INTEGRATED SOLID WASTE MANAGEMENT

WUXI NEW DISTRICT (WUXI MUNICIPALITY)
PEOPLES' REPUBLIC OF CHINA

Integrated Solid Waste Management Plan

Volume –I

Strategic Action Plan

UNEP

WND

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Introduction

WND is one of top ten national level development zones, located 160 km west of Shanghai. It covers an area of 200km^2 and has a population of 250,000 including 140,000 industrial workers. There are more than 2,000 enterprises in WND. The total output is more than RMB 166 billion.

Since its foundation in 1992, WND has evolved to be a major industrial park in the Yangtze River Delta. WND has been a strong showcase for the rapid industrial development that the People's Republic of China has achieved in the last few decades. A broad range of industries has been set up in the WND, and its economic growth has spurred the entire region, including the Microelectronic, precision machinery and auto-parts sectors. Related service/supporting industry sectors are also emerging rapidly in WND. WND is owned and managed by the New District Administrative Committee of Wuxi People's Municipal Government, second largest city in Jiangsu Province of the People's Republic of China.

The rapid and high industrial development of WND has attracted not only domestic and international companies, but also increasing population numbers to support the growth. A resulting situation of this multifaceted growth is a drastic increase in the quality and quantity of wastes generated by different sources. This situation has highlighted the need to look at waste management in an integrated manner, handling both industrial and municipal wastes being generated in the WND.

To address this situation, WND has identified a clear need to assess the current practices of waste management, including quantification and characterisation of waste generated from all sources. The gaps in the current system will have to be addressed by promoting waste recycling and identify technologies for treatment and disposal of residual waste. To develop a supporting framework, there is a need to identify appropriate policy interventions, including economic instruments, and build capacities at the local level for technology specification, procurement and implementation, and monitoring.

It is within the above context that WND and UNEP have agreed to launch the project on "Development and Implementation of an Integrated Waste Management Plan for Wuxi New District". It aims at developing and implementing an Integrated Waste Management Plan (IWMP) to address the issue of solid waste being generated both from industrial as well as domestic sources.

The project is divided into three phases. In the first phase (completed), the current status of waste management in WND was studied in order to assess the gaps and identify areas for improvement. The second phase (currently ongoing) will develop an Integrated Waste Management Plan (IWMP) to address the issue of solid wastes from both municipal and industrial sources. The third phase will develop a comprehensive implementation programme for the IWMP covering capacity building, policy instruments, and technologies specification, acquisition and installation.

The project is based on the concept of integrated waste management so that the waste is constituents are recycled and reused to the maximum possible extent and the development of the city can take place in harmony with the environment. The project consists of the following main elements:

(a) Baseline data collection: (source identification, quantification and characterization of different types of waste including industrial, municipal, commercial, agricultural sectors and special wastes such as medical waste, including projections for future waste generation);

(b) Assessment of present waste management system: (assess the efficacy and effectiveness of the existing waste management system covering all aspects; waste collection, segregation, transportation, treatment and disposal);

(c) Identifying issues of concern: (identify and prioritize issues of concern so that they could be addressed in a systematic and effective way in the project, covering all areas such economic, technical, environmental and social);

(d) Development of an Integrated Waste Management Plan (IWMP): (Based on the results of the earlier three elements, an Integrated Waste Management Plan is developed to address the issues identified and tackle the problem of solid waste in a comprehensive manner).

This document, prepared in consultation with project partners and local stakeholders, is the IWM Plan that provides a set of policy options for the generation, collection, transformation, transfer stations, treatment and disposal of wastes (including recycling and reuse). The Plan will serve as a roadmap for dealing with solid waste in WND. Based on the Plan, a supportive framework (including awareness raising and capacity building, policy tools, technologies etc.) will be developed in order to implement the Plan.

1 Generation, Collection and Transportation

1.1 Waste Generation and Prevailing Collection and Transportation System[1]

Waste generation rates have been increasing rapidly due to urbanization and industrialization in WND. The waste data clearly shows that waste quantity will be rapidly increasing in next 15 years and organic waste will remain the dominant component of municipal waste. Construction and demolition waste as well as industrial non-hazardous waste contain higher percentage of recycling waste. Current and future waste generation rates for various sources are shown in Table 1

Table 1 Waste generation and future projections (tons/day)

	Baseline Study (2006)	**2010**	**2020**
Municipal waste from residential and commercial sources	333	390	560
Municipal waste from industries	82	100	140
Municipal waste from all sources	415	490	700
Industrial non-hazardous waste	586	692	988
Industrial hazardous waste	82	97	138
Hospital waste – total	0.3	0.4	0.5
Hospital waste – hazardous	0.2	0.3	0.4
Sludge	8	10	19
Construction & demolition debris	32,805	38,733	55,333

The important quantitative and qualitative features of solid waste, from all sources, are:

1. Per capita waste is 0.8 kg per day from residential source; however, it is about 1 kg per day for combined municipal waste from residential, commercial and industrial sources.
2. Future projections show an increase of 18 percent from 2006 to 2010 and further 42 percent from 2010 to 2020 (415, 490, and 700 tons per day respectively).
3. Municipal waste from residential and commercial sources contains about 70% of kitchen and yard waste, i.e. 233 tons/day and that will increase to about 230 tons/day in 2010 and up to 280 tons/day in 2020. Other wastes, including paper and plastics, are 118 tons/day and it will increase to about 160 tons/day in 2010 and up to 280 tons/day in 2020(Table 1). This is based on the assumption that the content of organic waste will reduce from the current 70 percent to 50 percent in 2020 as shown in a World Bank Study (2005).
4. Food waste content of municipal waste from industries is about 13 percent. It is about 12 tons/day and it will increase to about 15 tons/day in 2010 and up to 20 tons/day in 2020. Other wastes are about 70 tons/day and will increase to about 85 tons/day in 2010 and up to 120 in 2020 (Table1).

[1] Guidelines for waste quantification and characterization and assessment of prevailing waste management system were prepared and local staff of WND Project Team was trained for data collection and analysis through training workshops and field training. WND Project Team collected the data and baseline reports for waste characterization and quantification, and prevailing waste management system were prepared accordingly. The future trends were calculated by using two indicators, economic and population growth in line with the World Bank Report 2005: Waste Management in China – Issues and Recommendations.

5. Plastic waste is another major component as residential, commercial and industrial (municipal) waste contains 17, 14 and 22 percent of plastics respectively.
6. Paper is 6 percent in waste from residential and commercial sources, while it is more than 50 percent from industrial sources.
7. Quantities of metal and glass waste are not substantial in municipal waste
8. There is a huge quantity of industrial non-hazardous waste (processing waste) - 213,826 tons per year.
9. Industrial waste generation rate is about 20.15 tons/year per million Yuan production output. Hazardous waste generation from industries is at the rate of about 2.45 tons/year per million Yuan production output.
10. Hospitals generate waste at the rate of about 0.77 kg/day/bed including about 0.5 kg/day/bed of hazardous waste.
11. Generation rate for wastewater sludge is about 200 tons/year per million ton of wastewater treated.
12. Currently, out of 333 tons/day of municipal waste, 224 tons/day is collected and transported via six transfer stations. This is about 70 percent of the total municipal waste from domestic and commercial sources. Municipal waste from industries is 82 tons/day, which is all collected and transported via one separate transfer station[2]
13. Management of industrial waste lies with the generators (industries), which arrange their transportation and recycling/disposal on their own. The local government only monitors if industries are not dumping the waste with the municipal waste.
14. Construction and demolition waste is being reused and recycled outside the municipal waste management system. It is expected that this trend will continue and municipal government will not be required to manage this waste.

1.2 Targets for Waste Segregation and Collection [3]

Short-term Targets（2006-2010）

- Ten percent reduction in waste generation in each source category
- 70 percent of organic wastes (food and yard wastes) segregated at source
- 100 percent of hazardous/toxic wastes segregated at source
- 100 percent collection of all wastes generated

Long-term Targets（2011-2020）

- 30 percent reduction in waste generation in each source category
- 100 percent of organic wastes (food and yard wastes) segregated at source

1.3 Stakeholders’ Concerns – Waste Generation & Collection[4]

1.3.1 Municipal Waste Segregation and Collection

- For municipal waste, the major concern and suggestion was regarding segregation of food waste from other wastes.

[2] WND has a role to monitor proper disposal of non-municipal waste. Waste generators make direct arrangements with waste collection and disposal services. They also make a direct deal to sell recycling waste to other companies. Nevertheless, WND Project Team can calculate number of vehicles and trips based on the information on waste quantities available here, and based on the information on the size of the vehicles available in WND or in Wuxi.
[3] These targets are set as preliminary targets by WND based on discussions with stakeholders. There were some concerns for achieving targets on organic waste (food and yard wastes); however, it was suggested by WND that these targets be maintained, and may be revised, if required.
[4] Stakeholders’ concerns were identified during Stakeholders Workshop in WND on 27 March 2007.

- It was suggested that if food wastes are segregated at source, then most recyclable wastes may be recovered as clean waste, and food waste can be converted into ethanol, compost and/or biogas.
- It was also suggested to draw a detailed strategy to promote segregation of food waste and hazardous waste at source by awareness-raising of households and through fiscal and regulatory policies.
- The residential complexes management agency suggested that with proper segregation, it would be easy to collect and transport wastes up to transfer stations, as it is their responsibility.
- The local government mentioned that there are no standardized vehicles for primary collection, as it is responsibility of local communities to transport their waste up to transfer stations. The vehicles are neither environmentally safe nor technically designed to collect the waste, resulting into leakages, odour, noise pollution and inefficient collection and unloading practices.
- It was also suggested that with the segregation of food waste and with proper primary collection, there may be less requirement for transfer stations, as the waste can be directly transported for sorting/recycling and for treatment/disposal.
- The representative of a housing company mentioned that although there are classified collection bins in the district, the citizens are not throwing their solid waste into the right trash bins; hence the government can improve the collection system by marking the bins in different colors and persuading the citizens to classify their solid waste and throw them into the right bins.
- There was a suggestion that with proper segregation and collection, scavengers will not be scavenging near residential areas and they may be able to get jobs in the formal system for material recovery and recycling.
- One company, which provides collection and transportation service, mentioned that due to high oil prices, they wanted to raise the collection price, but it is difficult to raise the price, especially for old residential areas; thus, they need some financial support from government.
- The company also mentioned that it would like to get the financial support from the government to avoid the losses or a subsidy through their tax (currently the company has to pay 300,000 RMB per year);
- The company also wants the government to introduce a policy to increase service (transportation) charges because the service price standards were set ten years ago and the current situation requires higher charges to run waste transportation system smoothly.
- The company also requested the government to ask more solid waste generators to transport their waste through this company to achieve economies of scale and to run the transportation system at appropriate price for the customers. The company also wanted their workers to receive continuous training to improve their professional ability.
- Operators of the landfill plant asked the government to form strategies to reduce solid waste generation as capacity of landfill will be exhausted in a few years.
- Incineration operators suggested that waste should be segregated at source and waste with higher moisture content should not be sent for incineration.

1.3.2 Collection and Transportation of Industrial and Healthcare Waste

- For industrial and healthcare wastes, a major concern was the charges/fee for waste collection, as the cost for the collection and treatment is rising due to rising oil prices and due to cost of modern technology.

- The service providers suggested mobilizing government subsidies, as the increase in waste collection charges/fee for their customers (industries and hospitals) may lead to drop in their customers and may encourage illegal disposal of waste by industries.
- The hospital representative mentioned that they have to pay the sanitary department to buy special yellow bags for hazardous waste, and they also have to pay the company that collects and treats hazardous waste; thus, it is becoming very costly for them and they have to charge in-patients accordingly. The current charges are: a) 0.3 Yuan per bag of the size 30cm x 60cm and the bags can't be kept in the hospitals for more than two days, and b) Two Yuan per day per patient for waste disposal.
- The representative from hospital mentioned that it would be helpful to get some support from the government for smooth hazardous waste management. They would also like to seek new technology for the collection and destruction of sharps and injections as the current collection system poses risk to employees.
- One representative suggested that some industrial waste, which is of no use for the waste generator (industry) could be useful for another industry. Hence waste exchange strategies may help to divert waste from one industry to another industry under the supervision of EPB of WND.
- The representative of hazardous waste collection and the disposal company mentioned that enterprise lacks the professional staff and they need specialist staff to manage the hazardous solid waste. They also mentioned that the hazardous solid waste is not labeled properly and this results in inconvenience during the routine disposal process.

1.4 Strategies for Waste Reduction

The targets indicated earlier in section 1.2 are set to reduce waste generation, with reference to current levels, through various policy and voluntary measures. These measures are suggested at the waste generation level. The important measures at generation level, to reduce the disposable waste, focus on the reduction and reuse of waste. Policy measures, both regulatory and fiscal, are a vital part of these measures to address all the waste generation sources including households, commercial sector, industrial sector, and hospitals. In addition to the policies, awareness raising leading to voluntary actions is also a crucial measure for waste reduction and reuse at source.

1.4.1 Policies for Waste Reduction and Reuse at Source

To encourage waste reduction and reuse, the specific regulations and/or fiscal policies are required for different waste generation sources and type of waste. A combination of following policy measures may encourage waste generators in WND to segregate waste at source:

Municipal waste from residential areas[5]:

The basic target is the source segregation of food waste and hazardous waste from other waste. Policy measures, including regulations as well economic tools, can be designed to promote segregation at source at household level:

- Regulations on source segregation of hazardous waste including batteries, tube lights, containers for paint and other chemicals, etc.
- Charge system based on the level of source-separation by residents' committees, while WND to supply bags for food waste to promote source separation

[5] The policy-making is usually at national, provincial and municipality level. WND can only promote voluntary actions and once these voluntary actions are established, then WND can recommend the policy-making institutions to consider policies based on these experiences.

Examples from other countries:

- Take back system in Germany
- Payment to Residents' Committee in Nonthaburi, Thailand for recycling waste
- Payback on cans and bottles in USA
- Payback for not asking supermarkets to provide shopping bags in Japan
- Replacing new TVs, Computers, etc. with old one with discount prices in some developing countries

Municipal waste from commercial areas:

- Regulations on source separation of hazardous waste
- Regulations on source separation of food waste at food markets, restaurants and other food-related businesses
- Charge system for waste from commercial sector, including office buildings.
- Subsidies to recycle organic waste at site, such as subsidies on composting plant and biogas plant for vegetable or food markets.

Examples:

- Biogas plant at Thiru. Vi. Ka. Municipal Vegetable Market, Pollachi, India
- Biomethanation (0.15 MW) of vegetable market waste by Vijayvada Municipal Corporation, India

Industrial waste:

- In addition to similar charge system for 'normal' waste and specific regulations or fiscal policies for motivating industries to reduce and reuse some of its waste, specific technologies or processes based regulations to reduce the generation of waste per output may be explored.
- Assistance for installation of biomethanation power plants at the industries, generating huge amount of organic waste in a similar way as suggested above for vegetable markets

1.4.2 Voluntary Actions for Waste Reduction and Reuse at Source

Voluntary actions, through awareness raising and capacity building, are useful to achieve the targets for waste reduction and reuse at source. These voluntary measures are also useful for transition to implement a new regulatory or fiscal policy.

A combination of following voluntary measures may encourage waste generators in WND to segregate waste at source.

Municipal waste from residential areas:

- Voluntary measures of waste generation at household level on monthly basis to develop waste generation chart and then chalk out voluntary measures at household level to reduce waste.
- Payback system for electronic appliances, furniture and other items, which could be recycled. This payback can be either in cash or in terms of providing handling and transportation of these items.
- Retailers of consumer goods, including electronics and furniture, to take back the old items and provide discount on the new items.
- Payback on soft drink cans and bottles.
- Take back packaging after delivery of consumer goods.

Municipal waste from commercial areas:

- Similar volunteer actions as suggested for municipal waste from residential areas

- Volunteer measures for reduced packaging at super markets, reduced consumption of paper at offices, and efficient handling of perishable items including vegetables and fruits

Industrial waste:

- Similar volunteer actions as suggested for municipal waste from residential and commercial areas
- Volunteer measures to improve the resource efficiency and reuse to reduce waste generation in production process

Awareness raising and capacity building:

- Awareness raising package for all the actors to raise the awareness on waste reduction and reuse and to strengthen their understanding for their role to be part of waste reduction and reuse strategies
- Capacity building on various voluntary measures and actions for households, commercial sector and industrial sector

1.5 Strategies for Source Separation

Hazardous waste should be separated at source, as mixing of even a small quantity of hazardous waste with non-hazardous may contaminate all the waste. The other approach is to segregate organic waste from rest of the waste at source. The following regulatory and fiscal policies, voluntary actions, and technological measures will help to achieve these targets.

1.5.1 Policies for Source Separation

Based on the targets to separate hazardous and non-hazardous waste at source, and to separate kitchen waste (organic waste) from other wastes, the following regulatory policies and fiscal incentives and disincentives could be introduced:

- Regulations banning mixing of hazardous waste with non-hazardous waste
- Regulations for disposing kitchen (food) waste in separate bags or bins
- Providing free collection system (bins) for hazardous waste from residential sources
- Collection of recyclable waste (plastic, paper, etc.) from households and after selling the recyclable waste, some proportion of earnings can be handed over to residents' committee as an incentive
- Providing free bags for disposing food waste[6] and cost of the bags and transportation could be recovered from biomethanation or compost plants – or cost of bags can be cross-subsidized from the earnings for the waste bags for other waste. Annexure A provides the guidelines to calculate costs and benefits (earnings) including subsidies for ISWM
- Establishment of monitoring system by residents' committees for source separation
- Reduced monthly charges for households, practicing source-separation, by residents' committees
- New housing complexes may be given a choice to be charged as per big container/skip as the office of housing complex can collect the waste collection fee from their residents
- The regulations and policies for source separation are already in place for industrial and healthcare waste. Strict enforcement of these regulations and policies would make sure that waste is segregated at source and hazardous waste is not mixed with non-hazardous waste. Enforcement for proper handling, collection and transportation is also required for industrial and healthcare waste, including hazardous waste

[6] guidelines are provided as annexure A to calculate economic burden

1.5.2 Voluntary Actions for Source Separation

Voluntary actions are useful to compliment regulations and fiscal policies. These are also useful as a transition towards implementation of regulations and fiscal policies. To promote voluntary actions, awareness raising and training are very important to motivate the stakeholders and to build their capacity for these actions. The following voluntary actions are suggested:

- Residents' committees and voluntary groups to encourage waste generators to segregate waste according to organic (food and yard) waste, mixed waste and hazardous waste
- Holding regular meetings and informal monitoring by the volunteer groups – awareness raising for residents' organizations
- Volunteer groups for awareness raising

1.5.3 Technological Measures for Source Separation

Source separation requires proper bins or bags for each type of waste including hazardous waste, organic (food and yard) waste, mixed waste and hazardous waste. The following technological measures are designed for effective and efficient source separation:

Municipal waste from residential areas:

- Transparent plastic bags by WND for the residents to separate food waste– special plastic bags can be produced for waste collection[7].
- Bins for hazardous waste and mixed waste by WND or residents' committees.
- Community bins/skips for collection of segregated waste for source separated waste (hazardous, mixed and food waste). For housing complexes, an enclosure is provided for residents to put their waste bags. The current waste collection points for new housing complexes can be upgraded by fencing and partition for organic and non-organic waste bags. The collection points for old housing streets can be constructed at points where most of the households do not need to walk for more than 100 meters to put their waste bags[8].
- Marked bins for hazardous waste at convenient points
- Big and heavy items (more than 50 cm in any dimension and/or 5 kg weight) should not be thrown with the normal waste

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[7] Oxo-biodegradable and other degradable plastic bags have certain useful applications when used as rubbish bags. Organic waste can be put into oxo-biodegradable plastic sacks and put straight into the composting plant, unopened, thus reducing smells, disease transmission by insects, and handling hazards. The resulting compost may be used by farmers and growers. Since oxo-biodegradable plastic (unlike the starch-based alternative) releases its carbon slowly, it produces high quality compost. Oxo-biodegradable plastic does not degrade quickly in low temperature "windrow" composting, but it is suitable for "in-vessel" composting at the higher temperatures required by new animal by-products regulations. Oxo-biodegradable plastics become peroxidised and embrittled, and behave like natural waste. It is bio-assimilated by the same bacteria and fungi, which transform the degraded plastic products to cell biomass, like lignocellulosic materials. Oxo-biodegradable plastic is designed to fragment by a process which includes both photo-oxidation and thermo-oxidation, so it can degrade in the dark.
The bags are also made from Polylactic acid (PLA) a biodegradable polymer derived from lactic acid. It is a highly versatile material and is made from 100% renewable resources like corn, sugar beets, wheat and other starch-rich products. Polylactic acid exhibits many properties that are equivalent to or better than many petroleum-based plastics, which makes it suitable for a variety of applications, emits fewer greenhouse gases, and contains no toxins.
Normal transparent plastic bags are also used in some countries. For example, ln Japan, waste bags are available in volume, i.e. 20 litres, 45 litres, etc.

[8] This distance may vary from one area to another based on population density, type of roads and type of collection service or vehicles.

Municipal Waste from commercial areas:

- Similar domestic type bags for small commercial entities and offices – Small commercial entities can be described as small shops and individual food or vegetable sellers on streets (outside a big market)
- Mini skips or jumbo bins of various sizes (from $2m^3$ to $5m^3$) for different type of non-hazardous wastes (for example food waste from restaurants or packaging from super markets)
- Special marked/coloured bags or containers for hazardous waste

Industrial waste:

- Mini or big skips (ranging from $2m^3$ to $30m^3$ or more) for different type of non-hazardous wastes
- Special marked/coloured containers for hazardous waste. Industrial sludge is also hazardous and dry sludge is currently transported in special bags.

1.6 Strategies for Collection and Transportation

Collection and transportation is the most crucial stage as most of the budget for solid waste management could be spent on this activity, and deficiency in this activity could affect the effectiveness and efficiency of whole solid waste management process. Keeping in view the targets and stakeholders' concerns, specific policies, voluntary actions and technological measures may be required:

1.6.1 Policies for Collection and Transportation

Collection and transportation policies address various issues including frequency of collection, timing of collection, type of collection vehicle and charges for collection for different type of waste and for different waste sources:

Municipal waste from residential areas:

- Daily collection of organic (food) waste from community skips/bins from all the streets and from enclosed waste storage areas for housing complexes
- Weekly collection of recyclable, hazardous waste and other waste
- Big and heavy items to be collected based on the request with separate collection charges payable to waste collection company
- Waste is collected early in the morning or late in the evening to avoid congestion on the roads
- Waste collection vehicles from residential areas to transfer station or treatment plant: rear loading commercial covered trucks
- Collection charges to be recovered from the cost of bags for other waste, earning from sale of organic waste to organic waste treatment plant, and earning from sale of recyclable waste – Guidelines for Cost Estimation are provided as Annexure A

Municipal waste from commercial areas:

- Daily collection of all type of waste with separate vehicles for organic waste, recyclable waste and non-recyclable waste[9] – Waste collection from commercial sources is preferred after the close of markets and other commercial entities
- Collection and disposal charges based on number and size of skips/bins for non-recyclable waste – directly payable to collection company[10]

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[9] It is a usual practice in many places to collect daily all the waste after the closing of commercial entities, including markets. Hazardous waste collection only matters for the entities, which are producing substantial amount of hazardous waste, such as laboratories.

- Higher collection and disposal charges for hazardous directly payable to the hazardous waste management company
- Lower collection charges for organic and recyclable waste in accordance to earning from sale of organic waste to organic waste treatment plant and sale of recycling waste – directly payable to collection company[11]

Industrial waste:
- Waste generators are responsible to arrange collection and disposal services for industrial waste through the waste collection and disposal companies in line with the prevailing system
- Government may further strengthen its regulatory and monitoring role to check illegal dumping of waste, proper handling of all types of waste in line with their characteristics, and to continuously collect information on the quantification and characterization of waste to promote waste recycling and waste exchange – eco town concept

Overall – for all waste sources and types:
- National and local standards and regulation apply for collection vehicles for transporting organic waste, recyclable waste, non-recyclable waste and hazardous waste[12]
- National and local regulations for safety and maintenance of vehicles, including noise and air pollution, leakages and cleanliness of collection vehicles[13]

1.6.2 Voluntary Actions for Collection and Transportation

Collection and transportation of solid waste is a regulated activity. Nevertheless, the following voluntary actions help to improve its efficacy and efficiency, and can minimize negative impacts on environment:
- Voluntary groups to motivate and monitor punctuality in putting the waste at proper place in proper manner to be collected and transported
- Respect for sanitary workers and waste collectors to motivate them for efficient work
- Avoid creating congestion for waste collection vehicles

1.6.3 Technological Measures for Collection and Transportation

Selection of appropriate collection equipment, including type of vehicles is important for better efficiency and lower environmental impacts from waste transportation activities. Type of vehicles may vary in accordance with the type of waste (organic, recyclable, non-recyclable and hazardous waste) and quantity of waste, which needs to be correlated with the frequency of collection.

Residential waste:
- Waste collection vehicles for recyclable waste from residential areas to transfer station or treatment plant: rear/side-loading commercial covered trucks[14]

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[10] This is also a common practice to charge as per the size of bin/skip (volume of waste). However, based on volume-to-weight calculations, the mechanism could be drawn to charge based on weight for specific items – again based on the size of bins/skips

[11] Costs and earnings are to be calculated (Annexure A) to adjust waste collection charges

[12] There should be some standards and WND Team needs to find out the information on the current fleet of waste collection vehicles and current regulations for type and O&M of waste collection vehicles

[13] WND has to follow national and local regulations; however, they can introduce SOPs (Standards Operating Practices) for collection timings, cleaning of vehicles, etc.

[14] Rear loading is common due to narrow residential streets. Side and front loading is more common at commercial entities such as super markets with separate storage and parking areas for waste collection vehicle

- Waste collection vehicles for non- recyclable waste from residential areas to transfer station or treatment plant: compactor trucks
- Waste collection for organic waste from residential areas to transfer station or treatment plant
- If one type of waste is not substantial in quantity, then the collection vehicle with two compartments will be used

Municipal waste from commercial areas:

- Waste collection vehicles for recyclable waste from commercial areas to transfer station or treatment plant: rear or side loading commercial covered trucks or recycling hauler
- Waste collection vehicles for non- recyclable waste from commercial areas to transfer station or treatment plant: rear or front loading compactor trucks
- Waste collection for organic waste from commercial areas to transfer station or treatment plant: compactor trucks with leachate leak proof system

Industrial waste:

- Waste collection vehicles for recyclable waste from commercial areas to transfer station or treatment plant: rear or side loading commercial covered trucks or recycling hauler
- Waste collection vehicles for non- recyclable waste from commercial areas to transfer station or treatment plant: rear or front loading compactor trucks
- Waste collection for organic waste from commercial areas to transfer station or treatment plant: compactor trucks with leachate leak proof system

1.7 Operational Plan for Collection and Transportation[15]

Operational plan for waste collection and transportation from generation point to transfer station or treatment plant is determined based on decisions on what is to be done with the collected waste and how much would the cost be for transportation between two points (collection to transfer station or treatment plant).

Keeping in view the initial target of segregation of 70 percent organic waste and stakeholders' concerns for difficulties in meeting this target, three overall options can be outlined for very optimistic situation (100 percent segregation of organic waste), targeted situation (70 percent segregation of organic waste) and situation based on stakeholders' concern (no segregation – mixed waste, at least for initial few years):

I. Transporting organic (food) waste directly, bypassing transfer stations, to organic treatment plant and transporting other waste to transfer station for sorting and material recovery for recycling

II. Transporting 70 percent organic waste directly, while all the other waste and 30 percent organic waste transported to transfer stations for sorting

III. Transporting all the waste to transfer stations for sorting

1.7.1 Baseline Information:

All of these three options are based on the same baseline information, which was collected and projected by WND Project Team.

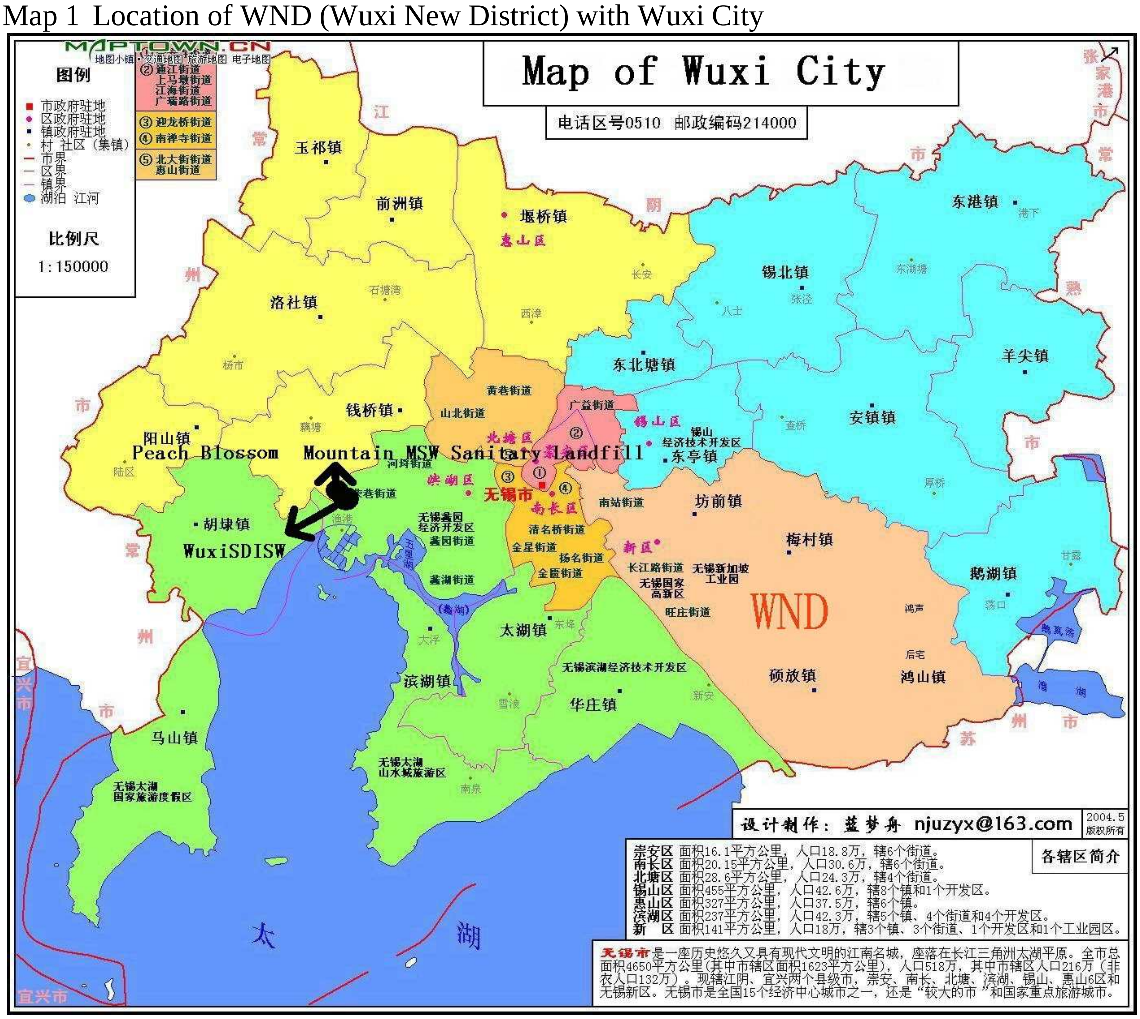
[15] In WND, transfer stations are responsible for collection of the waste within their areas. The hire the companies to collect and transport the waste up to the respective transfer stations. The size and type of vehicles also vary from one area to another area due to type of roads and other local characteristics. Therefore, they will draw a detailed operation plan for waste collection. This section can be used as a guidance tool.

