategic assessment, at times the objective of the technological intervention may not merely be legal compliance, but could be something more - say recycling, remediation etc. It is essential to ensure that the proposed technology meets this objective. Decision on this criterion can be made using information such as technology fact sheets, expert opinions and information from vendors.
Tier 2: Scoping Criteria			
Technical Suitability			

Group Heading	Criteria	Indicators	Guidance Notes
	Availability of local expertise	**Low / Medium / High/ Not Applicable**	It would be essential to have the necessary local expertise for commissioning as well as operation and management of the new technology system. Depending on the expertise requirement vis-à-vis availability, one can rate Low Medium or High accordingly. Use vendor information and technology fact sheets, vis-à-vis available local expertise to make the decision on this criterion.
	Track record on performance	**Low / Medium / High / Not available**	Before making a decision about any technology system option, it is essential to check the track record of the technology as well as vendor. Technology fact sheets, market intelligence, site visits to similar installations can help in deciding on this aspect. Depending on the track record, one can assign a rating of Low, Medium or High accordingly.
	Compatibility with existing situation *(technology, management systems)*	**Low / Medium / High / Not Applicable**	In some cases, it is quite possible that the new technology system would build upon some existing system. As such, it is essential that the new system is compatible with the existing infrastructure/technology systems as well as the organization’s management systems. It is possible to make this decision with the help of expert opinions supplemented by the technology fact sheets and vendor information. Depending on the level of the compatibility with the existing system, it is possible to assign the rating of Low, Medium or High for this criterion.
	Adaptability to future situations	**Low / Medium / High / Not Applicable**	In order to get the maximum benefit from the technology intervention, it is essential to check the flexibility or adaptability of the technology system for the future scenarios. This may, for instance, include the scale-up / expansion possibility or technology upgrade for improving efficiency in order to meet the changing needs. Ratings can be assigned for this criterion by referring to the technology fact sheets and expert opinions. It may also be essential to revisit situation analysis and undertake some simulation / scenario building exercises to be able to decide on this aspect. Depending on the adaptability with the future situations, can rate Low Medium or High.
	Process stability	**Low / Medium / High**	The stability of the proposed technology systems during its operation phase is a very

Group Heading	Criteria	Indicators	Guidance Notes
			important consideration to get the desired results. The technology system must perform in a stable manner in the various scenarios / situations during the operation phase such as shock loads, sudden variations in process parameters etc. For making this decision, it is essential to rely on expert opinions and also by referring to the technology fact sheets, past similar case studies as well as vendor information. Based on the stability of the proposed technology system under different conditions, it is possible to rate the systems as Low, Medium or High against this criterion.
	Level of automation / sophistication	**Low / Medium / High**	Level of automation, sophistication for the proposed technology system can be assessed by referring to vendor information, technology fact sheets and expert opinions. Accordingly, it is possible to assign rating as Low, Medium or High against this criterion.
	Level of pre-treatment required	**Low / Medium / High**	Level of pre-treatment needed for the candidate technology systems can be assessed by referring to vendor information, technology fact sheets and expert opinions. Accordingly, it is possible to assign rating as Low, Medium or High against this criterion.
Environment, health and safety risks			
	Risk levels for workers	**Low / Medium / High**	Before making the decision on the proposed technology system, it is essential to assess the potential environmental, health and safety risks to the workers, communities / beneficiaries as well as to the environment / biodiversity. Depending on the scale and sensitivity of the proposed technological interventions, it may be essential to conduct a full-fledged risk assessment exercise in some instances, while in other cases, this decision can simply be made by expert opinion supported by technology fact sheets, vendor information and expert opinions. Based on the potential risk levels, one can rate them as Low, Medium or High. *It is important to note that higher scores should be assigned for lower risks, while assigning the scores for the ratings during weighted sum matrix. This is different from many other criteria, where high rating corresponds to high scores.*

