- Density of waste. Density is defined as mass per unit volume (kg/m^3). Density is the most significant physical characteristic of waste. Waste should be compacted to maximum density so that it occupies less area in a sanitary landfill. For up to 75% of waste, the volume can be reduced by any compaction equipment. This results in an increase in initial density of 100–400 kg/m^3 (CED 2012). Density frequently varies as waste goes through the various processes from the source of generation to ultimate disposal and becomes affected by decomposition and changes in temperature.
- Size. Size of waste plays a significant role in identifying equipment such as separators and shredders that are suitable for the processing of particular sizes of waste. Size distribution analysis is performed in the same manner as for soil particles.

Chemical characteristics provide knowledge of various chemical elements of waste as well as heating value. The principal components of chemical waste include the following:

- Lipids. These are fats, grease, and oils that are generated from food waste, cooking oils, fats, and so on. The calorific value of lipids is about 38,000 kJ/kg, which makes them more suitable for energy recovery (CED 2012). They become liquid at ambient temperature and are biodegradable in nature but the rate of degradation slows because of the low solubility of lipids in water (CED 2012).
- Proteins. These consist of elements such as carbon, nitrogen, oxygen, hydrogen, and organic waste with amines. Proteins are generated from food and garden wastes. Protein containing the amine group produces an unpleasant odor on partial decomposition.

Proximate analysis is carried out to examine various parameters of combustible components of solid waste. These parameters include moisture content, volatile combustible matter, and fixed carbon and ash content.

- Moisture content is defined as the loss of the moisture in combustible waste when heated to 105°C for 1 h (Tchobanoglous et al. 1993).
- Volatile matter is the combustible solid waste that directly evaporates when heated to 950°C in a covered crucible for 7 min.
- Fixed carbon is the combustible waste that remains after removal of volatile substances, ash, and moisture content. It must be burned in a solid state (ASTM D3172, 2013).

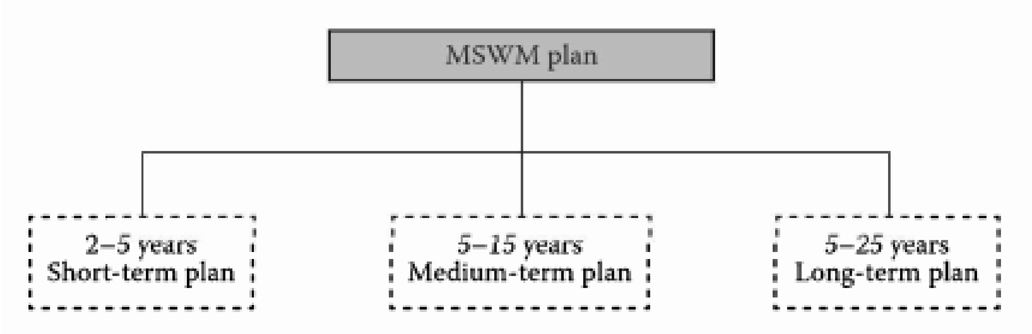
$$\% \text{ Fixed carbon} = 100\% - \%\text{Moisture} - \%\text{Ash} - \%\text{Volatile matter}$$

The ultimate analysis of combustible solid waste includes an examination of percentage carbon, nitrogen, hydrogen, oxygen, sulfur, and ash. Halogens are also included in the analysis as they contribute to emission during the combustion process (ASTM D3172, 2013). Ultimate analysis is also performed to identify the chemical characteristics of organic waste in MSW (Tchobanoglous et al. 1993). Ultimate analysis includes an examination of cellulose, proteins, lignins, fats, hydrocarbon polymers, and inorganic content in MSW (Tchobanoglous et al. 1993; ASTM D3172, 2013). Ultimate analysis is also performed to examine waste mix suitable for achieving the required carbon-to-nitrogen (C/N) ratio for biological conversion processes.

The heating value is defined as the amount of heat generated during the combustion of solid waste under standard conditions. It is analyzed to determine the potential of a solid waste sample to be used as fuel in the incineration process. Plastic wastes have a high heat value, a low ash and low to moderate moisture content. Paper and cardboard have intermediate heating values due to average carbon content as well as a moderate moisture content; whereas food waste or green waste has a very low heating value due to a high moisture content (ASTM D3172, 2013). Various studies have shown that solid waste generated in high-income countries have higher heating values due to the presence of high carbon content in waste; whereas low-income countries or developing countries have little heat value because of high moisture content and low carbon content in waste (CED 2012).

8. Waste Planning - PENNGATE offer here advice on short, Medium to Long Term Planning to enhance MSW collection, transportation and treatment

Fig 19. Short-Term to Long-Term Planning



TEMPORARY Landfill sites & Energy Plants

Integrated Waste Management with Energy Plants

Material Recovery Facilities (MRF's) & Energy Plants

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MSWM is an integral part of every human society. The approach to MSWM should be in accordance with global trends and should be compatible with the environment. The financial status of the country determines whether or not the particular option selected for MSWM will be sustainable. High-income countries such as Japan and South Korea can spend more on the 4R technologies (reduce, recycle, recover, and reuse). The world, today, is focusing on the concept of zero waste and zero landfill. This goal is quite expensive for financially weak countries such as India or Indonesia to attain. Hence, there is a need to assess the effects of implementing MSWM systems

It is clear that developing countries are far behind developed countries in terms of the practical implementation of the MSWM technologies available. Although cost-effective technologies are available for use in developing countries, the effective laws are, in many cases, not sufficiently stringent. Also, the economic condition of the government is so poor that it cannot afford to use the new technologies. The modern MSWM techniques for developing countries are presented in the following section.

Techniques Available for Implementation of MSWM Systems in Developing Countries

With the advancement in developing countries, people are no less aware of the pollution created by MSW. The public in developing countries now understand the importance of implementing good management systems to combat the SWM problem. Concerns about waste management are now understood widely. Increasing apprehension can be seen in the level of demand for more viable technical assistance in the field of waste management. Simply borrowing advanced and expensive technology from developed countries cannot solve the problem of waste management in developing countries. The urgent need is to design an appropriate technology that is more functional in developing countries.

In some cases, the introduction of sophisticated, expensive techniques from developed countries has resulted in failure because they are unfit for the prevailing system of management. Matsufuji Yasushi of Fukuoka University lists "six M's."

- Machines
- Manpower
- Material
- Management
- Maintenance
- Motivation

These are very necessary to the improvement of SWM in developing countries. The major obstacles that hinder SWM are financial resources, manpower, and physical resources in the form of materials.

- MSW collection is the responsibility of municipal corporations. Community bins in most cities placed at different points and these sometimes lead to the creation of unauthorized open collection points. House-to-house collection is being introduced in the megacities.
- With the help of nongovernmental organizations (NGOs), municipal corporations have teamed up to manage a huge quantity of waste in cities. Private contractors have also been brought in for secondary transportation of community bin waste or for transporting waste from open collection points to the disposal site (Wang 2014).
- At present, some of the NGOs and citizen's committees supervise segregation, collection, and disposal of waste. At some places, welfare associations on monthly payment arrange the collection of

waste. Sweepers are allotted a specific area (around 250 m^2) (Colon and Fawcett 2006; Nema 2004; Malviya et al. 2002; Kansal et al. 1998; Bhide and Shekdar 1998).

- In developing countries, waste sometimes remains uncollected because the streets are both unplanned and overcrowded, and this causes discomfort to people. Most cities are unable to provide a specific waste collection system for all parts of the city.
- In developing countries, two innovative concepts of waste disposal are being implemented. These are composting and waste-to-energy (WtE). The composting method includes both aerobic and vermicomposting whereas WtE includes different treatment processes such as incineration, pelletization and bio-methanation (Sharholy 2007). Techniques such as WtE are tested with positive results in many developed countries. In some developing countries such as India, WtE is a relatively a new concept. Therefore, landfill is still the final destination for the disposal of waste (Fulekar et al. 2014).

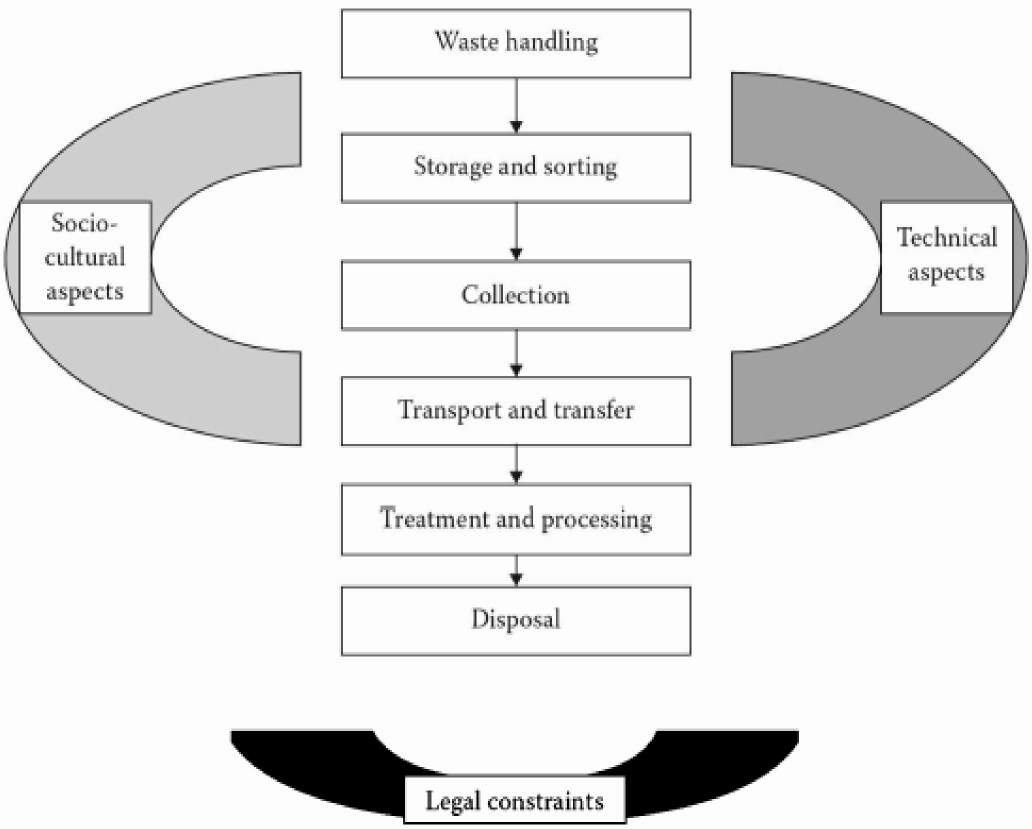
- Due to inappropriate MSW management, 90% of waste is directly disposed of onto the land of various cities and towns. In many coastal areas, such dumping leads to leaching of heavy metals (Dev and Yedla 2015). The availability of land for waste disposal is very limited in developing countries (Mor et al. 2006; Siddiqui et al. 2006; Sharholy et al. 2006; Gupta 1998; Das et al. 2015; Kansal et al. 1998; Chakrabarty et al. 1995; Khan 1994). In most urban centers, MSW is disposed of in low-lying areas mostly outside the cities without following the ideology of sanitary landfill where waste is dumped at a particular site and allowed to degrade biologically, chemically, and physically in isolation from human settlement (Dev and Yedla 2015).
- Incineration is a thermal treatment option that reduces the volume of waste and, thus, saves the encroachment of waste onto land. It also lessens the extra environmental burden. This process is quite expensive due to complex technology. Incineration requires large-scale burning and it also causes air pollution, which adds extra work to manage. In developing countries such as India, incineration is not very practical as the waste contains high moisture content and high organic content and, also, the calorific value is quite low, that is, 800–1100 kcal/kg (Kanal 2008; Bhide and Shekdar 1998). Therefore, the developing countries with waste having the same characteristics might undergo anaerobic digestion and biomethanation. These two techniques are less costly and they are appropriate for the process of degrading high organic matter as a renewable resource.