Amount of waste from residential and commercial sources is 333 tons/day which will increase to 390 tons/day in 2010 and up to 560 tons/day in 2020. Out of this, kitchen and yard waste is 215 tons/day, which will increase to 230 tons/day in 2010 and up to 280 tons/day in 2020. The other waste, including paper and plastics, is 118 tons/day, which increase to 160 tons/day in 2010, and up to 280 tons/day in 2020.

WND is located southeast of Wuxi Municipality (Map 1). WND waste for landfilling is transported out of WND to a sanitary landfill located southwest of the Wuxi Municipality (Map 2). Hazardous waste treatment and disposal facility (Wuxi SDISW) is also located near this sanitary landfill. Hence, waste for landfilling and hazardous waste is transported outside WND. Incineration plant and recycling businesses and transfer stations are located within WND (Map 3).

Waste collection in WND is carried out by seven transfer stations as shown in Map 3. Out of seven transfer stations, one transfer station is dedicated to receiving municipal waste from industries, while other six transfer stations receive waste from residential and commercial sources. Current waste generation and collection rates are shown in Table 1. Total waste generation, its breakdown in organic waste and other waste with future trends for areas catered by these six transfer stations in WND is shown in Table 2[16]: Composition of municipal waste is shown in Table 3.

Map 1 Location of WND (Wuxi New District) with Wuxi City



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[16] In the original data, collected by WND Project Team, organic waste is 71% of municipal waste collected from residential and commercial areas.

Map 2 Location of Sanitary Landfill and Hazardous Waste Treatment Facility

Map 3 Location of Transfer Station, Incineration Plant and Recycling Business in WND

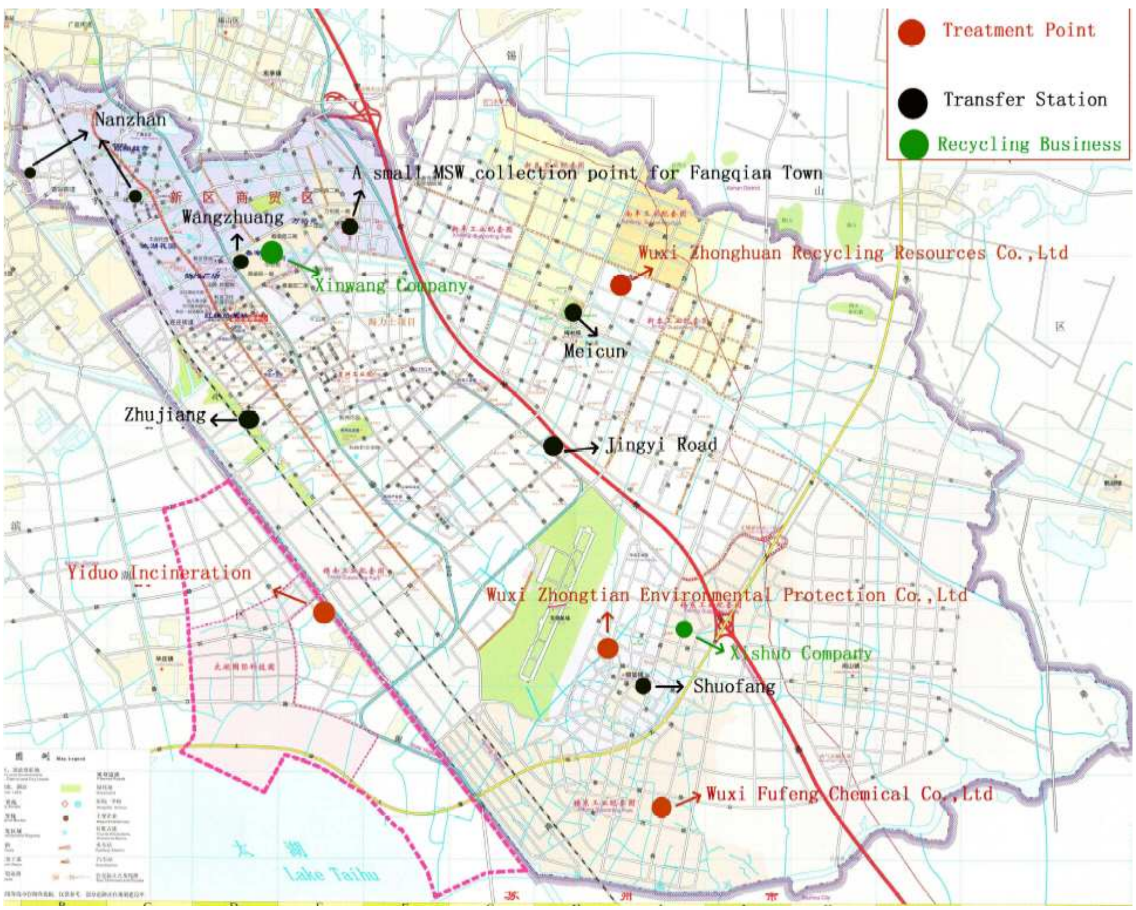

Table 2 Waste generation collection and disposal rates

Transfer Stations (Neighbourhoods Coverage)	*Population*	*Generated Waste Tons/day*	*Collected/ Treated Waste Tons/day*	*Treatment Methods Tons/day*
Wang Zhuang	109918	68	68	51 IN 17 LF
Nan Zhan	65442	60	50	39 IN 11 LF
Fang Yin	42019	30	21	21 LF
Mei Cun	51134	50	40	33.5 IN 6.5 LF
Shuo Fang	83493	55	25	12.5 IN 12.5 LF
Hong Shan	72936	70	20	20 LF
Industries		82	82	50 IN 32 LF
Total	424942	415	306	186 IN 120 LF

Table 3 Total and organic waste generation with future trends

Transfer Stations	**Total Generated Waste Generation (tons/day)**			**Organic Waste Generation (tons/day)**			**Other Waste Generation (tons/day)**		
	2006	**2010**	**2020**	**2006**	**2010**	**2020**	**2006**	**2010**	**2020**
Wang Zhuang	68	80	114	48	52	57	20	28	57
Nan Zhan	60	70	101	42	46	50	18	25	50
Fang Yin	30	35	50	21	23	25	9	12	25
Mei Cun	50	59	84	35	38	42	15	21	42
Shuo Fang	55	64	92	38	42	46	17	23	46
Hong Shan	70	82	118	49	53	59	21	29	59
Total	*333*	*390*	*560*	*233*	*253*	*280*	*100*	*137*	*280*

Table 4 Composition of municipal waste from domestic, commercial and industrial sources

Components	Industrial		Domestic + Commercial		Total	
	%	Weight (tpd)	%	Weight (tpd)	%	Weight (tpd)
Food waste	13.40	10.99	71.40	237.75	59.94	248.74
Plastic	21.20	17.38	16.85	56.11	17.71	73.49
Paper	53.40	43.79	6.62	22.05	15.86	65.84
Metal	1.60	1.31	0.38	1.28	0.62	2.59
Glass	0.00	0.00	1.71	5.68	1.37	5.68
Textile	10.40	8.53	2.37	7.90	3.96	16.43
Ceramics	0.00	0.00	0.51	1.69	0.41	1.69
Hazardous waste	0.00	0.00	0.26	0.86	0.21	0.86
Total	100.00	82.00	100.00	333.00	100.08	415.00

1.7.2 Options 1: Segregation of all organic waste from other waste

If waste is well segregated at source, then transfer stations could be bypassed and all organic waste can be directly transported to organic treatment plant. For this option, the underlying assumption is that waste segregation is in line with the standards. For example, in some countries, organic waste, with ten percent non-hazardous impurities is considered as safe to be converted into a resource such as compost, biogas, ethanol, bio-methane and etc. The other waste is first taken to transfer station and then sorted as recycling and non-recycling waste, which is transported to disposal sites (incinerator and landfill).

There is no organic waste treatment plant to convert organic waste into a resource such as compost, biogas, ethanol, bio-methane, etc. It is assumed that an organic waste treatment plant will be constructed. It is also assumed that this organic waste treatment plant is located near the landfill. This location would also be useful if organic waste is of low quality and / or the compost is not suitable for agriculture, in which case, the waste/compost can directly go to landfill. This would help to avoid emission problems, which are normally encountered when organic waste is directly sent to a landfill, without prior biological treatment (composting).

1.7.3 Options 2: Segregation of 70% of organic waste

If some areas, where organic waste segregation has not yet picked up quite well, then the organic waste from areas, where segregation is being practiced, can be directly transported to organic treatment plant. For this option, the underlying hypothesis is that waste segregation is in line with the standards for about 70% of areas within WND. The other waste is fist taken to transfer station and then it is sorted out for recycling and non-recycling waste, which is transported to disposal sites (incinerator and landfill).

1.7.4 Options 3: No segregation – all mixed waste

Under this option, all the waste is transported to transfer station for sorting to recover recycling waste. First assumption is that as all the waste is dirty, only 5% recycling waste is recovered instead of 20% (Option I). Second assumption is that due to high moisture content, all the waste is not suitable for incineration and it is transported to landfill.

Note: The calculations, based on generic types of waste collection, are shown as follows (time is calculated in hours):

Option I: No source separation for food waste (current situation)

Transfer station areas	**Wangzhang**			**Nanzhan**			**Fangqian**			**Meicun**			**Shuofang**			**Hongshan**		
Total amount of solid waste (tons)	68	80	114	60	70	101	30	35	50	50	59	84	55	64	92	70	82	118
5% was recovery，95% was sent to landfill site	64.6	76	108	57	66.5	96	28.5	33.3	47.5	47.5	56.1	79.8	52.3	60.8	87.4	66.5	77.9	112
Number of trips	17	19	27	15	17	24	8	9	12	12	14	20	14	16	22	17	20	28
transport time required for each trip from transfer station to landfill plant）	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2	2	2	2.5	2.5	2.5	2.5	2.5	2.5
Total time for transport （from transfer station to incineration plant）	25.5	28.5	40.5	22.5	25.5	36	12	13.5	18	24	28	40	35	40	55	42.5	50	70
Rest time per vehicle	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
working time per vehicle	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Time available for collection trips	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Number of trips per vehicle	5	5	5	5	5	5	5	5	5	4	4	4	3	3	3	3	3	3
Number of vehicles	4	4	6	3	4	5	2	2	3	3	4	5	5	6	8	6	7	10

Option II: 70% source separation for food waste (as targeted)

Transfer station areas	Wangzhang			Nanzhan			Fangqian			Meicun			Shuofang			Hongshan		
Total amount of solid waste (tons)	68	80	114	60	70	101	30	35	50	50	59	84	55	64	92	70	82	118
Quantity of organic solid waste（70%）	47.6	56	79.8	42	49	70.7	21	24.5	35	35	41.3	58.8	38.5	44.8	64.4	49	57.4	82.6
Quantity of Separated organic solid waste（70%）	33.3	39.2	55.9	29.4	34.3	49.5	14.7	17.2	24.5	24.5	28.9	41.2	27	31.4	45.1	34.3	40.2	57.8
Number of trips	9	10	14	8	9	13	4	5	7	7	8	11	7	8	12	9	10	15
Time required per trip（from transfer station to biologic treatment plant）	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2	2	2	2.5	2.5	2.5	2.5	2.5	2.5
Total time for transport（from transfer station to biologic treatment plant）	13.5	15	21	12	13.5	19.5	6	7.5	10.5	14	16	22	17.5	20	30	22.5	25	37.5
Rest time per trip	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Working time per trip	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Time required for transport	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Number of trips per vehicle	5	5	5	5	5	5	5	5	5	4	4	4	3	3	3	3	3	3

Number of vehicles	2	2	3	2	2	3	1	1	2	2	2	3	3	3	4	3	4	5
15% solid waste was recovered, 36% was sent to the incineration plant	24.5	28.8	41	21.6	25.2	36.3	11	13	18	18	21.2	30.2	19.8	23	33.1	25.2	29.5	42.5
Trips required	7	8	11	6	7	9	3	4	5	5	6	8	5	6	9	7	8	11
Time required per trip （from transfer station to incineration plant）	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Total time required for transport （from transfer station to incineration plant）	7	8	11	6	7	9	3	4	5	5	6	8	5	6	9	7	8	11
Rest time per trip	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Working time per trip	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Time required for transport	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Number of trips per vehicle	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Number of trips	1	1	2	1	1	2	1	1	1	1	1	1	1	1	2	1	1	2

Option III: 100% source separation for food waste

Transfer station areas	Wangzhang			Nanzhan			Fangqian			Meicun			Shuofang			Hongshan		
Total amount of solid waste (tons)	68	80	114	60	70	101	30	35	50	50	59	84	55	64	92	70	82	118
Quantity of organic solid waste（70%）	47.6	56	79.8	42	49	70.7	21	24.5	35	35	41.3	58.8	38.5	44.8	64.4	49	57.4	82.6
Total trips required for transport	12	14	20	11	13	18	6	7	9	9	11	15	10	13	16	13	15	21
Time required per trip （from transfer station to biological treatment plant）	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2	2	2	2.5	2.5	2.5	2.5	2.5	2.5
Total time required for transport （from transfer station to biological treatment plant）	18	21	30	16.5	19.5	27	9	10.5	13.5	18	22	30	25	32.5	40	32.5	37.5	52.5
Rest time per trip	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Working time per trip	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Time required for transport	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Number of trips per vehicle	5	5	5	5	5	5	5	5	5	4	4	4	3	3	3	3	3	3
Number of vehicles	3	3	4	3	3	4	2	2	2	3	3	4	4	5	6	5	5	7

20% solid waste was recovered, 10% was sent to the incineration plant	6.8	8	11.4	6	7	10.1	3	3.5	5	5	5.9	8.4	5.5	6.4	9.2	7	8.2	11.8
Number of trips required for transport	2	2	3	2	2	3	1	1	2	2	2	3	2	2	3	2	3	3
Time per trip （from transfer station to incineration plant）	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Total time required for transport（from transfer station to incineration plant）	2	2	3	2	2	3	1	1	2	2	2	3	2	2	3	2	3	3
Rest time per vehicle	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Working time per vehicle	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Time required for transport	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Number of trips per vehicle	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Number of vehicles	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Comparison of transport time and vehicle of three options：

Transfer station areas	Wangzhang			Nanzhan			Fangqian			Meicun			Shuofang			Hongshan		
Total amount of solid waste (tons)	68	80	114	60	70	101	30	35	50	50	59	84	55	64	92	70	82	118
Option I： Number of hours (time) required	25.5	28.5	40.5	22.5	25.5	36	12	13.5	18	24	28	40	35	40	55	42.5	50	70
Option I： Number of vehicles required	4	4	6	3	4	5	2	2	3	3	4	5	5	6	8	6	7	10
Option II： Number of hours (time) required	20.5	23	32	18	20.5	28.5	9	11.5	15.5	19	22	30	22.5	26	39	29.5	33	48.5
Option II： Number of vehicles required	3	3	5	3	3	5	2	2	3	3	4	4	4	4	6	4	5	7
Option III： Number of hours (time) required	20	23	33	18.5	21.5	30	10	11.5	15.5	20	24	33	27	34.5	43	34.5	40.5	55.5
Option III： Number of vehicles required	4	4	5	4	4	5	3	3	3	4	4	5	5	6	7	6	6	8

*The incineration ash was use to make bricks, instead of landfill disposal.

** In most areas of WND, the transport work of municipal solid waste from generation sites to transfer station is undertaken by informal and small vehicles. Therefore, the time calculations for this process are not included

1.7.5 Transition from mixed waste to segregated waste

It is highly probable, that transition from current mixed waste collection (Option III) to segregated waste collection (Option I or Option II) may take a few years. To accommodate this transition time in the planning for collection and transportation of municipal waste from commercial and residential sources, the system could be designed for mixed waste (Option III) for few initial years and then for 70 percent organic waste segregation (Option II) and finally for 100 percent segregation of organic waste (Option I).

1.7.6 Municipal Solid Waste from Industries

Table 3 indicates that municipal waste, generated from industries contains only 13 percent organic waste, while it contains more than 20 percent of plastic waste, more than 50 percent of paper waste, more than ten percent of textile waste and some metals. Organic waste in industries is usually generated at restaurants; hence it could be easily segregated at source. This segregation at source can help to recover most of the recycling waste, especially plastic, paper, textile and metals. Assuming 13 percent organic waste is segregated and about 85 percent waste is recovered for recycling, then only less than five percent of 82 tons/day will be left for treatment and disposal. This remaining waste would only require one trip a day; however, keeping in view more collection time required to cover all the industries, one dedicated vehicle of five tons could be sufficient.

1.7.7 Construction and Demolition Waste

In WND, construction and demolition waste is generated from three sources: municipal works, residential construction and industrial construction (Table 4 through Table 6). However, most of the waste is recycled within this sector. Hence, WND government does not foresee the need to make an operational plan for construction and demolition waste.

Table 5 Construction waste from municipal works

Components	*Generation Tons/10,000m^2*	*Recovery Tons/year*	*Treatment*
Asphalt	38.46	500	Reuse
Concrete	653.85	8500	Refill
Soil	1538.460.16	20000	Refill or sell to other construction sites
Total		29000	

Table 6 Residential Construction Waste

Components	*Generation Tons/10,000m²*	*Recovery Tons/year*	*Treatment*
Bricks/blocks	909	92758.63	Refill
Soil	36000	3673609.20	Refill or sell to other construction sites
PVC pipe	0.1	10.25	Landfill
Steel wire	4.55	464.30	Sell for recovery
Wood	81.82	8349.30	Sell as fuel
Paint containers	0.45	45.92	Reuse
Glass	small	102.10	Landfill
Total		3775339.60	

Table 7 Industrial Construction Waste

Components	*Generation Tons/10,000m²*	*Recovery Tons/year*	*Treatment*
Bricks/blocks	14.12	3212.38	Refill
Soil	36000	8190194.40	Refill
PVC pipe	0.16	36.40	Landfill
Steel wire	3.92	891.82	Sell for recovery
Wood	3.92	891.82	Sell as fuel
Paint containers			Reuse
Glass			Landfill
Total		8195226.82	

1.7.8 Sludge from Wastewater Treatment Plants

Currently there are three wastewater treatment plants that treat about 15 million tons of wastewater per annum. They generate about 3,000 tons of sludge per annum. It is assumed that quantity of sludge will also increase, inline with future trends for municipal solid waste, up to about 3,500 tons/annum in 2010 and up to 7,000 tons/annum in 2020. All the sludge is required to be transported by sludge tanker trucks with either vacuum suction or mechanical collection of sludge. The size of sludge tanker trucks is assumed to be ten tons. All the sludge is transported to incineration plants and the ash is transported to landfills.

A) Number of sludge collection vehicles from WWTP to incineration plant
Amount of sludge to be transported = 3,000 tons/annum = 8.2 tons/day
Currently one vacuum truck is sufficient.

B) Number of collection vehicles from incineration plant to landfill[17]

Amount of ash could be assumed as 20 percent of total sludge. Weight of dry sludge is less than weight of wet sludge. Assuming average moisture content of 70 percent in the sludge, 30 percent of solids (about 2.5 tons out of 8.2 tons of sludge) are incinerated producing 20 percent ash (0.5 tons). This ash would be transported along with other ash produced from incineration.

1.7.9 Hazardous Waste Collection System (Hospitals and Industries)

Currently, there are two qualified enterprises for the collection and incineration of Hazardous waste: Wuxi Safe Disposal of Industrial Waste Co. Ltd (WuXi SDISW) and Zhongtian Environment Protection Co. Ltd.

Hazardous waste from hospitals is about 72 tons/annum, and from industries is about 30,000 tons/annum. With additional the policy, technical and voluntary measures (presented in previous sections), current operations for collection and disposal of hazardous waste can continue.

A strict monitoring system should make sure that hazardous waste is not mixed with non-hazardous waste by any chance and proper collection and handling of each type of hazardous waste is in line with the standards. Expansion of the services is required in line with the increase in hazardous waste. Industrial hazardous waste generation is about 2.45 tons/annum for one million yuan production output. Hospital waste is predicted to increase from 72 tons/annum to 133 tons/annum in 2010 and to 168 tons/annum in 2020.

1.7.10 Industrial Waste Collection

Non-hazardous industrial waste from processing activities amounts about 220,000 tons/annum. Currently most of the waste is recycled within the same or within other industries. Only a small portion of industrial waste requires transportation for up to incineration plant or landfill. The companies provide collection service to the industries and tipping charges are covered by incineration plant or landfill. Hence, WND is not required to provide additional services for collection of industrial waste.

1.7.11 Information Centre for Waste Recycling & Waste Exchange

Increasing number of industries being established in WND is resulting in rapid growth in solid waste, including recyclable waste. An information centre in WND would help the buyers and sellers of recycling waste to provide details of their recycling waste beforehand. In this case the buyers and sellers (including transfer stations for municipal waste) can optimize their operational plan for collection of recycling waste, if destinations are determined before hand through Waste Recycling & Waste Exchange Centre.

1.7.12 Economic Analysis of Various Options

In most of the developing countries, bigger portion of the municipal budget for solid waste management is utilized on waste collection and transportation services. Hence, selection of a better option, with respect to economic efficiency, can benefit whole solid waste management system in WND. Annexure-A provides guidelines to carryout economic analysis of various options to prioritize these options with respect to their economic efficiency.

1.7.13 Assessment of Technologies

Solid waste management system requires a combination of various technologies for waste collection and transportation, sorting and material recovery for recycling, treatment and resource recovery and final disposal. The assessment of technologies goes beyond their economic efficiency and also includes technical efficiency, social acceptance and

[17] This calculation is for illustration purposes only. Available ash at incineration plant, to be transported to landfill, will be outcome of incineration of waste from all the transfer stations.

environmental soundness. Sustainability Assessment of Technology (SAT) is a process to identify appropriate technologies with respect to technical, economic, social and environmental aspects. SAT guidelines are provided in Annexure-B.

1.7.14 Assessment of Reduced GHG Emissions

There are considerable environmental advantages of ISWM based on 3R approach. At global level, the major advantage is in terms of reduced emissions of green house gases (methane and carbon dioxide) which can be calculated in million metric tons equivalent of carbon equivalents (MMTCE). The following activities in integrated solid waste management are responsible for green house gas (GHG) emissions and reduced level of waste generation and diversion of waste for recycling and resource generation can reduce GHG emissions as shown in Table 7

Table 8 GHG emissions from waste management activities

Waste Management Activity	**GHG Emissions (CH_4 and CO_2) Sources**
Collection (recyclables and mixed waste)	Combustion of diesel in collection vehicles Production of diesel & electricity for garage
Material recovery facilities	Combustion of diesel used in rolling stock (front-end loaders) Production of diesel and electricity (for building/ equipment)
Composting facility	Combustion of diesel used in rolling stock Production of diesel and electricity (used for equipment)
Incineration Plant (with waste to energy)	Combustion of waste Offsets from electricity produced
Landfill Decomposition of waste	Combustion of diesel used in rolling stock Production of diesel Offsets from electricity or steam produced
Transportation	Combustion of diesel used in vehicles Production of diesel
Reprocessing of recyclables	Offsets (net gains or decreases) from reprocessing recyclables recovered; offsets include energy- and process-related data

Note: Alternative energy sources, such as bio-fuels, could be used in place of diesel and electricity (produced from fossil fuels) to offset the GHG emissions.

2 Sorting, Treatment and Disposal

2.1 Prevailing Systems, Targets and Stakeholders’ Concerns

After collection and transportation, sorting of waste at transfer stations for material recovery, biological and thermal treatment for resource recovery, and final disposal of residual waste, with resource recovery, completes the integrated waste management system. In Wuxi New District, prevailing waste management system includes 7 transfer stations, one thermal treatment plant, one sanitary landfill (in Wuxi Municipality) and one hazardous waste treatment and disposal plant (in Wuxi Municipality) - Map 2 and Map 3.

To make the improvements, an assessment of prevailing system was carried out and targets were set by WND and discussed in stakeholders’ workshop, where stakeholders’ also highlighted some concerns and provided suggestions for ISWM Plan.

2.1.1 Salient features of prevailing waste sorting, treatment and disposal system

- There are seven transfer stations, where sorting equipment can be installed
- Yiduo waste incineration plant has capacity of handling 1000 tons waste per day and can generate 200 million kilowatt-hour/year of electricity
- Due to high moisture content and low calorific value of waste, 20 per cent of coal is required for incineration
- Phase II of incineration plant would be ready by mid 2007 to increase its treatment capacity by additional 250 tons of municipal solid waste and 500 tons of sludge per day
- Bottom ash constitutes about 50 to 70 per cent of the in-feed mass and most of it is used to produce construction materials
- Fly ash is about 5 per cent of the total residual waste (ash) and due to its hazardous nature, requires proper treatment and handling
- The prevailing stack emission control system consists of: a) semi-dry calcium hydroxide injection for recovery of sulfur oxides and chlorine; b) activated carbon injection for further adsorption of pollution; and c) bag filter type dust collectors to remove particulates. There are no systems to control the emission of dioxins/furans
- There is no biological treatment to convert food waste into compost and/or to produce biogas
- Landfill was built in 1998 with a design life for 12 to 15 years and it has disposed of 45 million tons of municipal solid waste by the end of 2005. Phase II of the landfill is under implementation with a design life of 20 years
- Waste pickers collect waste at community collection points where they are exposed to bad and dangerous conditions
- The measures for leachate collection and treatment seem to be inadequate and may require modification to make it more efficient
- There is no system for methane recovery for electricity generation / heating

2.1.2 Targets for sorting, treatment and disposal system

Following targets were set by Wuxi New District to improve current infrastructure and operations and to introduce new options such as biological treatment:

- RESOURCE RECOVERY: Waste is sorted and processed for material recovery (recycling and reuse where appropriate)
- BIOLOGICAL TREATMENT: Organic wastes (food and yard wastes) are composted and where feasible, biogas is extracted.

- HAZARDOUS WASTES: All hazardous and toxic wastes are segregated at source, treated and safely disposed
- TREATMENT: Incineration, if practiced, should be carried out in an environmentally sound manner.
- DISPOSAL: Ensure that all landfill sites are sanitary landfills

Quantitative targets (2010)

- 50% of wastes at transfer stations are sorted for material recovery
- 50% of organic waste (food and yard wastes) is composted, and bio-gas recovered
- 100% of incineration facilities are equipped with pollution control measures/technologies at par with standards
- 100% of non-hazardous waste, including residual waste from treatment plants, is disposed in sanitary landfills (equipped with leachate and methane collection and treatment) and no waste is disposed of in illegal dumps or through illegal burning.
- 100% of all hazardous and toxic wastes is properly treated and disposed in special processing facilities and secured facilities

Quantitative targets (2020)

All the targets, set for 2010, will also be applicable in 2020, except the following targets for material recovery at transfer stations and level biological treatment for resource recovery:

- 70% of inorganic wastes sorted at transfer stations for material recovery
- 70% of organic waste is composted and biogas is recovered

2.1.3 Stakeholders' concerns

Sorting and material recovery from municipal waste

- It was suggested that currently there is no formal material sorting and recovery at most of the transfer stations; hence there is a need to implement formal material sorting as this will help to increase the rate of recycling and also provide jobs and better working conditions through formal sector
- It was also suggested that with formalization of sorting and material recovery activities, scavengers will get jobs there and there will be no nuisance in the streets
- There was a concern about the demand for recycling materials, and it was suggested to formulate strategies to increase the demand
- There was a concern that sorting and material recovery cost could be more than the earnings from sale of recycling materials; therefore, a strategy should be adopted to either reduce the costs for sorting and material recovery or to increase the demand/price through price regulations for raw materials, etc.
- The government, in response to requests from stakeholders for financial support and subsidies, explained that economic efficiency and environmental protection are the important priorities and fiscal policies will be formulated accordingly

Treatment and disposal of municipal waste

- The management of incineration plant expressed concern on the high moisture rate of the mixed waste, which requires additional coal to burn the waste
- The incineration plant operator suggested that there should be more subsidies or financial help from government, as cost of incineration is increasing
- It was mentioned that the technology for incineration is from Japan and there is high cost for pollution control measures
- The local government expressed concern that targets for biological treatment to produce compost/bio-gas or bio-diesel from food waste may be very high, as there is

not much demand for compost, costs to produce compost are high due to land costs nearby city, and there are various environmental issues related with producing compost

- It was suggested that a study should be done to assess the technologies and feasibility for biological treatment of food waste
- The operator of the landfill, which serves the whole Wuxi Municipality, mentioned that current capacity of landfill is almost exhausted and with the second phase, which will be completed during this year, there will be additional capacity; however, the amount of waste could be reduced through segregation at source and material recovery for recycling
- The operator of landfill also mentioned that they are registered with UNEP for CDM and they are selling carbon credits to Toyota (Japan) based on methane recovery for electricity generation

Treatment and disposal of industrial and healthcare Waste

- The operator of hazardous waste management suggested that the cost of treatment and disposal is rising, but it is difficult to raise the price for the customers

2.2 Transfer Station and Sorting for Material Recovery

Municipal waste is the only waste that is transported to transfer stations from residential, commercial and industrial sources. Industrial processing waste is segregated at source for material recovery. Industries are themselves responsible to sell the recycling waste and manage the residual waste on their own. Therefore, the policy, technological and volunteer measures for transfer stations are in line with the quantity and composition of municipal waste (Table 3) and the targets for material recovery from municipal waste. The recyclable waste, separated from mixed waste at transfer stations, will increase the amount of already available recyclable waste, especially from industries, and will raise the possibility for growth in recycling-based industries.

The important targets for transfer stations are to sort at least 50% of waste by 2010 and 80% of waste by 2020. Table 3 indicates that municipal waste from residential and commercial sources contains fewer quantities, in proportion, of recyclable waste such as plastic and paper then municipal waste from industries which is handled separately at one transfer station. This practice of separately handling of industrial waste may be continued even if the same transfer station is used for municipal waste from residential and commercial sources.

As per Table 3, plastic waste is the major component of municipal waste after food waste and if targets for segregation of food waste at source are achieved then plastic waste will be the lead component in waste arriving at transfer stations. After plastic, paper is another important recyclable waste component in municipal waste. This is followed by textile waste, metals, and ceramics. With the segregation of food waste at source, most of plastic, paper and textile waste could be recovered as “clean” recyclable waste.

In addition to material recovery, the other function of transfer station is compaction and/or baling of residual waste for onward transportation to the treatment plant or disposal site. In case, if smaller size of vehicles are used to collect waste from narrow residential and commercial areas, then at transfer stations, the collected waste, after sorting, is compacted and/or bailed and put on bigger vehicles to its onward journey to a treatment/disposal site.

Following policy, technological and volunteer measures will help to maximize resource recovery at transfer station as well as to improve the efficiency in transporting waste to a treatment/disposal site.

