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TA-8566 REG: Mainstreaming Integrated Solid Waste Management in Asia - Solid Waste Management Team (46248-001)

Report on possible options and practices for reducing GHGs in the SWM sector

March 2017

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Executive Summary

The challenges in municipal solid waste (MSW) management to developing countries may be more acute in comparison with more developed countries. Africa, East Asia and Pacific region, Eastern and Central Asia and South Asia regions are likely to experience relatively higher growth rate of waste generation and per capita MSW generation by 2025. On top of the anticipated higher generation, MSW could be a more severe challenge to the developing countries because of various limitations such as technical and financial capacities, government regulations and policies, land availability, social perspective and institutional mechanisms, as well as lack of long term planning and strategies.

Asian Development Bank (ADB) initiated a Regional Capacity Development Technical Assistance (R-CDTA) project namely “Mainstreaming Integrated Solid Waste Management in Asia” which aims to support three shortlisted countries, tentatively including Philippines, Sri Lanka and Thailand. This project comprises selection of five case study cities (CSCs), formulation of integrated solid waste management (ISWM) strategies, identification of feasible solid waste management projects and delineating their structures, and providing recommendations on possible policy and regulatory reforms and institutional development to foster private-public partnership in this sector.

This report is formulated based on various waste disposal methods, greenhouse gas (GHG) emissions sources and technologies available to mitigate those emissions. The report explains the suitable practices prevailing globally and appropriate technologies to be selected for different waste disposal methods.

Table of Contents

List of figures

List of tables

ABBREVIATIONS

AD	Anaerobic digestion
BTU	British Thermal Units
C/N ratio	Carbon/Nitrogen ratio
CFM	Cubic Feet per Minute
CH_4	Methane
CHP	Combined heat power plant
CO	Carbon mono-oxide
CO_2	Carbon di oxide
GHG	Greenhouse gases
HAP	Hazardous air pollutants
kW	kilo Watt
LFG	Landfill gas
MSW	Municipal solid waste
MW	Mega Watt
MWh	Mega Watt hour
NO_X	Nitrous oxides
NSPS	New Source Performance Standards
OECD	Organisation for Economic Co-operation and Development
psi	Pounds per Square Inch
RDF	Refuse derived fuel
SO_X	Sulphur oxides
WTE	Waste to Energy

1. Municipal solid waste (MSW)

Asia is the highest populated continent in the world accommodating more than one billion people in its cities. The high rate of population growth and urbanization, together with economic growth, not only accelerates consumption rates in developing cities of Asia, but also accelerates the generation of wastes. The generation of large quantities of wastes is difficult and costly to manage. By 2025, Asia will be inhabited by more than four billion people, half of them in cities and will produce more than 180 million tons of municipal solid waste (MSW) per day[1]. This huge amount of MSW creates enormous challenges for all Asian cities across the whole economic spectrum.

Municipal solid waste refers to the wastes from household such as organic, food, paper etc., streets, public places, shops, offices, hospitals and small industrial wastes. Management of these wastes falls under the responsibility of municipal or other governmental authorities. Currently, the collection rate of MSW around the world is between 50% and 90%[2]. Figure 1-1 shows the MSW generated from various regions.