- In developing countries, MSW is openly dumped and this is not advisable either for human health or for environmental care. Open dumping is found in 90% of India, 85% of Sri Lanka, 65% of Thailand, and 50% of China (Ojha et al. 2012). Appropriate technologies such as composting and WtE methods should be used in order to have a proper waste management system.
- The sustainability of any waste management technique depends on costs and the financial status of a region. An organized method of segregation and collection exists in developed countries as they are economically strong enough to purchase any costly technology but developing countries lack this financial foundation. Manual segregation and cheap technologies are still used in developing countries.
- Proper segregation of waste and recycling should be adhered to in developing countries as most of the valuable material that can again be used as a secondary resource is lost due to lack of segregation practice. Figure 2.2 shows the percentage of physical characteristics found in MSW in different countries.
- The aim of developing countries is to eliminate landfill in MSWM systems. These countries experienced rapid growth in the latter years of the twentieth century. Regular follow-up in the system provides reliable data for well-run operations in the waste management system and this lays the basis for technical training in these fields.
- Recycling is being increased in developed countries to reduce the burden on landfill. Extended producer responsibility (EPR) is being implemented to ensure the safe dumping of waste.
- Similarly, notable literature is available on diverse features of MSWM. Manual labor can be substituted by required techniques. Sustained planning and funding is made available so that different processing remains uninterrupted. The awareness level about waste management is quite high. The current global trend contributes toward sustainable ideology. National programs have been launched in Japan,

- The Integrated Municipal Solid Waste Management (IMSWM) system is an interrogative concept of waste prevention. It touches on all aspects of waste management such as recycling, composting, and dumping programs. A successful IMSWM system encompasses an authentic plan that covers all the compartments of waste management, including environmental and human health. This concept is widely practiced in developed countries.
- System analysis is also a very important technique for handling MSW through a wide range of comprehensive methodologies. It includes certain engineering models and assessment tools for solving the challenges and barriers involved in waste management.

Fig 20. Different Waste Plans – Short Term, Medium & long Term

Municipal Solid Waste Management in Developing Countries



Role of the municipal corporation. (Modified from Sharholy et al., *Journal of Waste Management* 27(4), 490–496, 2007.)

Source: Municipal Solid Waste Management in Developing Countries – 2015 - International Standard Book Number-13: 978-1-4987-3774-6

Along with the official sector of MSWM, there is another unceremonious and unofficial sector consisting of people who work informally. The people of this sector are called *ragpickers*, who pick up rags and recover recyclable waste and other resources; they receive little recognition and are highly vulnerable. Their activities epitomize the informal sector, as this is labor-intensive, low-technology, low-pay, unrecorded, and unregulated work, often completed by individuals or family groups.

The job of the ragpickers is to sort and collect unused valuable waste, consisting of plastics, bottles, cardboard, tins, aluminum, iron, brass, and copper. After collection, these people sell the waste to scrap dealers. They provide primary collection and process collected materials into intermediate or final products using creativity and innovation to respond cost-effectively to market needs (Ahmed and Ali 2004).

In the trade of ragpicking, there are all types of people in groups irrespective of cast, creed, sex, or age, all belonging to the lowest economy. Informal waste recycling is carried out by poor and marginalized social groups, who

resort to scavenging and waste picking for income generation and some even for everyday survival (Medina 2000).

There are three categories of ragpickers:

1. *Street waste pickers*: Collect the secondary raw materials recovered from mixed waste discarded on the street.
2. *Municipal waste pickers*: Collect waste from the vehicles that transport MSW to disposal sites.
3. *Dump site waste pickers*: Collect waste from dump sites. Dump sites contain waste from all across the city and are thus desirable places for waste pickers.

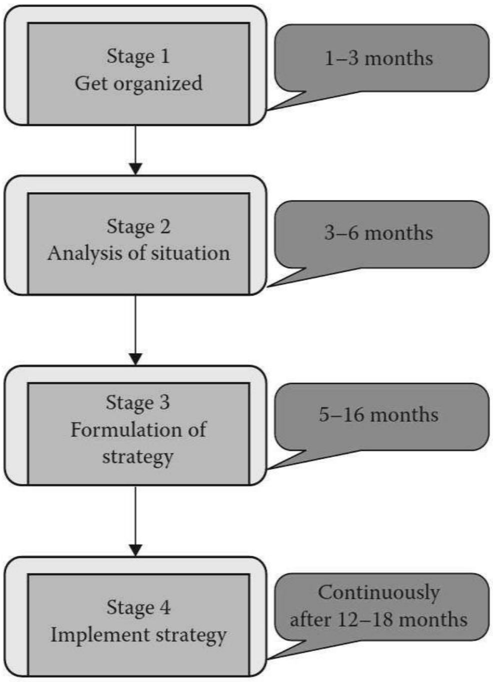
Informal recycling systems can bring significant economic benefit to developing countries. From a macroeconomic perspective, they are well adapted to the prevailing conditions: there is an abundant workforce, which earns very limited capital. They minimize capital expenditures and maximize hands (Haan et al.1998; Scheinberg 2001).

Though ragpickers contribute to a great extent in the minimization of waste and in sorting valuable secondary raw material, on a personal level they have poor living conditions and limited access to facilities and infrastructure. Ragpickers have a high risk of occupational health hazards, and they often suffer injuries and dog bites. The occupational health risks to waste pickers in developing countries are high because of their manual handling of materials and lack of protective clothing/equipment, resulting in direct contact with waste (Cointreau 2006).

Source: Municipal Solid Waste Management in Developing Countries – 2015 - International Standard Book Number-13: 978-1-4987-3774-6

Problems to Be Faced while Implementing MSWM Systems in Developing Countries

Fig 21. Strategy for Waste Plans – Short Term, Medium & long Term



Strategies regarding long- and short-term planning. (Modified from VNG International, *Municipal Development Strategy Process: A Toolkit for Practitioners*, The Hague, the Netherlands: VNG International, 2010.)

Source: Municipal Solid Waste Management in Developing Countries – 2015 - International Standard Book Number-13: 978-1-4987-3774-6

There are several guidelines and procedures that need to be followed before starting any implementation techniques for MSWM systems. But if, in any sector, these guidelines are not being followed, then several problems might hinder the path of its implementation.

The countries that can best achieve environmental, social, economic, and technical goals are best at managing their implementation techniques. Implementing MSW management in developing countries is a little more problematic as they face several problems in different sectors. The basic problems faced in developing countries are enumerated in this section.

- Developing countries are facing rapid urbanization and population growth, and this sometimes exceeds the system threshold capacity, causing problems in managing the waste.
- Public health, environment, and waste management are interlinked. If proper waste management is not followed, it affects both public health and environment thus causing a major disruption in the waste management system.
- Waste management hierarchy is one of the biggest challenges and it needs a broad and comprehensive range of diverse treatment options such as composting and recycling to form a reliable infrastructure.
- Despite suitable planning models, insufficient information regarding segregation at source plays a major role in calculating the amount of material separated from the collected waste. The quantity of material segregated depends on the following factors with regard to coverage of collection system, separation efficiency of waste produce, and participation rate of waste producers.

Not much attention has been given to the following important factors in developing countries. In developing countries due to rapid urbanization and improving lifestyles, there are characteristic changes in the composition and quantity of waste. Municipal corporations are quite unable to complete the task. More than a quarter of waste remains uncollected (Pachuri and Batra 2001). Current findings show that unmanaged disposal of waste causes serious human health and environment concerns. This problem is quite well resolved by developing countries.

In practical terms, municipal governments tend to allocate low budgets to tackling waste. The public are less aware of waste management issues and so lower funds are made available, and this ultimately leads to further degradation in quality of service.

The revenue collected from the SWM is deposited in general municipal accounts with not much of it being spent on the particular purpose of waste management. The misallocation of waste funds is exacerbated when revenue is transferred to central government instead of local bodies. There is an absence of connection between revenue and the real level of service provision. In developing countries, due to lack of expertise and the availability of traditional waste management techniques, MSWM faces many problem. There is no universal remedy for the solid waste problem in developing countries.

Over 70% of the world's population lives in developing countries. Waste management in these countries is a major issue as the population is increasing at a faster rate than has ever been the case in industrialized countries (Olaosebikan et al. 2012) and waste management is an impending problem that needs to be solved.

Categories of Problems Common to Waste Management in Developing Countries

Waste management in developing countries is hindered by different problems. These problems are further categorized into three categories:

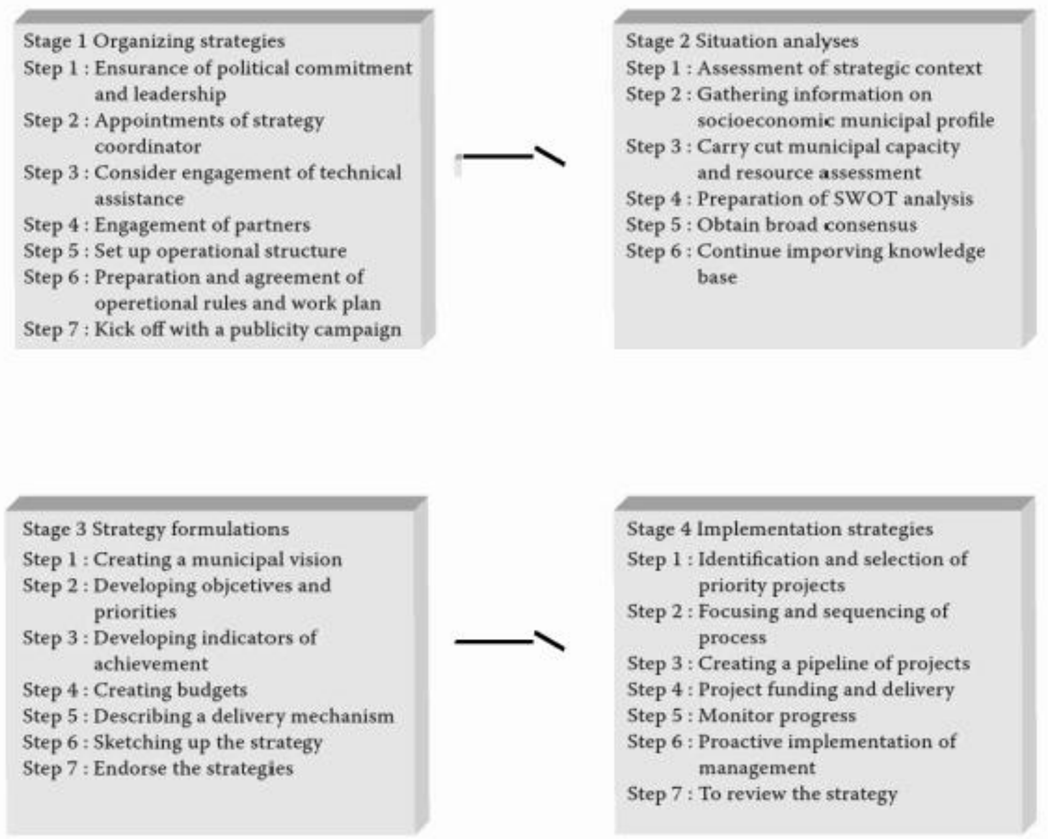
- External problems
- Simultaneously external and internal problems
- Internal problems

The different problems faced by developing countries that hinder the smooth functioning of MSWM are presented in Table 2.4.