2.2.1 Policies for transfer stations[18]

Policies for transfer stations are aimed to achieve the desired objectives of setting up transfer stations without harming environment and public health. The objectives of transfer station are as follows:

- Hazardous waste is not allowed at transfer stations
- E-waste has to be separated carefully from the waste, which is bound for landfilling and incineration
- Reduces overall community truck traffic by consolidating smaller loads into larger vehicles.
- Offers more flexibility in waste handling and disposal options. Decision-makers can select among different disposal options and secure the lowest disposal fees or choose a desired method of disposal (e.g., landfilling, waste-to-energy). • Reduces air pollution, fuel consumption, and road wear by consolidating trash into fewer vehicles.
- Allows for screening of waste for special handling. At many transfer stations, workers screen incoming wastes on concrete floors or conveyor belts to separate out readily recyclable materials or any inappropriate wastes (e.g., tires, automobile batteries) that are not allowed in a landfill or a waste-to-energy facility.
- Reduces traffic at the disposal facility. The fact that fewer vehicles go to the landfill or waste-to-energy facility reduces congestion and operating costs and increases safety.

Policies for environment and public safety

- National and local work related safety regulations should be followed at all transfer stations. Accordingly, design of various facilities and installations should be in line with national and local safety regulations
- Environmental safety regulations should be catered at all the transfer stations and second level contamination should not be permitted. Accordingly, pollutant emissions, noise and odour should be within the limits set by the standards/regulations

Policies for traffic

- Select sites that have direct access to truck routes
- Provide adequate space within the facility site so that the vehicles waiting to use the transfer station do not interrupt traffic on public roads or impact nearby residences or businesses
- Designate haul routes to and from the transfer station that avoid congested areas, residential areas, business districts, schools, hospitals and other sensitive areas
- Design safe intersections with public roads

Policies for noise

- Confine noisy activities within buildings or other enclosures as much as possible
- Use landscaping, sound barriers, and earth berms to absorb exterior noise
- Arrange the site so that traffic flows are not adjacent to properties that are sensitive to noise
- Provide setback distances, called buffer zones, to separate noisy activities from adjacent land uses
- Conduct activities that generate the most amount of noise during the day

[18] In this zero draft, these are policy recommendations for the consideration of WND. After selection of appropriate policies by WND, these will be part of first draft of ISWM Plan – WND team to follow up with WND for selection of final set of policies for each stage of ISWM Plan (collection and transportation, transfer stations, treatment with resource recovery and final disposal)

Policies for odour

- Adopt “First-in, first-out” waste handling practices that keep waste on site only for short periods of time
- Remove all waste from the tipping floor or pit by the end of each operating day so that these surfaces can be swept clean and washed down
- Adopt “Good housekeeping” measures, including regular cleaning and disinfecting of surfaces and equipment that come into contact with waste
- Install water misting and/or deodorizing systems

Policies for minimizing nuisance from rodents and birds

- Remove all waste delivered to the facility by the end of each day
- Clean the receiving floor daily
- Receive waste only within an enclosed structure
- If problems persist in the vicinity, bait and trap rodents

Policies for litter

- Position the main transfer building so that predominant winds are less likely to blow through the building and carry litter off-site
- Install perimeter landscaping and fencing to reduce wind speeds at the transfer station site and to trap any litter
- Ensure that tarpaulin covers on open trucks are held securely
- Provide skirting around loading chutes
- Remove litter frequently to reduce the opportunity for it to travel offsite
- Patrol nearby access roads to control litter from truck traffic

Policies for air emissions

- Require trucks delivering and picking up waste at the facility to reduce unnecessary engine idling
- Work with fleet operators to reduce engine emissions (e.g., engine improvements or use of cleaner fuels).
- Spray dusty wastes with water as they are unloaded
- Ensure that street sweeping operations use enough water to avoid kicking up dust
- Pave all surfaces where trucks operate

Policies for economic/fiscal efficiency

- The government support will be provided for the most economic efficient and environmental friendly technologies based on the calculations of costs and benefits (Annexure A)[19]

2.2.2 Technological measures at transfer stations[20]

- Bulky items (appliances, furniture, etc.) should be manually removed from the waste prior to mechanical processing
- Proper equipment for manual separation of materials should be installed. This usually includes a sorting belt or table and containers for storing the separated materials
- Mechanical separation could be considered for the sake of higher efficiency and workers’ safety. This will include installation of equipment for size reduction, air

[19] As discussed in Section 1, WND Team will provide cost and benefits (Figure A-! in Annexure A) for each technology / operational stage of ISWM to assist WND in developing fiscal policies to support various technological options under each stage of ISWM

[20] For details please see Annexure C

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

- Selection of technology should be based on a structured methodology covering all aspects (technical, economic, social and environmental). Once such methodology is Sustainability Assessment of Technologies (SAT) Framework (Annexure B)[21]
- Waste compactors should be used at transfer stations to compact the waste before transporting to treatment/disposal sites
- Bailing systems should be installed for bailing voluminous materials such as cardboard, magazines, paper, plastics, solid waste, textiles, aluminum cans, steel cans, copper, radiators, extrusions, etc.

2.2.3 Voluntary measures at transfer stations

- Awareness raising and environmental education facilities for communities
- Arrangement of visits for students and communities to know the process and benefit of resource recovery and environmentally sound technologies

2.2.4 Improvements in existing transfer stations

Currently, there are 6 transfer stations to handle municipal waste from residential and commercial sources and one transfer station to handle municipal waste from industries. These seven transfer stations will continue to perform their functions with technologies for resource recovery (Annexure 3).

Based on the detailed calculations for waste segregation at source for food waste, and collection and transportation in Chapter 1, the transfer stations will receive following amount of waste (Table 2 and Table 8)

Option 2 is taken as the usual waste quantities arriving at each transfer station with a possibility for expansion, in case if waste generation rates increase beyond prediction or waste segregation falls below 70%. Resource recovery facility for each transfer station includes size reduction, screening, separation and cleaning (Annexure 3). The residual waste is compacted with stationary compactor and baled for onward transmission to treatment/disposal site.

Table 9 Quantity of waste at each transfer station by year 2020 (tons/day)

Transfer Stations	**Option 1 (100% food waste segregated at source)**	**Option 2 (70% food waste segregated at source)**	**Option 3 (Food waste is not segregated at source)**
Wang Zhuang	58	75	115
Nan Zhan	51	66	101
Fang Yin	26	33	51
Mei Cun	42	55	84
Shuo Fang	47	61	93
Hong Shan	59	77	118
Industries	18	54	138
Total	*301*	*421*	*700*

[21] WND Team will identify the available technologies in PRC which could be considered by WND to select the appropriate technologies for each stage of ISWM (Annexure C). While identifying the technologies, WND Team may consider the following points and points raised in Annexure B:
1) reliance upon proven technologies (appropriate to the particular location) and fundamental principles of engineering and science; 2) consideration given not only to the characteristics of the waste from which the desired materials are to be recovered, but also to the specifications of the recovered materials; 3) preservation or improvements to the quality of the recovered material; 4) processing flexibility to accommodate potential future changes in market conditions; 5) recovery of the largest percentage of materials that is feasible given the conditions that apply to the recovery project, and 6) protection of the workers and of the environment.

2.3 Biological and Thermal Treatment and Resource Recovery

Based on Table 8, Option 2, it is anticipated that by 2020 out of a total waste of 700 tons per day from WND, about 280 tons per day of organic waste will be diverted for biological treatment and remaining 420 tons per day will be sent for incineration/landfill.

In addition to food waste, sludge from municipal wastewater treatment plants can also be taken for biological treatment if it is not contaminated.

To achieve the benefits of energy recovery from waste through biological and thermal treatment, following policy, technological and volunteer measures are recommended for WND.

2.3.1 Biological Treatment Plants

WND emphasizes on energy recovery as the top priority. Hence, biodegradable waste (food waste) will be converted into biogas through anaerobic digester. Following strategies (policies, technological measures and voluntary actions) cover all the major options for biological treatment, so that if there is a change in the demand or priorities, then other options, such as composting, may also be available as a part of integrated solid waste management plan.

2.3.1.1 Policies for biological treatment plants

Biological treatment plants have to be coupled with energy recovery to improve their economic viability. Generally, energy recovery may also attract national and international financing/subsidies for renewable energy and reduction in global green house gas (GHG) emissions.

However, food can be a more putrescible material to handle than yard trimmings or manure, and must be handled appropriately. To avoid odour and health and safety concerns, it should be collected and treated in a timely and efficient manner and in line with the following policies:

- Supportive policy framework to encourage modern anaerobic digesters for producing biogas.
- National and local work related safety regulations should be followed at all the treatment and resource recovery plants (composting, biogas and ethanol). Accordingly, design of various facilities and installations should be in line with national and local safety regulations
- Environmental safety regulations should be enforced and second level contamination should not be permitted at all the treatment and resource recovery plants (composting, biogas and ethanol). Accordingly, pollutant emissions, noise and odour should be within the limits set by the standards/regulations
- No hazardous waste or contaminated waste should be treated at these plants

Policies for traffic, noise, odour, nuisance, litter and air emissions

The policies for transfer stations in section 2.2.1 will be applicable for composting/biogas/ethanol plants to control traffic congestion, noise pollution, odour levels, nuisance from rodents and birds, litter and air emissions.

Policies for economic/fiscal efficiency

- The government support will be provided for the most economic efficient and environmental friendly technologies based on the calculations of costs and benefits (Annexure A)

Additional policies specifically for composting plants[22]

[22] The above policies are intended only for the operations of composting plant and not for the compost itself. Separate national and local policies are available for the quality of compost for various uses. Some international guidelines, for example, are as follows:

Compost quality is measured by several criteria, including the following:

- Moisture content
- Nutrient content
- Particle size distribution
- Colour, texture and smell
- Stability
- Content of other elements (e.g. heavy metals)
- Product consistency over time
- Pathogen levels

Moisture content: The moisture content of the compost product is controlled by storing the product so as to avoid significant moisture addition by rainfall. The product must be dry enough to allow hauling with conventional loading, hauling, and spreading equipment / methods. The 45 percent moisture content criterion for efficient screening also provides a dry enough product to meet these needs. Care must also be taken not to over-dry the product as well. When compost is too dry, it will generate dust when handled, and dry compost can be difficult to re-wet.

Nutrient content: The nutrient content of compost is also a quality component. The major plant nutrients supplied by compost are nitrogen, phosphorus, and potassium. Most minor plant nutrients are also contained in compost and these also contribute to its quality. The level of nutrients in compost is controlled by the chemical composition of the material. While not a fertilizer, compost is often used as a fertilizer supplement.

Particle size distribution: This quality parameter is primarily a function of the screen size used. Different end-users of compost will have different requirements for particle size distribution of the compost. The most demanding user in this regard will be horticulturists that will use the material in potting mixtures. The specifications for particle size distribution requirements can be ascertained from users. Those who will use the compost to amend field soils (e.g., landscapers, orchardists, field crop growers) will have less stringent requirements, but still should be provided samples of the product to test prior to deciding on an appropriate particle size specification.

Colour, texture and smell: Aesthetic parameters, such as colour and texture, are also important because people choose compost products primarily by appearance. For example, dark compost is assumed to be better than a lighter-coloured one. Mature compost is a usually a rich brown and fairly even texture. Good compost will not leave black colour on the hands during its handling. The bad compost may leave a residue like dye that stains clothing as well as skin. For texture, it should feel bit looser than good garden soil. Good compost will clump a little, but will not squeeze into hard balls as clay does or sift through the fingers like sand. For smell, it should smell pleasant like freshly turned earth and it should not stink very badly or smell like decaying wood chips or fermented fir bark.

Stability: The term "stability" as used here means a product that will not undergo rapid decomposition or produce nuisance odors when applied by users. If the compost has undergone the adequate composting and curing procedures, there should be no problem in achieving a stable product. Assuring a minimum curing period of 30 days is important to producing a stable compost product.

Content of other elements: The content of undesirable elements in compost, such as heavy metals, (e.g. cadmium, copper, zinc, lead, mercury, nickel, and chromium) is generally at very low levels in yard debris and the final compost product. Weed seeds are controlled by maintaining temperatures suitable to meet PFRP requirements.

Product consistency over time: This quality parameter is one of the most important to users. In order to incorporate compost into their operating practices, users must be certain that each batch of materials has the same properties, within relatively narrow limits. Inconsistency in product quality will result in reduced consumer confidence and will jeopardize future marketing efforts.

Pathogen reduction criteria: Agricultural waste compost is not required by regulation to comply with the pathogen reduction criteria that is stipulated for municipal sludge (biosolids) compost. However it is good practice and may be required if a site permit is required for non-farm organic waste material. The compost product should fulfil the following criteria:

The compost product should be brought to a minimum temperature of 131oF (55oC) for three consecutive days for ASP (or 15 days with 5 turns for turned windrow) in order to fulfil the requirements of a biosolids stabilization process to further reduce pathogens (PFRP).

In addition to PFRP stabilization, these elevated temperatures are effective at killing weed seeds, which is a very important product quality concern.

The compost product should be exposed to a minimum composting period of 42 calendar days and a minimum curing period of 30 calendar days prior to distribution.

- Control surface water flowing onto the site and prevent surface water from leaving the site
- Control on-site and prevent off-site nuisance conditions such as noise, dust, odors, vectors, and windblown debris
- Prevent water pollution at or beyond the site boundaries
- Control access in order to prevent illegal dumping

Additional policies specifically for biogas plants

- A pre-treatment stage where the food waste is heated at 70℃ for one hour before digestion, to ensure complete sterilisation and resulting in the destruction of most pathogens and parasites
- Preferential policies would be developed separately such as unit rate of production, guarantees for access to grid and financing/subsidies under available environmental financing if applicable

2.3.1.2 Technological measures

- Modern anaerobic digesters are recommended to maximize biogas recovery and to minimize secondary contamination
- In case, if composting plant is to be established, then the technology for compost should have all the three important functions: "pre-processing" of food waste and to check any contaminations, "processing" to convert waste into compost and safe and nuisance-free storage and/or the upgrading of the product so as to enhance its utility and marketability
- For only producing compost, aerobic process should be encouraged based on "forced-air systems"
- Biofiltration should be encouraged for treating and lessening the intensity of the odours generated from the processing of organic materials
- A proper leachate collection and treatment system should be in operation and continuous monitoring of soil and nearby water sources should be done to check leakage of leachate
- Modern anaerobic digesters should be encouraged for biogas production from food waste
- Proper equipment should be designed and operated for all the three stages to produce biogas, viz.: polymer breakdown, acid forming and methane forming
- Proper equipment should be installed to avoid leakage of gases and leachate during biogasification
- Pre-treatment should be in place because with rare exception, most of the carbon in waste is bound in highly complex molecules and, thus, is unavailable to all but a few highly specialised microorganisms. This bound carbon can be made accessible to the desired microorganisms through a process that disrupts the complex molecules -- namely, hydrolysis. Thus, hydrolysis is an essential step
- Selection of technology should be based on a structured methodology covering all aspects (technical, economic, social and environmental). Once such methodology is Sustainability Assessment of Technologies (SAT) Framework (Annexure B)

2.3.1.3 Voluntary measures

- Industrial use of biogas produced from food waste
- Awareness raising and environmental education facilities for communities

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Monitoring of the compost product for pH, percent total solids, volatile solids reduction, nutrients, and heavy metals concentration should be done on a regular basis.

- Arrangement of visits for students and communities to know the process and benefit of resource recovery and environmentally sound technologies

2.3.2 Thermal Treatment Plants (Incinerators)

2.3.2.1 Policies for incineration plants

Incineration activity could bring serous environmental and health hazards if it is not properly managed. Modern technology, especially sophisticated pollution control measures are very essential to avoid any short-term and long-term impacts on environment and health of its workers and the community. Modern technology requires skilled people and work-related safety procedures to operate and maintain the plant. This also requires timely availability of spare parts.

Incineration plants are now coupled with energy recovery to improve their economic viability. Generally, this energy recovery attracts national and international financing/subsidies for renewable energy and reduction in global green house gas (GHG) emissions.

Therefore, based on the critical issues involved with incineration, these plants should be in line with the following policies:

- National and local work related safety regulations should be followed at all the treatment and resource recovery plants (incinerators)
- Accordingly, design of various facilities and installations should be in line with national and local safety regulations
- Environmental safety regulations should be catered at all the treatment and resource recovery plants (incinerators)
- Second level contamination should not be permitted
- Accordingly, pollutant emissions, noise and odour should be within the limits set by the standards/regulations
- No hazardous waste or contaminated waste should be treated at these plants
- Specially designed treatment plants, in line with national and local regulations, should treat hazardous waste as per the standards
- Incineration plants should not operate beyond their operational capacity
- A continuous pollution/emissions monitoring system should be in place

Policies for traffic, noise, odour, nuisance, litter and air emissions

The policies for transfer stations in section 2.2.1 will be applicable for incineration plants to control traffic congestion, noise pollution, odour levels, nuisance from rodents and birds, litter and air emissions.

Policies for economic/fiscal efficiency

- The government support will be provided for the most economic efficient and environmental friendly technologies based on the calculations of costs and benefits (Annexure A)

2.3.2.2 Technological measures

- All incineration activities should be coupled with waste to energy (WtE) for resource recovery from waste
- All incineration plants should be designed on self-sustained combustion principles
- Appropriate waste for self-sustained combustion should be accepted/used
- Based on market survey, an appropriate type of incineration plant, such as refuse derived fuel based incinerator or mass-burn or modular incinerators, should be selected

- Modern equipment for air pollution control (APC system should be in place to keep emissions levels within standards – special equipment to control and monitor dioxins and furans should to on top most priority
- Selection of technology should be based on a structured methodology covering all aspects (technical, economic, social and environmental). Once such methodology is Sustainability Assessment of Technologies (SAT) Framework (Annexure B)

2.3.2.3 Voluntary measures at transfer stations

- Awareness raising and environmental education facilities for communities
- Arrangement of visits for students and communities to know the process and benefit of resource recovery and environmentally sound technologies

2.4 Final Disposal

It is anticipated that residual waste for final disposal will not increase substantially, if targets for segregation of organic waste at source and its biological treatment for resource recovery. In this case, the current landfill in Wuxi Municipality may continue to cater the needs of WND. However, if there will be need for a new landfill in WND, then the following policy, technological and voluntary measures will be followed.

For the expansion and operations of current landfill, Wuxi Municipality may use the following measures as guidelines, if required.

2.4.1 Policies for landfills

Construction and operations of sanitary landfills for non-hazardous waste and controlled landfills for hazardous waste will be in line with the following policy measures:

- Respective national and local work related safety regulations should be followed at all the sanitary and controlled landfills. Accordingly, design of various facilities and installations should be in line with national and local safety regulations
- Environmental safety regulations should be enforced and second level contamination should not be permitted at all the sanitary and controlled landfills. Accordingly, pollutant emissions, noise and odour should be within the limits set by the standards/regulations
- No hazardous waste or contaminated waste should be treated at sanitary landfills
- The hazardous waste should be treated before disposal at controlled landfill
- Sewage sludge, processed sewage sludge, etc should not be disposed at sanitary landfill, except if specially permitted
- Chemical or petroleum spill clean-up materials should not be disposed at sanitary landfill
- Automobiles and E-waste should not be disposed of at sanitary landfill

Policies for traffic, noise, odour, nuisance, litter and air emissions

The policies for transfer stations in section 2.2.1 will be applicable for sanitary and controlled landfills to control traffic congestion, noise pollution, odour levels, nuisance from rodents and birds, litter and air emissions.

Policies for economic/fiscal efficiency

- The government support will be provided for the most economic efficient and environmental friendly technologies based on the calculations of costs and benefits (Annexure A)

2.4.2 Technological measures

- Sanitary landfill "cells" are covered completely (including working face) with a thin, continuous and compacted layer of soil at the end of day
- The stability of slopes should be properly maintained/checked for protecting the safety of landfill workers
- A proper leachate collection and treatment system, including reliable liners and effective wastewater treatment system, should be in operation and continuous monitoring of soil and nearby water sources should be done to check leakage of leachate
- Lanfill gas should be recovered and converted into energy (gas or electricity) with proper equipment to avoid second level contamination
- All the equipment for landfill operations, such as track-type tractors with push-blades (bulldozers), landfill compactors, wheel loaders, track-type loaders, track-type excavators motor graders, soil compactors, pneumatic tire compactors and self-propelled vibratory drum compactors should be procured and properly maintained
- Selection of technology should be based on a structured methodology covering all aspects (technical, economic, social and environmental). Once such methodology is Sustainability Assessment of Technologies (SAT) Framework (Annexure B)

2.4.3 Voluntary measures at transfer stations

- Awareness raising and environmental education facilities for communities
- Arrangement of visits for students and communities to know the process and benefit of resource recovery and environmentally sound technologies

2.5 Environmental Benefits of ISWM Plan[23]

A separate manual could be developed to assess and quantify environmental benefits of implementation of ISWM Plan in WND. The major benefits will be gained in the following areas:

1. Reduced amount of waste due to 3R (reduce, reuse, and recycle) and segregation at source resulting in reduced number of trips for waste transfer – benefits in terms of reduction in local air pollution and GHG emissions
2. Increased level of material recovery (recycling) at transfer stations
   - benefits in terms of savings in environmental resources
3. Increased level of resource recovery such as compost
   - benefits in terms of savings in production of chemical fertilizer and improvements in fertility of soil
4. Increased level of energy recovery (gas/fuel/electricity) at treatment plants
   - benefits in terms of savings in imports of gas, petroleum and electricity
   - benefits in terms of reduced amount of GHG emissions due to reduced burning of fossil fuels
5. Reduced level of waste disposal at landfill and landfill gas recovery
   - benefits in terms of reduced use of energy and land
   - reduced amount of GHG emissions as landfill gas is captured
   - benefits in terms of saving in imports of gas, petroleum and electricity
   - reduced amount of GHG emissions from equal amount of burning of fossil fuels

Quantification of these benefits may lead to the help towards implementation of various technologies in ISWM. Composting/biogas/ethanol plants, incinerators with energy recovery, and sanitary landfill with landfill gas recovery may attract national and international

[23] WND team could be able to quantify environmental benefits of ISWM

financing/subsidies under various programmes and initiatives such as renewable energy, waste to energy, and Kyoto Protocol.

A Guidelines for Financial Analysis for ISWM

1 Stages and Activities under ISWM Chain

Integrated solid waste management (ISWM) is consisted of five stages, viz.: waste collection, sorting and material recovery, transportation, treatment and resource recovery and final disposal. At each stage of ISWM, various activities are carried out as discussed in the main text and shown in Table A-1 for non-hazardous waste and in Table A-2 for hazardous waste.

Table A-1 Broad Activities under ISWM (Non-hazardous waste)

Stages in ISWM Chain	Activities
Collection	Segregation at Source – provision of different bags/bins Primary collection – maintenance of collection points Transportation to transfer station (mixed waste) Transportation to treatment plants or recycling points (segregated waste)
Transfer Station	Sorting & material recovery – provision of sorting system Compaction and/or baling Transportation to treatment plant / recycling point
Treatment	Treatment Plant – installations and operations Resource recovery – facilities for storage & transmission Residual waste – transportation to disposal site
Final Disposal	Landfill – installation and operations of landfill

Table A-2 Broad Activities under ISWM (Hazardous waste)

Stages in ISWM Chain	Activities
Collection	Segregation at Source – provision of different bags/bins Primary collection – maintenance of collection points Transportation to treatment plants
Treatment	Treatment Plant – installations and operations Residual waste – transportation to disposal site
Final controlled disposal	Landfill – installation and operations of landfill

2 Calculating Cost Stream

Each activity involves some costs, which should be determined to calculate overall cost of implementing ISWM. All the activities have some cost components, which should be identified and their costs should be calculated, based on the market prices[24]. Major cost components, under each activity, are shown in Table A-3 for non-hazardous waste and in Table A-4 for hazardous waste. This table also indicates that who would bear the costs. Waste generators include residential and commercial sources, industries, hospitals, and so on. Service providers could be local government or specialized private or public companies. Service providers recover these costs from various sources including direct and indirect charges for waste generators as discussed in the next section.

[24] In this case, only financial cost analysis, based on market prices, is being carried out. Economic cost analysis, based on true costs, could also be carried out, if required. For a local government, it is important to know how much would be the cost for ISWM and what could be the possible sources to finance ISWM in line with market prices.

Table A-3 Cost Components for ISWM (Non-hazardous Waste)

Activities	**Cost Components**	**Responsibility**
Segregation at source	Bags for at least two types of waste – organic and other waste	Waste generators
	Bins for segregating hazardous waste and recyclables (cans, pet bottles, etc.)	Waste generators/ Service providers
Primary Collection	Setting up collection points	Waste generators/ Service providers
	Maintenance of collection points	
Transportation of organic waste to treatment plant	Procurement of collection vehicles	Service providers/ Plant operators
	Operations (vehicles and human resources)	
Transportation of other waste to transfer station	Procurement of collection vehicles	Service providers
	Operations (vehicles and human resources)	
Transportation of recyclables	Procurement of collection vehicles	Recycling companies
	Operations (vehicles and human resources)	
Transfer stations	Setting up transfer stations with equipment	Service providers
	Operations of transfer stations	
Transportation of sorted waste to incineration plant	Procurement of collection vehicles	Service providers/
	Operations (vehicles and human resources)	Plant operators
Transportation of sorted waste to landfill	Procurement of collection vehicles	Service providers/
	Operations (vehicles and human resources)	Plant operators
Transportation of sorted recyclables	Procurement of collection vehicles	Recycling companies
	Operations (vehicles and human resources)	
Organic waste treatment plant to generate compost/biogas/ethanol	Setting up biological treatment plant	Plant operators
	Operations	
	Storage and transmission of the resource	
	Storage and transportation of residual waste	
Thermal treatment plant (incineration) to generate electricity/gas	Setting up thermal treatment plant	Plant operators
	Operations	
	Storage and transmission of the resource	
	Storage and transportation of residual waste	
Final disposal (landfill)	Setting up a sanitary landfill with equipment	Landfill operators
	Operations	

Table A-4 Cost Components for ISWM (Hazardous Waste)

Activities	**Cost Components**	**Responsibility**
Segregation at source	Bags for various types of hazardous waste	Waste generators
	Bins for segregating hazardous waste	Waste generators
Primary Collection	Setting up collection points	Waste generators/ Service providers
	Maintenance of collection points	
Transportation to the treatment plant	Procurement of collection vehicles	Service providers/ Plant operators
	Operations (vehicles and human resources)	
Hazardous waste treatment plant	Setting up hazardous waste treatment plant	Plant operators
	Operations	
	Storage and transportation of residual waste	
Final disposal (controlled landfill)	Setting up a controlled landfill with equipment	Landfill operators
	Operations	

3 Calculating Benefit Stream

For a smooth implementation of an ISWM Plan, costs of ISWM has to be recovered from various sources such as earnings from consumer charges applied to waste generators, selling recyclables and generated resources (compost, biogas, electricity, etc), cross subsidies from other earnings, subsidies from local and national governments and through international cooperation. The first step would be to determine the activities, where waste generators could be charged. After identification of these activities, a limit on the charges could be set in line with the earnings from sell of recyclables and generated resources as well as earnings from available subsidies and support or vice versa. Table A-5 indicates direct earnings (benefit) stream.

Table A-5 Earnings for ISWM

Earnings	Source
Sell of bags and bins for disposal of segregated waste	Waste generators
Collection charges	Waste generators
Tipping fee for thermal/biological/hazardous treatment	Waste generators
Tipping fee for landfill for direct waste	Waste generators
Tipping fee for landfill for residual waste from treatment plant	Plant operators
Sell of recyclables	Recycling companies
Sell of resources (compost, biogas, energy, etc)	Consumers/companies
CDM based earnings from sell of carbon credits	Companies/agencies
Subsidies	Government
International Cooperation for equipment and infrastructure	International Agencies

4 Waste disposal fees or charges

Targets of ISWM provide the basis to design waste disposal charges. The targets of ISWM Plan for WND include waste reduction, segregation of organic waste, material and resource recovery, and proper collection, treatment and disposal system. The national and local goals for sustainable development focusing income distribution, economic growth and environmental protection should also be the primary criteria for designing waste disposal fees or charges.

For designing charges, another important issue is the cross-subsidy among various activities of ISWM. For example, charges for waste disposal bags can be priced as such to also recover charges for collection, transportation, treatment and disposal. This could be ascertained after calculating earnings from material and resource recovery as well as after the inclusion of subsidies. Sometimes, subsidies are calculated, after deciding waste charges based on affordability and other socioeconomic and environmental aspects. In some cases, the charges are different for different waste generation sources to cross-subsidize the services. Industrial and commercial sources might pay more than residential sources. Therefore, this exercise is done in continuous consultation with government and other stakeholders.

To simplify the process, usually charges for industrial, commercial and hospital waste are calculated as true market costs for providing the service. However, the charges for residential sources are calculated in different ways to suit the socioeconomic conditions and to achieve ISWM targets. Some of the methods to calculated charges are briefly highlighted as follows:

Pay As You Throw (PAYT) is introduced in various countries. It varies from one country to another; however, its basic objective is same, i.e. to achieve environmental sustainability, economic sustainability and equity. Environmental sustainability is achieved through reduction of final waste by decreasing levels of waste generation and by diverting waste for reuse and recycling. Economic sustainability is achieved through earnings from waste charges to help ISWM services to sustain. Equity is achieved by charging more to the residents who throw more and charging less to the residents who throw less.