Group Heading	Criteria	Indicators	Guidance Notes
	Risk levels for communities / beneficiaries	**Low / Medium / High**	
	Risk to the environment e.g. to biodiversity	**Low / Medium / High**	
Environment: resources and emissions			
	Space requirement	**Low / Medium / High / Not Applicable**	Various aspects related to resource usage can be assessed by referring to vendor information, technology fact sheets and expert opinions. Accordingly, it is possible to assign rating as Low, Medium or High against this criterion. *It is important to note that higher scores should be assigned for lower space requirement, energy, water and raw material consumption while assigning the scores for the ratings during weighted sum matrix. This is different from many other criteria, where high rating corresponds to high scores.*
	Energy consumption per unit	**Low / Medium / High / Not Applicable**	
	Extent of use of renewable energy	**Low / Medium / High / Not Applicable**	
	Extent of use of waste materials as input	**Low / Medium / High / Not Applicable**	
	Water consumption	**Low / Medium / High / Not Applicable**	
	Raw material consumption	**Low / Medium / High / Not Applicable**	
	Resource augmentation	**Low / Medium / High / Not**	The proposed technology intervention may result in remediation or

Group Heading	Criteria	Indicators	Guidance Notes
	capabilities	**Applicable**	recovery/augmentation of resources as a side effect /additional benefit and must be considered in the making the decision regarding the technology system. For this decision, one can rely on expert opinions and also by referring to the technology fact sheets, past similar case studies as well as vendor information. Accordingly, it is possible to rate the systems as Low, Medium or High against this criterion.
	Emissions	**Low /Medium / High/ Not Applicable**	Various aspects related to emissions, odor, usage of hazardous materials can be assessed by referring to vendor information, technology fact sheets and expert opinions. Accordingly, it is possible to assign rating as Low, Medium or High against this criterion. *It is important to note that higher scores should be assigned for lower emissions, odour etc., while assigning the scores for the ratings during weighted sum matrix.*
	Odour	**Low / Medium / High**	
	Extent of use of hazardous materials	**Low / Medium / High**	
	Extent of pollutant removal after treatment	**Low / Medium / High**	Various aspects related to pollutant removal (e.g. removal of noxious gases by air pollution control equipment, treatment of wastewater through a wastewater treatment process, etc.), can be assessed by referring to vendor information, technology fact sheets and expert opinions. Accordingly, it is possible to assign rating as Low, Medium or High against this criterion.
Economic / financial aspects			

Group Heading	Criteria	Indicators	Guidance Notes
	Capital investment	**Low / Medium / High**	Various aspects related to costs and benefits can be assessed primarily by referring to vendor information, technology fact sheets and sometimes expert opinions. Accordingly, it is possible to assign rating as Low, Medium or High against this criterion. *It is important to note that higher scores should be assigned for lower costs (and higher benefits) while assigning the scores for the ratings during weighted sum matrix. This is different from many other criteria, where high rating corresponds to high scores.*
	Operation and maintenance costs	**Low / Medium / High**	
	Benefits (*energy, fertilizer, reclaimed land, enhanced biodiversity*)	**Low / Medium / High / Not Applicable**	
Social / cultural aspects			
	Acceptability	**Low / Medium / High**	Criterion related to social aspects can be assessed by using information colleted through relevant socio-economic survey, census data etc. In addition, it may be essential to refer to the vendor information and expert opinions. Accordingly, it is possible to assign rating as Low, Medium or High against these criteria. *It is important to note that higher scores should be assigned for lower extent of resettlement required while assigning the scores for the ratings during weighted sum matrix. This is different from many other criteria, where high rating corresponds to high scores.*
	Extent of necessary resettlement and rehabilitation of people	**Low / Medium / High / Not Applicable**	
	Income generation potential	**Low / Medium / High**	
Tier 3: Detailed assessment criteria			

Group Heading	Criteria	Indicators	Guidance Notes
Environment: resources and emissions			
	Land/space requirement	**Area of land occupied by installation of the technology (including surrounding buffer margins) vis-à-vis availability**	`In this tier of assessment, detailed information is collected for the listed criteria for this level of assessment using information collected from vendors and technology fact sheets. It would be essential to resort to expert opinion to study and analyze the collected information and accordingly assign the ratings for each criterion.
	Fuel	**Type of fuel** **quantity per unit operating hours or unit output**	
	Emissions	**Quantity per unit output or production**	
Economic / financial aspects			
	Capital costs		
	O&M costs		
	Benefits (*energy, fertilizer, reclaimed land, enhanced biodiversity, carbon credits*)	**Economic returns**	
	Economic viability	NPV, IRR, C/B ratio, payback period	

5 An illustration of SAT Framework for identification of ESTs

This section attempts to provide an illustration of the proposed methodology for the assessment of ESTs, based on the discussion in the **Sections 2 & 3** of this document. Municipal Solid Waste (MSW) management has been used as the sector for illustration.