Source: Municipal Solid Waste Management in Developing Countries – 2015 - International Standard Book Number-13: 978-1-4987-3774-6

Fig 22 Strategies expanded

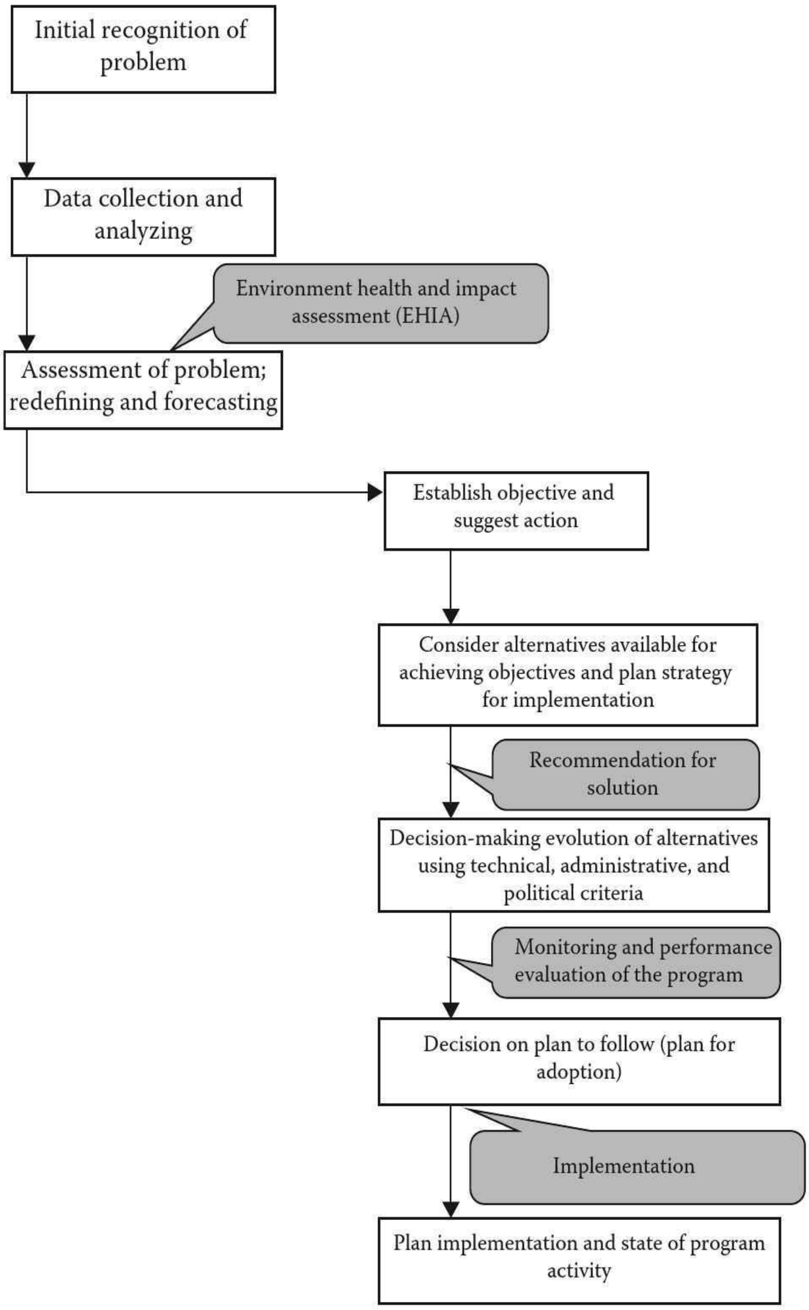
Substages of strategies for long- and short-term planning. (From WastePortal.net, Municipal strategic planning for solid waste management: Concepts and tools. http://wasteportal.net/en/waste-aspects/environmental-and-health-aspects/municipal-strategic-planning-solid-waste-management-c).



Source: Municipal Solid Waste Management in Developing Countries – 2015 - International Standard Book Number-13: 978-1-4987-3774-6

Fig 23. Basic Waste Planning Model

A basic planning model. (From The Central Public Health and Environmental Engineering Organisation (CPHEEO). *Manual on Water Supply and Treatment*. 2000. http://cpheeo.nic.in/Watersupply.htm.)



Source: Municipal Solid Waste Management in Developing Countries – 2015 - International Standard Book Number-13: 978-1-4987-3774-6

Fig 24. Current practise and ideal waste management practices for developing Countries

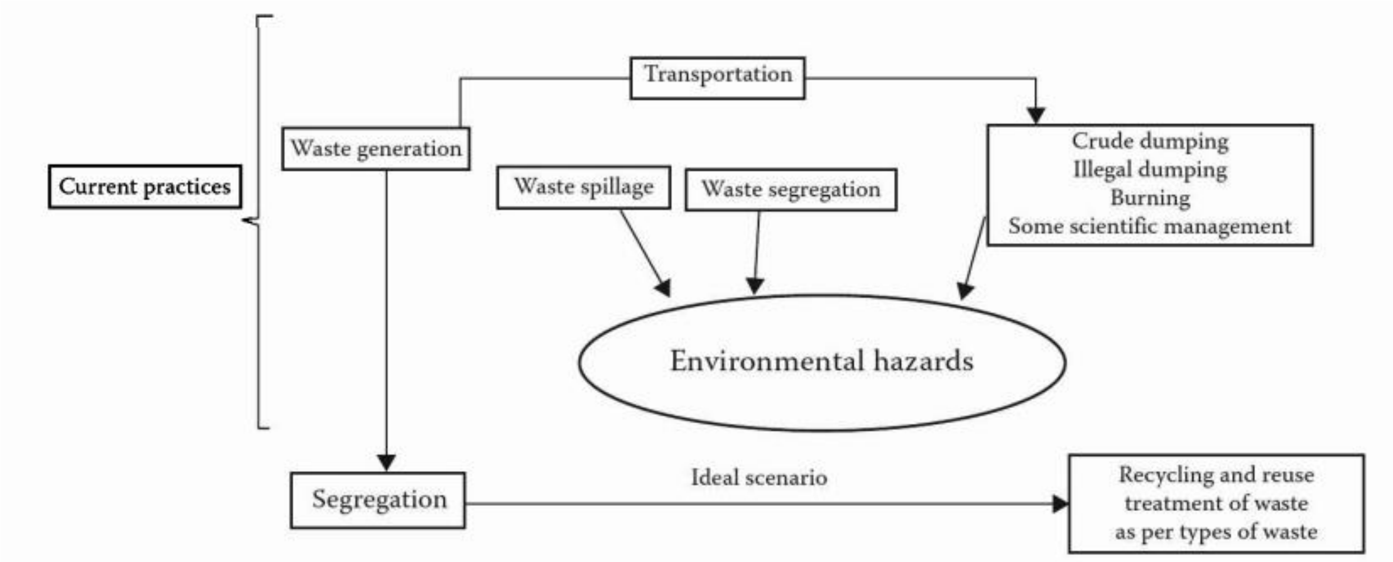


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Fig 25. Plan for an ideal routing system for waste collection

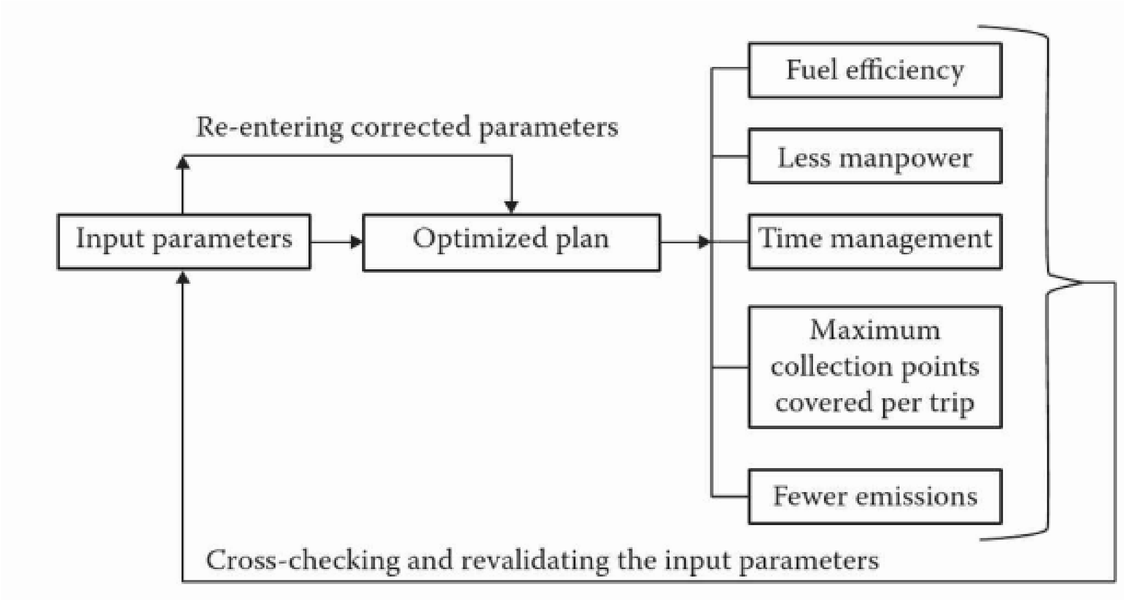

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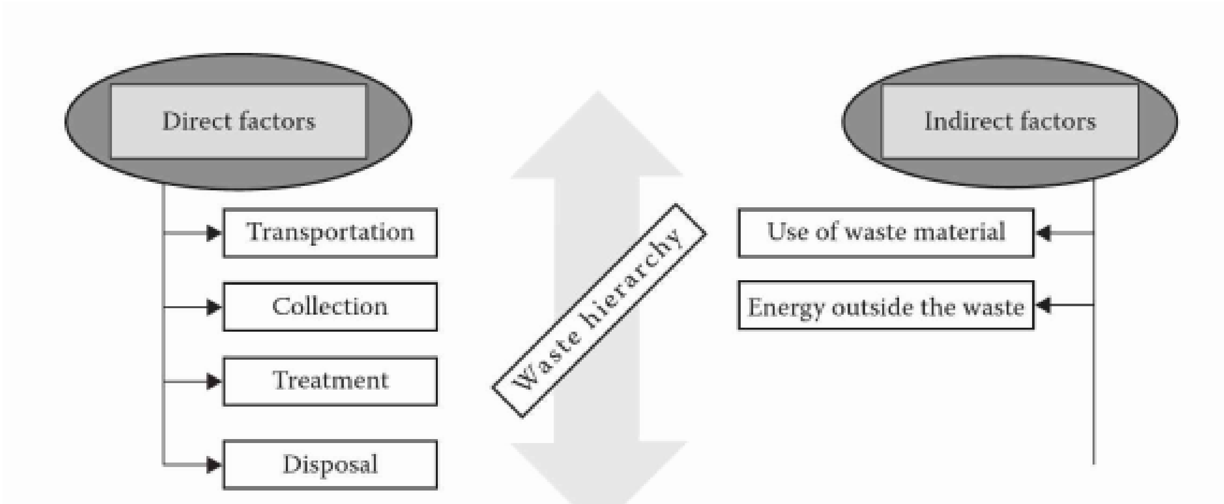
Fig 26. Planning an Integrated Waste Management system -direct & Indirect factors