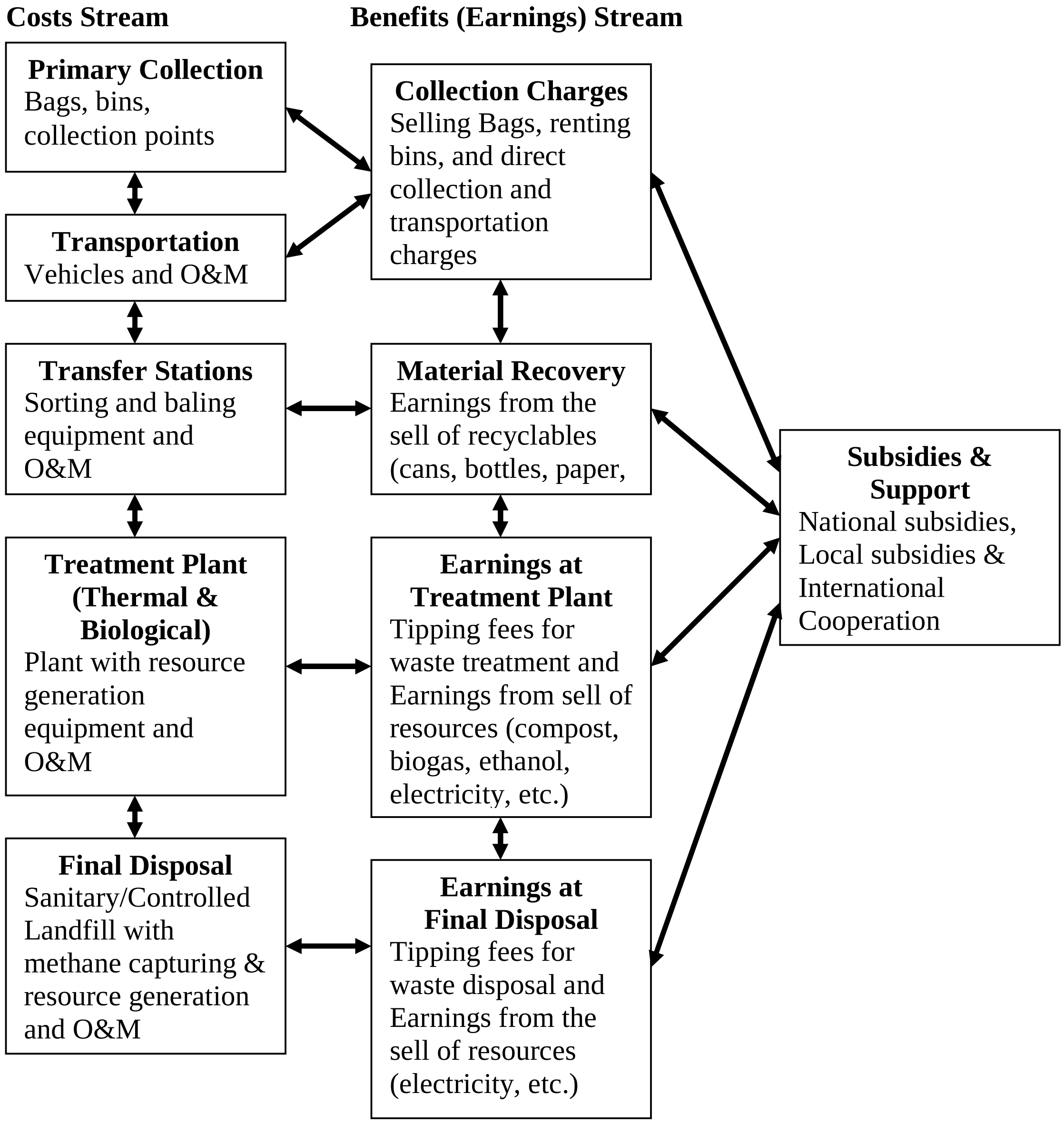
There are two broad types of PAYT. One is “Proportional” and the other one is “Variable.” Proportional systems create the most direct relationship between trash amounts and price as residents have to pay the same mount of money for each unit of waste they throw. The price is based on the number of bags. Sometimes, tags or stickers are also introduced for the waste, which is voluminous (e.g. furniture) or special (e.g. electronic waste). Variable rate pricing means charging different amounts per unit of garbage, as residents can use different size of bags. This means price can be either increasing or decreasing for additional amount waste, based on the targets.

In some countries, there is a combined system, where the basic waste generation levels per capita and its composition is estimated. Thereafter, every household is provided with different type of same size bags to segregate waste at source. If household’s waste generation levels exceeds, then they have to buy additional bags. The additional bags could be sold at higher price to discourage higher levels of waste generation.

5 Designing waste disposal fees or charges for WND

ISWM for WND covers residential, commercial, construction and demolition industrial, healthcare and municipal (e.g. sludge from wastewater treatment plants) sources. Following flowchart (Figure A-1) could be one of the ways to design waste disposal fees for WND.

Figure A-1 Flow Chart for Estimation of Costs and Benefits



Details of cost stream and benefit (stream) can be worked out for each component. For example, number of bags for food waste and other waste could be calculated based on the data on waste quantification and characterization. In WND, municipal waste from residential and commercial sources is 333 tons/day and out of that, about 70% is food waste (about 233 tons/day). Based on the current targets for 70% segregation of food waste (i.e. 163 tons/day), 50% waste is disposed of in bags by residents and 50% in skips by commercial entities. If all the bags are of uniform size, for example 112cm(H) X 38cm (W) and 38cm (diameter) having a capacity of 55 litres and can carry 15kg of food waste, the a total number of bags required for 81,000 tons of food waste would be 5,400. The number of skips depends on their size, as it can vary based on the waste generation rates by each commercial entity. Some indicative measurements for skips are shown as follows

Bulk or Skip Bin Dimensions

	Skip	Skip	Skip	Skip	Skip
Capacity	1. 1m³	1.5m³	2.0m³	3.0m³	4.5m³
Height	1465mm	910mm	865mm	1225mm	1570mm
Depth	1070mm	905mm	1400mm	1505mm	1605mm
Width	1360mm	1810mm	1830mm	1805mm	1805mm

The cost for each bag and rent for skip may also include collection and transportation charges. In some cases, for commercial entities, full cost recovery is desired and that includes charges for collection & transportation, treatment and final disposal.

6 Case studies from other countries

Wight-based charging system in Denmark

As per a study by DEPA (Danish Environmental Projection Agency) in 2000, approximately 20 small and medium sized Danish municipalities have weight-based schemes for municipal waste from residential source. In Bogenese municipality, the households are equipped with two-wheeled 260 litre double container with a partition (40% for organic waste and 60% for other waste). If waste generation exceeds, then another 140 litre container is delivered at owner's request. Household fee varies across municipalities in the range of 594 to 1066 DKK per household per year. The fixed fee for households covers 5 kg waste per collection. For every additional kg of waste, an additional "variable" fee is charged as shown below:

Fee categories	Fee in DKK , incl. VAT, 25%, and waste tax [d)]
Fixed fee [a)] for households per year	1,063 DKK
Fixed fee for summerhouses per year	813 DKK
Variable fee per kg organic/residual waste [b)]	3.75 DKK
Additional waste container[c)]	375 DKK

a) Covers collection and recycling/disposal of up to 5 kg of domestic waste per 14 days, recyclables, waste from recycling station and administration

b) Fee on a weight-basis for residual waste and organic waste is paid for waste exceeding 5 kg per collection.

c) Fixed fee for renting an additional waste container. The fee for the waste collected from an additional waste container is paid on a weight-basis.

d) Waste tax: Incineration 330 DKK/tonne. Landfilling 375 DKK/tonne.

Municipality	1 person	2-4 persons	> 4 persons	Average
Bogense, per year	1,371 DKK	1,794 DKK	2,177 DKK	304 kg
Oelstykke, per year	2,800 DKK	2,800 DKK	2,800 DKK	707 kg

Pay per bag scheme in Italy

In Bergamo Province (population: 1,000,000) a province-wide source separation of municipal waste was 42.5% in 1998 which was lower then the average rates among municipalities engaged in source separation. Bergamo Province introduced pay-per-bag based on the variable quota of waste tariff. This includes a fixed quota to cover fixed costs of collection and transportation and a variable quota through sale of bags.

Combined volume and weight based scheme in Luxembourg

In order to implement the polluter-pays-principle and cost-effective system of waste management, a new calculation system waste tested in a pilot project in two communities. The waste fee structure is shown as follows:

Waste fraction	Waste Fee
Waste paper (bin)	Per emptying 120 l: 2.7 €; 240 l: 4.0 €; 1100 l: 9.9 € per emptying
Metal scrap (by call)	Per collection, 19.8 €/call
Compostables (bin)	Per weight; 0.09 €/kg
Residual waste (bin)	Basic fee 7.8 €/(month and bin) Additional per weight 0.11 €/kg and additional per emptying 120 l: 1.2 €; 240 l: 1.9 €; 1100 l: 4.7 € per emptying
Bulky waste (by call)	Per collection and treatment, 31.6 €/call
Refrigerators etc.	Per collection and treatment, 19.8 €/collection and 27.2 €/treatment
Container (recyclables)	Financed by basic fee from residual waste
Amenity site	Financed by basic fee from residual waste
Compost plant	Financed by basic fee from residual waste
Administration SICA	Financed by basic fee from residual waste
Information and public relations	Financed by basic fee from residual waste

The impact of waste charges was also visible in the waste generation levels in different municipalities:

	Total waste [t]		
Community	**1994**	**1995**	**1996**
Koerich	612	390	294
Kopstal	1,020	731	541
Mamer	2,078	1,906	1,817
Steinfort	1,406	1,297	1,332

Weight and volume based system at apartment blocks in Germany

In apartment blocks, waste segregation rates are low, organic waste content is high and amount of dry recyclables I very low. This mainly due to high occupant density and tenants being anonymous, tenants often change and the existence of waste fees which are calculated based on the living area. A pilot project was introduced in IPW centre:

IPW Centre	
Duration of pilot project	5 months
Residential area	Blocks of flats (5 storeys), approx. 800 tenants
Waste system	IPW centre with 6 containers (1.1 m^3 each)
Description of the system	Weighing of waste, fee according to the mass (chip card); pressing of the waste, opening of the lock gate with a chip card, information and "what to do" on a display, automatic change of the containers and the actual filling capacity of the total system, connection to a PC for data transfer
Equipment	Concrete foundation necessary (max. 2,000 €), electricity
Costs	Total IPW centre approx. 19,400 € (incl. tax), laptop approx. 2,000 € (incl. tax)

The feel structure is shown as under:

	Before installation of IPW centre	After installation of IPW centre
Amount of waste		Approx. -45 %
"incorrect" waste in residual waste fraction	30 to 35 %	10 to 15 %
"incorrect" waste in dry recyclable fraction	Up to 30 %	5 to 10 %
Calculation of fees	Fixed fees; based on living area	Polluter-pays-principle; related to mass
Capacity of waste container needed		Less than before
Waste collection	Twice per week	One time per week
Time needed for waste collection	Container at different places	All containers at central position
Costs per month per household (example for 3 persons per household)	220 €	171 €
Distance to container for tenants	15 meters	79 meters

B Guidelines for Identification of ESTs

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

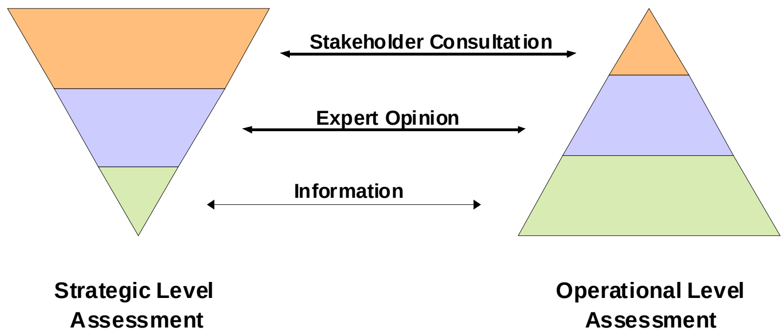
To identify appropriate technologies under each technological measure, a set of criteria is to be developed. This should cover technological, economic, social and environmental aspects of the technologies. Based on the criteria, technologies are identified and ranked to assist decision-makers to make 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

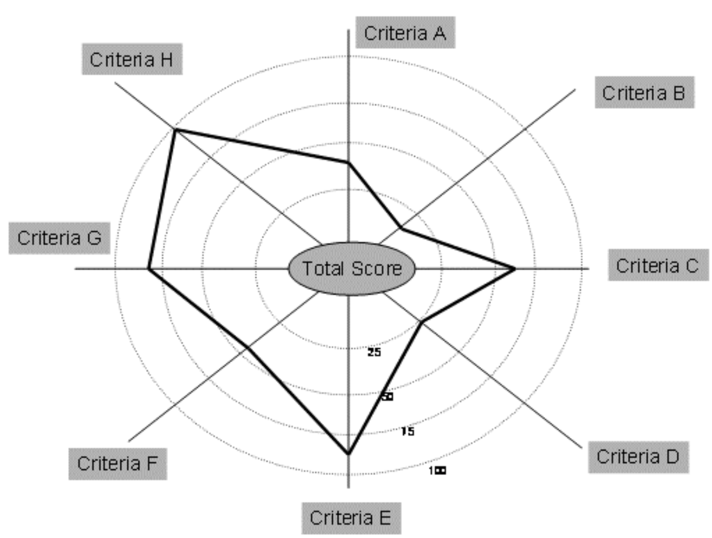
In the process of developing the weighted sum matrix, it can be seen that at times the difference between the total scores for some options may be very marginal. In other words, if the group decides to change the weights or scores for some of the criteria or technology options, then the ranking of the 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 technology system suitable for geographical or climatic condition or not? Is it giving any secondary impacts such as groundwater*

Group Heading	Criteria	Indicators	Guidance Notes / Verification Requirements
			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, 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

Group Heading	Criteria	Indicators	Guidance Notes / Verification Requirements
			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 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

Group Heading	Criteria	Indicators	Guidance Notes / Verification Requirements
			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.
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**	

Group Heading	Criteria	Indicators	Guidance Notes / Verification Requirements
Environment: Resources and Emissions	**Resource Usage**		
	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

Group Heading	Criteria	Indicators	Guidance Notes / Verification Requirements
			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**	
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**	
	Benefits (*Energy, fertilizer, reclaimed land, enhanced biodiversity*)	**Low / Medium / High / Not Applicable**	

Group Heading	Criteria	Indicators	Guidance Notes / Verification Requirements
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			
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		
	Fuel	**Type of Fuel Quantity per unit operating hours or unit output**	
	Electricity	**Quantity per unit operating hours or unit output**	

Group Heading	Criteria	Indicators	Guidance Notes / Verification Requirements
	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			
	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

Group Heading	Criteria	Indicators	Guidance Notes
			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 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

Group Heading	Criteria	Indicators	Guidance Notes
			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.*
	Risk levels for communities / beneficiaries	**Low / Medium / High**	
	Risk to the environment e.g. to biodiversity	**Low / Medium / High**	
Environment: resources and emissions			

Group Heading	Criteria	Indicators	Guidance Notes
	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 information. Accordingly, it is possible to rate the systems as Low, Medium or High against this criterion.

Group Heading	Criteria	Indicators	Guidance Notes
	Emissions	**Low /Medium / High/ Not Applicable**	Various aspects related to emissions, odour, 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			
	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			

Group Heading	Criteria	Indicators	Guidance Notes
	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			
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		

Group Heading	Criteria	Indicators	Guidance Notes
	Benefits (*energy, fertilizer, reclaimed land, enhanced biodiversity, carbon credits*)	**Economic returns**	
	Economic viability	NPV, IRR, C/B ratio, payback period	

4 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
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 ▪ Gasification ▪ Sanitary landfill ▪ Aerobic composting ▪ Anaerobic digestion / biomethanation	▪ Manual landfilling ▪ Vermicomposting

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:[25]

- Mass burn
- Modular incineration
- Fluidized bed incineration[26]
- RDF
- Sanitary landfilling[27] combined with aerobic (windrow)[28] composting
- 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.

[25] 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.

[26] 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.

[27] 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.

[28] 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, other 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 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[29]	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.

[29] 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) [30]

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[31]	40	4	40	3	30	10	100	10	100	10	100
Past experience (under similar conditions)[32]	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
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 (∑ weight * assigned score)			**210**		**251**		**221**		**423**		**443**		**429**

[30] 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.
[31] 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.
[32] 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-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

H. 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)[33]

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)[34]	8	0	0	8	64	0	0
Pay back period[35]	8	7	56	6	48	5	40
NPV / IRR	8	4.5	36	6	48	4	32
Secondary contaminant generation[36]	9	7	63	7	63	8	72
Require PPE[37] for staff?	7	5	35	5	35	6	42
Level of safety risk for workers and communities[38]	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

[33] 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.
[34] The government of Inafix provides a rebate for waste treatment-cum-disposal technologies that can earn credit for reducing GHG emissions.
[35] Includes consideration of costs for backend pollution control technologies
[36] 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).
[37] Stands for “personal protective equipment”
[38] Pertaining to fire in this case.

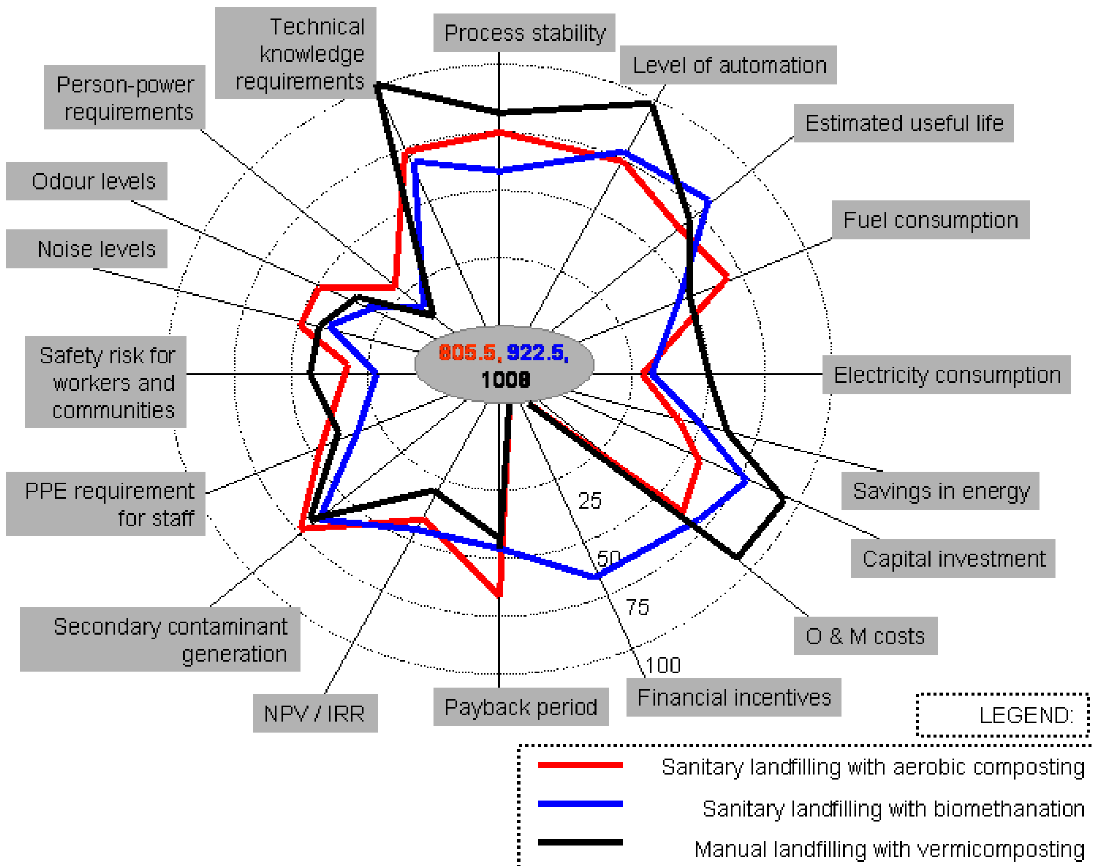
Criteria	Weight	Sanitary landfilling with aerobic composting		Sanitary landfilling with biomethanation		Manual landfilling with vermicomposting	
		Score	**Weigh t*score**	**Score**	**Weigh t*score**	**Score**	**Weight *score**
Person-power requirements	5	3	15	4	20	1	15
Technical knowledge requirements (qualifications/special knowledge needed)	10	7	70	7	70	10	100
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[39]



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

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

C Sketch of Technologies for ISWM

There are various technologies available to perform various activities within ISWM chain. Choice has to be made for most efficient and effective type of technologies for waste collection and transportation, transfer stations, biological and thermal treatment plants and landfills. To identify appropriate technologies for decision-makers to take final decision, Sustainability Assessment of Technologies (SAT) Framework would be adopted as shown in Annexure B.

This annexure provides sketches of technologies with respect to their technical function and operational aspects. Based on the understanding of this information, available technologies could be short-listed to analyze them through SAT Framework.

This information is only for the purpose of let the reader know about the function and operational aspects of basic technologies for ISWM. It is not intended to promote certain make or brand of any particular type of technology. Most of the information is taken from UNEP publication on Solid Waste Management (http://www.unep.or.jp/Ietc/Publications/spc/Solid_Waste_Management/index.asp). However, some other sources were also consulted to provide clearer picture of each type of technology. The details and photographs are only for the reference purpose.

1 Collection System

Essentially, there are four basic collection systems, depending upon the level of effort required on the part of the generator. The types of systems are: communal, block, kerbside, and door-to-door. Communal storage and collection may require delivery of the wastes by the generator over some distance. In block collection, the generator delivers the wastes to the vehicle at the time of collection. In kerbside collection, the generator sets out the full container and later retrieves it. In door-to-door collection, the collector enters the premises, and the generator basically is not involved in the collection process.

Communal collection

The planning and organisation of refuse collection is greatly simplified by the use of large communal storage sites. Although the use of large communal sites may seem to be a fairly inexpensive and simple solution, it may transfer much of the burden of refuse collection onto the street cleaning service and actually increase total costs. It is less expensive to collect refuse directly from a residence or business than to sweep it up from the streets. Furthermore, the use of large, widely spaced communal storage sites generally fails because the demand placed on the generator goes beyond his willingness to cooperate. If communal storage sites are going to be used, the storage points should be at intervals convenient to the generators.

Large masonry enclosures, as well as small concrete bins, are inefficient in the use of labor and vehicles. As previously indicated, wastes have to be manually removed from these types of containers by rake or shovel and basket. This is a relatively slow process and vehicle waiting time during the loading process is excessively non-productive. In addition, the idle collection vehicles impede other traffic in the street. The following performances have been recorded: 1.4 Mg/worker/day and 7 Mg/vehicle/day for masonry enclosures, and 1.2 Mg/worker/day and 6 Mg/vehicle/day for concrete pipes. Drums having a capacity of 200 L are not an ideal solution; however, two workers can generally empty them into vehicles with a low load line. The use of 200-L drums increases collection performance to about 5 Mg/worker/day and 10 Mg/vehicle/day.

Block collection

In this system, a collection vehicle travels a regular route at a frequency of two to three times per week. The vehicle stops at all street intersections, and a bell is rung. At this signal, the residents of all the streets leading from that intersection bring their containers of waste to the vehicle and hand them to the crew to be emptied. Typically, a driver and a crew of two are sufficient for this type of system since they do not need to leave the vehicle to perform collection of the waste.

Block collection should be operated frequently; otherwise, the quantity of wastes to be carried to the vehicle may require more than one trip or may be beyond the carrying capacity of some of the residents. This method of collection has a significant advantage over kerbside collection since the containers are not left out on the street for long periods of time while awaiting the arrival of the collection vehicle.

Block collection is operated in some cities in Latin America. The results of a study carried out in Mexico City indicated that it took about 2.5 hr to service approximately 840 dwellings. The route was 2.7 km long, and each dwelling delivered about 4.3 kg. The performance achieved by this system was about 3.5 Mg/worker/day and 7.0 g/vehicle/day.

Kerbside collection

This system of collection requires a regular frequency and a fairly precise schedule, for optimal efficiency and convenience. Residents must place their containers on the curb before the time of collection and remove the containers after they have been emptied. It is important that the containers be of a standard type. If standard containers are not used, it is likely that wastes will be set out in any type of container such as baskets or cardboard boxes, or even in piles. Under these conditions, the wastes may be scattered by animals and wind, thus making the collection process very inefficient. In developing countries, kerbside collection is not entirely satisfactory. Some of the problems associated with kerbside collection include: the contents of the containers may be sorted by scavengers; and the containers may either be stolen, overturned by animals, or left on the street for long periods of time.

However, kerbside collection is unavoidable for collection of waste from some types of structures, and it is one of the least expensive methods of house-to-house collection. A high labour productivity can be achieved when the rate of waste generation is high and collection infrequent. For example, in one city in the United States, a one-person crew collects up to 10 Mg/day (400 dwellings at an average of 25 kg/dwelling). In most economically developing countries, however, the rate would be lower since the average quantity of waste collected per dwelling is much less than in the United States.

Door-to-door collection

In this system, the householder does not participate in the collection process. The collector enters the premises (backyard or garden), carries the container to the vehicle, empties it, and returns it to its usual place. This system is costly in terms of labour because of the high proportion of time spent walking in and out of premises and from one dwelling to the next. However, in some situations, it is the only satisfactory system.

The main difficulty with door-to-door waste collection in developing countries is that vehicle productivity would be less than that in Europe or the United States if the collection frequency were high. Since one of the main objectives in developing countries is to achieve high vehicle productivity, door-to-door collection by the conventional western method of heavy reliance on motor vehicle and crew is very unlikely to be a viable system unless the collection frequency is about once a week. This may not be feasible in countries with tropical climates unless high standards of waste containment at the place of generation are practiced and enforced.

Collection vehicles

Light commercial trucks

This type of vehicle is available almost worldwide. It is primarily designed for the transport of construction materials. However, it is also 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 m^3 and is suitable to carry high-density materials such as bricks and aggregates. One of the major disadvantages of the vehicle in its standard form 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 4 Mg. It is, therefore, common practice to extend the height of the sideboards in order to increase the volumetric capacity. This practice, however, makes it necessary to either use ladders to load the vehicle or to place workers inside the body to receive containers handed up to them by collectors.

The advantages of this type of truck are the following: it is relatively inexpensive, it is sturdy and easily obtainable, it has good ground clearance, and it performs well on rough roads. In applications involving the collection of solid wastes, the truck should have a carrying capacity of at least 2 m^3/Mg. In addition, the loading height should not exceed 1.6m. There are some modifications that can be made to a conventional light commercial truck that enable these requirements to be met without complex mechanisation of the body.

Some of these modifications include: reduction in the height of the chassis by using wheels of a diameter smaller than standard - this change, however, would result in the reduction of both the maximum permissible load and ground clearance; use of full forward control (cab-over engine) to increase space on the chassis for the body; extension of rear overhang; and use of a long wheelbase.

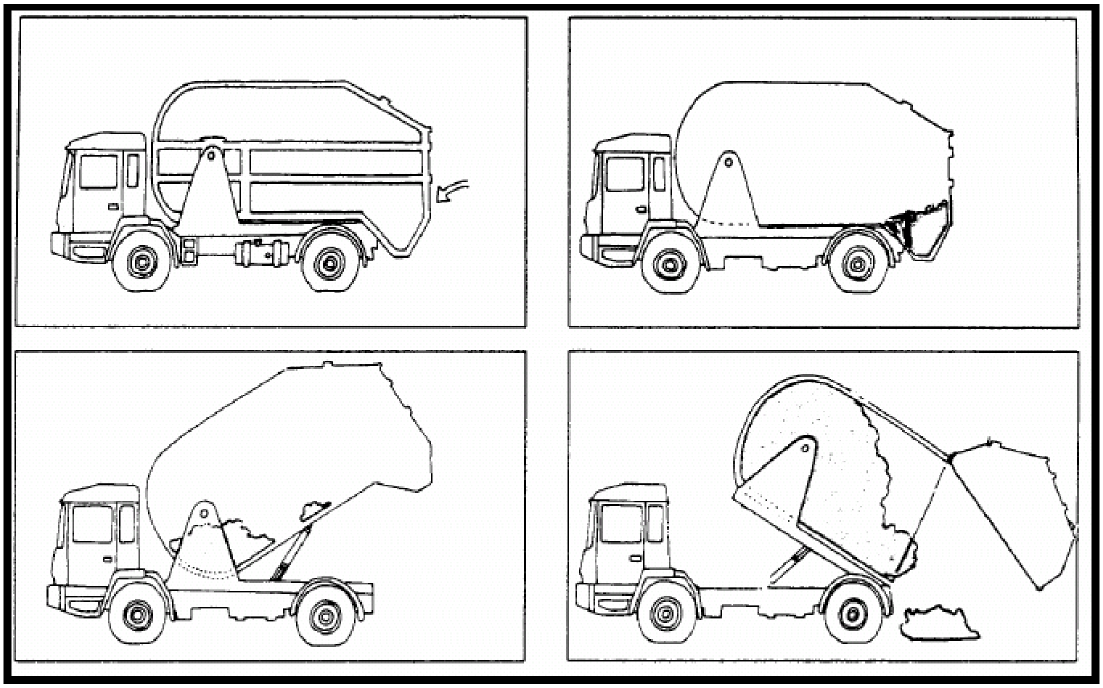
The application of these design modifications allows the use of an enclosed body. The body could have a capacity of about 8 m^3 without exceeding the desired loading height of 1.6 m. The most common type of body having these design features is the side-loader. The side-loader has three or four loading apertures along each side. The apertures can be closed by means of sliding shutters. The shutters are usually plain sheets of metal running in grooves. The load can be distributed within the body by the use of rakes. During the final stages of loading, the waste can be piled against closed shutters along one side. Because of the potential difficulty of unloading, it is advisable to equip these vehicles with hydraulic tipping gear.

Fore and aft tipper

This design appeared in the mid-1930s and was used in Europe until about ten years ago. Its distinguishing feature is that the body can be tipped two ways: toward the front of the body during the loading process and toward the rear for unloading. This relatively simple mechanism achieves a result similar to the hydraulic ram at the rear of a compactor vehicle. However, the compression effect is much lower than that obtainable with the compaction unit. The forward tipping operation may be required about 12 times per load. A suspended barrier inside the body prevents the wastes from falling back after tipping. This type of vehicle utilises body capacities of about 12 m^3.

This design approximates that of a compactor and is suitable for densities from 250 kg/m^3 and upward. The vehicle can be built on a standard chassis with normal wheel diameter, and presents few maintenance problems. A schematic diagram of the fore and aft tipper is shown in Figure C-1.

Figure1 Schematic diagram of fore and aft tipper



Container-hoist

This unit utilises a standard commercial chassis (in the range of 5 to 10 Mg) equipped with two hydraulically-operated lifting arms. The arms are used to lift metallic containers on or off the floor of the vehicle. The containers have a capacity of 3 m^3 or more. 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; it is cheaper, faster, and less liable to be damaged by vandalism than the tractor-trailer units. On the other hand, the cost of a container vehicle is about twice that of an agricultural tractor and in many cases the container transports a considerably smaller load than that possible using a tractor-trailer.

The main reason for the relatively low payload appears to be that the container vehicles are manufactured to collect and transport wastes that have a relatively high bulk density. It is not advisable that developing countries implement container systems based on capacities on the order of 3 to 4 m^3.

Compactor vehicles[40]

Compactor vehicles have added advantage of compaction to increase the capacity of waste collect on each trip. Following are some of the common types of compactor vehicles:

Front loaders generally service commercial and industrial businesses using large waste containers with plastic lids [dumpsters (US), Biffa bins or wheely bins being the smaller household version (UK)]. The truck is equipped with automated forks on the front which the driver carefully aligns with sleeves on the waste container using a joystick or a set of levers. The waste container is then lifted over the truck. Once it gets to the top the container is then flipped upside down and the waste or recyclable material is emptied into the vehicle's hopper. Once the waste is dumped, it is compacted by a large blade called a "packer blade" that pushes the waste to the rear of the vehicle. Most of the newer WCVs have "pack-on-the-go hydraulics" which lets the driver pack loads while driving, allowing faster route times.

Rear loaders commonly service residential areas. They have an opening at the rear that a waste collector can throw waste bags or empty the contents of bins into. Often in many

[40] Information from compactor vehicles is collected from http://en.wikipedia.org/

areas they have a lifting mechanism to automatically empty large carts called *toters* without the operator having to lift the waste by hand. Typical bin sizes are 35-95 gallon carts. Another popular system for the rear loader is a rear load container specially built to fit a groove in the truck. The truck will have a wire / chain or strap system for lifting in the two "eyes" on the rear top. The waste will then slide into the tray of the truck. Normal sizes are 6 to 22 m^3. The disadvantage of the large containers is that it requires a lot of free space upwards, while the smaller bins never reach higher than the truck itself.
The rear loader usually compacts the waste with a sweep-and-slide system that digs in the waste and compresses it against a moving wall, that will move it towards the front of the vehicle as the pressure forces the hydraulic valves to open.