It must be noted here that this is merely an illustration and that the results of the same example may differ depending on the decisions arrived at by the stakeholder consultations groups.

A. Problem statement

Having geographical area of 4,000 sq. km. and population of about 15 million, the City of Inafix is one of the most important cities of Alsatia, a rapidly developing country.

About 3,700 ton/day biodegradable organic waste, 2,000 ton/day of soil, debris, building material and 500 ton/day of recyclable dry waste are generated. The sources of generation of waste are households, shops & commercial establishments, hotels, markets, institutional wastes i.e., schools, offices, hospitals, etc., construction activity, street sweeping, stables, silt removed from drain cleaning activities. The waste collected and transported from 6,000-odd collection points is handled by the MSW Department of the Municipal Authority for Inafix (MAI).

Being a relatively small city with this large a population, MAI is finding it increasingly difficult to dispose of its solid waste “efficiently”. The present practice of unsanitary open dumping has been followed for a long time, without thought for either environmental aspects or public health. The plots of land being used for open dumping are almost full to capacity and the paucity of land in this space-crunched city does not help. The residents of areas near the dumping grounds have become increasingly wary of the hazards posed by the practice of open dumping, so much so that seeing their plight, residents of locations earmarked for new dumping grounds have strongly protested to their localities being used for the purpose. Additionally, the workers at MAI’s MSW Department do not possess the skills and scientific knowledge to handle more “complicated” technologies to mitigate the problem. To make matters even worse, the processes of accelerated population growth and rapid urbanization will translate into a growing volume of wastes being generated in the future.

Recognizing the problems posed by this scenario, MAI is seeking a cost-effective, relevant and socially acceptable solution to the problem of the city’s MSW treatment/processing-cum-disposal.

B. MSW characteristics

Out of 4000 MT solid waste generation per day, recyclable dry waste constitutes approximately 500 – 600 MT. **Table B-A** is a compilation by MAI of the various characteristics of waste generated in Inafix,

Table B-A Characteristics of the MSW generated in Inafix

Parameter	%
Total wet organic material	57.5

Parameter	%
Total dry organic matter	15.05
Recyclable with heat value	18.68
Recyclable without heat value	0.93
Inert materials	11.26
Calorific value (K Cal/Kg)	951
C/N ratio	25
Moisture (%)	68.18
Materials suitable for composting	57.5
Materials suitable for RDF	89.05
Calorific value after removing inerts	1070
Calorific value after drying up to 15 % moisture	2012

C. Situation analysis

On summing up the problem statement, it can be seen that the situation at Inafix exhibits the following aspects (**Table B-B**):

Table B-B Situation Analysis (translating issues into targets)

Issues	**Issues translated into targets**
▪ MSW having a high organic and moisture content, with comparatively less potential for recycle and recovery (i.e. in terms of weight of waste generated)	▪ Use of a technology system that works well with waste having these characteristics
▪ Severe paucity of land space	▪ Use of a technology system that does not require as much land space and/or pre-treats waste to reduce its volume sufficiently before the remainder can be landfilled
▪ Serious negative environmental and public health issues due to unsanitary and unscientific disposal of MSW	▪ Use of a technology system that is safe in terms of containment/treatment of disposed wastes and any generated residues over time (e.g. leachate, odours, etc.)
▪ Strong NIMBY (Not-in-my-backyard) sentiments from residents near existing/future dumping grounds	▪ Use of a technology system that addresses social and cultural concerns (including the above point as well)