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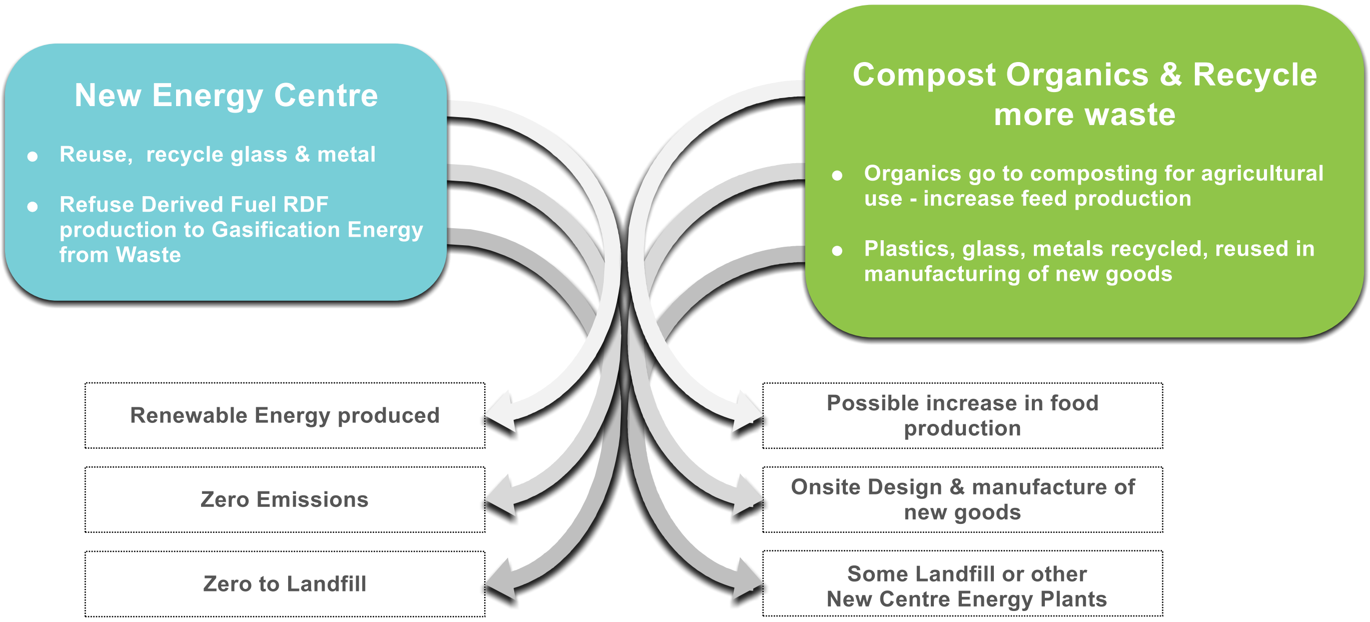
Two Possible Waste Scenarios



Types of Municipal Solid Waste Transportation Vehicles

The MSW collected from waste containers is transported to the final disposal sites using different types of vehicles. In towns and rural areas, tricycles or tractor-trailers are commonly utilized for the transportation of waste. Lorries and light motor vehicles are mainly used in large towns and cities. In metropolitan cities, trucks are used to transport waste from collection points to disposal sites (Pak EPA 2005).

Transfer Stations

Transfer stations are facilities where MSWs are unloaded from collection vehicles and briefly held; from there they are reloaded onto big vehicles for long-distance transportation to final disposal sites or landfills. Communities can save money on the labor and operation costs of shifting waste to faraway places by combining the loads of several individual waste collection trucks into a single load. Hence, there is a decrease in the total number of vehicles traveling to and from the disposal site. Though waste transfer stations have the advantage of reducing the impact of trucks going to and from the dump site, they can also cause an increase in traffic in proximity to where they are situated. Transfer stations should be carefully located, designed, and operated to avoid problems for dwellings nearby (Tchobanoglous and Kreith 2002)

Optimization of Transportation Routes

An integrated MSW system is needed to develop a cost-effective and environmentally sustainable approach (Ionescu et al. 2013; Eriksson et al. 2014). Globally, municipal waste collection is recognized as accounting for the majority of expenditure on solid waste management. Low- and middle-income countries spend 80%–90% and 50%–80% of their waste management budgets, respectively, on the collection of waste (Weng and Fujiwara 2011). Therefore, MSW collection and transportation are issues that create

difficulties in the development of an integrated waste management system (Consonni et al. 2011). Civil authorities are encouraged to develop sound strategies, especially in urban areas, to decrease the cost of transportation and collection (Massarutto et al. 2011). Therefore, the optimization of MSW collection and transport from source becomes an important aspect of waste management system design. In any city, waste sources are located at various places throughout the area in a heterogeneous way, causing an increase in waste collection and transportation costs (Das and Bhattacharyya 2015). Hence, a suitable waste collection and transportation approach can efficiently decrease waste gathering and transportation costs.

Fig 27. Implementing a Waste Planning system

Goals and focus of IMSWM. (Modified from Ramachandra, Integrated management of municipal solid waste. *Environmental Security: Human and Animal Health*, pp. 465–484. Lucknow, India: IBDC, 2011.)

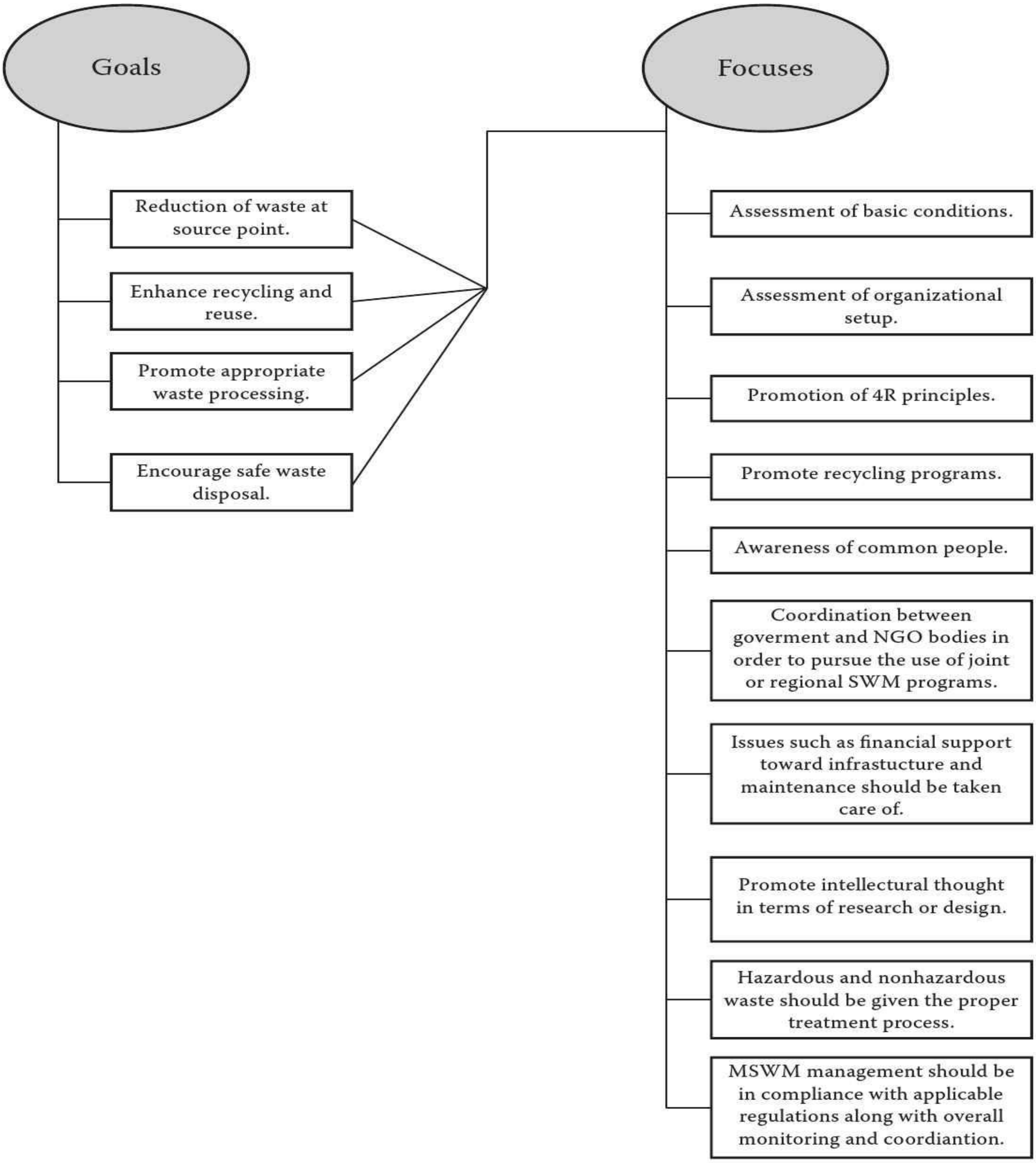


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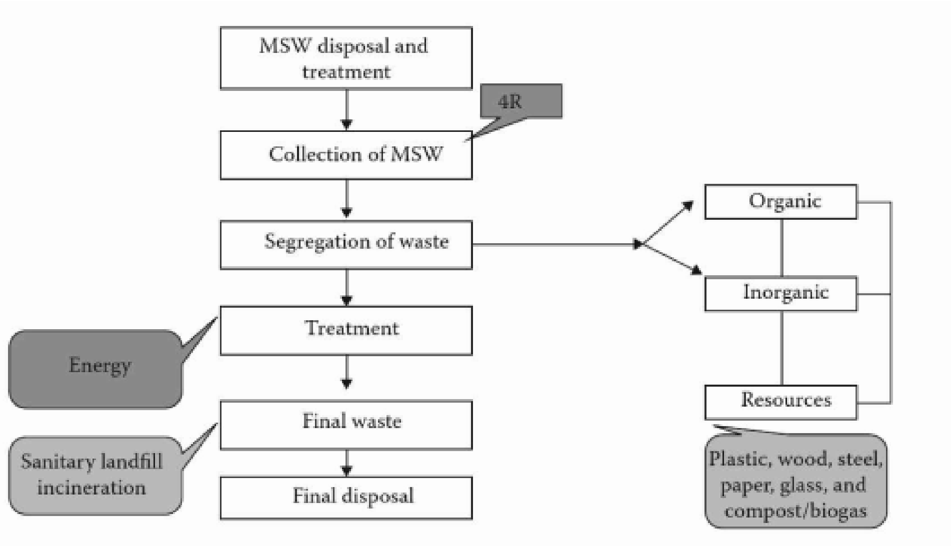
Fig 28. Strategic Planning

Generation-based IMSWM. (Data from UNEP, *Developing Integrated Solid Waste Management Plan Training Manual*, 4, 66–88. Osaka, Japan. UNEP, Division of Technology, Industry and Economics International Environmental Technology Centre, 2012.)