Side loaders are trucks very similar to front end loaders. The differences are that a side loader only picks up smaller containers such as toters. 96,64 and 35 gallon trash carts with attached lids commonly used for residential waste collection. Automated Side Loaders are mostly used only in residential areas. Another difference is that ASL trucks pick the container up over the side and not over the front. The mechanical arm can have a reach of up to 9 feet, which allows trash to be collected around obstacles such as parked cars, mail boxes etc. The arm is operated by either a joystick just like a front end loader or by four switches. An ASL truck only uses one operator where as a traditional rear load garbage truck in town areas often require two or three people; driver and one or two men unloading trash bins.

Pneumatic collection WCVs have a crane with a tube and a mouthpiece that fits in a hole, usually hidden under a plate under the street. From here it will suck up waste from an underground installation. The system usually allows the driver to "pick up" the waste, even if the access is blocked by cars, snow or other barriers.

Grapple trucks enable the collection of bulky waste. A large percentage of items in the solid waste stream are too large or too heavy to be safely lifted by hand into traditional WCVs. These items (furniture, large appliances, branches, logs) are called bulky waste or "oversized". The preferred method for collecting these items is with a grapple truck. Grapple trucks have hydraulic knucklebooms, tipped with a clamshell bucket, and usually include a dump body or trailer.

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

Compaction ratios achieved with wastes from industrialised countries (with initial densities in the range of 130 to 190 kg/m^3) varies from 2:1 to 4:1, the final density in the vehicle being about 400 to 550 kg/m^3. Wastes in most developing countries have an initial density similar to that of compacted industrialised wastes.

The compaction mechanism imposes a need for additional maintenance facilities that may not be readily available in some cities.

Compactor vehicles usually need to be imported, which may lead to problems in foreign exchange and acquisition of spare parts.

The compaction mechanism substantially increases fuel consumption.

The capital cost of a compactor vehicle is significantly greater than that of a conventional truck.

Vehicle standardization

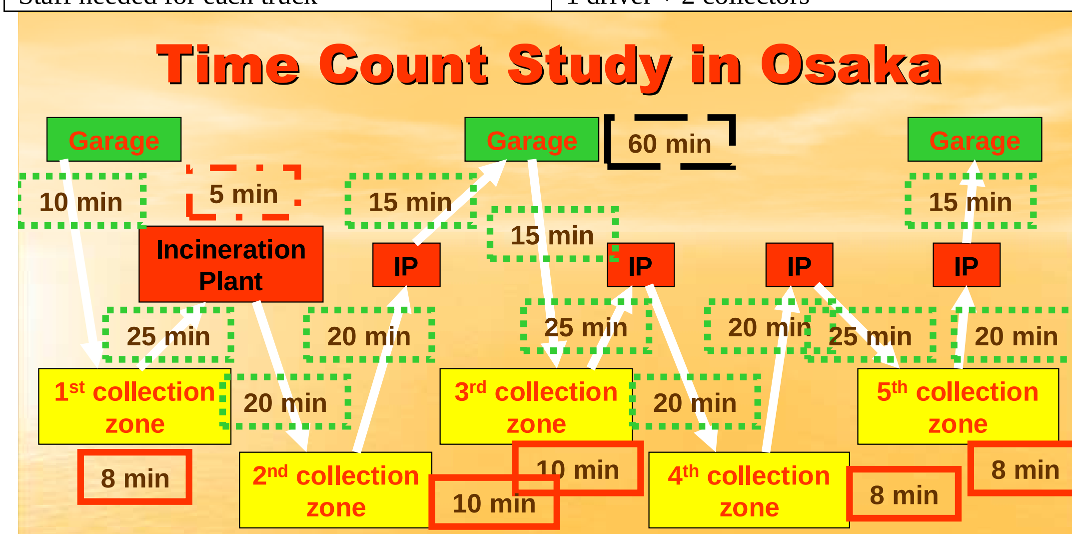
In the conduct of several projects throughout Asia, Africa, Latin America, and the Caribbean, the authors have observed that a large number of countries have mixed vehicle fleets and extremely low vehicle serviceability. In fact, in extreme situations, the authors have observed municipalities that own and operate vehicles that require metric tools and vehicles that require English tools. In some instances, the serviceability is as low as 50% to 60%. These two factors may be related to one another. If many different models of vehicles or vehicles of different manufacturers compose the collection fleet, it is extremely difficult (and costly) to maintain an adequate stock of spare parts. Consequently, vehicles may be off the road for long periods of time while replacement parts are purchased and delivered, sometimes through a centralised purchasing organisation. In fact, it is very common in developing countries to see a large number of vehicles broken down and used as sources of spare parts. The use of a centralised purchasing organisation may cause additional delay by requiring competitive bidding for even minor items.

Inventory control can be simplified and availability of spare parts improved by standardising the fleet. Furthermore, major spare items (engines, transmissions, axles, and hydraulics) can be kept in stock. These spare items are used to replace defective parts in a vehicle, which can then be put into service within a few hours. The items that have been removed can subsequently be repaired at leisure.

Standardisation, however, does not imply that the same type of vehicle should provide service to every area in a community. As mentioned previously, low-income areas may require different types of vehicles.

Collection system in Osaka (Japan)[41]

Number of trips per day per truck	AM 2 trips, PM 3 trips
Average distance covered per day (in kms)	Distance is not so important, focus is on zones
Pick-up points covered in one trip	266 points (average)
Total volume of garbage collected per truck	1.27 ton (average)
Time taken for one trip	1st trip: 43 minutes 2nd trip: 50 minutes 3rd trip: 135 minutes 4th trip: 48 minutes 5th trip: 53 minutes
Staff needed for each truck	1 driver + 2 collectors



Working Hour		8.00 hour	100 %
Travel Time	10+25+20+20+15+15+25+20+20+25+20+15=230min	3.83 hour	48 %
Collection Time	8+10+10+8+8=44min	0.73 hour	9 %
Dump Time	5X5=25min	0.42 hour	5 %
Lunch Time	60 min	1.00 hour	12 %
Maintenance Time	35 min	0.58 hour	7 %
Unnecessary Time	86 min	1.43 hour	19 %

[41] Information collected through GEC (Global Environmental Centre Foundation, Japan) - http://gec.jp/

Dustbin and Load Study

	No. of Dustbin	Load (ton)
1st Trip	313	1.420
2nd Trip	273	1.280
3rd Trip	254	1.290
4th Trip	298	1.470
5th Trip	193	0.870
Total	1,331	6.330

Full Capacity = 1.8ton, Standard Capacity = 1.5ton

Full Capacity	**1.8ton×5trips=9ton**
Collected Load	**6.33 ton**
No. of Dustbin	**1,331**
Crew Member	**1 driver + 2 collectors**

Vehicle Efficiency

- Load / Working hour = 6.33 / 8 = 0.79 (ton/hour)
- Load / Collection time = 6.33 / 0.73 = 8.67 (ton/hour)
- (Actual load / Capacity load) X 100% = (6.33 / 9)×100 = 70 %

➢ Load / Total operation distance (ton / km)

➢ Load / Total collection zone distance (ton / km)

Labor Efficiency

- Labor efficiency rating (Time efficiency rating)

= 100% ×((No. of driver × (Working hour – break time – unnecessary time)) + (No. of collectors×collection time)) / ((No. of driver + No. of collectors)×Working time)

$$= 100\ \% \times \frac{1\times(8-1-1.43) + 2\times0.73}{(1+2)\times8} = 29.3\ \%$$

- (Gross man × minute) / Load

= ((No. of driver + No. of collectors) Working hour) ×60 / Load

=((1+2)×8) ×60 / 6.33 = 227.5 (min/ton)

- (Net man × minute) / Load

= ((No. of driver × (Working hour – break time – unnecessary time) + No. of collectors × Collection time)) ×60 / Load

= ((1×(8-1-1.43) + 2×0.73)×60 / 6.33 = 66.6 (min/ton)

- (Collection time / Load) × minute

= (0.73 / 6.33) × 60 = 6.92 (min/ton)

Others

- (Load ×1,000kg) / Total No. of dustbin

= (6.33 ×1,000) / 1331 = 4.76 (kg)

- (Collection time ×60 ×60(second)) / Total No. of dustbin

= (0.73 ×60 ×60) / 1331 = 1.97 (Sec)

- Collection time ×60(min) / Load

= 0.73 ×60 / 6.33 = 6.9 (min/ton)

- Collection time (min) / Total no. of dustbin × served population
- Total no. of dustbin / Total no. of station
- Mean distance between 2 stations
- Net speed in the collection area (km/hour)
- Gross speed in the working hour (km/hour)
- Generation rate per population per day (gram/person/day)

2 Transportation System

Transportation system waste transportation from waste generation to transfer station and then to waste treatment/disposal site. Basic transportation system is already covered in section 1. However, in many countries, bigger vehicles are employed to transfer waste from transfer stations to treatment/disposal sites. This increases the efficiency of transportation system. Some of the commonly used bigger vehicles are:

Open top trailers

As their name implies, these trailers are open at the top and are equipped with doors at the rear. Once full, the waste in the trailer is covered with a net or tarp to prevent spillage during transport. Open-top trailers are loaded from the top by gravity feed through a hopper or opening. The trailers can also be loaded from the rear by means of the pre-load compaction loading system.

Closed-top trailers

These trailers have a top, sidewalls, and doors at the rear. Closed-top trailers are typically loaded by pre-load compactors. The untied “bale” of waste is forced (extruded) from the compactor into the trailer.

Compactor-compatible closed-top trailers

These trailers have a top, sidewalls, and doors at the rear. Closed-top trailers that are compatible with compactors are loaded by the system described above, and the top and siding of the unit are reinforced to be able to withstand the compaction forces.

Self-contained compaction trailers

These trailers are closed at the top, except for an opening used to receive waste near the front. The trailers have sidewalls and doors at the rear. The movable bulkhead is mounted at the front of the trailer and pushes waste from the front toward the rear. The sidewalls, top, and rear doors are reinforced to be able to support the forces applied by the waste as it is compacted by the movable bulkhead. The bulkhead is also used for ischarging the waste at the disposal site by pushing the waste out the rear of the unit. The allowable load limit used in the design of roads and bridges varies from country to country. Generally, the limit fluctuates between 32 and 42 Mg (gross vehicle weight). The most typical value used in developing countries is 33 Mg gross vehicle weight. The weight of an average truck tractor capable of pulling 33 Mg is about 6 Mg. The weight of the trailer is a function of the material from which it is manufactured and of the extent of reinforcing provided. Most trailers used to transfer waste have vertical sidewall bracing. In the case of the design of trailers that will be subjected to the forces exerted by the waste as it is compacted, the spacing of the bracing may be closer than when the trailers are loaded by gravity with uncompacted waste. In addition, when the trailers are designed to withstand compaction forces, the areas that are prone to receiving the greatest force must be designed with horizontal sidewall bracing. Trailers are commonly made of either steel or aluminium. The weight of aluminium trailers is generally 15% to 30% less than that of steel trailers with comparable volumetric capacity. For example, the weight of an empty 75m^3 open-top aluminium trailer is about 5 Mg, and that of a steel trailer is about 6 Mg. An empty, self-compacting steel trailer weighs significantly more than a compactor-compatible steel trailer of the same volume. For example, a 75m^3 self-compacting steel trailer weighs about 13 Mg; whereas, a compactor-compatible steel trailer weighs about 8 Mg. Aluminium trailers, since they are lighter, can carry a heavier payload than steel trailers of similar volume. However, the cost of aluminium trailers is 40% to 60% higher than that of steel trailers. Furthermore, aluminium trailers are more costly to repair than steel trailers because the welding of aluminium requires considerable skill, and welding materials are more costly. In addition, aluminium is more brittle and has a lower yield strength than steel; consequently, aluminium is more likely to crack or tear. In order to determine whether or not aluminium trailers are more cost effective than steel, the incremental vehicle productivity of the aluminium trailers must be assessed versus their higher purchase price and potentially higher operation and maintenance costs. Transfer stations can also be designed to simply load containers (e.g., roll-off boxes) rather than to load trailers designed to be pulled by truck tractors. The containers can then be loaded onto a roll-on tilt frame chassis of a truck tractor, on flatbed freight cars, or on barges.

Discharge system

Unloading of waste from vehicles also involves various technical options. Unloading system may either be part of transfer vehicle (self-contained) or located at treatment/disposal site. Some of the commonly used unloading systems are:

Push-blade discharge system consisting of a single, tilted blade, sized to fit within the trailer body. The blade travels from the front of the vehicle toward the rear, in order to force the waste out of the vehicle. The blade is pushed by either one or two hydraulic cylinders mounted between the blade and the front of the trailer. In order to discharge its load, the transfer vehicle is driven onto the landfill area and backed up to the working face, the rear doors are opened, and the load is forced out by the blade. The push-blade system is compatible with closed-top trailers that have been loaded by stationary compactor or pre-load compactor systems.

Live-floor discharge system is consisting of a series of longitudinal slats mounted on tracks in the floor of the trailer. The tracks move sequentially and alternately in a reciprocating motion to "walk" the load out of the trailer; thus, the use of the term "live-floor". Hydraulic cylinders mounted below the floor induce the unloading motion. In order to discharge its load, the transfer vehicle is driven onto the landfill area and backed up to the working face, the rear doors are opened, and the load is discharged by the live-floor. The live-floor system is compatible with open- and closed-top trailers, as well as with the following loading systems: direct, stationary compactor, and pre-load compactor.

Frame-mounted tipper uses two hydraulic cylinders mounted on the frame of the trailer to tip the waste out of the vehicle. The cylinders lift the front of the trailer chamber such that the inclination of the body, combined with the weight of the load, causes the material under gravitational force to slide out the rear of the unit. In order to discharge its load, the transfer vehicle is backed up to the working face, the rear doors are opened, the trailer is tipped by means of the hydraulic system, and the load is discharged. The tipping system is compatible with open-top trailers that have been loaded by direct dumping from collection vehicles into the trailers and with closed-top trailers that have been loaded by pre-load compactor.

Mobile tipper is not a self-contained (i.e., trailer mounted) discharge system. The mobile tipper is a machine mounted on a track. The track is located near the working face of the landfill and is used for tilting and emptying the transfer vehicles. Typically, the transfer vehicle is driven onto the mobile tipper and the vehicle's rear doors are opened. Hydraulic cylinders lift the front of the tipper's platform, along with the transfer vehicle. The weight of the load causes it to slide out through the rear opening of the trailer. A bulldozer, stationed near the rear of the mobile tipper, pushes the discharged load away, making sufficient room for discharging the next load. The mobile tipping system is compatible with open-top trailers, which have been loaded by direct dumping from collection vehicles, and with closed-top trailers, which have been loaded by pre-load compactor.

3 Transfer Stations

Basic function of a transfer station is sorting of waste for material recovery and/or compacting/baling of waste for efficient transportation to treatment/disposal site. For ISWM, one of the objectives is to reduce the amount of final waste by maximizing reuse and recycling of waste through material recovery at sources as well as at a transfer station. Therefore, this sketch provides the information on a transfer station with material recovery facilities.

Manual separation

In the case of mixed waste processing, bulky items (appliances, furniture, etc.) and specified contaminants (e.g., hazardous waste) generated in some of the industrializing economies can be, and oftentimes are, manually removed from the waste prior to mechanical processing. With few exceptions, a completely manual separation of materials from mixed waste beyond this initial separation is reserved for small operations, i.e., less than 20 Mg/day. Manual separation is also applicable to the removal of contaminants from source-separated materials. (Here, "contaminants" refers to components other than the materials specified for separate collection.) Ranges of sorting rates and of recovery efficiencies can be established that cover the usual set of operating conditions at processing facilities.

Equipment involved in manual separation of materials usually includes a sorting belt or table, which contains a mixture of materials. Workers ("sorters") are stationed on one or both sides of the belt or table. Hoppers or other receptacles for receiving removed items are positioned within easy reach of the sorters.

The design of processes that rely on manual separation requires a good understanding of basic principles of time and motion, of the composition of the waste, and of the comfort and safety requirements of the sorters. The application of simple, labour-intensive designs does not imply a disregard for safety and environmental control within the facilities.

Mechanical separation

Mechanical separation usually involves the use of several types of unit processes, five of which are size reduction, air classification, screening, magnetic separation, and non-ferrous (e.g., aluminium) separation. The sequence of the processes for mixed waste processing varies, although either size reduction or a preliminary screening (trommel) usually is the first step. The term "size reduction" has a number of synonyms in solid waste management, including "shredding" and "grinding". The term "shredding" has been widely adopted in reference to size reducing mixed waste. In the case of processing source-separated materials, size reduction using granulators and grinders is sometimes practiced for certain types of plastics and for glass, respectively (Figure C-2).

Air classification is a process of separating categories of materials by way of differences in their respective aerodynamic characteristics. The aerodynamic characteristic of a particular material is primarily a function of the size, geometry, and density of the particles. The process consists of the interaction of a moving stream of air, shredded waste material, and the gravitational force within a confined volume. In the interaction, the drag force and the gravitational force are exerted in different directions upon the particles. The result is that waste particles that have a large drag-to weight ratio are suspended in the air stream, whereas components that have a small ratio tend to settle out of the air stream. The suspended fraction conventionally is referred to as the "air classified light fraction" and the settled fraction is termed "air-classified heavy fraction". The confined volume in which the separation takes place is called an "air classifier". Air classifiers may be one of a number of designs. The three principal groups of designs (horizontal, inclined, and vertical) are diagrammed in Figure C-3.

Screens are used for achieving efficient separation of particles through dependence on differences between particle sizes with respect to any two dimensions. Assuming 100% screening efficiency, the separation results in a division of the feedstock into at least two size fractions, one of which has a minimum particle size larger than that of the individual screen openings and the second, a maximum particle size smaller than that of the openings. The first group is retained on or within the screen. This fraction is termed “oversize”, and its constituent particles become “oversize particles”. The second fraction passes through the openings and accordingly is termed “undersize”, and its constituent particles become “undersize particles”. There are various technologies for different levels of screening. The trommel is a downwardly inclined, rotary, cylindrical screen. Its screening surface is either a wire mesh or a perforated plate. The tumbling action efficiently separates adhering items, “sandwiched” undersize particles, or an item from its contents. The tumbling action is essential in the screening of mixed waste because of the need for a high degree of screening efficiency, coupled with a minimum of screening surface. Disc screens have been employed in many waste processing facilities. The predominant applications to date are effecting the separation of inorganic materials from refuse-derived fuel fractions, from paper materials, or from wood waste. Magnetic separation is a process used to segregate magnetic (i.e., ferrous) metal from a mixture of different types of materials, e.g., mixed waste or commingled metal, glass, and plastic containers. The process is technically simple and of relatively low cost (Figure C-4).

Designing a processing facility

The design of a successful processing facility should incorporate certain concepts, among which are the following: 1) reliance upon proven technologies (appropriate to the particular location) and fundamental principles of engineering and science; 2) consideration given not only to the characteristics of the waste from which the desired materials are to be recovered, but also to the specifications of the recovered materials; 3) preservation or improvements to the quality of the recovered material; 4) processing flexibility to accommodate potential future changes in market conditions; 5) recovery of the largest percentage of materials that is feasible given the conditions that apply to the recovery project, and 6) protection of the workers and of the environment.

Design concepts pertaining to operation include provisions for: 1) receiving mixed waste, source-separated materials, or both; 2) accommodating the various types of vehicles that deliver wastes to the facility, as well as the frequency of the deliveries; 3) relying upon manual labour when current automation technology is lacking, unproven, or marginally effective; and 4) storing of materials (Figure C-5).

Waste compactors and baling equipment

Stationary waste compactors are commonly used at transfer stations (Figure C-6). A stationary compactor, commonly known as a breakaway because the actual compactor is mounted to the ground, while the container is detachable. When the container is hauled to the landfill, the compactor stays in place. This is a chute through the wall installationIn stationary compactors, waste is loaded into the hopper to ensure that the material, when fully compacted, is evenly and/or appropriately distributed in terms of weight, binds to the rest of the compacted mass, does not adhere to the inside of the container or chamber, and is distributed so as to minimise any potential risk in terms of combustion or other adverse chemical reaction. Baling systems include semi-automatic and fully automatic machines that are capable of baling several materials such as cardboard, magazines, paper, plastics, solid waste, textiles, aluminum cans, steel cans, copper, radiators, extrusions, etc.

Figure C-2 (Clockwise) Horizontal hammer-mill, vertical hammer-mills, commercial horizontal hammer-mill and shredder

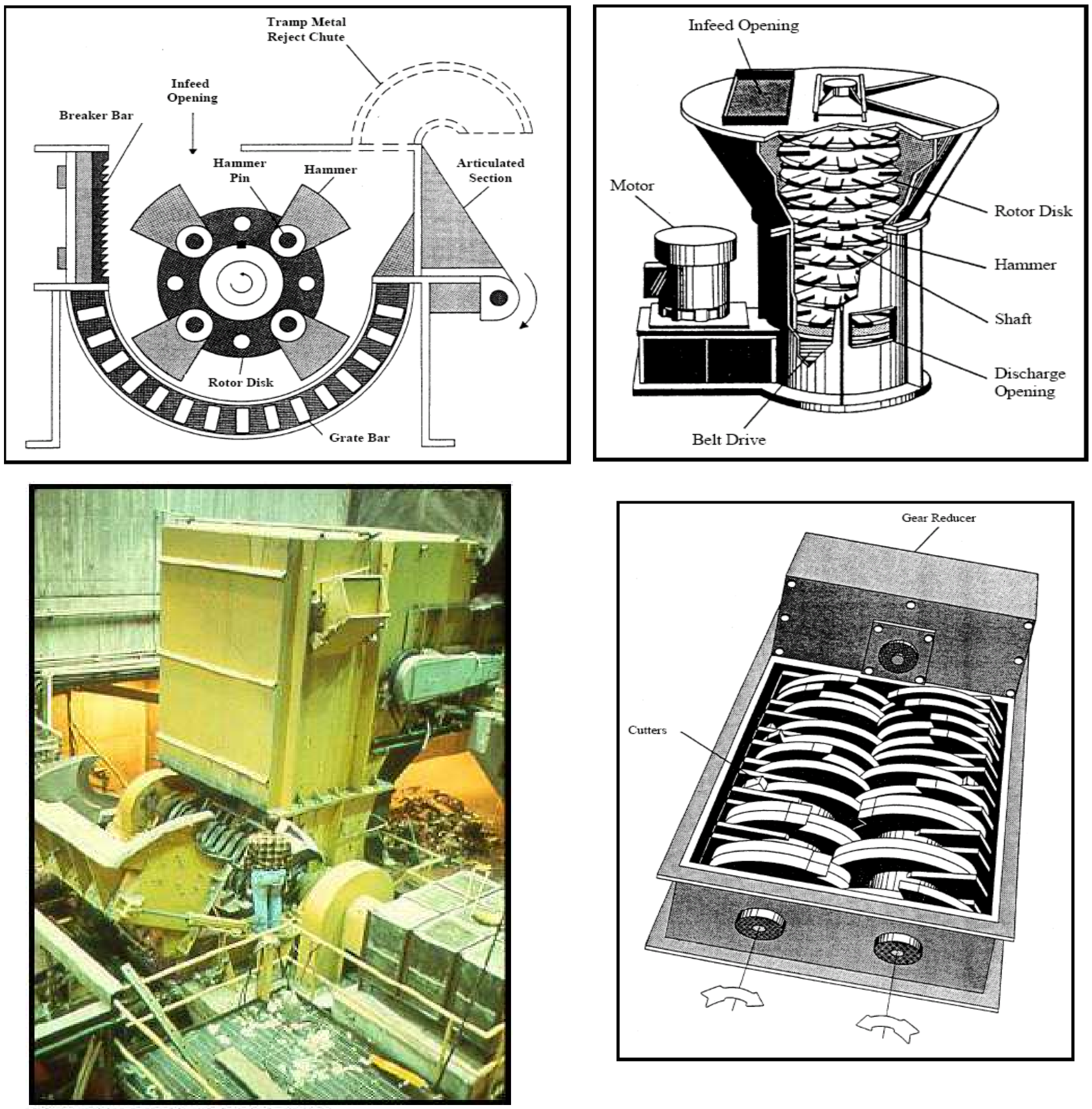


Figure C-3 (Clockwise) Horizontal air classifier, vertical air classifier, vibrator air classifier and inclined air classifier

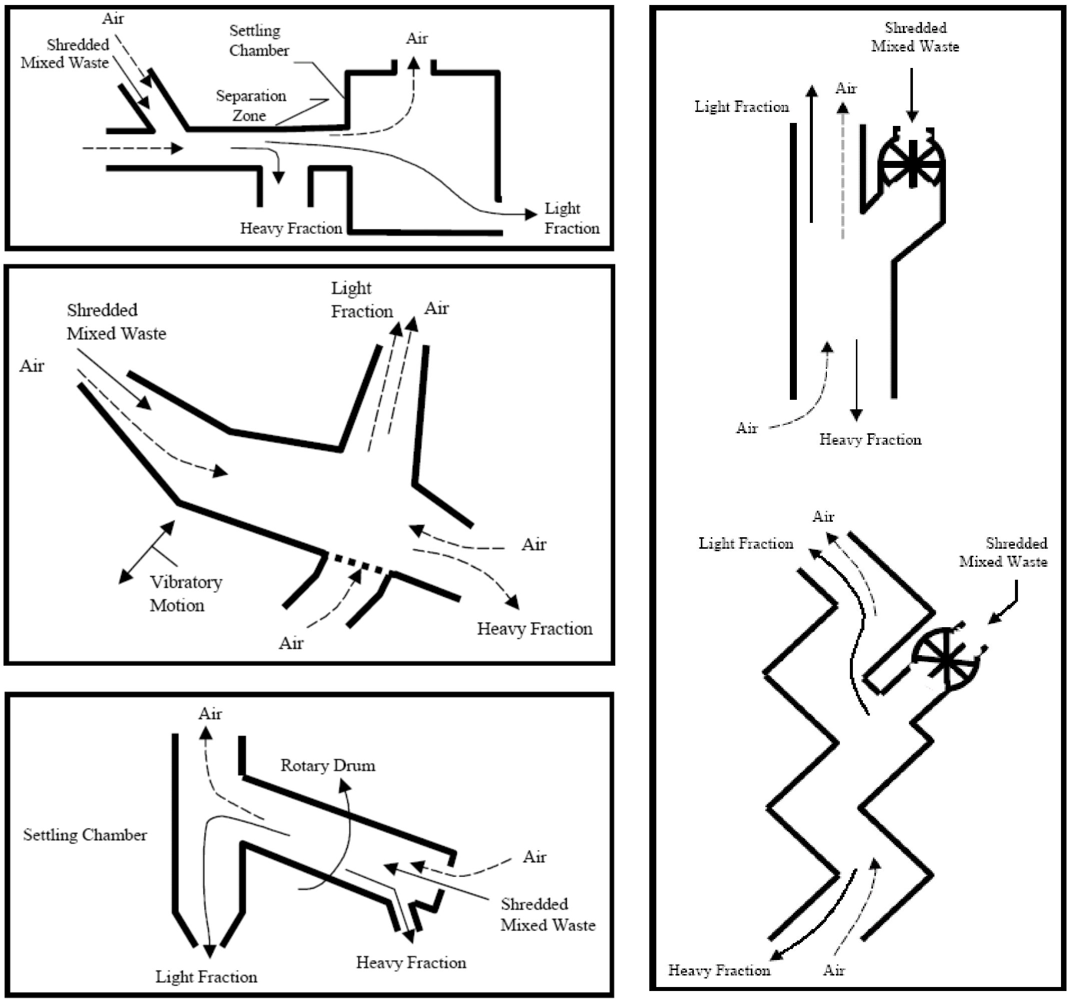


Figure C-4 Magnetic separators

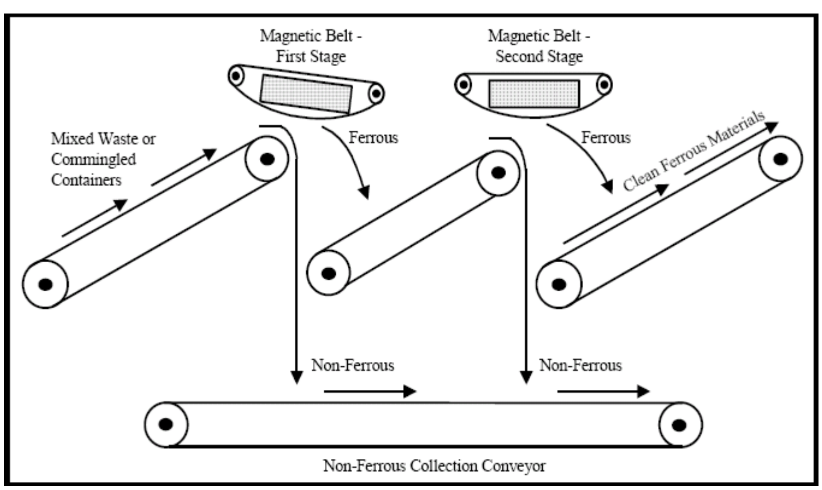


Figure C-5 Layout of transfer station

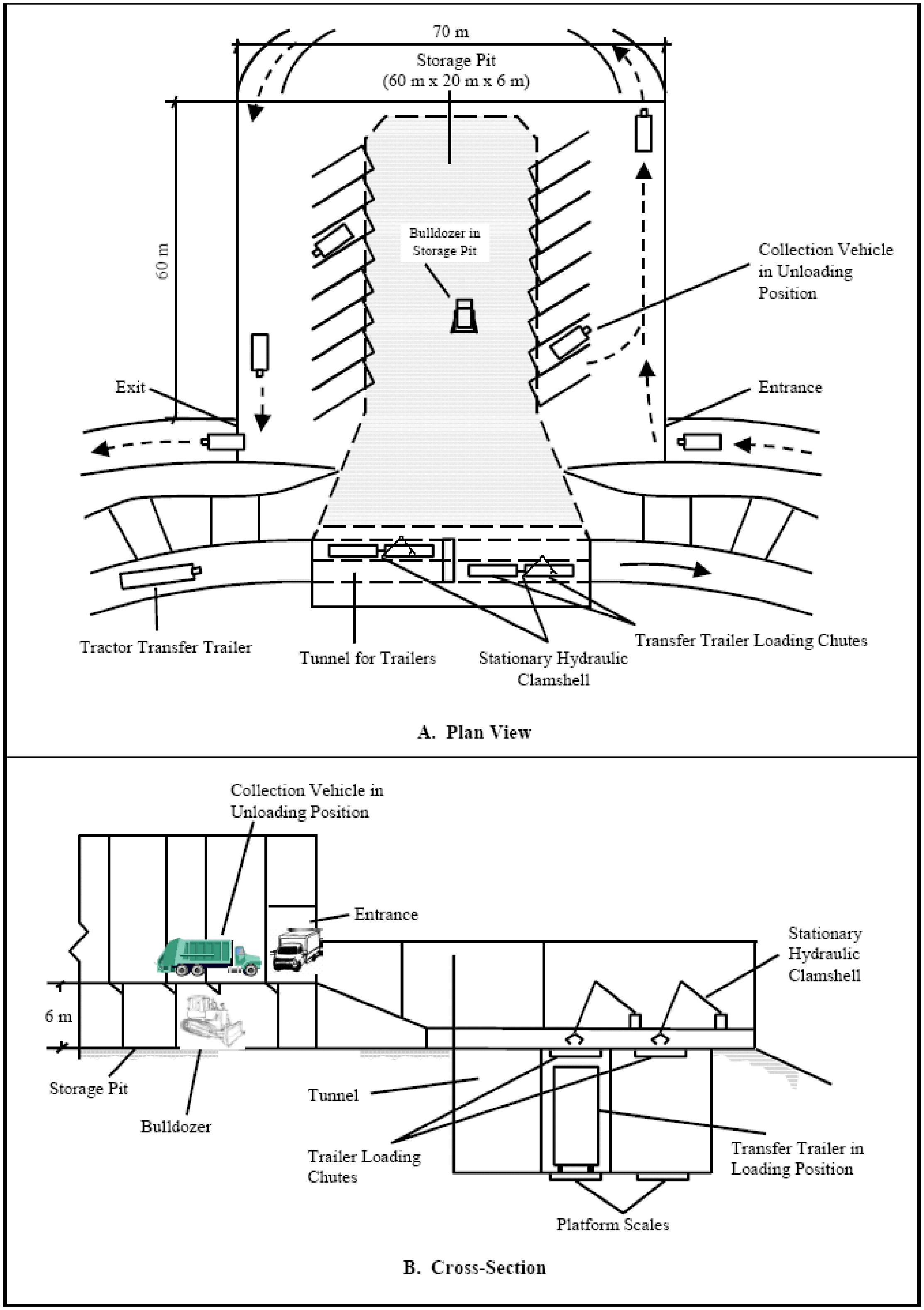
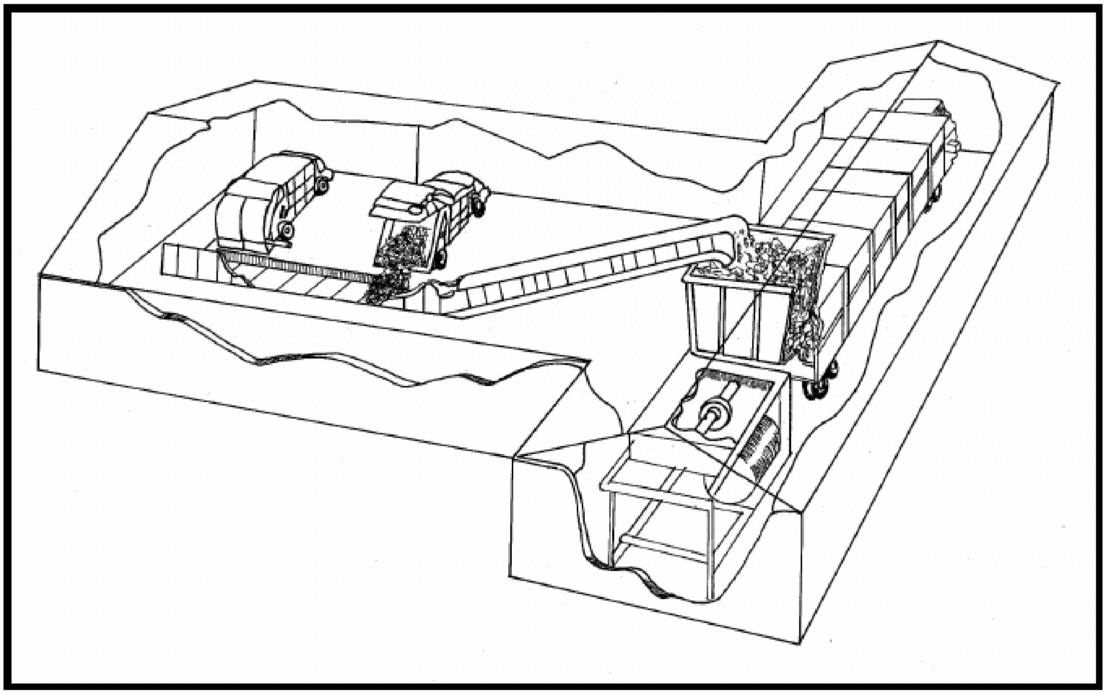