▪ Lack of skills and technical knowledge to operate "complicated" technologies	▪ Use of a technology system that is not so complicated that it cannot be handled efficiently
▪ Rapidly growing population leading to ever-increasing amounts of waste in the future	▪ Use of a technology system that can be up-scaled easily and/or that can be easily duplicated at other locations as and when the need arises, and/or that is stable handling increasing amounts of waste over time

D. The approach

The proposed EST assessment methodology has been designed for application at the individual technology level for a particular unit operation. However, it goes beyond and recommends assessing the "*technology system*" which comprises a number of individual technologies. This is mainly due to:

- Various technology elements reacting differently when pooled together in a system (e.g. in terms of treatment efficiency, pre-treatment requirement, etc.) and,
- The circumstances of the particular problem that has to be solved using the methodology (e.g. paucity of land space, characteristics of the waste, scale of operation, etc.).

In keeping with this understanding, this illustration attempts to recommend a particular technology system out of a number of systems most appropriate towards solving the problem presented.

It must be noted here that some technologies can address the MSW issue completely and may be considered as a "system", while others may need to be combined with preparatory steps in order to effectively address the issue. For e.g., mass burn practice accepts refuse that has undergone little or no pre-processing and hence is a "technology system" in itself. On the other hand, aerobic composting requires the waste to go through a preparatory step involving segregation of inorganic material at its source before it may be applied to the organic portion of the waste.

The question that remains is – disposal of the segregated inorganic material. This required an additional technology such as sanitary landfilling or incineration.

E. Strategic level assessment or tier 1 assessment

In the fact sheets for MSW management, the technology elements for treatment/processing-cum-disposal of MSW have been classified roughly into thermal and non-thermal. Referring to these fact sheets, the following technology elements may be considered for **strategic level assessment**.

Centralized technology elements	**Decentralized technology elements**
▪ Mass burn ▪ Modular (incineration) ▪ Fluidized bed incineration ▪ Refuse derived Fuel (RDF) ▪ Pyrolysis	▪ Manual landfilling ▪ Vermicomposting

Centralized technology elements	Decentralized technology elements
▪ Gasification ▪ Sanitary landfill ▪ Aerobic composting ▪ Anaerobic digestion / biomethanation	

F. Centralized versus decentralized systems

The decision whether to prefer centralized or decentralized options for sanitation is a strategic one. The Strategic Assessment Stakeholder Group is aware that like many developing cities, Inafix has a mix of well-heeled urban areas (middle-upper income residents) as well as less economically well-off slum areas (estimated to comprise between 45-60% of the total population of the city).

Middle / upper income residents' lifestyle and consumption patterns tend to follow those of the developed world. In these areas, the methods and equipment for collection, transport and disposal used may resemble those of the industrialized countries – i.e. the use of centralized systems makes sense.

However, a decentralized MSW management system is necessary for Inafix to better respond to the needs of residents located in slums. The proposed system recognizes the fact that low-income and middle / upper-income neighbourhoods have different physical and socioeconomic conditions, and that the waste generated tends to be also dissimilar. Consequently, their needs diverge, and a decentralized system uses a different approach for MSW management for low-income neighbourhoods.

Keeping this in mind, the Strategic Assessment Stakeholder Group has decided to retain technology elements of both centralized and decentralized systems at this stage of the assessment. It has further identified the following as appropriate technology systems given the facts of the situation analysis:[1]

- Mass burn
- Modular incineration
- Fluidized bed incineration[2]
- RDF
- Sanitary landfilling[3] combined with aerobic (windrow)[4] composting

[1] Pyrolysis and gasification are considered as sunrise technologies requiring a fair amount of sophistication in operation, and were thus eliminated from consideration by the stakeholder group.

[2] Being a developing country, people tend to re-use and recycle materials to a great extent. Thus, the rate of removal of recyclables is very high – an essential pre-requisite for fluidized bed incineration. Hence, this technology element may be used as a standalone for consideration in the next stage of technology assessment.

[3] Sanitary landfilling has not been considered as a standalone technology element since the requirement for land is high for this technology element, something which Inafix cannot provide.