Life cycle–based IMSWM. (Data from UNEP, *Developing Integrated Solid Waste Management Plan Training Manual*, Vol. 2. Osaka, Japan. Assessment of Current Waste Management System and Gaps Therein. United Nations Environmental Programme Division of Technology, Industry and Economics International Environmental Technology Centre 2009.)

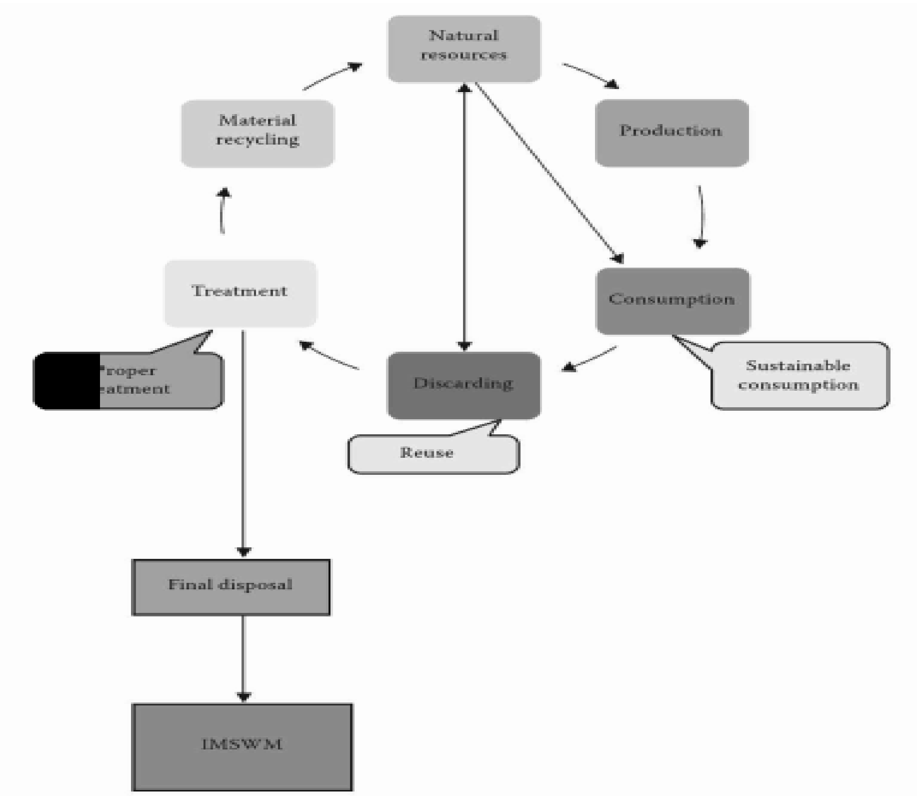


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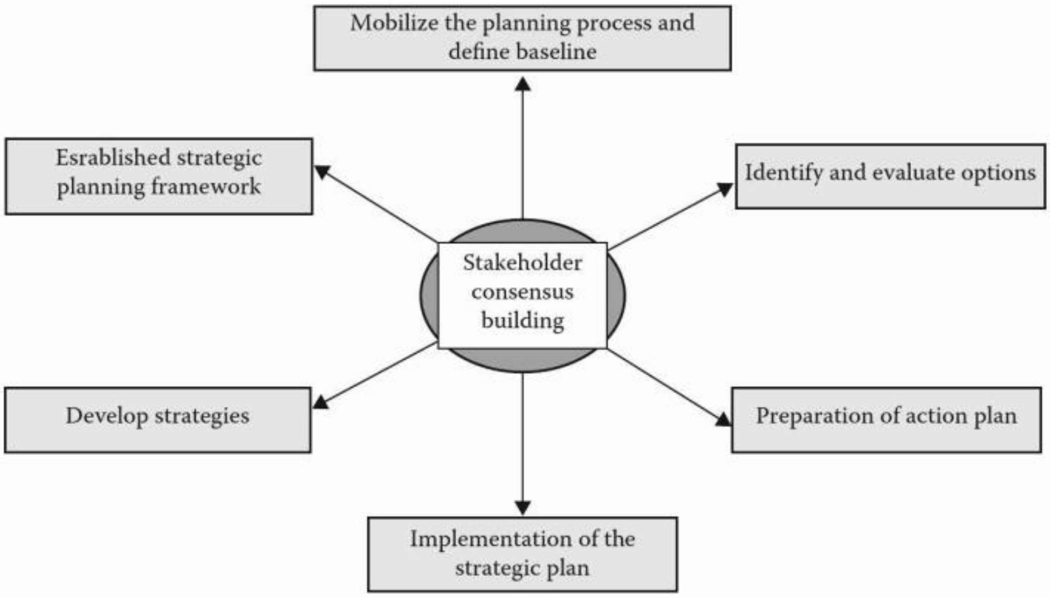
Fig 29. Steps towards Strategic Planning for Waste Management

Steps toward strategically planning municipal solid waste management practices. (Modified from VNG International, *Municipal Development Strategy Process: A Toolkit for Practitioners*, The Hague, The Netherlands, VNG International, 2010).



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Biological and Thermal Processing Methods

Composting

Composting is the controlled microbial decomposition of the organic fraction of solid waste, under aerobic conditions, where microorganisms convert waste into a stable end product such as compost. The term *co-composting* is described as the composting of two or more substances together. In the composting process, the decomposition of the organic fraction of waste causes a reduction in its volume, weight, and moisture content, minimizes potential odor, decreases pathogens, and increases potential nutrients for agricultural application. The composting process may reduce the spread of disease because of the destruction of some pathogens and parasites at elevated temperatures. This process has been practiced for decades as a modern waste management alternative both in developed and developing countries. It diverts a significant portion of organic waste from municipal collection services and from final disposal sites, and therefore enhances the economic and environmental sustainability of waste management systems (Hsu and Lo 1999).

During composting, readily degradable organic waste stabilizes into carbon dioxide and water. Stabilization in the composting process depends on the end user's use of the by-product; also, users cannot achieve 100% stabilization, as this would destroy the soil-building properties of compost (Graves et al. 2010). During the thermophilic phase, high temperatures accelerate the breakdown of proteins, fats, and complex carbohydrates such as cellulose and hemicellulose. As these high-energy compounds become exhausted, the compost temperatures gradually decrease and mesophilic microorganisms once again overtake other types of microorganism during the final phase of maturation (Fourti et al. 2008). The rate of MSW decomposition and the activity of these microorganisms is encouraged through management of the carbon-to-nitrogen (C:N) ratio, pH, temperature, moisture content, and other nutrient levels, as well as by the composition of the starting materials.

A well-balanced composting process increases the rate of natural decomposition and generates sufficient heat to destroy weed seeds, pathogens, and fly larvae (Delgado-Moreno et al. 2009). Microorganisms play an important role in the decomposition of organic waste. Various species of unseen aerobic microorganisms decompose organic material as they grow and reproduce. Proper management of the composting process requires the nutrient balance, moisture content, oxygen supply, temperature, and pH levels to be maintained.

The nutrient balance in the compost mix is calculated by C:N. A C:N ratio between 20:1 to 40:1 is required for rapid composting (Graves et al. 2010). The ideal moisture content needed for the solid waste sample to prepare a quality compost mix is around 60% after mixing the ingredients (Graves et al. 2010). The proper biological process requires an adequate amount of oxygen, as oxygen affects the temperature, moisture, and carbon dioxide content in the compost pile. An increase in the temperature of the compost pile indicates the presence of active microbes and the breaking down of complex organic matter into a simpler form. The optimum range of pH for composting is 6.0–7.5 (Graves et al. 2010). To increase the rate of the composting process, it is necessary to balance and manage all these components.

While composting, waste passes through two periods: the first is active composting and the second is curing. During the active period, readily degradable waste is broken down into simple matter by individual aerobic microorganisms, whereas in the curing period, degraded material further breaks down into a simpler form, and at the end of the period stabilized compost forms
The following is the oxidation process that occurs during composting:

Fig 30. Different stages of composting

Different stages of the composting process. (Modified from Lekasi et al. 2003. Cattle manure quality in Maragua District, Central Kenya: Effect of management practices and development of simple methods of assessment. *Agricultural Ecosystems and Environment*, 94, 289–298.)

$$\text{Organic materials} + O_2 + \text{microorganisms} \rightarrow CO_2 + H_2O + NH_3 + PO_4^{2-} + SO_4^{2-} + \text{energy}$$

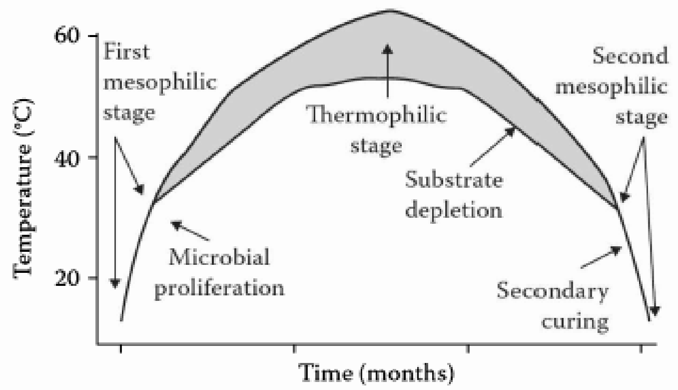


Table 11 Moisture content of MSW constituents in composting process

Common Feed Stocks and Their Characteristics for the Rapid Composting Process

Feedstocks	Moisture Content	C:N Ratio	Bulk Density
High Carbon Content			
Hay	8–10	15–30	—
Corn stalks	12	60–70	32
Straw	5–20	40–150	50–400
Corn silage	65–68	40	—
Fall leaves	—	30–80	100–300
Sawdust	20–60	200–700	350–450
Brush, wood chips	—	100–500	—
Bark (paper mill waste)	—	100–130	—
Newspaper	3–8	400–800	200–250
Cardboard	8	500	250
Mixed paper	—	150–200	—
High Nitrogen Content			
Dairy manure	80	5–25	1,400
Poultry manure	20–40	5–15	1,500
Horse manure	65–80	10–20	—
Cull potatoes	70–80	18	1,500
Vegetable wastes	60–65	10–20	—
Coffee grounds	14–18	20	—
Grass clippings	8–10	15–25	—
Sewage sludge	—	9–25	—

Source: Rynk et al., *On-Farm Composting Handbook*, pp. 6–13, 106–113. Ithaca, NY: Northeast Regional Agricultural Engineering Service, 1992; Wong et al., *Bioresource Technology*, 100, 3324–3331, 2009.

Compost systems currently in vogue can be classified into three broad categories:

- Windrows
- In-vessel systems
- Vermicomposting

1. *Windrows*: Windrows are a simple composting technology requiring minimal engineering design or labor and are a widely used method for the composting of yard trimmings and MSW. They require minimum investment regarding equipment and finance. Windrow composting is an inappropriate technology for MSW because of odor emission and the attraction of vectors (e.g., rodents, flies, etc.). Hence, it is progressively being abandoned but increasingly being used for garden waste only. As one would suspect, the designation *windrow systems* reflects the distinguishing feature of such systems—namely, the use of windrows. There are two types of windrow system: *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 in the turned version, aeration involves demolishing and reconstructing the windrow (UNEP 2005). The principle steps involved in the windrow composting process are
   - Inclusion of a bulking agent into the waste
   - Construction of the windrow
   - Composting
   - Screening of the composted mixture
   - Curing and storage

For proper aerobic conditions and uniform decomposition of waste, compost piles are frequently turned so that the cooler outer layer is exposed to higher temperatures and the aerobic composting process takes place uniformly. Turned windrow operation is conducted under shelter or in an outside area on a firm surface to stop the percolation of leachate into the soil (Tiquia et al. 1996; Wong et al. 2001). The size of the windrow reduces with time with the decomposition of material into a simpler form. Windrow height depends on the feedstock, the season in which composting is conducted, the region, the compaction capacity of the compost material, and the turning equipment. To prevent excessive heat and to insulate the composting material, an ideal windrow height of 1.5 to 1.8 m is suggested.