Figure C-6 Compacting at Transfer Station



Equipment for mechanical sorting

Material Handling Equipment
- Belt conveyor
- Screw conveyor
- Apron conveyor
- Bucket elevator
- Drag conveyor
- Pneumatic conveyor
- Vibrating conveyor
- Debagger

Separating Equipment
- Magnetic separator
- Eddy current device (non-ferrous separator)
- Disc screen
- Trommel screen
- Vibrating flat bed screen
- Travelling chain curtain
- Air classifier

Size Reduction Equipment
- Can shredder
- Glass crusher
- Plastics granulator
- Plastics perforator

Densification Equipment
- Can densifier/biscuiter
- Can flattener
- Baler

Environmental Control Equipment
- Dust collection system
- Noise suppression devices
- Odour control system
- Heating, ventilating, and air conditioning (HVAC)

Other Equipment
- Fixed storage bin
- Live-bottom storage bin
- Floor scale for pallet or bin loads
- Truck scale
- Belt scale

4 Biological Treatment

Food waste and yard waste can be converted into a resource such as compost, biogas, single-cell protein and ethanol. A variety of technical options are available for each resource generation category. Common technical options for compost, biogas and ethanol generation are discussed below:

Compost

Compost technology has three important functions, the first of which is "pre-processing". Preprocessing consists of the preparation or processing of a raw waste such that it constitutes a suitable substrate for the compost process. The second function is the conduct of the compost process. The third function is the preparation of the compost product for safe and nuisance-free storage and/or the upgrading of the product so as to enhance its utility and marketability.

The principal role of equipment is to provide an economically and technologically feasible set of optimum environmental conditions or factors for the microbes. Ranking high in the set of factors is the oxygen availability supplied by aeration of the composting mass. Recognition of this importance is reflected by the emphasis placed upon the development of effective aeration in the design of compost equipment, reactors, and procedures.

In several compost systems, the particles remain stationary and only the interstitial air is exchanged more or less continuously. The exchange consists of removing interstitial air saturated with CO_2 and replacing it with fresh air. Surface air also is continuously exchanged. The exchange is accomplished by forcing fresh air into, and simultaneously exhausting spent air from, the composting mass. Appropriately, systems involving such an exchange are termed "forced-air systems". The effectiveness of a forced-air system is determined by both the rate and the extent to which the forced air is uniformly distributed throughout the entire composting mass.

The composting process generates odours as a byproduct of the process. The types and intensities of the odours are a strong function of the types of feedstocks, compost process design, and operating conditions that are employed at the facility. Biofiltration is an effective method of treating and lessening the intensity of the odours generated from the processing of organic materials. A biofilter can be constructed as follows: the gases to be treated are conveyed to a network of perforated pipes. The pipes are placed at the bottom of the bed to serve as the air distribution system. A 45-cm layer of round, washed stones is placed over the perforated piping.

In order to prevent clogging of the perforations and to allow the upward migration of the gases, a filter layer is placed on top of the stones. One alternative that is commonly used in composting facilities in the United States is the application of geotextiles. Proper functioning of geotextiles depends upon the size of openings in the fabric. After the geotextile (or any other type of filter) is in place, a 100- to 120-cm layer of filter medium is placed on top. The filter medium should be properly selected in order to perform according to specifications. In some cases, an additional 30-cm layer of a different filter medium is placed on top of the previous layer. The effectiveness and efficiency of the filter medium depend upon the following parameters: temperature, moisture content, C:N, nutrient content, and others.

Application of appropriate decision factors is essential not only to the rational selection of system and equipment but also to the successful implementation of an entire compost enterprise. Among the other key decision factors is one directly related to economics. Simply stated, the selected system must be adaptable to the economic and work force conditions of the locale in which it is to be used.

An important guiding decision factor is one that is related to the evaluation of prospective systems to operate an automated system. Such an evaluation should take into consideration the tendency of some vendors to make unrealistic claims of superior performance regarding acceleration of the process, magnification of efficiency, or production of a superior product. Claims regarding process time should account for all stages of the compost process -- namely, incubation, active (high temperature and curing), and maturing. Ideally, an evaluation would include firsthand observation of a candidate system while it is in operation. It is essential that the observation and evaluation be made by an individual or individuals who are thoroughly conversant with composting as well as with solid waste management.

Moreover, the compost product should be sampled and inspected directly at the compost facility on the day it is produced. Finally, being a biological process, composting is subject to the limitations characteristic of all biological systems. Thus, the rapidity at which a process progresses and the extent to which decomposition proceeds under optimum substrate, environmental, and operating conditions are ultimately functions of the genetic makeup of the active microbial populations. As a result, further sophistication of reactors and/or equipment could not bring about further advances in rapidity and extent of decomposition.

Compost systems currently in vogue can be classed into two broad categories, namely, “windrow” and “in-vessel”.

Windrow system reflects the distinguishing feature of such systems -- namely, the use of windrows. Windrow systems can be mechanised to a considerable extent and may even be partially enclosed. Two versions of windrow systems are practiced at present -- namely, static (stationary) and turned. The principal difference between the “static” version and the “turned” version is the fact that in the static version, aeration is accomplished without disturbing the windrow; whereas with the “turned” version, aeration involves tearing down and rebuilding the windrow.

The current consensus is that the turned windrow approach antedates the forced-air (static) approach. A windrow composting process involves the following principal steps: 1) incorporation of a bulking agent into the waste if an agent is required (e.g., biosolids), 2) construction of the windrow and aeration arrangement, 3) the composting process, 4) screening of the composted mixture to remove reusable bulking agent and/or to meet specifications, 5) curing, and 6) storage (Figure C-7).

Manual turning is a very appropriate approach in small-scale operations in any location but particularly applicable in areas where there is a surplus of unskilled labourers. When manual turning is not feasible, some form of mechanised turning must be used. Forms presently available can be conveniently classified into two broad categories: 1) machines specifically designed to turn windrowed compost material, and 2) machines designed to move earth. Machines in the first category are often termed “mechanised turners”. Several types of mechanical turners are on the market. The machines differ among themselves in degree of effectiveness and durability (Figure C-8).

Capacities vary with the model of machine; with some models the capacity may be on the order of 1,000 Mg/hr, with other models it may be as much as 3,000 Mg/hr. Prices range from about US$20,000, to more than US$180,000, FOB.

An idealised version of a windrow compost installation is one that would be housed in a shelter. The shelter would be provided with the ventilation equipment needed to control and treat gaseous emissions. Windrows would be turned by means of an automatic turning machine. Maturation could take place either within the shelter or outside. Plastic particles and similar contaminants in the compost product can be removed by way of screening. Inasmuch as the screen oversize consists mainly of plastics, it is removed immediately.

The tendency of plastics to be concentrated in the oversize stream is due to the low density of plastics combined with their characteristically two-dimensional shape and, of course, their tendency to be oversize in terms of screen opening size. Should the finished product contain glass particles, a second stage of size reduction can be included into the process. The degree of size reduction used in the process, particularly in developing countries, must be carefully evaluated since size reduction is an energy- and maintenance-intensive process.

Figure C-7 Metro-channel type system with channels and agitator

Courtesv: CalRecoverv. Inc.

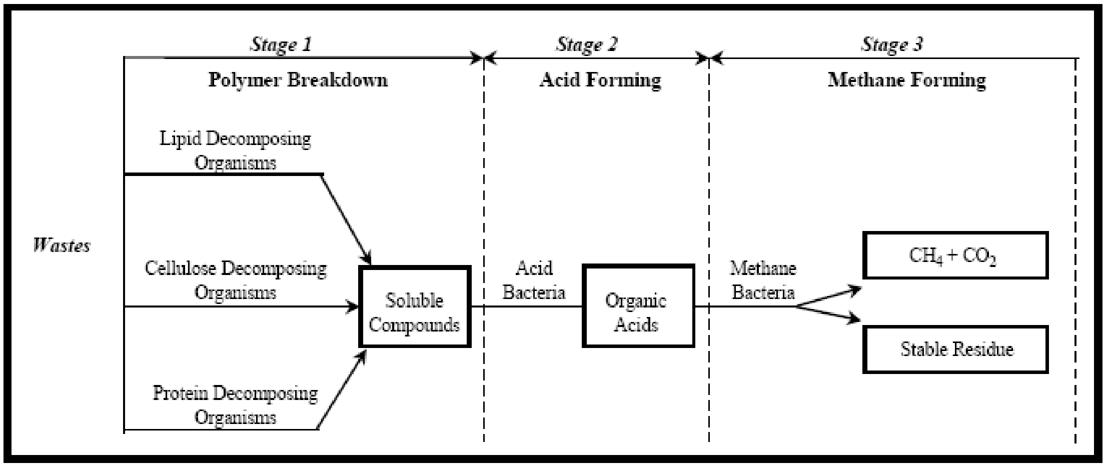
Figure C-8 Windrowing vehicles

Biogas

This is one of the methods to convert waste into energy or commonly known as Waste to Energy (WtE). The possibility of biologically recovering energy in the form of the combustible gas, methane, has prompted an interest in applying biogasification to waste treatment in developed and developing countries alike. The attraction to the concept arises from the fact that biogasification of solid waste serves a twofold function -- namely, waste treatment and energy production. Among the terms frequently used as synonyms for biogasification are “methane fermentation”, “methane production”, and “anaerobic digestion”.

The entire process begins with the polymer stage. In the polymer stage, organic wastes are acted upon by a group of facultative microorganisms that enzymatically hydrolyse the polymers of the raw waste into soluble monomers. The monomers (short-chain organic acids, acetic acid, etc.) become the substrate for the next stage (acid stage). Some carbon dioxide also is formed. The organic acids form the substrate for the bacteria active in the final methane-production stage. In this stage, the methane producers (methanogens) break down the organic acids into, primarily, methane. Methanogens are strict anaerobes, and as such do not tolerate free oxygen, i.e., atmospheric oxygen (O_2). Methanogens produce methane in two ways: 1) they can ferment an organic acid (e.g., acetic acid) to methane and carbon dioxide; and 2) they can reduce carbon dioxide to methane through the use of hydrogen or formate produced by other bacteria. The interrelationship of the three steps is diagrammed in Figure C-9

Figure C-9 Process for biogasification



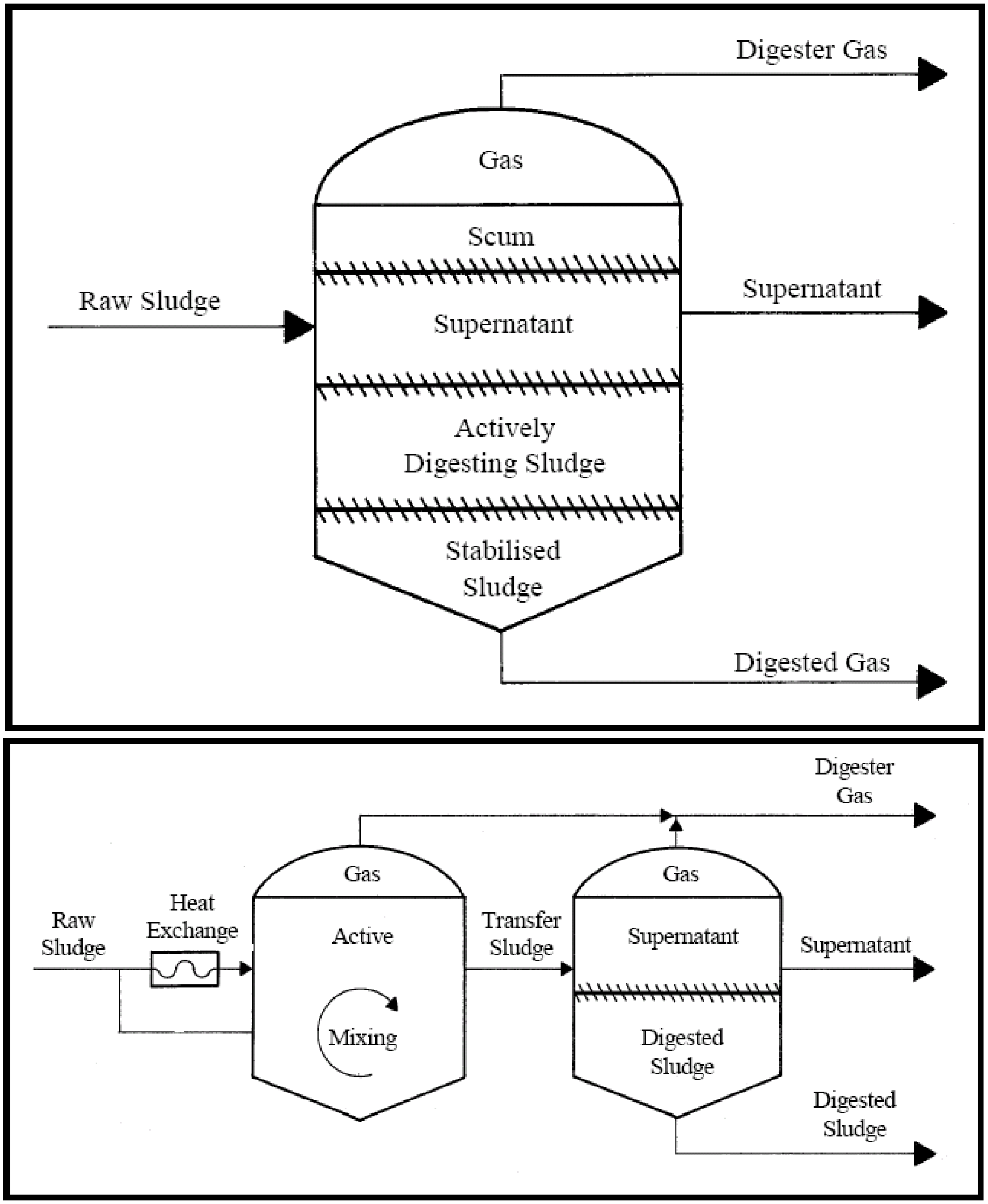
Potential limitations imposed by each of the three stages on the rate of the biogasification (digestion) process as a whole have practical effects on equipment design and specifications, and on operation. The rate limitation imposed by the polymer stage originates in its role of rendering essential nutrients bound in the raw feedstock (waste) available to bacteria involved in the second and third stages of the biogasification process. The stage is rate limiting because it is needed for solubilizing insoluble cellulose and complex organic nitrogenous compounds. The cellulose is converted into soluble carbohydrates by way of extra cellulases. As stated earlier, acid-forming bacteria convert the soluble carbohydrates to low molecular weight fatty acids in the second stage. The third stage is the final rate determinant. In fact, it often is regarded as the rate-limiting stage for the process as a whole, because it is the final step and because the methanogens are basically slow growing. In the third stage, acids and certain other intermediate decomposition products are converted into CH_4 and CO_2.

Key environmental factors (i.e., those that relate to culture and growth conditions) are oxidation-reduction level, hydrogen ion concentration (pH), temperature, and substrate. A direct relation exists between extent and intensity of microbial activity and temperature level within a temperature range tolerated by the organisms. Each range characteristically has a minimum level below which no activity occurs and a maximum level above which all activity ceases and the microbes do not survive. In practice, temperature ranges have been grouped into two broad classes or types -- namely, mesophilic and thermophilic. Correspondingly, the microorganisms that have mesophilic ranges are termed mesophiles; those having a thermophilic range are termed thermophiles. The mesophilic range begins at about 10° to 15°C, peaks or plateaus at about 35° to 38°C, and ends at about 45°C. The thermophilic range begins at 45° to 50°C, peaks at 50° to 55°C, and ends at 70° to 75°C.

Generally, thermophilic cultures are more sensitive than are mesophilic cultures. For example, a thermophilic culture does not thrive under mesophilic conditions. Their sensitivity is an important decision factor because restoring a failed thermophilic culture or replacing it with a new culture is a time-consuming process. The situation is far less serious when a mesophilic culture fails (e.g., unplanned exposure to thermophilic temperatures). Development of a replacement culture can be accomplished in a much shorter time.

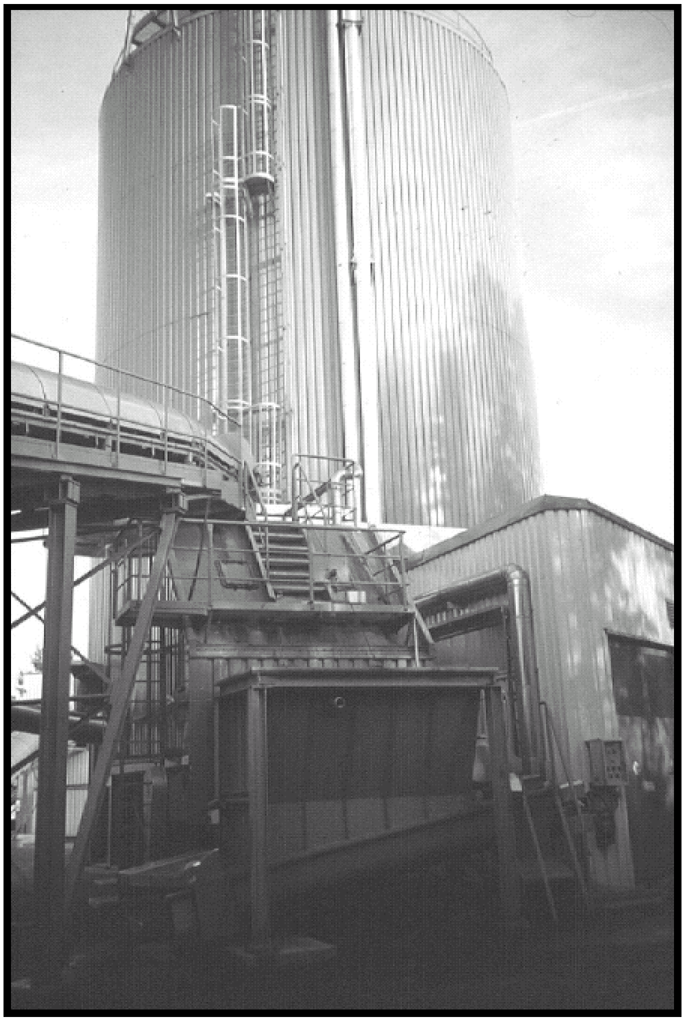
Operational procedures include mixing, loading, detention time and starting of a digester for both conventional digestion and high-rate digestion (Figure C-10).

Figure C-10 Conventional digestion (low solids) and high-rate digestion (low solids)



Large-scale facilities for high-solids are not yet very common in developing countries due to technology and economic issues. However, rapidly growing countries, with a large quantity of food waste may soon find these issues resolved due to home-grown capacity and affordability. Figure C-11 shows a large-scale facility facility in Salzburg, Austria and processes on the order of 18,000 Mg/yr. The digested residue is dewatered and composted in tunnel reactors. A portion of the gas produced by the digester is used to generate electricity for use by the facility. The remainder of the gas is burned in a flare. Digesters of this type operate under the following conditions: digester loading, 10 to 30 kg of COD/m^3 of digester volume-day; temperature, 50° to 58°C; and a detention time of 15 to 30 days. Based on these conditions, one could expect a production of about 4 to 8 Nm^3 of biogas/m^3 of digester volume per day, with a concentration of methane of about 60% (by volume)

Figure C-11 Example of high-solids anaerobic digestor



Courtesy: CalRecovery, Inc.

Single-cell protein and ethanol

Hydrolysis involves the use of waste materials as feedstock to produce single-cell protein and ethanol. Strictly speaking, two concepts are involved, the first of which is the production of a nutritious food for consumption by livestock. The second concept is the production of ethanol that can serve as a fuel in the production of energy. However, both concepts have a distinguishing characteristic -- namely, the use of a carbonaceous waste as the major source of carbon for the microorganisms that are involved.

The implementation of the first concept is a one-step process that consists of the use of waste as substrate in the culture of the single-cell microorganisms that collectively constitute an edible feedstuff that is highly nutritious for humans and livestock. Microorganisms that constitute the feedstuff are varieties or strains of the yeast, *Saccharomyces cerevisae*, or of some other comparable species.

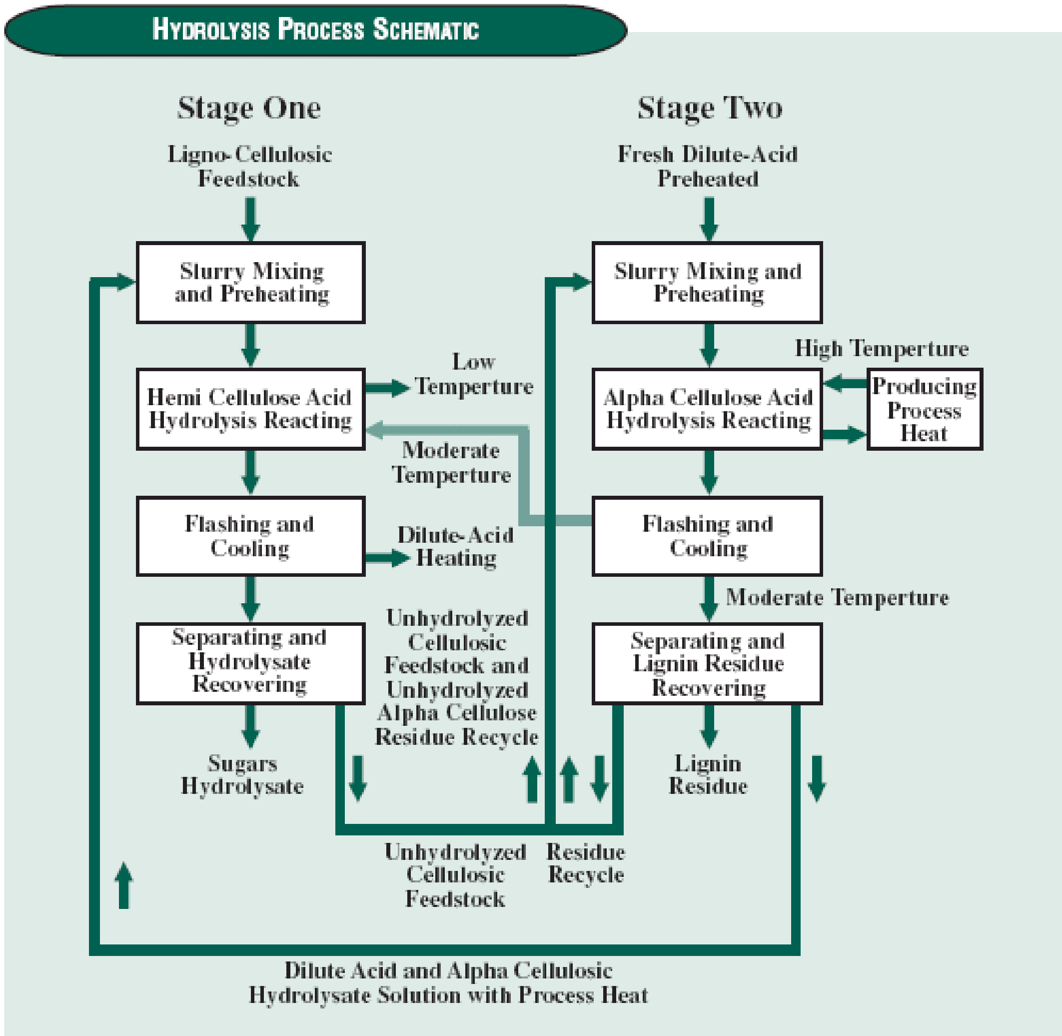
The implementation of the second concept is an integrated two-part process that consists first in the culture of microorganisms capable of fermenting sugars to ethanol, followed by harvesting the microorganisms and mixing them with sugar to produce ethanol. The microorganisms may be a particular yeast or bacterial species noted for its ethanol fermentation capability.

Pre-treatment is essential for both of the processes because, with rare exception, most of the carbon in waste is bound in highly complex molecules and, thus, is unavailable to all but a few highly specialised microorganisms. Fortunately, the bound carbon can be made accessible to the desired microorganisms through a process that disrupts the complex molecules -- namely, hydrolysis. Thus, hydrolysis is an essential step.

The bei cellulose hydrolysis process and reactor system (BEI CHP&RS)[42]: The BEI CHP&RS uses a double tube reactor, which is automatically and precisely controlled to convert cellulose to sugars that may be yeast-fermented to ethanol, other organic chemicals, or commercial products. The process uses low pressure, high temperature oil as a process heat source, which is superior to high-pressure steam that is commonly used in such processes. Process heat and dilute-acid chemicals are recovered in the second stage that are transferred and used in the first stage. Continuous, precise, automated process control ensures polysaccharides present in the raw materials are hydrolyzed to maximum yield. Feedstock conversions are as high as 70% to 80% for hemi-cellulose (Stage One) and 60% to 70% for alpha-cellulose (Stage Two) as shown in Figure C-12.