[4] In-vessel composting also requires costly equipment and electrical power. Large-scale composting projects in Africa and Asia were too expensive and inappropriate to the local conditions. As a result, some facilities closed, others were scaled down, and many operate below their planned capacities. The windrow composting method is likely to be more appropriate to the conditions prevalent in developing countries. This method uses solar energy to decompose organic wastes and employs unskilled labour, thus creating jobs. The windrow method also requires lower construction costs than in-vessel composting. Finally, scavenging activities can facilitate the process and

- Sanitary landfilling combined with biomethanation
- Manual landfilling combined with vermicomposting (decentralized option)

G. Operational level assessment or tier 2 assessment

Once the macro-level or strategic level options are finalized, the EST assessment moves on to more operational level where engineers, technical staff etc. take over to assess available technology systems.

Table B-C shows the criteria for **Tier 1 (screening)** applied to these technology systems.

It can be seen that modular incineration has been rejected as a technology system. **Table B-D** shows the criteria for **Tier 2 (scoping)** applied to the remaining technology systems, using the weighted sum method. The information given in the fact sheets, information from technology vendors and expert opinions would be used to arrive at the ratings.

improve the resulting compost by removing the inorganic materials. (Source - *Globalization, Development, and Municipal Solid Waste Management in Third World Cities* from www.gdnet.org/pdf/2002AwardsMedalsWinners/OutstandingResearchDevelopment/martin_medina_martinez_paper.pdf

Table B-C Tier 1 (screening) criteria applied to identified technology systems

Criteria	**Mass burn**	**Modular incineration**	**Fluidized bed incineration**	**RDF**	**Sanitary landfilling with aerobic (windrow) composting**	**Sanitary landfilling with biomethanation**	**Manual landfilling with vermicomposting**
Compliance with local environmental laws	Yes	Yes	Yes	Yes	Yes◊◊	Yes◊◊	Yes◊◊
Compliance with national environmental laws	Yes	Yes	Yes	Yes	Yes◊◊	Yes◊◊	Yes◊◊
Compliance with MEAs	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Safe to use?	Yes*	No[5]	Yes*	Yes*	Yes*	Yes*	Yes*
Provides savings on resources?	Yes^	Yes^	Yes^	Yes^	Yes	Yes	Yes

◊◊ - Organic fraction of waste to be segregated before landfilling

* - Safe to use with the right pollution control / containment equipment in place.

^ - In the sense that these are waste-to-energy (WTE) systems, although their conversion efficiency may not be high.

[5] There have been widespread concerns over the consistency and adequacy of air pollution controls.

Table B-D Tier 2 (scoping) criteria applied to technology systems retained from Table C (using the weighted sum method) [6]

Criteria	**Weight**	**Mass burn**		**Fluidized bed incineration**		**RDF**		**Sanitary landfilling with aerobic (windrow) composting**		**Sanitary landfilling with biomethanation**		**Manual landfilling with vermicomposting**	
		Score	**Weight *score**	**Score**	**Weight *score**	**Score**	**Weight *score**	**Score**	**Weight *score**	**Score**	**Weight *score**	**Score**	**Weight *score**
Suitability of waste characteristics for technology application	10	4[7]	40	4	40	3	30	10	100	10	100	10	100
Past experience (under similar conditions)[8]	10	0	0	0	0	0	0	8.5	85	7.5	75	10	100
Land requirements	10	7	70	7	70	7	70	4	40	5	50	3	30
(Overall) pollutant removal efficiency	10	7	70	9	90	7	70	8	80	9	90	8	80

[6] The higher the assigned rating, the more favourable the technology option for that particular criterion. Other criteria unique to the sector (i.e. over and above generic criteria) have also be considered.

[7] For incineration technologies such as mass burn, RDF and fluidized bed incineration, it is envisaged that additional fuel may be needed to sustain combustion, thus raising the cost of an already expensive technology.