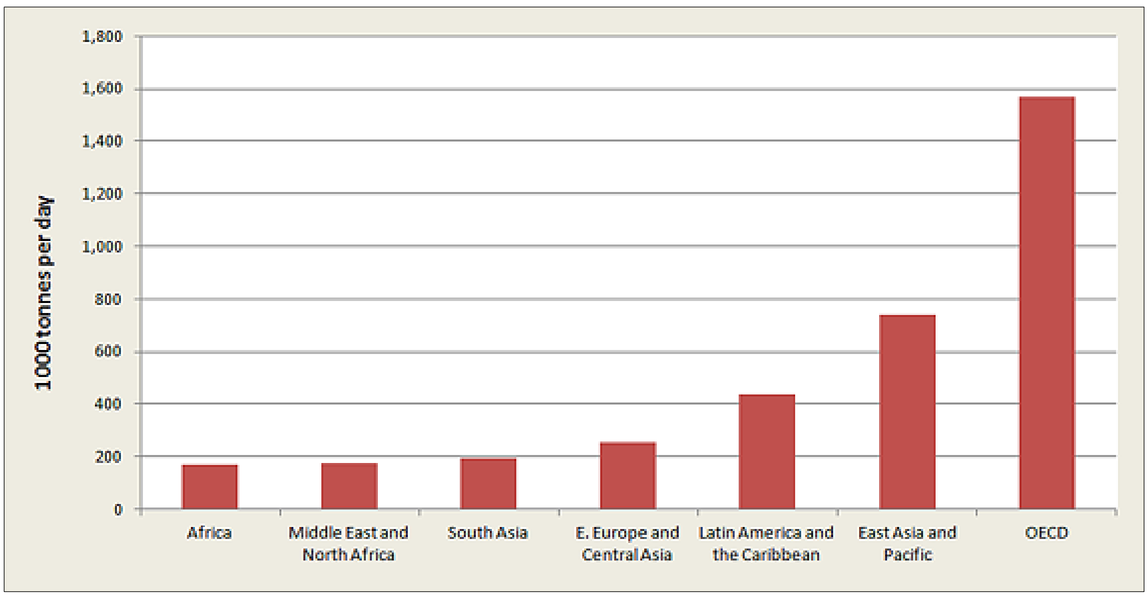


Figure 1-1 Worldwide MSW generation trend

By 2020, MSW sector will contribute 11% of the total global methane emissions. Figure 1-2 explains the contribution of various sources towards global anthropogenic methane emissions. Emissions from enteric fermentations (methane generation due to digestive process in animals) tops the major contributor followed by oil &gas usage and MSW landfills.

[1] http://waste-management-world.com/a/eastern-prospect-municipal-solid-waste-management#notes

[2] What a waste: a global review of solid waste management, 2012

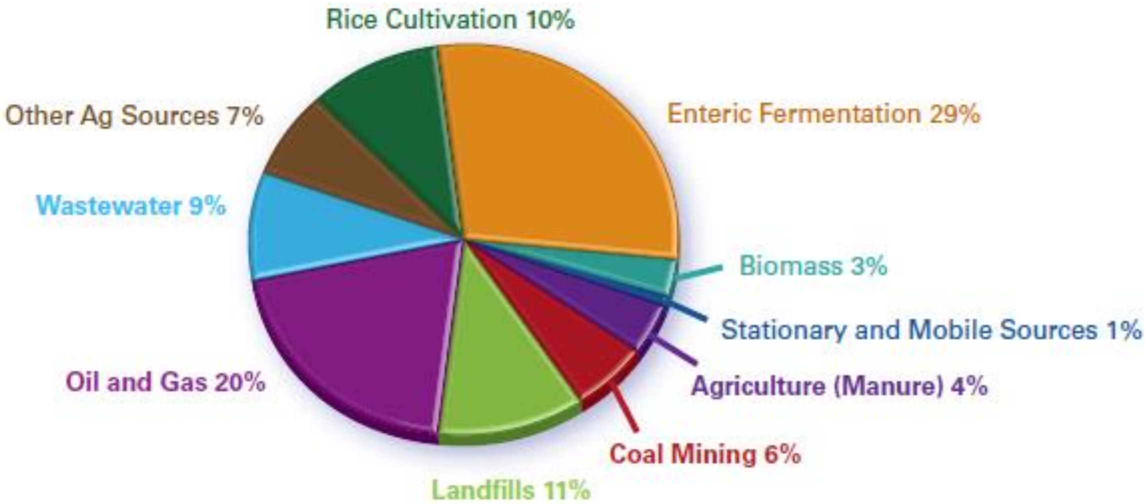
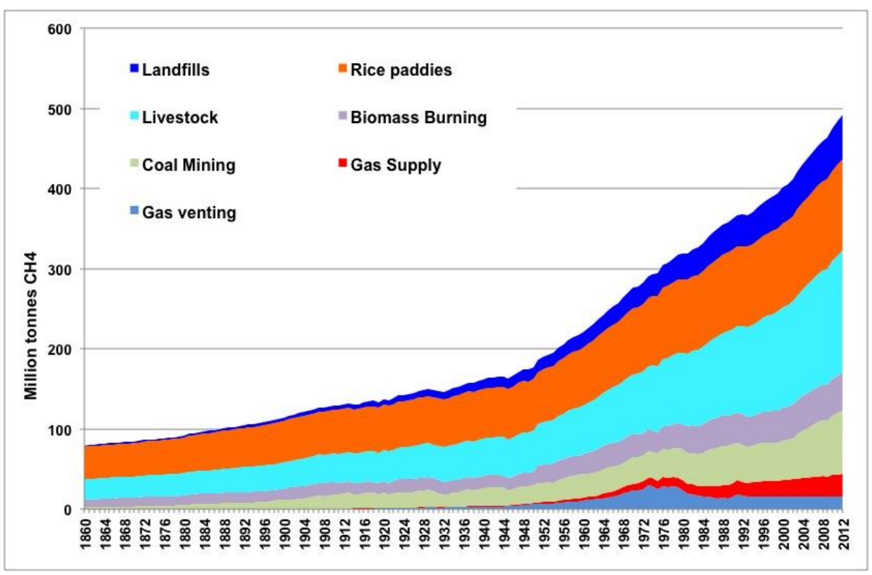


Figure 1-2: Sources of global methane emission by sectors[3]

The improper method of handling MSW leads to the emission of huge amount of methane and increases the level of GHG. It is estimated that the global emission of methane from uncontrolled landfill sector will be 959 million tCO_2e by 2030[4]. Figure 1-3 presents the increasing trend in methane emissions from MSW landfills.