[42] http://www.eere.energy.gov/inventions/pdfs/bei.pdf

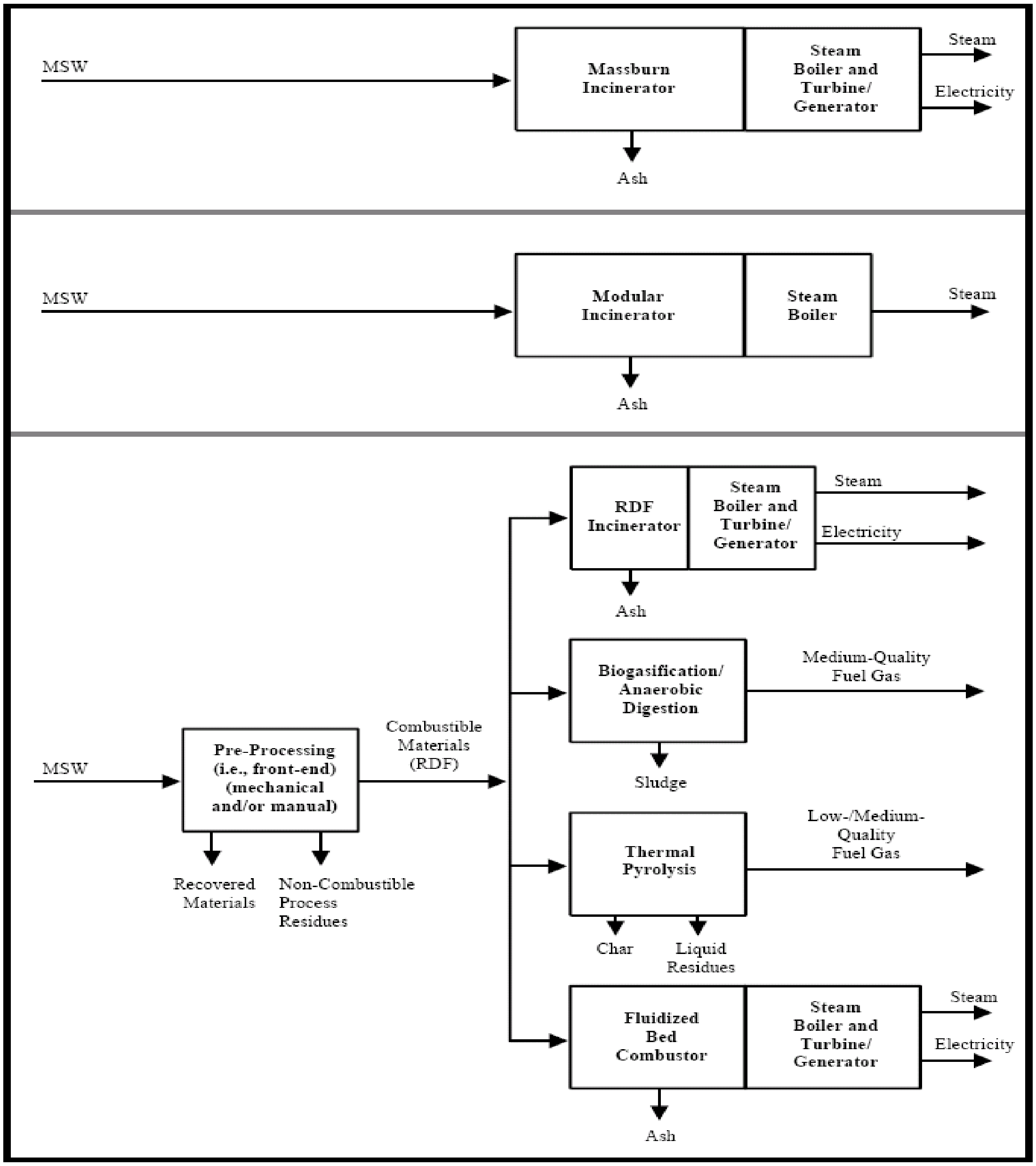
Figure C-12 BEI CHP&RS



5 Thermal Treatment

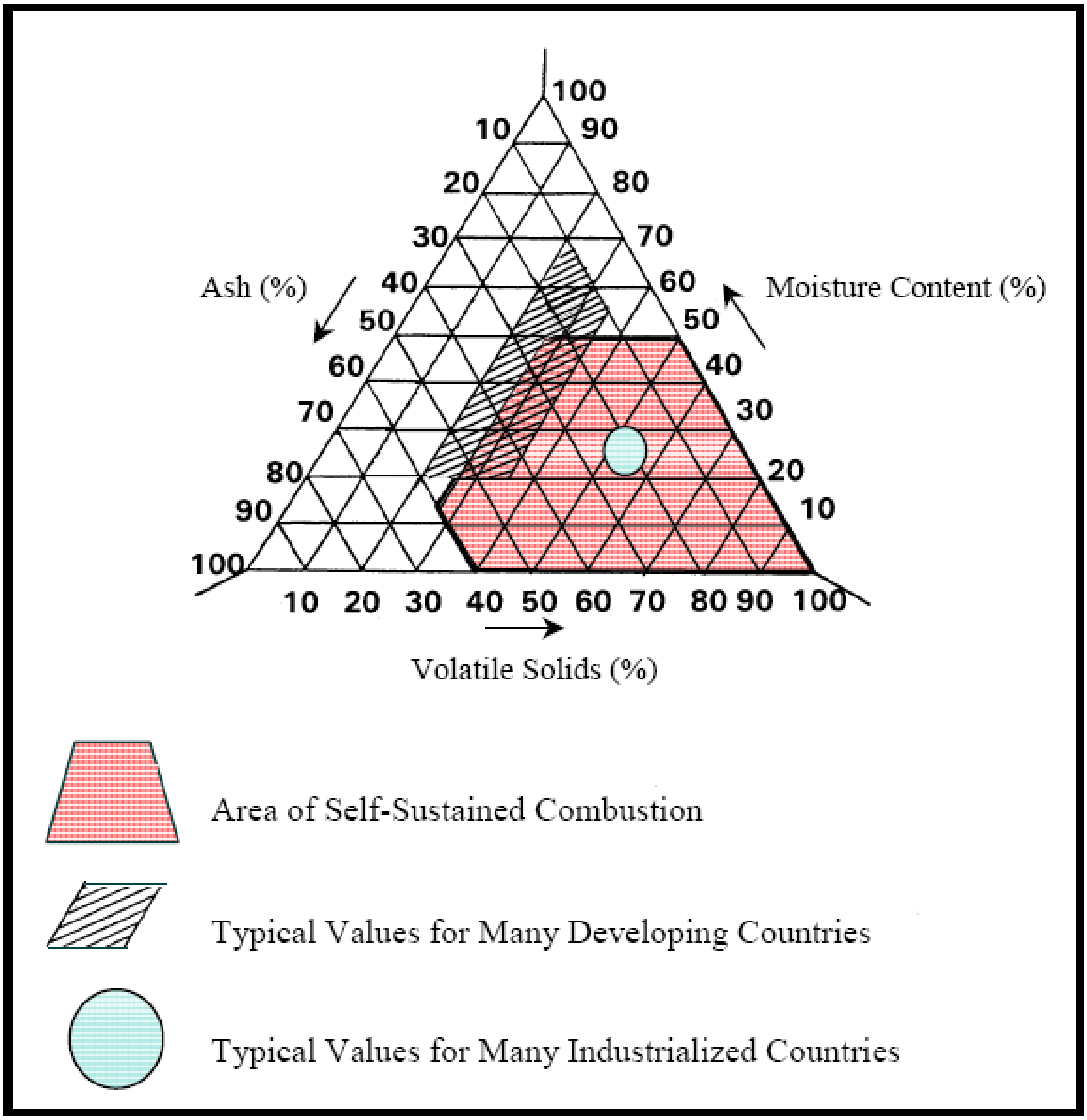
Incineration is one of the most commonly used processes converting waste into energy and now many initiatives in advanced countries under WtE (Waste to Energy) adopt thermal treatment (incineration) for waste, which is not easily biodegradable. Few decades ago, incineration was only one of the ways to get rid of waste, especially, where land is not readily available for landfill. However, with advancement in technology and especially with superior controls over emissions, incineration is becoming a popular way to covert waste into a resource. Various methods of thermal treatment are available as shown:

Figure C-13 Methods of recovering energy from solid wastes



Thermal characteristics of solid waste are one of the major considerations along with the availability of modern technology equipped with emission control measures. Thermal characteristics on the one hand derive the option for self-sustained combustion (Figure C-14) and on the other hand, dictate the level of emission control measures.

Figure C-14 Comparison of thermal characteristics of MSW and those required for self-sustained combustion



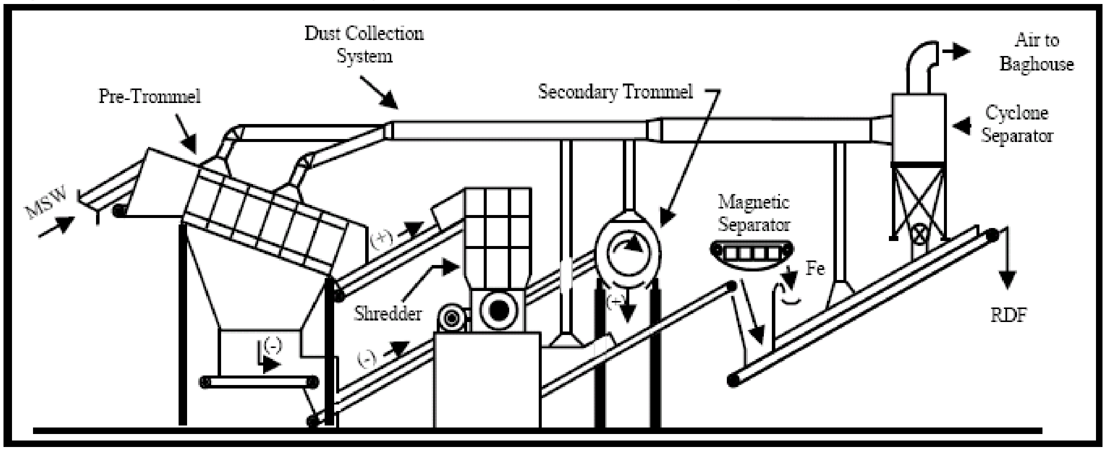
RDF based options

Refuse-derived fuel (RDF) based thermal treatment provides a variety of options as shown in Figure C-13. For all the options, pretreatment or production of RDF from MSW is required. Typically, the production of a combustible fraction (i.e., fuel) from mixed municipal solid waste (MSW) and its thermal conversion requires two basic and distinct subsystems -- namely, the "front-end" and the "back-end". The composition of the recovered combustible fraction is a mixture that has higher concentrations of combustible materials (e.g., paper and plastics) than those present in the parent mixed MSW. Thus, the rationale for recovering a prepared fuel from mixed MSW is that the recovered fuel fraction is of higher quality than is raw (i.e., unprocessed) MSW itself.

Typically, systems that recover a combustible fraction from mixed MSW utilise size reduction, screening, and magnetic separation. Some designs and facilities have used screening, followed by size reduction (e.g., pre-trommel screening), as the fundamental foundation of the system design, while others have reversed the order of these two operations.

An example of a pre-processing system to recover RDF is illustrated in Figure15. The processing configuration depicted in the figure utilises a pre-trommel screen, secondary trammel screen, one stage of size reduction, and a magnetic separator as the key unit operations to effect recovery of a high-quality RDF.

Figure C-15 RDF production system with pre-trommel configuration



In terms of applications, RDF has been used in industrialised countries as a fuel supplement for coal-fired utility boilers and as the sole fuel for firing in dedicated boilers (i.e., boilers that use RDF exclusively). When fired as a supplemental fuel in coal-fired boilers (i.e., co-fired), experience has shown that RDF with heating values in the range of 12,000 to 16,000 J/g (wet wt basis) can successfully contribute up to about 30% of the input energy. RDF can also serve as a feedstock for other types of thermal systems, e.g., pyrolysis and fluidized bed systems. The relative uniformity of properties and higher quality of RDF compared to mixed MSW has led in the past to a preference for RDF in some applications.

However, the experiences had with the co-firing of RDF and pulverized coal in suspension-fired coal boilers, which have no bottom grates, fell well short of expectations except in some isolated cases. The reasons for the disappointment included difficulty in feeding RDF into the boiler, higher percentage of excess air, inadequate residence time for complete combustion of the RDF while in suspension, and its lower heating value when compared to most coals. The incomplete combustion of the RDF, along with its higher production of ash per unit of energy released, combined to cause overloading of the ash handling systems of the suspension-fired coal boilers. Additionally, incomplete combustion adversely affected the overall thermal efficiency of the energy recovery system.

Environmental considerations are the major issue for deciding an appropriate technology. Although RDF has relatively high concentrations of paper and plastics, both of which have a high heating value (paper, about 17,460 J/g; plastics, about 37,250 J/g) in comparison to most coals, it also contains materials that: have a relatively high percentage of ash, can be damaging to burners and boilers, and can exert a seriously adverse effect on the quality of the exhaust gases. For example, RDF typically contains materials that have substantial concentrations of chlorides. During the course of combustion, some or all of the chlorine may be converted to hydrogen chloride (HCl) by combining with the hydrogen released from the water inherent in the combustible fraction or with the water formed from the oxidation of hydrogen. As is well known, under many conditions HCl can have a corrosive effect on the internal surfaces of the burner and sections of the boiler, especially the boiler tubes. Of course, mixed MSW also contains chlorides and, therefore, it also suffers from these same shortcomings when viewed as a potential fuel.

The presence of small particles of metal and of glass fines (<0.125 cm) in RDF can present problems in the combustion system. The exclusion of these small particles in RDF is a difficult exercise in process design as a consequence of their inherent physical and aerodynamic characteristics and of the inherent inefficiencies of mechanical processing equipment. Although the resulting contamination in pre-processed MSW may be considerably less than 1% by wt, a build-up of silicon dioxide and metal oxide deposits on the heat transfer surfaces of the boiler eventually occurs (the combustion of MSW shares this drawback also). The resulting fouling can lead to the loss of the heat transfer capacity of the surfaces. In extreme cases, the fouling could be sufficiently extensive as to necessitate a premature (i.e., unscheduled) shutting down and overhauling of the boiler. An encouraging note is that recent advances in metallurgy and in surface coatings for boiler tubes have led to substantially reduced fire-side corrosion in solid waste-fired boilers.

With respect to ash, in the production of a given amount of energy, ash production resulting from combustion of RDF can be four to six times that which would be experienced with the combustion of coal. Consequently, even with the use of RDF in a co-firing situation with coal, some provision must be made for handling the additional burden of ash. Even though RDF more closely approaches homogeneity than does raw solid waste, the approach is far from great enough to justify RDF being regarded as a clean or high-quality fuel in terms of combustion. The reason is that RDF is a combination of many materials, each of which has its particular set of characteristics. The consequence is that in comparison to more homogeneous solid fuels, such as wood or coal, the maintenance of an efficient combustion process is more difficult when RDF is used as a fuel.

Incineration Plants

These may be classified in a variety of fashions: by type and form of the waste input; by the throughput capacity (with or without heat recovery); by the rate of heat production (for systems with energy recovery); by the state in which the residue emerges from the combustion chamber (e.g., slagging); and by the shape and number of furnaces (e.g., rectangular, multiple). The key system elements involved in the incineration of urban wastes are: 1) tipping area, 2) storage pit, 3) equipment for charging the incinerator, 4) combustion chamber, 5) bottom ash removal system, and 6) gas cleaning equipment (i.e., air pollution control system). If energy is to be recovered, a boiler is included.

Combustion air may be classified either as “underfire” or as “overfire” air. Underfire air is that which is forced into the furnace through and around the grates. Overfire air is forced into the furnace through the sides or the ceiling. Overfire air typically is introduced through jets located at specific points in the furnace. It is used to regulate and complete the combustion of combustible gases evolved by the thermal reactions that are occurring in the lower part of the furnace. The flow of air and combustion gases through the furnace can be controlled by means of forced draft and induced draft fans. The forced draft fan, as its name implies, forces air into the furnace, while the induced draft fan draws the air. Both types are used in modern combustion units. Forced draft fans provide for the central overfire and underfire air, and induced draft fans for the exhausting of the flue gases.

The furnace (i.e., combustion chamber) is the essential element of an incineration system. Types of furnaces include rectangular, cylindrical, and multi-chamber. The size and shape of a furnace usually are determined by the manufacturer, and are based upon a number of parameters, including: solids and gas flow rates, residence time, combustion temperature, and depth of ash bed. In some cases, secondary combustion chambers are included as part of the design. They are connected to the primary chamber, and their main function is to provide the proper conditions needed to complete the combustion process.

Generally speaking, two types of solid residues are generated from incineration: 1) bottom ash, and 2) fly ash. The two residues collectively are known as "ash" and, in the case of industrialized nations, typically are equal to approximately 20% to 40% (by wt) of the incoming solid waste (besides the inherent ash content of MSW, fly ash can also contain additional mass by virtue of chemical reagents used to treat the inherent fly ash). Systems must be included in the facility design to handle and treat the two ash streams. Depending on conditions, the bottom ash and fly ash may be processed separately or in combination. The ash that is produced from incineration is hot and must be cooled prior to disposal. The normal method of cooling is quenching in water. After quenching, the ash is dewatered to facilitate storage or landfilling on the incinerator site or transport to a remote disposal site. Both the quench water and the ash must be treated and disposed properly.

Taken in combination, the grate system, bottom ash removal, and quenching and dewatering system compose the material handling system for the bottom ash. Historically, the bottom ash handling system has been one of the systems in an incineration facility that has experienced, and is particularly susceptible to, extraordinary wear and tear and frequent breakdowns.

Years ago, incinerators were designed to burn waste that had a low heating value. The reason was primarily to accommodate wastes with a high moisture content. Consequently, features were incorporated that were designed to: 1) dry and ignite the refuse, and 2) deodorise the off gases. Little or no waste heat was available for energy export. As the composition of municipal waste in industrially developed countries changed (i.e., substantial paper and plastic content, small putrescible fraction), the heating value of the solid waste increased. To accommodate the increase, the designers of modern incinerators include in their designs provision for the utilization of excess energy. This is done by introducing a waste heat boiler for steam generation.

In industrialised nations, incineration systems must have complex air pollution control (APC) systems in order to meet the required limits for protecting the quality of the ambient air and human health. The complexity is a result of the fact that modern APC systems include provisions for controlling a number of pollutants to very low concentrations (e.g., parts per million or per billion). The provisions include control and manipulation of the combustion process itself within the combustion chamber and the use of post-combustion techniques, including the use of chemical reagents and of special mechanical and electrical systems to process the combustion gases. The principal pollutants that are controlled in industrial countries are listed in Table 1, along with the typical methods of control and levels of pollutant reduction. Because of their complexity, modern APC systems can account for up to 30% of the capital cost of incineration systems.

In the last 10 to 15 years, considerable research and development effort has been expended on "trace" air pollutants formed as byproducts of solid waste combustion, the relevant chemistry, and methods of control. Examples of these trace pollutants are mercury, and dioxins and furans.

Air pollutants from solid waste incineration and methods of control[43]

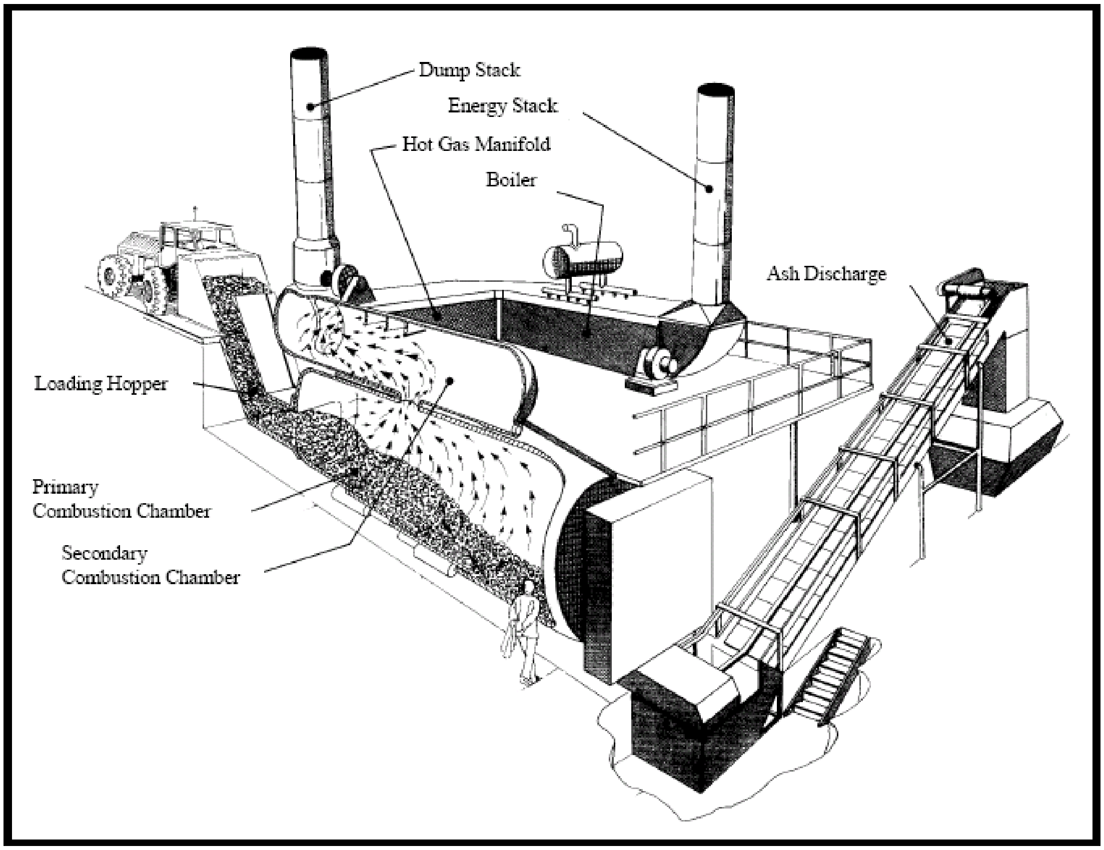
Pollutant	Control Methods	Typical Reduction (%)
Oxides of nitrogen (NO_2)	• Selective catalytic reduction	10 to 60
	• Selective non-catalytic reduction	
	• Flue gas recirculation	
	• Combustion control	
Acid gases (SO_2 and HCl)	• Wet scrubber	50 to 85 SO_2
	• Dry scrubber	75 to 90 HCl
	• Fabric filter	
	• Electrostatic precipitator	
Carbon monoxide (CO)	• Combustion control	50 to 90
Heavy metals	• Dry scrubber	70 to 95
	• Fabric filter	
	• Electrostatic precipitator	
Particulates	• Electrostatic precipitator	95 to 99.9
	• Fabric filter	
Toxic organics (including dioxins and furans)	• Combustion control	50 to 99.9
	• Combination of dry scrubber and fabric filter	

Three types of incinerators, modular (small capacity, less than about 300 Mg/day), large-capacity stoker, and fluidised bed satisfy the majority of applications of incineration (with or without heat recovery) that will exist in many of the developing nations for the next several years. Additionally, large-capacity stoker systems have been subdivided into two subtypes due to the different forms of solid waste that are combusted: 1) municipal solid waste, and 2) refuse-derived fuel.

Modular combustion systems are so named because each combustion unit is of relatively low throughput capacity in comparison to the typical capacity of a massburn or RDF incinerator. As used here, a unit, or module, consists of one primary combustion chamber (i.e., a chamber in which the solid waste is converted to gaseous compounds). To achieve an equivalent processing capacity of a typical large-capacity, stoker-type massburn or RDF incinerator, multiple modules would be required; thus, the derivation of the term “modular” for this type and capacity of combustion technology (Figure C-16). A modular incinerator/steam production facility of moderate capacity for MSW can cost from US$75,000 to US$100,000 per Mg of daily capacity.

[43] Original reference:
Savage, G.M., D.L. Bordson, and L.F. Diaz, “Important Issues Related to Air Pollution at Municipal Solid Waste Facilities”, presented at 25th Annual Governmental Refuse Collection and Disposal Association (GRCDA) Conference in St. Paul, Minnesota, USA, August 1987, *Environmental Progress*, 7(2):123-130, May 1988.

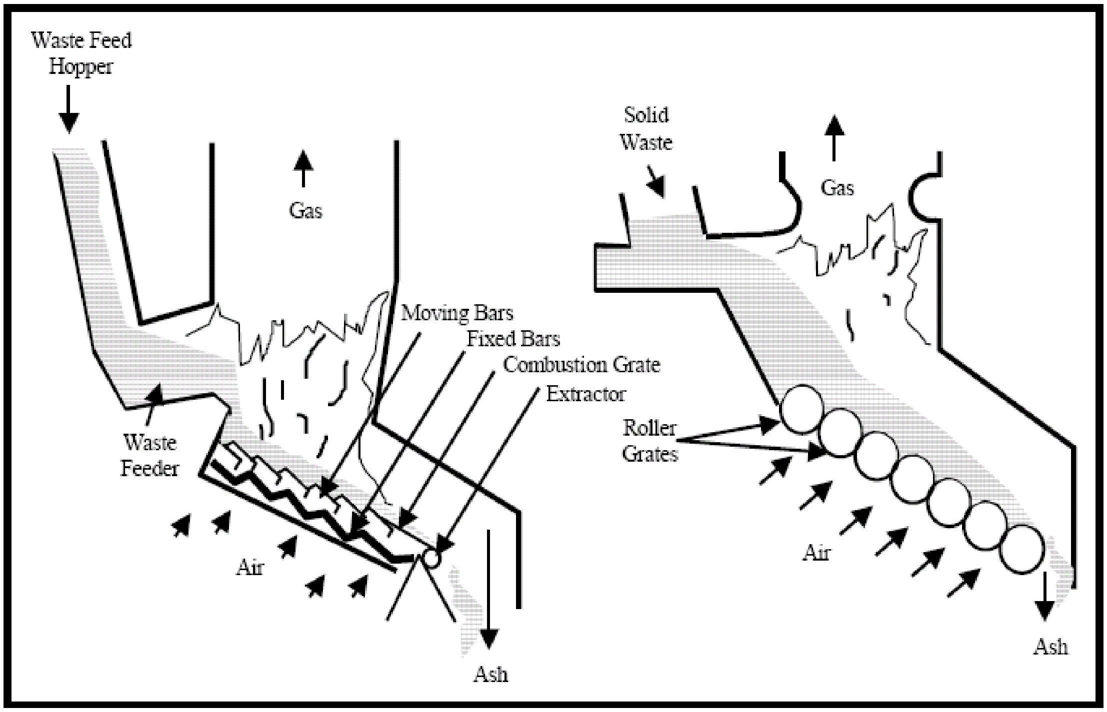
Figure C-16 Illustration of modular combustion unit for MSW and selected industrial wastes



A stoker is a system of grates that moves the solid fuel through the combustion chamber. A variety of types of stokers are available. Typically, the grates in large-capacity massburn incinerators are movable (vibrating, rocking, reciprocating, or rotating) to provide agitation to the wastes, thereby promoting combustion. The movement also serves to remove the residue from the furnace. The stoker commonly employed in large incinerators designed to combust RDF is a "travelling" grate; a travelling grate consists of a set of hinged grate sections that are configured as a conveyor belt.

Two examples of stokers used in massburn incinerators are shown in Figure C-17. In the case of massburn systems, the primary combustion of the waste occurs on the grate.

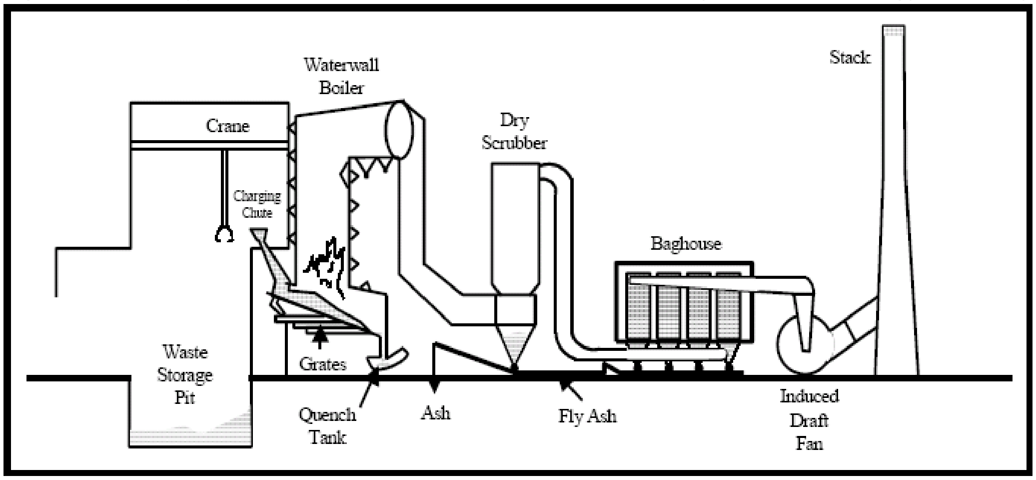
Figure C-17 Grate systems used in massburn MSW combustors



In a typical massburn incinerator operation, the MSW to be burned is unloaded from the collection vehicles onto the tipping floor or directly into a storage pit. A pit is included so that sufficient solid waste can be stored to permit a continuous operation of the incinerator (i.e., 24hr/day, 7 day/wk). The pit also serves as an area in which large non-combustible materials can be removed, and the wastes can be blended to achieve a fairly uniform and constant charge. From the pit, the waste is transported to a charging hopper. Charging hoppers are used for maintaining a continuous feeding of waste into the furnace. Massburn incinerators do not use pneumatic or mechanical systems for injecting or charging the waste into the combustion chamber. (Mechanical and pneumatic injection systems are typically used when RDF is the feedstock.) Wastes fall from the hopper onto the stoker (i.e., grate system) where the combustion takes place.

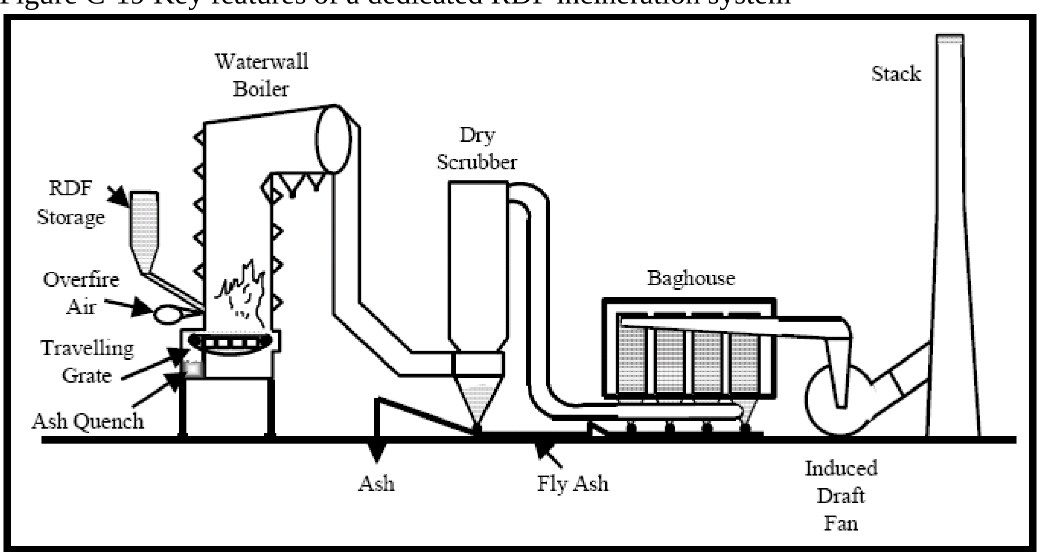
An illustration of a large-capacity massburn incinerator and its key components is shown in Figure C-18. A modern massburn/electricity production facility having a capacity in the range of 800 to 2,500 Mg/day may cost approximately US$90,000 to US$135,000 per Mg of daily capacity.

Figure C-18 Key components of a massburn incineration system with energy recovery



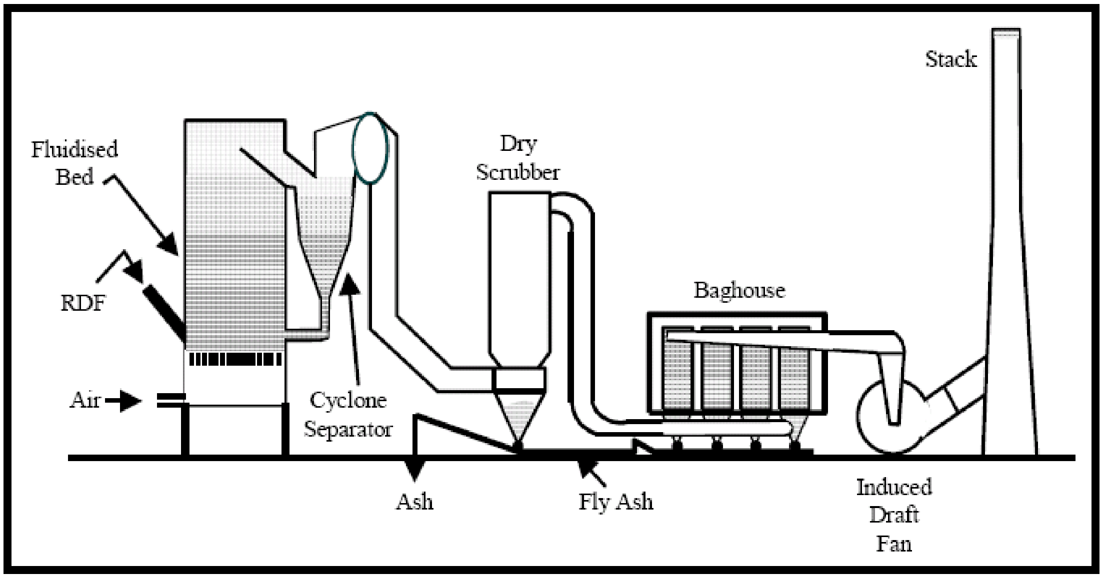
Large RDF-fired incinerators are similar in overall design to massburn units. However, key distinctions exist between the designs. As mentioned previously, RDF incinerators usually have a travelling grate at the bottom of the furnace, as opposed to the agitating form of grates used in most massburn incinerators. Secondly, since RDF has a finer size distribution than raw MSW, the charging system is different. RDF combustion systems commonly employ a ballistic type of feeding system, i.e., the fuel is injected into the combustion chamber above the grate at a relatively high velocity using mechanical or pneumatic injection, or a combination of the two injection methods. On the other hand, as noted above, massburn incinerators are fed by gravity through a charging chute. An illustration of an RDF incinerator and its key equipment is presented in Figure C-19. A modern RDF/electricity production facility, including pre-processing and combustion systems, with a capacity in the range of 1,000 to 2,000 Mg/day, can cost in the neighbourhood of US$100,000 to US$150,000/Mg/day.