[8] Source - *Globalization, Development, and Municipal Solid Waste Management in Third World Cities* from www.gdnet.org/pdf/2002AwardsMedalsWinners/OutstandingResearchDevelopment/martin_medina_martinez_paper.pdf)

Criteria	**Weight**	**Mass burn**		**Fluidized bed incineration**		**RDF**		**Sanitary landfilling with aerobic (windrow) composting**		**Sanitary landfilling with biomethanation**		**Manual landfilling with vermicomposting**	
		Score	**Weight *score**	**Score**	**Weight *score**	**Score**	**Weight *score**	**Score**	**Weight *score**	**Score**	**Weight *score**	**Score**	**Weight *score**
Acceptability (to the public)	10	3	30	3	30	3	30	9	90	10	100	7	70
Income generation potential	7	0	0	3	21	3	21	4	28	4	28	7	49
TOTAL **(Σ weight * assigned score)**			**210**		**251**		**221**		**423**		**443**		**429**

Table B-E shows the rankings given to the various technology systems options based on the results from **Table D**.

Table B-E Ranking the technology systems from results in Table D

Rank number	Score	Technology system
6	210	Mass burn
5	221	RDF
4	251	Fluidized bed incineration
3	423	Sanitary landfilling with aerobic (windrow) composting
2	429	Manual landfilling with vermicomposting
1	443	Sanitary landfilling with biomethanation

G. Detailed assessment or tier 3 assessment

Of these, the first three ranked technology systems (shaded cells in **Table B-E**) can be short-listed and taken for further assessment using the criteria in **Tier 3 (detailed assessment criteria). Table B-F** shows the calculations for the technology systems' assessments, once again using the weighted sum method.

Table B-F Application of Tier 3 criteria to short-listed technology systems (using the weighted sum method)[9]

Criteria	**Weight**	**Sanitary landfilling with aerobic composting**		**Sanitary landfilling with biomethanation**		**Manual landfilling with vermicomposting**	
		Score	**Weigh t*score**	**Score**	**Weigh t*score**	**Score**	**Weight *score**
Process stability	9	7.5	67..5	6.5	58..5	9	81
Level of automation / sophistication	10	7.5	75	7.5	75	10	100
Estimated useful life	10	7	70	8	80	6.5	65
Fuel consumption	7	7	49	7	49	7	49
Electricity consumption	7	3	21	5	35	7	49
Savings in energy	8	4	32	6	48	8	64
Capital investment	10	6	60	7.5	75	9	90
Operation and maintenance costs	10	6.5	65	7	70	9	90
Financial incentives (e.g. rebates from government)[10]	8	0	0	8	64	0	0
Pay back period[11]	8	7	56	6	48	5	40

[9] The higher the assigned rating, the more favourable the technology option for that particular criterion. Other criteria unique to the sector (i.e. over and above generic criteria) have also be considered.

[10] The government of Inafix provides a rebate for waste treatment-cum-disposal technologies that can earn credit for reducing GHG emissions.

[11] Includes consideration of costs for backend pollution control technologies

Criteria	**Weight**	**Sanitary landfilling with aerobic composting**		**Sanitary landfilling with biomethanation**		**Manual landfilling with vermicomposting**	
		Score	**Weight*score**	**Score**	**Weight*score**	**Score**	**Weight*score**
NPV / IRR	8	4.5	36	6	48	4	32
Secondary contaminant generation[12]	9	7	63	7	63	8	72
Require PPE[13] for staff?	7	5	35	5	35	6	42
Level of safety risk for workers and communities[14]	7	3	21	3	21	6	42
Noise levels near installation during operation	7	5	35	5	35	6	42
Odour levels near installation during operation	7	5	35	4	28	5	35
Person-power requirements	5	3	15	4	20	1	15
Technical knowledge requirements (qualifications/special knowledge needed)	10	7	70	7	70	10	100

[12] Assuming that the sanitary landfill generated gas is captured and put to use, that contaminants (leachate) from the manual landfill will be contained and that the closure of the manual landfill will be scientific (along the same lines as that for sanitary landfills).

[13] Stands for "personal protective equipment"

[14] Pertaining to fire in this case.