2. *In-vessel systems*: In-vessel composting refers to a group of methods that confine the composting materials within a building, container, or vessel. In-vessel systems attempt to create optimum conditions for the microorganisms, thereby giving improved control of the composting process and accelerating decomposition. As in all composting systems, the supply of air to all the material being composted is the primary factor that determines the effectiveness of the process.

   In-vessel systems can be used for the treatment and handling of a large amount of organic waste (mainly MSW scale), and the resulting stabilized form can be used as soil amendment. This system can also be used with aerated static piles, with the inclusion of removable covers over them. To minimize and control foul odors, a higher C:N ratio is maintained, with proper ventilation facilities to increase aeration. Coarse-grade carbon material is also used to allow better air circulation through the compost. Biofilters are provided to prevent and capture any naturally occurring gas from aerobic composting. Advanced systems are designed to reduce odor issues, and the integration of an in-vessel system with anaerobic digestion will result in higher energy and resource output. In this type of system, organic matter is first passed through anaerobic digestion and then composting is done under forced aerated conditions. In-vessel systems take 14 days to produce stabilized compost (UNEP 2005).

Various types of in-vessel systems have been developed over the years, such as the Dano drum, the naturizer system, the metro and channel types, and the Fairfield reactor. The primary aim of designing an in-vessel reactor is to accelerate the composting process and to produce an ambient environment by the elimination of undesirable conditions (UNEP 2005). The aeration design of an in-vessel system consists of features such as forced aeration, stirring, and tumbling. Forced aeration is conducted in most of the systems, whereas stirring is done via the rotation of plows or augers. Tumbling can be done by dropping compost material from one level to a lower level (UNEP 2005).

3. *Vermicomposting*: Vermicomposting is a process that uses red earthworms to consume organic waste, producing castings (an odor-free compost product that can be used as mulch), soil conditioners, and topsoil additive. Bacteria and millipedes help in the aerobic degradation of the organic material. Vermicomposting is especially useful for processing food waste since the worms consume the material quickly and there are fewer problems with odor. Vermicomposting does not generate temperatures high enough to kill pathogens. For this reason, vermicomposting is more appropriate for food, paper, and yard waste. The most common types of earthworms used for vermicomposting are brandling worms (*Eisenia fetida*) and red

worms or red wigglers (*Lumbricus rubella*) (Yadav and Garg 2011; Khwairakpam and Bhargava 2009). These worms are generally found in aged manure piles and have alternating red and buff-colored strips. In this process, various worms and microorganisms are involved at different stages of compost development; this also contains various worm castings. Earthworm castings in the home garden often contain 5–11 times more nitrogen, phosphorous, and potassium than the surrounding soil (Baoyi et al. 2013; Sen and Chandra 2006). Red worms in vermicompost act in a similar fashion, breaking down food wastes and other organic residues into nutrient-rich compost. The nutrients in vermicompost are often much higher than traditional garden compost. Finished vermicompost should have a rich, earthy smell if properly processed by worms. Vermicompost can be used in potting soil mixes for house plants and as a top dressing for lawns. Screened vermicompost combined with potting soil mixes makes an excellent medium for starting young seedlings. Vermicompost also makes an excellent mulch and soil conditioner (Li et al. 2011). Parameters that can be considered for the selection of appropriate vermicomposting technology include

- The amount of feedstock for processing
- Availability of funds
- Site and space restrictions
- Climate and weather conditions
- Regulatory restrictions
- Facilities and equipment on hand
- Availability of low-cost labor

Vermicomposting is of four types.

- Windrows
- Wedge systems
- Bed and bin systems
- Reactor systems

Windrows are employed both open and under cover, but the major disadvantage is that they require a large surface area. It is difficult to conduct the vermicompost process without earthworms, so a mechanical harvester is commonly used for these operations. The wedge system is a modified windrow system that maximizes space and simplifies harvesting, as there is no need to separate the worms from the vermicompost. Organic materials are placed at an angle of 45° against the finished windrow. The piles can be placed inside a covered space or outdoors if it is covered with a tarp to avoid the leaching of nutrients. A front-end loader can be used to build a windrow 1–3 m wide by whatever length is appropriate (Yadav and Garg 2009; Xing et al. 2012). The windrow is started by spreading a 30–45 cm layer of organic materials the length of one end of the available space. Up to 500 g of red worms are added per square meter of windrow surface area. Subsequent layers of 5.0–7.5 cm of organic material are added weekly, although 7–15 cm layers can be added in colder weather. After the windrow reaches 0.6–1.0 m thick, it can be led sideways by adding the next layers at an angle against the first windrow (Shermann-Huntoon 2000). Once this is achieved, worms start migrating from the first windrow to the fresh windrow. It is a labor-intensive process to harvest worms and vermicompost by hand. The major advantage associated with hand-driven vermicompost is that when the worm beds get too hot, the worms can burrow deeper to where the temperature remains below 23°C, and then the system is kept undisturbed for 3 days, compared with automated reactors, which require daily inspection for moisture and temperature levels (Shermann-Huntoon 2000). The disadvantage is that the worms and castings must be separated manually. Feed stocks are added daily in layers on top of the mesh or grate. Finished vermicompost is harvested by scraping a thin layer from just above the grate, which falls into a chamber below. These systems can be relatively simple and manually operated or fully automated with temperature and moisture controls. For maximum efficiency, they should be under cover.

The advantages of vermicomposting are as follows.

- Earthworms efficiently break and fragment the organic waste into a stable, nontoxic material with high economic value as a fertilizer.
- Properly produced vermicompost has excellent structure, porosity, aeration, drainage, and moisture-holding capacity.
- Vermicompost supplies a suitable mineral balance, improves nutrient availability, and can act as complex fertilizer granules.
- As with the composting process, vermicomposting provides a significant reduction in waste bulk density, although this tends to take longer.
- The low-technology systems can be easily adapted and managed on small farms or livestock operations.
- Vermicomposting produces compost in about 3 weeks.

The main disadvantages are that vermicomposting requires more management and maintenance than other composting systems to maintain healthy worms, and it has not yet been successfully used for large-scale treatment. The environmental effects are similar to composting, and windrows may need proper designing to prevent leachates. The odor and leachate problems are controlled in other types of vermicomposting.

Biomethanation

Biomethanation is a process in which the organic matter of solid waste is decomposed by microorganisms to produce biogas under anaerobic conditions (i.e., without air). Biogas includes various gases: mainly methane, carbon dioxide, hydrogen, and hydrogen disulfide. In this process, oxygen is not required for the decomposition of waste; the anaerobic process is inherently the most energy-efficient option for the safe disposal of garbage. All other options are either energy intensive, inconvenient, or environmentally unsafe. A wide variety of process applications for the biomethanation of wastewater, slurries, food waste, and solid waste have been developed (Angelidaki et al. 2011). For over 100 years, this technology has been used in different practical situations, demonstrating itself as a viable platform. Nevertheless, technical improvements are in progress (EPA 2008). The characteristic properties of biogas are mainly affected by changes in pressure and temperature; moisture content also plays a significant role in biogas production. The following is an explanation of the anaerobic process:

- Anaerobic degradation of organic material is a two-stage process in which complex organic material breaks down into short-chain volatile fatty acids, which is then further converted to methane and carbon dioxide.
- The complex polymer and acids are fermented at the same time in a single-phase system, whereas the separation of acidogenic and methanogenic bacteria occurs in a two-phase system. The retention period of material in a biomethanation chamber depends on the chemical characteristics and the design of the system (single stage, two stage, multistage). The generalized formula of the anaerobic process is:

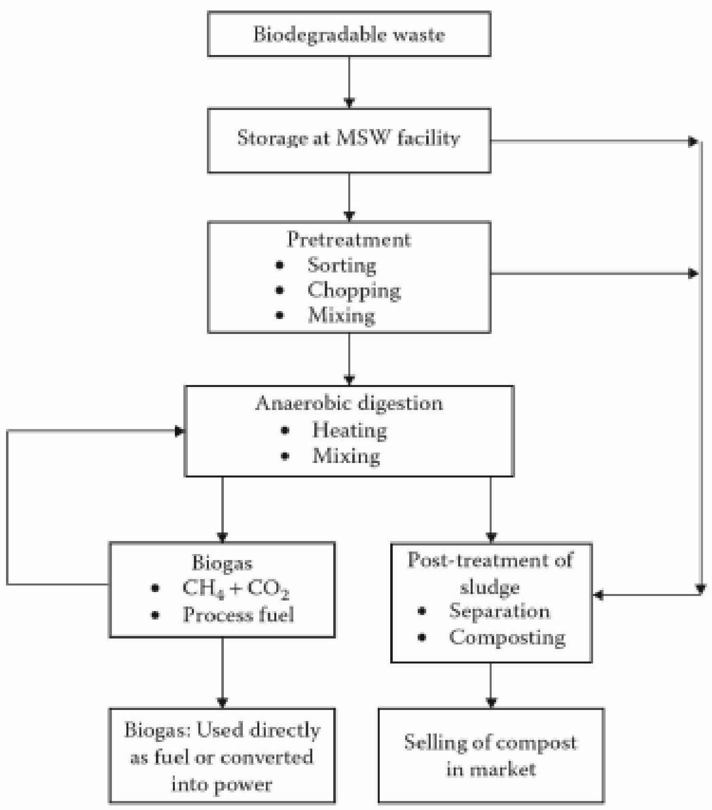
$$\text{Organic matter} + \text{anaerobic bacteria} \rightarrow CH_4 + CO_2 + NH_3 + H_2S + \text{other end products}$$

- A highly temperature-controlled process takes less time in the treatment of waste. Mainly, this process is suitable for wet, semiliquid waste such as food or sewage sludge, the composting of which is difficult because of improper air circulation (CED 2012).

The anaerobic digestion process is of two types.