Figure C-19 Key features of a dedicated RDF incineration system



Fluidised bed (FB) combustion technology under oxidizing conditions is appropriate for the efficient thermal conversion of a number of solid fuels, including coal. Consequently, the technology is suited for combustion of RDF, or for co-firing of RDF and coal. Two basic types of fluidised bed designs are commercially available: bubbling bed and circulating bed. The main difference in the designs is the higher air supply velocity used in the circulating bed technology. As the name implies, in a circulating bed unit, the bed medium is captured from the high-velocity combustion gas stream exiting the combustion chamber and subsequently cleaned of ash particulates and recycled into the bottom of the bed zone. In a bubbling bed system, the gas velocities are maintained at a low level so that the bed medium is maintained in the combustion chamber. Circulating bed designs have an economic advantage over bubbling bed designs when the energy output requirements are greater than 45,000kg steam/hr. The majority of commercial fluidised bed systems combusting low-grade fuels are of the circulating bed design. An illustration of a circulating fluidised bed system is shown is Figure C-20.

Figure C-20 RDF-fired circulating fluidised bed combustion system with energy recovery



The interest in the use of FB technology for the combustion of solid waste stems from several factors: 1) the performance of the combustion process is relatively insensitive to the flow rate of the feedstock (i.e., it has a high turndown ratio); 2) compared to standard incinerators, the combustion temperatures are relatively low and, therefore, emissions of nitrogen oxides are subjected to inherent control during the combustion reaction; and 3) reagents in solid form can be incorporated among the inert bed particles and used to control acid gas emissions. These methods of control ease, but do not necessarily eliminate, the need for exhaust gas treatment in cases where low concentrations of pollutants are desired or required by regulation.

A modern RDF-fired fluidised bed/electricity production facility (pre-processing and combustion systems), with a capacity in the range of 800 to 1,000 Mg/day, can cost in the range of US$135,000 to US$190,000/Mg/day.

6 Landfill

Sanitary landfills

These are essential for final disposal of non-hazardous waste. The current regulations in industrialized countries ask for pre-treatment of waste prior to landfill. There are physical, chemical and biological processes involved in landfill.

In general, significant physical reactions in the fill are in one of three very broad forms: compression (compaction), dissolution, and absorption. Compaction is an ongoing phenomenon that begins with compression and size reduction of particles by the compacting machinery and continues after the wastes are in place. The continuing compression is due to the weight of the wastes and that of the soil cover (burden). Sifting of soil and other fines is responsible for some consolidation. Settling of the completed fill is an end result of compression. This settling is in addition to the settlement brought about by other reactions (e.g., loss of mass due to chemical and biological decomposition). The amount of water that enters a fill has an important bearing on physical reactions. Water acts as a medium for the dissolution of soluble substances and for the transport of unreacted materials. The unreacted materials consist of animate and inanimate particulates. Particle sizes range from colloidal to several millimetres in cross-section. Absorption is another of the physical phenomena that takes place in a fill. It is significant in large part because it immobilises dissolved pollutants by immobilising the water that could transport them and suspended pollutant particulates out of the confines of the fill.

Oxidation is one of the two major forms of chemical reaction in a fill. Obviously, the extent of the oxidation reactions is rather limited, inasmuch as the reactions depend upon the presence of oxygen trapped in the fill when the fill was made. Ferrous metals are the components likely to be most affected. The second major form of chemical reaction includes the reactions that are due to the presence of organic acids and carbon dioxide (CO_2) synthesised in the biological processes and dissolved in water (H_2O). Reactions involving organic acids and dissolved CO_2 are typical acid-metal reactions. Products of these reactions are largely the metallic ions and salts in the liquid contents of the fill. The acids lead to the solubilization and, hence, mobilisation of materials that otherwise would not be sources of pollution. The dissolution of CO_2 in water deteriorates the quality of the water, especially in the presence of calcium and magnesium.

The wide variety of fill components that can be broken down biologically constitute the biodegradable organic fraction of MSW. This fraction includes the garbage fraction, paper and paper products, and "natural fibres" (fibrous material of plant or animal origin). Biological decomposition may take place either aerobically or anaerobically. Both modes come into play sequentially in a typical fill, in that the aerobic mode precedes the anaerobic mode. Although both modes are important, anaerobic decomposition exerts the greater and longer lasting influence in terms of associated fill characteristics. Because the ultimate end products of biological aerobic decomposition are "ash", CO_2, and H_2O, adverse environmental impact during the aerobic phase is minimal. The breakdown products of anaerobic decomposition can exert a highly unfavourable impact on the environment unless they are carefully managed. The products can be classified into two main groups: volatile organic acids and gases. The two principal gases formed are methane (CH_4) and CO_2. Gases in trace amounts are hydrogen sulphide (H_2S), hydrogen (H_2), and nitrogen (N_2).

Calculating lifespan

The following formula and Figure C-21 can be used to calculate the useful life of a sanitary landfill:

$L = V_T / 365(Q\ p\ (1+(F\ Qs))$

where:

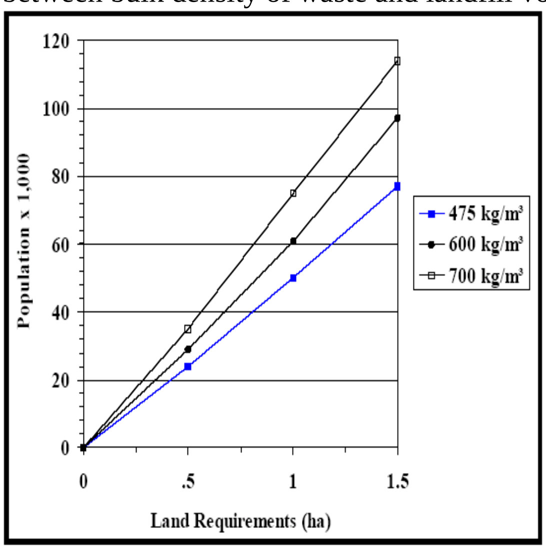
• L = useful lifespan in years,

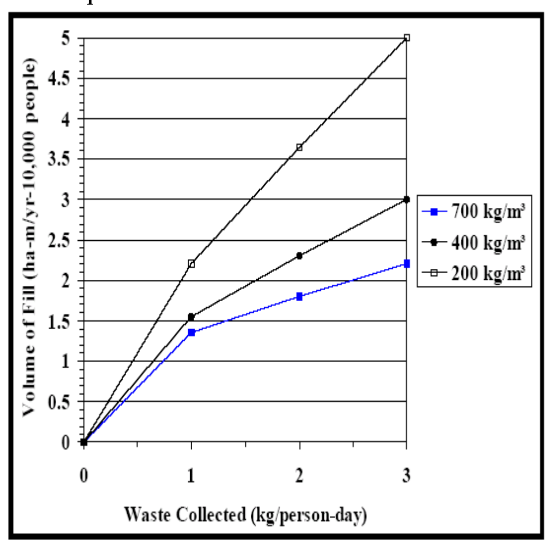
• V_T = volume of selected site in m3,
• Q_p = quantity of solid wastes in m3/day, and
• F_{Qs} = quantity of cover material expressed as a fraction of Q_p in m3/day.

The quantity of waste can be projected using estimates of population. The estimate can be carried out by using the following formula:
Qi = Qp(1 + r)n
where:
• Q_i = quantity of wastes to be collected in year "i",
• Q_p = present annual quantity of wastes collected,
• r = average annual growth rate in population as a decimal fraction, and
• n = number of years.

The surface area required for a particular volumetric capacity decreases as the depth of the landfill increases. The area requirements can be calculated by using the following formula:
A = VT / h
where:
• A = area required in m2,
• V_T = total volume of solid wastes and cover in m3, and
• h = average depth of fill in meters.

Figure C-21 Land requirements for a landfill as a function of compaction and relationship between bulk density of waste and landfill volume required



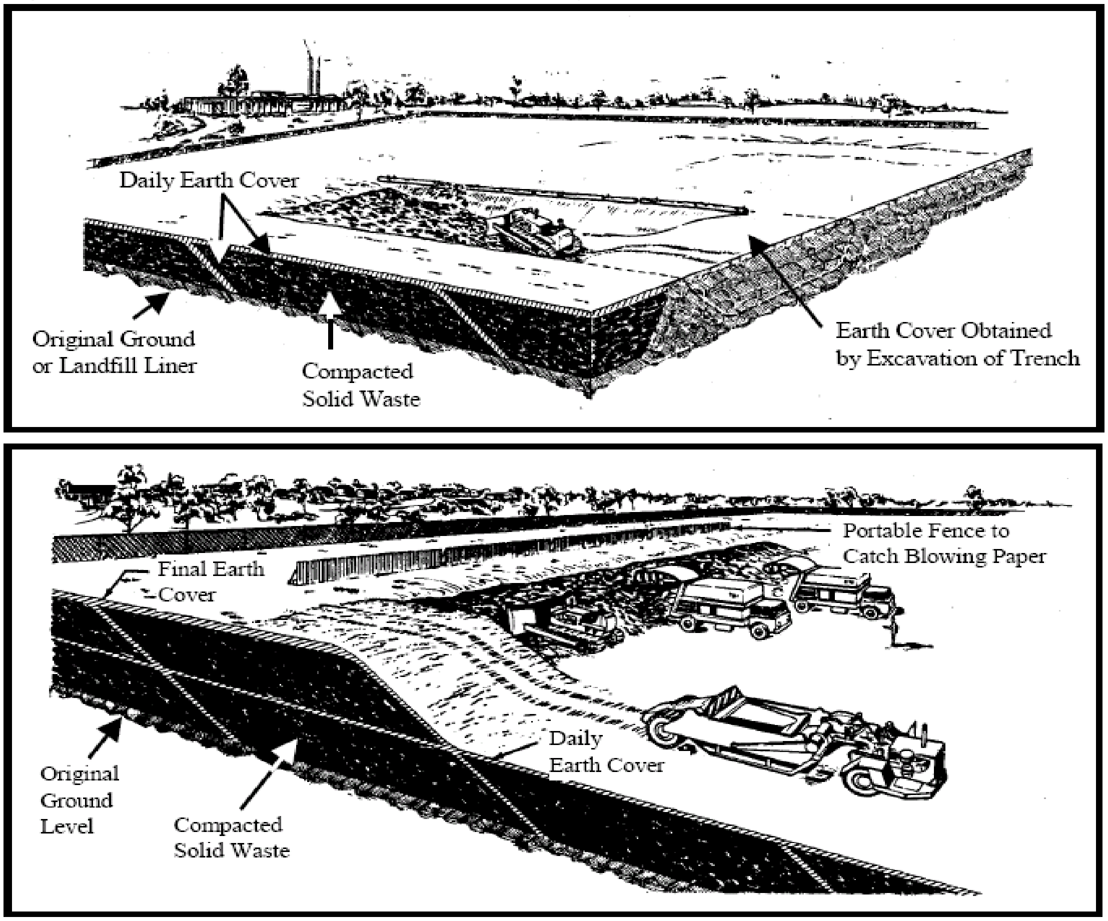


Landfill technology

This applies to a variety of aspects of the construction and operation of the landfill facility. The two basic types of landfill methods are the trend and the area as shown in Figure C-22. All true sanitary landfills consist of elements knows as "cells" which are built buy spreading and compacting solid waste into layers within a confined area and at the end of each working day or during the day, the compacted refuse is covered completely (including working face) 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. The minimum recommended cell widths based on rate of waste delivery are:

8 m for up to 50 Mg/day, 10 m for 51 to 100 Mg/day, 12 m for 101 to 225 Mg/day, and 15 m for 226 to 500 Mg/day.

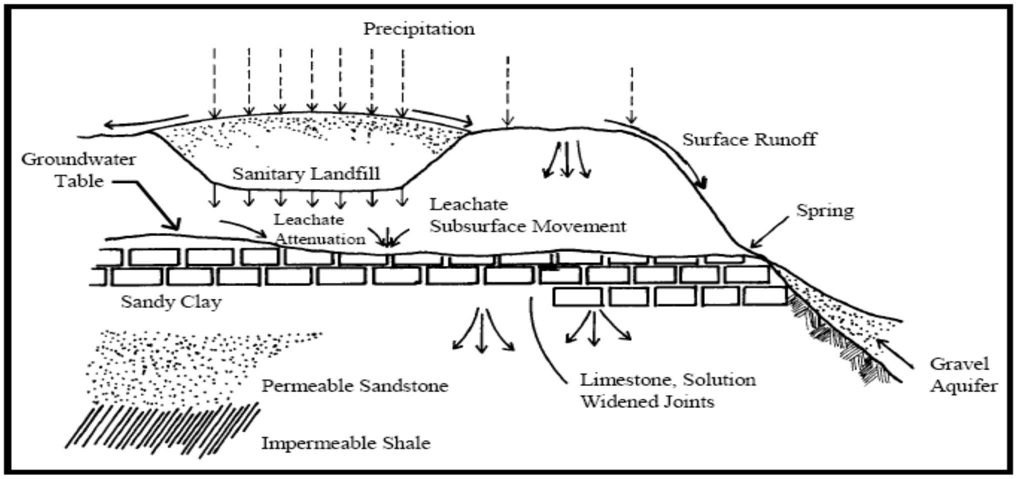
Figure C-22 Trend and area methods for sanitary landfill[44]



The stability of slopes of wastes and of waste/bottom liner interfaces in the landfill are importing in managing the fill cost effectively and in protecting the safety of landfill workers. The liner is an engineered system to contain and control the pollution of land and waste environments surrounding the land disposal operation (Figure C-23).

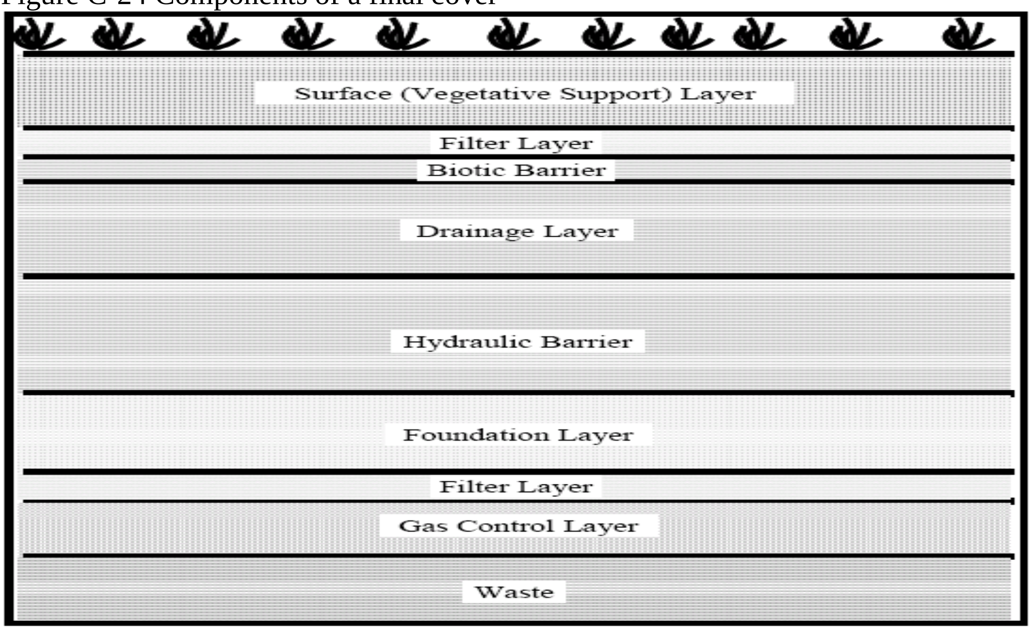
[44] Originally taken from
Brunner, D.R. and D.J. Keller, *Sanitary Landfill Design and Operation*, U.S. Environmental Protection Agency, Report No. SW-65ts, 1972.

Figure C-23 Interrelation between landfill and natural environments



Daily cover controls vectors, litter, odours, fire and moisture. Final cover is the layer that is placed on the completed surface of the fill to control infiltration of water, migration of landfill gas, supports growth of vegetation and provides barrier between the external environment and the waste. The main aspects of the design of a cover are its individual layers (Figure C-24).

Figure C-24 Components of a final cover

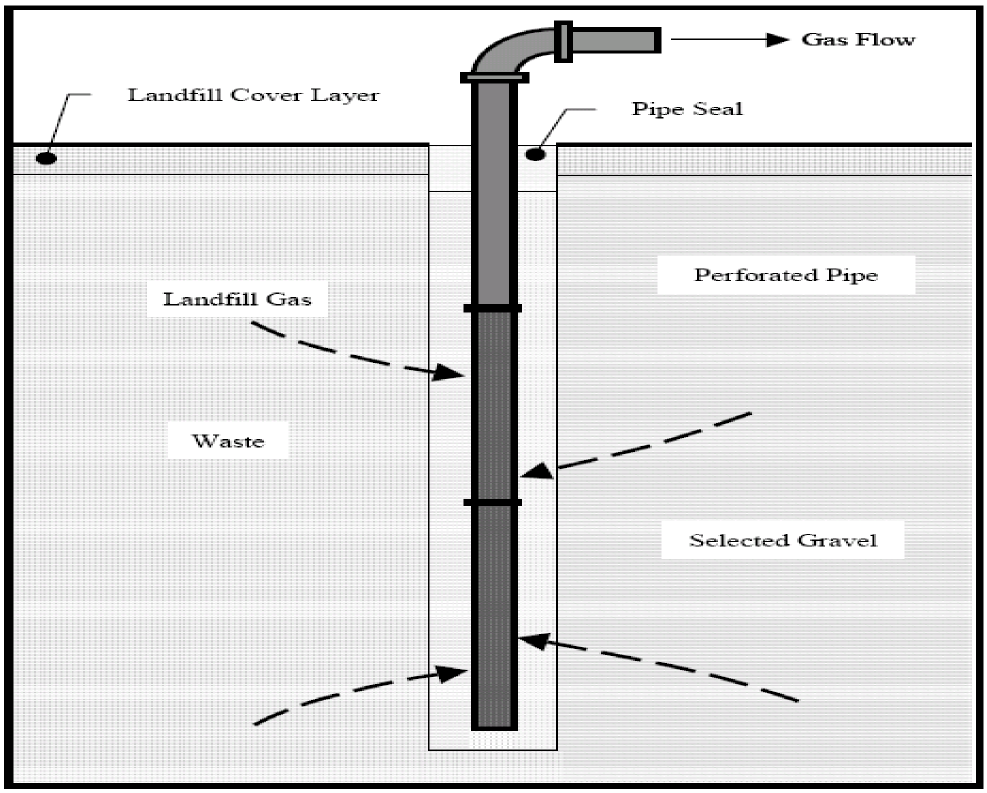


There are various options for liners under two types of liners: soil liners, membrane liners. A combination of both types of liners can provide effective emission control such as leachate penetration into ground water. A complete leachate collection and treatment system is required to avoid any negative impacts. Common types for leachate collection system are the sloped terrace and the piped bottom. Thereafter, leachate is reoved either by installing a pipe through the side of the fill or by placing a collectino pipe inside the fill. A proper designing and operation and maintenance is required to avoid damage and clogging. This leachate is stored in tanks, vaults or ponds. The collected leachate is treated properly either at on site facility or at off site common facility.

The other important consideration would be to recover landfill gas. Typically, the composition of landfill gas is on the order of 40% to 60% CH_4, 40% to 50% CO_2, 3% to 20%

N_2, 1% O_2, and traces of sulphides and volatilised organic acids. In general, the amount actually obtained from a landfill will be much less than the theoretical volumes predicted on the basis of organic waste content. Collected gas either can be used directly as a low-heat fuel, or can be processed (purified) to form a high-heat fuel. Collection is made possible by providing a combination of strategically spaced wells and areas of high permeability through which gases are channeled to collection points. This is done by installing underground venting pipes and a gravel layer between the cover and the waste, or gravel filled trenches. The gas is removed from the landfill by way of a piping or header system to transport the gas, and blowers to pull the gas from the fill through the headers (Figure C-25).

Figure C-25 Schematic diagram of gas well



The heat content of landfill gases ranges from about 7,500 to 22,000 kJ/m^3; whereas the lowest heat content of natural gas is approximately 37,300 kJ/m^3. Moisture content may be as low as 5% and as high as saturation. Oxygen content varies from trace levels to levels that are potentially explosive. However, the latter levels are reached very infrequently. Finally, the usually sizeable CO_2 and N_2 contents of landfill gas materially lower its heat content and, hence, the quality of the gas. The utility of landfill gas can be increased significantly by upgrading the gas. Among the uses for upgraded gas are onsite generation of electricity and/or injection into a public utility transmission line. Methods and procedures are available for removing H_2O (dehydration), CO_2, and N_2 from landfill gas, and thereby considerably raising its heating value.

Equipment

Equipment for landfill operations include track-type tractors with push-blades (bulldozers), landfill compactors, wheel loaders, track-type loaders, track-type excavators motor graders, soil compactors, pneumatic tire compactors and self-propelled vibratory drum compactors.

The function of bulldozers is to distribute and compact solid waste, as well as to perform site preparation, provide daily and final cover, and general earthwork. The bearing pressures exerted on the solid waste or soil typically are in the range of 0.5 to 0.8 kg/cm^2 for track-type tractors with power ratings in the range of 100 to 230 kW.

Landfill compactors spread and compact the incoming solid waste. This type of equipment is more versatile and faster than bulldozers. A typical 110 kW model will have a productivity of approximately 75 Mg/hr on flat surfaces. The productivity decreases to about 50 Mg/hr for a 30° slope.

Wheel loaders are designed to excavate soft ground (i.e., ground offering little resistance), load the excavated material onto trucks, and pick up or transport that material to distances not greater than 50 m to 60 m (for optimum efficiency). Wheel loaders also are able to perform efficient earthwork with clay-like soil, such as cell covering operations and preparation of sites to be landfilled.

Track-type loaders can perform similar functions to wheel loaders. Track-type loaders also are able to excavate tough ground. The optimum distance for a track-type loader to transport material does not exceed 30 m. In emergency cases, track-type loaders can be used to handle (i.e., to spread and compact) solid waste. They can also be utilised to contour and level the cover material.

The function of track-type excavators is typically to excavate soil, excavate trenches for the placement of solid waste, load trucks, and to apply the daily or primary cover of solid waste. Track-type excavators can also be used for certain tasks in earthwork operations.

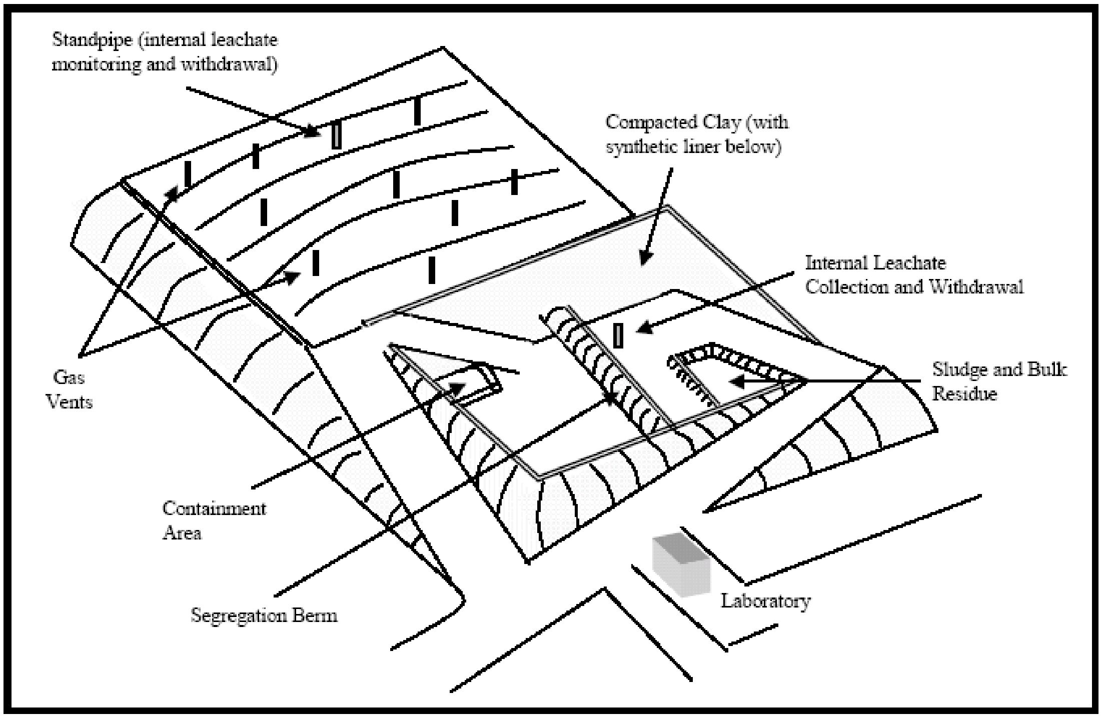
Motor graders are used in the construction and maintenance of hauling roads, embankments, and drainage ditches, and in the profiling and leveling of cover material. These machines can carry a scraper as an additional piece of equipment. The scraper is used to rip the ground to a depth of 0.1 to 0.3 m.

The function of soil compactors is to compact soils and embankments. Some machines have a mechanism that allows oscillation of the drums, which can facilitate uniform compaction, even on irregular layers of soil. While pneumatic tire compactors are designed to compact top soils and sub-layers, especially when loamy material is present. High and uniform densities can be obtained throughout the thickness of the layers. Vibratory drum compactors are designed to effectively compact soils and cover material formed by normal soils, whether granulated or clay-like.

Controlled landfill

Hazardous waste is treated and then disposed of in a controlled landfill. The waste in these landfills is completely enclosed with appropriate number and type of liners and leachate and other liquids are not allowed to seep through the liners. Groundwater quality is monitored continuously to check if there is a leak from the fill. As with all sanitary landfills, the design of a secure landfill largely depends upon the hydrogeological characteristics of the site. However, the design, operation, and monitoring of a secure fill is a complex process that requires the participation of skilled professionals. The various elements of a secure fill are diagrammatically indicated in Figure C-26. excavation of the completed fill should not be attempted since most buried hazardous wastes continue to be dangerous long after their burial. Excavation of completed, secured landfills can be a dangerous undertaking.

Figure C-26 Typical layout of a secure landfill



Bioreactor landfill

Recently, alternative methods to landfill and incineration have been promoted. These methods are meant to reduce the overall volume of final disposable waste by converting waste into a resource through anaerobic digestion, composting, mechanical biological treatment, pyrolysis and gasification and so on. The famous technologies among these alternative methods are bioreactor landfill and mechanical biological treatment (MBT). The landfills are designed to degrade the waste in a controlled fashion to accelerate the speed of degradation and to maximize the potential for landfill gas generation at the early stages and to produce compost as the final product. This helps to save the precious landfill space as well as to generate resources (energy and compost). Usually, in this process, water is injected, in addition to recirculation of leachate, into a specially designed landfill to cause accelerated decomposition due to addition of moisture and nutrients. The temperature and pH is controlled along with other inhibitors such as ammonia and nitrogen. This maximizes the generation of landfill gas, which is captured using a network of perforated pipes and burnt to generate energy, as well rapid stabilization of organic waste material; thus, reduces the time required to manage the site and/or to make use of the decomposed material as compost.

Bioreactor landfills can be operated as anaerobic and aerobic manner and may be mined for space and resource recovery. For anaerobic operations, leachate is re-circulated into the waste matrix by various means including pumping via horizontal trenches and via vertical wells. Sometimes, leachate is treated prior to re-injection to remove inhibitors such as high ammonia concentration. This process continues until the bioreactor is fully stabilized or until gas extraction is cost effective based on cost-benefit analysis. Then, the process could be converted into aerobic mode.

It is also important to focus on waste characterization, as it determines the degradation rate and methane generation rate. Smaller particle size can accelerate the process of degradation and moisture content between 35-65% is considered optimum. The garbage bags should be opened prior to filling waste cells. The moisture content of waste within cells is an important parameter to dictate the rate of decomposition of waste. Hence it should be monitored regularly at various locations. In tropical climates with high rainfall, leachate storage and treatment could be a major issue, especially where smell of evaporation ponds and open channels is a critical issue. Leachate COD may be around 25,000 after stabilization; however, it could reach up to 75,000 to 100,000 during initial stages of re-circulation. It could be managed on-site by concentration and burning by using landfill gas. The of-site management in municipal waste water treatment could be cost-effective. Nevertheless, full-blown leachate treatment systems are expensive and may not be effective.

The technical issues regarding bioreactors may include alternative liner design and materials in line with the impacts of leachate re-circulation and time requires for leachate to field capacity, physical stability of the cover and bottom liner during the lifecycle, stabilization measures and effect of leachate re-circulation on the rate and extend of landfill stabilization, design and operation specifications of bioreactors against their performance, rate and quality of gas generation and its quantity, interim and final covers, optimum moisture content and distribution methods, monitoring systems in line with the requirements, bioreactor technology impacts on current and post closure guidelines, and shredding of waste.

Mechanical Biological Treatment (MBT): In response to the new EU Directives, asking for diversion of biodegradable waste from landfills, and also as an alternative to incineration, some European countries have started introducing this technology. This is also known as “Mechanical biological Pre-Treatment,” or “Biological and Mechanical Treatment (BMT)” was originally developed as a way of treating residual municipal waste after source segregation. This process is basically a combination of waste preparation and separation, recovery of two or more waste streams for further utilization or landfill and stabilization of the bio-degradable fraction.

Fukuoka method, based on semi-aerobic process, was originated in Fukuoka, Japan. This is combination of anaerobic as well as aerobic processes. Unlike conventional landfills, leachate collection is rapid due to perforated pipe; thus, it is comparatively clear with low level of odor. The methane generation is also comparatively lower, and the stabilization rate is faster. The leachate pipe outlet is open to let air flow in for creating aerobic conditions. The landfill gas is captured and either could be converted into energy or can be burn to avoid its emissions. The faster degradation also makes it possible to recover decomposed waste after few years and to reuse landfill site.