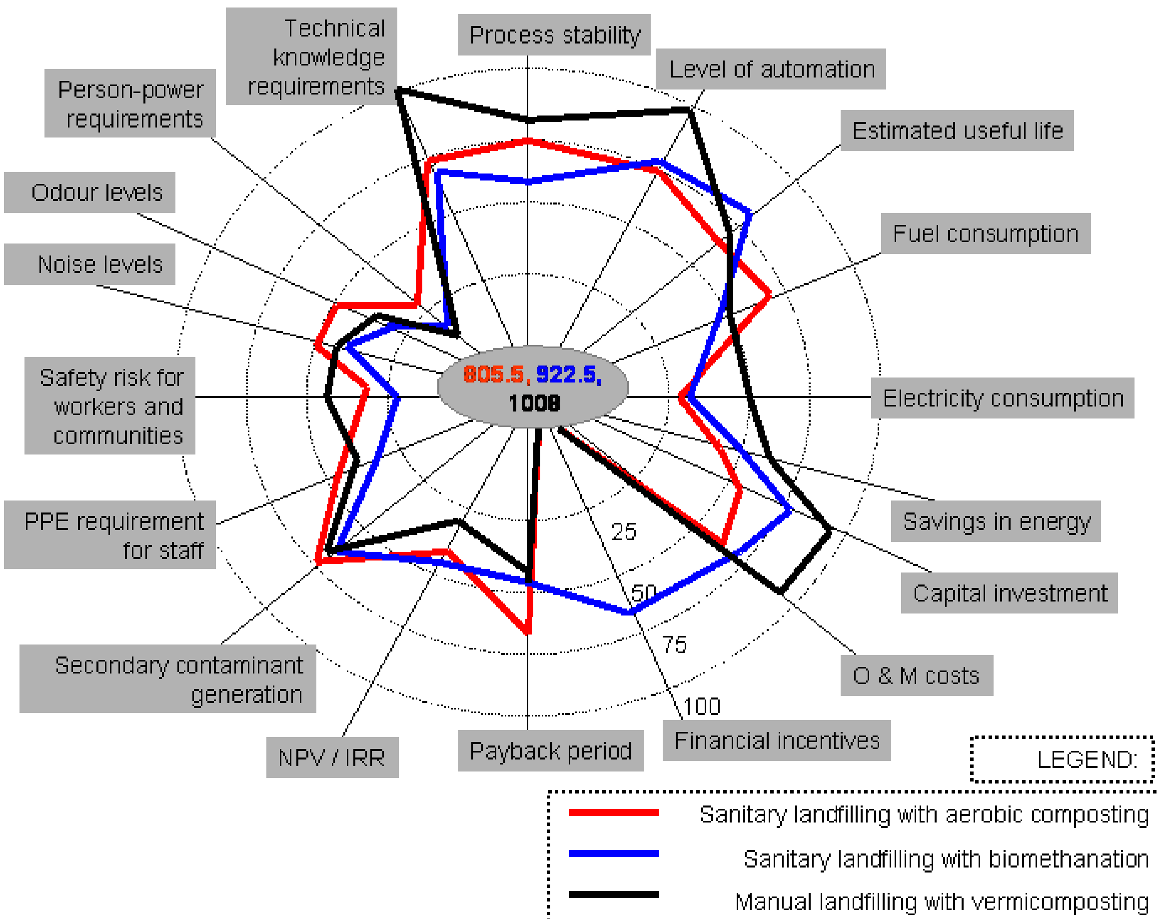
Criteria	**Weight**	**Sanitary landfilling with aerobic composting**		**Sanitary landfilling with biomethanation**		**Manual landfilling with vermicomposting**	
		Score	**Weight*score**	**Score**	**Weight*score**	**Score**	**Weight*score**
TOTAL **(∑ weight * assigned rating)**			**805.5**		**922.5**		**1008**

Table B-F shows the rankings given to the short-listed technology systems options based on the results from **Table B-E**.

Of these, the technology system option "manual landfilling with vermicomposting" has been found to be the most appropriate option of the three, followed by "sanitary landfilling with biomethanation" and "sanitary landfilling with aerobic composting" respectively.

The star diagram shown in **Figure B-C** provides an idea of the dominating criteria at this stage of the assessment.

Figure B-C Star Diagram at Tier 3 Level of Assessment[15]



As per the proposed EST assessment methodology, the next steps would be:

- Detailed engineering design and costing
- Implementation
- Monitoring and performance evaluation
- Issues to be addressed / problems to be solved

[15] Plotting is approximate; i.e. not to scale.