Fig 31. *Anaerobic digestion process*

Municipal Solid Waste Management in Developing Countries



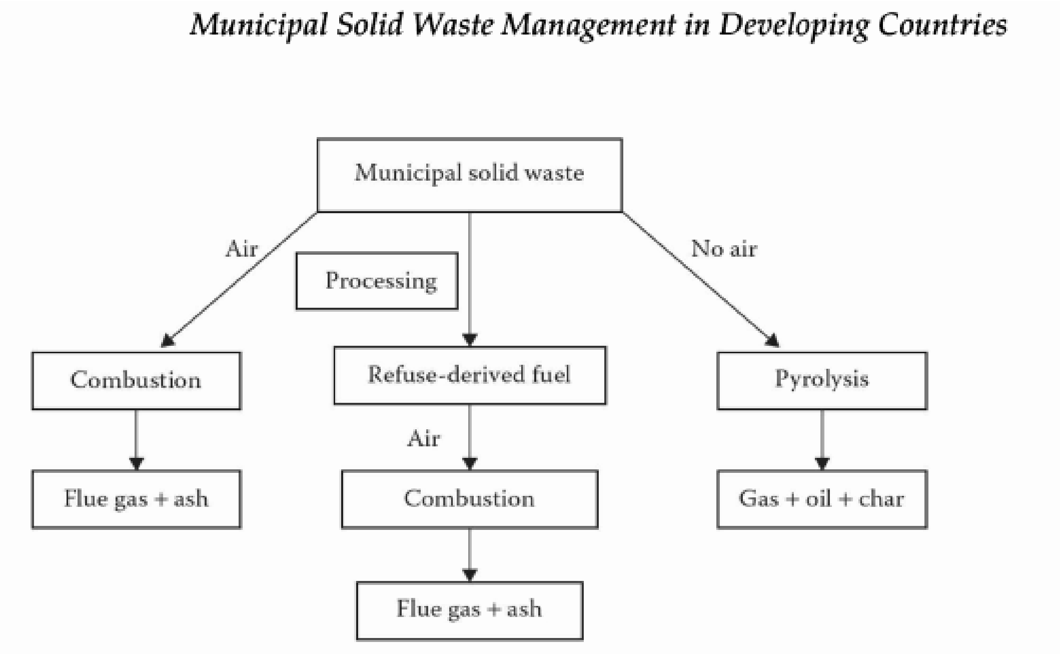
The anaerobic digestion process for biodegradable waste. (From William, *Waste Treatment and Disposal*, pp. 325–342. New York: Wiley, 2005.)

Source: Municipal Solid Waste Management in Developing Countries – 2015 - International Standard Book Number-13: 978-1-4987-3774-6

Thermal Processing of Municipal Solid Waste

Fig 32.

MSW thermal processing options.

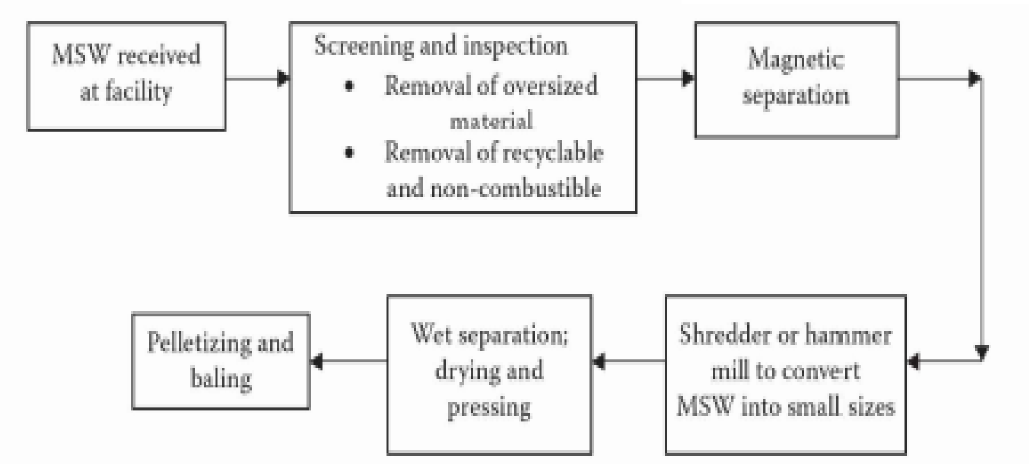


Source: Municipal Solid Waste Management in Developing Countries – 2015 - International Standard Book Number-13: 978-1-4987-3774-6

Thermal processing is burning out a combustible portion of solid waste in the presence of air or oxygen, to recover energy from solid waste as heat and steam. There are various processes for the thermal treatment of solid waste, such as combustion, gasification, pyrolysis, RDF, and so on

Fig 33.

Process showing the production of RDF at an MSW facility.



Source: Municipal Solid Waste Management in Developing Countries – 2015 - International Standard Book Number-13: 978-1-4987-3774-6

Gasification or

Pyrolysis

This is also known as Gasification the technology to be used in the new Energy Plants

The pyrolysis process is also called *destructive distillation*. Some solid waste management professionals consider gasification and pyrolysis the same process. In reality, they have significant differences: pyrolysis uses an external source of heat to perform the endothermic pyrolytic reaction in an oxygen-free environment, whereas gasification converts waste into gaseous substances using air but shows a partial combustion reaction. The pyrolysis process is highly endothermic in nature, whereby organic, thermally unstable substances break down through thermal cracking and condensation reactions in gaseous, liquid, and solid substances. The most suitable waste for pyrolysis contains plastics, paper, and biomasses composed of the major polymeric chains of cellulose, hemicellulose, and lignin. On thermal degradation, these longer, complex chains convert into simpler stable molecules, thus resulting in the formation of oil that can be used as fuel (William 2005). The pyrolysis process is classified into three different classes based on operating parameters

Types of Pyrolysis Process Based on Different Parameters

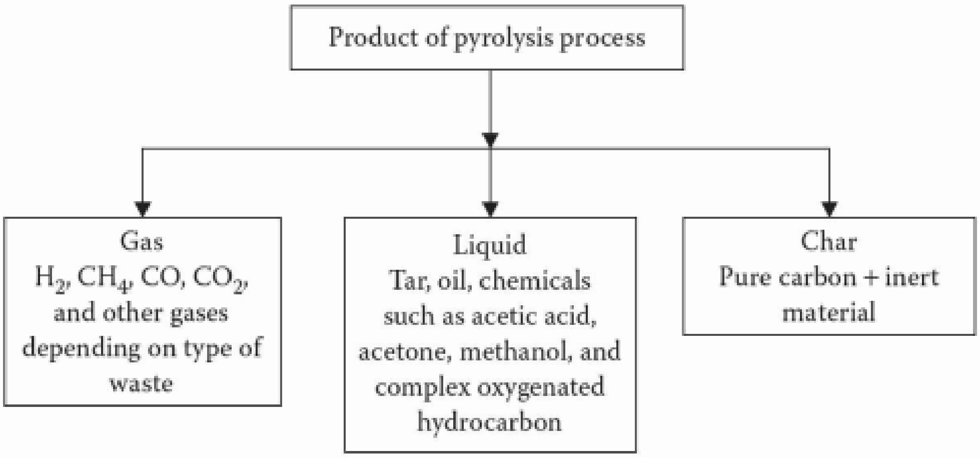
	Types of Pyrolysis Process		
Parameters	**Slow**	**Fast**	**Thermolysis**
Temperature (K)	550–900	850–1250	1050–1300
Heating rate (K/s)	0.1–10	10–200	>1000
Particle size (mm)	5–50	<1	<0.2
Retention time (s)	300–3600	0.5–10	<0.5

Source: Agarwal, M. 2014. An investigation on the pyrolysis of municipal solid waste. In PhD thesis from the School of Applied Sciences, College of Science, Engineering and Health, RMIT University.

Source: Municipal Solid Waste Management in Developing Countries – 2015 - International Standard Book Number-13: 978-1-4987-3774-6

Fig 34. Types of Pyrolysis (Gasification) based of Different Parameters

Component Technologies for Municipal Solid Waste Management



Source: Municipal Solid Waste Management in Developing Countries – 2015 - International Standard Book Number-13: 978-1-4987-3774-6

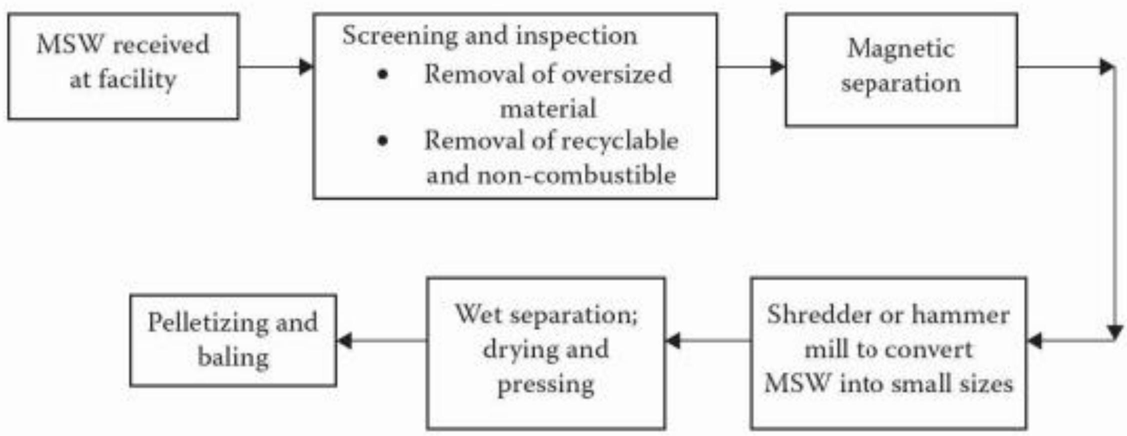
Refuse-Derived Fuel

RDF is generated from the mechanical processing of mixed MSW in which the noncombustible portion of solid waste is removed to produce the most homogeneous mixture. In comparison with mass-burn facilities, RDF-based facilities recover valuable recyclable products from mixed waste before converting them into pellets or fluff. RDF systems primarily perform two functions: production and combustion; production facilities remove recyclables such as glass and ferrous materials and reduce the size to produce different types of RDF such as fluff, pellets, and bricks. The most suitable waste for RDF production should have a high carbon content after the separation of recyclables

Fig 35

Types of RDF System

1. *Shred and burn system*: This is the simplest RDF system, in which minimal processing of unprocessed solid waste is done, such as the removal of ferrous materials. In this system, there is no provision for the removal of the noncombustible portion of solid waste. After



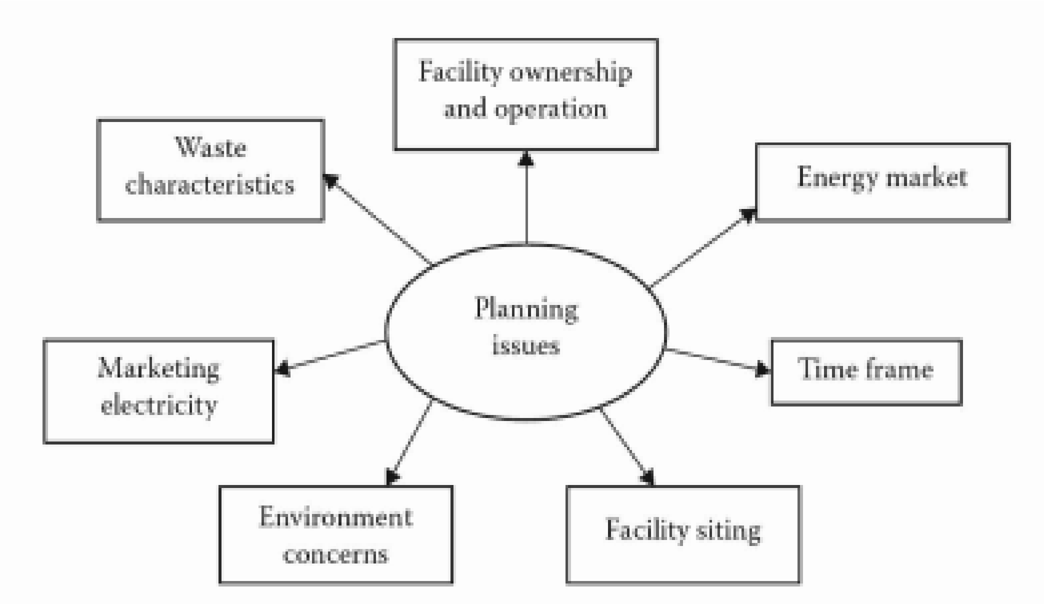
Source: Municipal Solid Waste Management in Developing Countries – 2015 - International Standard Book Number-13: 978-1-4987-3774-6

minimal processing, solid waste is shredded to the required particle size and then sent to the combustor.

2. *Simplified process system*: In this type of RDF system, mixed solid waste is processed mechanically to remove noncombustible, recyclable, and ferrous materials. After proper processing, solid waste is finally put into the shredder to create homogeneous particles 10–15 cm in size for optimal energy recovery during the combustion process (CED 2012).

In developing nations, MSW is found in heterogeneous forms with low heat value and high moisture content, due to which mass-burn facilities cause air pollution, whereas RDF-based incinerators solve this problem to some extent. Despite the fact that RDF facilities remove contaminants and recyclables from the combustion process, the production of RDF is a complex process that increases the operation and maintenance cost of the plant and, hence, reduces the reliability of the facility.

Fig 36. Planning issues of Energy Plants



Source: Municipal Solid Waste Management in Developing Countries – 2015 - International Standard Book Number-13: 978-1-4987-3774-6

9. LEGISLATION AND REGULATORY REQUIREMENTS:

The following pages 150 to 164 taken from the ENVIRONMENTAL RESOURCES MANAGEMENT report produced by Tullow Ghana Ltd. PENNGATE have taken note of this useful report.

Waste Management Policy and Legal Framework

Although Ghana currently has no specific waste law, general waste regulations or hazardous waste regulations, there is a policy framework that guides the management of hazardous, solid and radioactive wastes. This is embodied in the Local Government Act (1994), Act 462 and the Environmental Sanitation Policy (ESP) of 1999.

Ghana established an Environmental Protection Agency (EPA) in 1994 under the auspices of the Ministry of Environment and Science and has developed some environmental legislation, principally the Environmental Protection Agency Act 490 and Environmental Assessment Regulation LI 1652. The main tool of control is then the environmental assessment procedure.

The policy framework guiding the management of hazardous, solid and radioactive waste includes the Local Government Act (1994), Act 462 and the Sanitation Policy (ESP) of 1999. The Environmental Sanitation Policy lays down basic waste management policies with regard to solid wastes and industrial and hazardous wastes.

Specifically:

1. disposal of solid wastes must be in accordance with any standards and
2. procedures prescribed by the EPA and any other regulatory agencies;
3. industrial wastes must be conveyed to approved disposal sites; and
4. generators of hazardous wastes must comply with standards prescribed by
5. the relevant regulatory agencies for storage, collection, transportation and
6. final disposal.

While regulatory authority is vested in the EPA, general Municipal Solid Waste (domestic waste) MSW management in Ghana is the responsibility of the Ministry of Local Government and Rural Development, which supervises the decentralised Metropolitan, Municipal and District Assemblies (MMDAs). The MMDAs are responsible for the collection and final disposal of solid waste through their Waste Management Departments (WMDs) and their Environmental Health and Sanitation Departments.

To summarise, under this framework, the MMDAs are responsible for the collection and final disposal of solid waste through their WMDs and their Environmental Health and Sanitation Departments. Industrial wastes are, as is typically the case in other countries, the responsibility of the industry generating those wastes.

Historic Laws Governing Waste Management

The EPA Act 490 was the enabling legislation and, with regard to waste management, it enables the Minister to make regulations concerning: the type, quality or conditions or concentration of substances that may be released into the environment; and the collection, storage, recovery, recycling or disposal of substances which may be hazardous to the environment.

To date, no regulations have been made concerning the handling, treatment and disposal of industrial and hazardous wastes.

As indicated, one of the roles of the EPA is to prescribe standards and guidelines concerning the discharge of wastes and control of toxic substances. To date three relevant guideline documents have been published:

• Ghana Landfill Guidelines, May 2002;

• Guidelines for the Management of Healthcare and Veterinary Waste in Ghana, 2002; and

• Best Practice Environmental Guidelines Series No. 3 – Manual for the Preparation of District Waste Management Plans in Ghana, July 2002.

The Ghana Landfill Guidelines published by the EPA are an attempt to promote the phased upgrading of landfills, initially by improving site selection, waste compaction and drainage resulting in 'High Density Aerobic Landfills' (target is for all Metropolitan, Municipal and Large Urban landfills by 2010) and culminating in achieving operation of 'Sanitary Landfills' by 2020 (again for larger landfills). Progress is being made to achieve these targets.

The planning manual refers to the acceptability of disposal of industrial wastes at municipality landfills provided these are "previously identified and quantified by the assembly for handling". The guidelines do not clarify the meaning of this but it is presumed that this means that if an enterprise has quantified its wastes which are suitable for landfill and the municipality landfill has adequate planned capacity then the wastes can be accepted for landfill.

Waste Classification Systems

There is currently no full waste classification system in place in Ghana. The 1999 Environmental Sanitation Policy sub-classifies 'solid wastes' as:

a. solid wastes; and
b. hazardous and clinical (hospital) wastes.

The policy covers 'liquid wastes' (sewage etc) and also sub-classifies

'industrial wastes' as:

(i) solid wastes;
(ii) liquid wastes;
(iii) gaseous wastes; and
(iv) toxic, radioactive and other special wastes.

Permitting Requirements

The EPA is responsible for the environmental and operational permitting of waste management facilities; this includes treatment and final disposal facilities.

INTERNATIONAL AGREEMENTS AND CONVENTIONS

MARPOL Convention

Ghana is a signatory to the MARPOL Convention (Marine Pollution Convention), although not all parts are ratified yet, and as such is expected to have facilities for the reception of 'MARPOL wastes' which include oily wastes and refuse (and sewage when this part is ratified). Ghana currently has limited facilities capable of managing MARPOL wastes although Takoradi port has access to a good standard facility for oily wastes.

Basel Convention

Ghana has acceded to the Basel Convention on transboundary movement of hazardous waste, which implements controls on the movement of hazardous (and certain other) wastes into or between signatory countries.

Under the Basel Convention, transboundary movements of hazardous wastes or other prescribed wastes can take place only upon prior written notification by the State of export to the competent authorities of the States of import and each state of transit. Each shipment of hazardous or other prescribed waste must be accompanied by a movement document from the point at which a transboundary movement begins to the point of disposal. Transboundary movements are generally approved, if:

(a) the state of export does not have the capability of managing or disposing of the waste in an environmentally sound manner; and

(b) the receiving state has appropriate, environmentally sound facilities, and agrees to accept the waste.

Ghana acceded to the Basel Convention on 30 May 2003 (accession has the same legal effect as ratification) which means that it must comply with all the requirements of the Convention. Therefore, certain wastes generated in Ghana, or within its territorial waters, that are exported to another country, will be subject to the provisions of the Basel Convention.

Bamako Convention

Ghana is a signatory to the 1991 Bamako Convention on the Ban of the Import into Africa and the Control of Transboundary Movement of Hazardous Wastes within Africa. This convention is supplementary to the Basel Convention and covers movement of hazardous waste into or between signatory African countries. The Convention has many provisions virtually identical, or analogous, to the Basel Convention provisions.

WASTE MANAGEMENT INFRASTRUCTURE

Waste Collection and Transportation

There are a number of companies in Ghana collecting and transporting domestic-type solid wastes. The largest of these is ZoomLion which has a large number of collection vehicles ranging from tricycles to 40m container trucks and compacting waste collection trucks.

There are rudimentary capabilities for collection and transportation of liquid and hazardous wastes.

General Solid Waste Management

Waste management treatment and disposal infrastructure is currently underdeveloped in Ghana; for example, landfills are still at the stage of municipal dumps rather than sanitary or 'engineered' landfills. This is the situation in the Western Region. Whilst these facilities are principally intended for the collection and management of general solid wastes from domestic sources, general solid wastes from commercial and industrial sources are also disposed of at these facilities. Such facilities are therefore generally available for non-hazardous general solid wastes generated by oil and gas companies operating in Ghana (although the planning manual referenced specifies that this is acceptable only provided that they have been 'previously identified and quantified by the Assembly for handling').

The majority of these municipal dumps have no environmental protection measures and therefore are not considered Best Practicable Environmental Option (BPEO) and are unsuitable disposal sites for hazardous or potentially hazardous wastes. The lack of control at these sites and the typical extent of unsafe scavenging and potential for water pollution raises the issue as to whether these are suitable for general, non-hazardous, solid wastes generated by Tullow other than as a short-term measure.

A sanitary, lined, landfill funded by the World Bank was planned for Sekondi- Takoradi (with 10 cells and enough capacity for approximately 15 years of waste arisings) and development commenced but the project ceased and construction was never completed. The partially developed landfill at Takoradi remains a potential resource, however, if the project is reactivated. The Sekondi-Takoradi Metropolitan Assembly (STMA) is negotiating to reactivate this project with World Bank funding and a company is currently re-finalising the design.

Unfortunately, STMA is currently depositing waste at the site of the stalled World Bank landfill. At present the waste is being deposited away from the partially engineered leachate treatment area of the site but within the Phase 3 fill area. There is a risk that the longer this uncontrolled operation continues the more of the site will be unavailable for Phase 3 or even Phase 2 development. This waste could of course be moved to Phase 1 when it opens but this will make operations more complex and result in Phase 1 filling very rapidly. If the uncontrolled tipping at the site continues for much longer the World Bank may consider that the original plans to develop the site as a modern engineered landfill are no longer viable. It must be assumed that, in the short term, the only 'landfill' which will be available for solid wastes in the Takoradi area will be this site. It is currently operating as an uncontrolled dump; over which the EPA has expressed deep concern.

Industrial and Hazardous Waste Management

There are no dedicated facilities for industrial solid waste management or hazardous waste management other than fairly basic oil water separation facilities as described below.

Industrial solid wastes are generally disposed of to municipal dumps with or without any form of pre-treatment. There is also believed to be widespread illegal dumping.

There is an established procedure for generators of hazardous industrial wastes to inform the EPA (Chemicals Department) who will advise on sampling and analysis of the waste and then advise any necessary treatment and/or disposal procedures to be followed. This may include the supervision of the actual disposal of wastes by EPA staff. This pragmatic approach is commendable, has been adopted as a temporary measure in other countries, and works to a certain degree. However, from our discussions with local waste management operators, it appears that a great many generators of hazardous wastes are bypassing this system and dumping their hazardous wastes in an uncontrolled manner.

MARPOL Waste Management Facilities

There are a number of contractors in Ghana offering collection and disposal services for MARPOL wastes (oily and oil/water wastes). The majority of these technologies are very basic, comprising simple gravity separation, with no specific technologies to assist separation and no use of chemical surfactants.

The exception to this, in terms of companies operating in Takoradi, is Zeal Environmental, which has an arrangement with the Takoradi Power Station to utilise spare capacity of the power station's oil/water treatment system. This system features a three-stage separation system – gravity separation basin, separator and a Dissolved Air Flotation (DAF) separator. This facility may be regarded as BPEO - Best Possible Environmental Option - for oil and oil/water wastes. The only remaining issues are effluent discharge quality and the disposal of solid/sludge residues (duty of care auditing needed).

Refuse and sewage wastes are dealt with via the Metropolitan Assembly's normal routes for such wastes with refuse going to the existing waste dump. There are no facilities available for the management of chemical wastes in bulk or packaged form.