[3] https://www.globalmethane.org/documents/gmi-mitigation-factsheet.pdf

[4] https://www.globalmethane.org/documents/Landfill-MAC-Report-2014.pdf

Figure 1-3: Methane emissions trend[5]

Figure 1-4 shows the emission reduction potential by 2030 in relation to cost factor. 12% of the emission reduction potential is possible through proper handling and disposal of MSW at minimal cost. Further 49% emission reduction might be feasible with technology adaptation. Any further emission reduction would be possible only with very high investment cost.

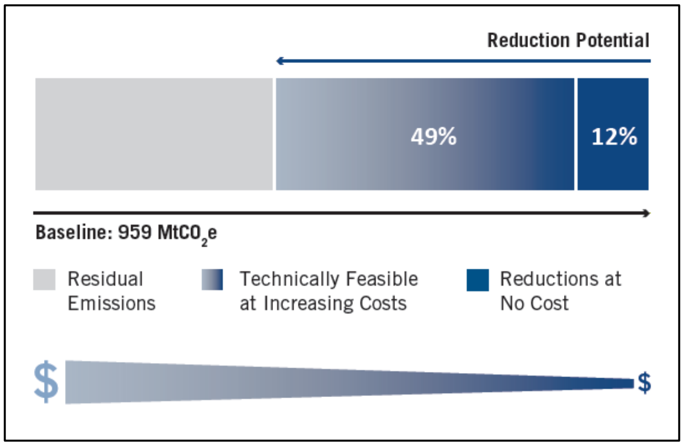


Figure 1-4: Methane emission reduction potential Vs cost factor, 2030[6]

1.1. Waste Composition

The waste generation pattern of each country is rapidly increasing due to increase in urbanization and industrial development of the country. MSW is generated from different types of sources according to income level and status of the population. The generators, source of generation and waste types are described in the Table 1-1.

Table 1-1 Sources of wastes and generators

Source	Typical waste generators	Types of solid waste
Residential	Single and multi-family units	Food wastes, paper, cardboard, plastics, textiles, leather, yard wastes, wood, glass, metals, ash, special wastes (e.g., bulky items, consumer electronics, white goods, batteries, oil, tires), and household hazardous wastes
Industrial	Manufacturing units, power and chemical plants	Housekeeping, packaging and food wastes, ashes, construction and demolition debris, hazardous wastes, special wastes
Commercial	Stores, hotels, restaurants,	Paper, cardboard, plastics, wood, food wastes, glass, metals, special wastes, hazardous

[5] http://www.manicore.com/anglais/documentation_a/greenhouse/evolution.html

[6] https://www.globalmethane.org/documents/Landfill-MAC-Report-2014.pdf

Source	Typical waste generators	Types of solid waste
	markets and malls	wastes
Institutional	Schools, hospitals, prisons, government offices	Paper, cardboard, plastics, wood, food wastes, glass, metals, special wastes, hazardous wastes
Construction and demolition	New construction sites, road repair, renovation and demolition sites	Wood, steel, concrete, dirt, stones etc.
Municipal services	Street cleaning, parks, beaches, and other recreational areas, treatment plants	Street sweepings, landscape and tree trimmings, general wastes from parks, beaches, other recreational areas, sludge
Process	Heavy / light extraction and process units, refineries	Process wastes, scrap materials, off-specification products, slag, mineral tailings, unused raw materials
Agriculture	Crops, farms, orchards, vineyards, dairies, feedlots	Spoiled food wastes, crop and animal wastes, hazardous wastes (e.g., pesticides)

Source: World Bank, 1999

In the MSW generation stream, waste is broadly classified into organic and inorganic wastes. The composition of waste differs for different countries and regions. However, 6 categories of waste are broadly classified for easy and effective solid waste management. The different categories and their types are described in Table 1-2.

Table 1-2: Categories of waste

Categories	Types of waste
Organic	Food scraps, leaves, grass, bushes, waste, wood, process residues
Paper	Paper scraps, cardboard, newspapers, magazines, bags, boxes, wrapping paper, telephone books, shredded paper and paper beverage cups.
Plastic	Bottles, packaging, containers, bags, lids, cups
Glass	Bottles, broken glassware, light bulbs, colored glass
Metal	Cans, foil, tins, non-hazardous aerosol cans, appliances (white goods),

	railings, bicycles
Others	Textiles, leather, rubber, multi-laminates, e-waste, appliances, ash, other inert materials

Collection and disposal of waste is a very hectic problem for the developing countries in Southeast Asia and their collection efficiency is still rated as very poor. Waste composition is influenced by factors such as culture, economic development, climate, and energy sources. Waste composition specifies the components of the waste stream as a percentage of the total mass or volume. According to World Bank, the developing countries have the high composition of organic waste and projected to increase three fold by 2025. The schematic diagram of waste composition in Southeast Asian countries is shown in Figure 1-5.

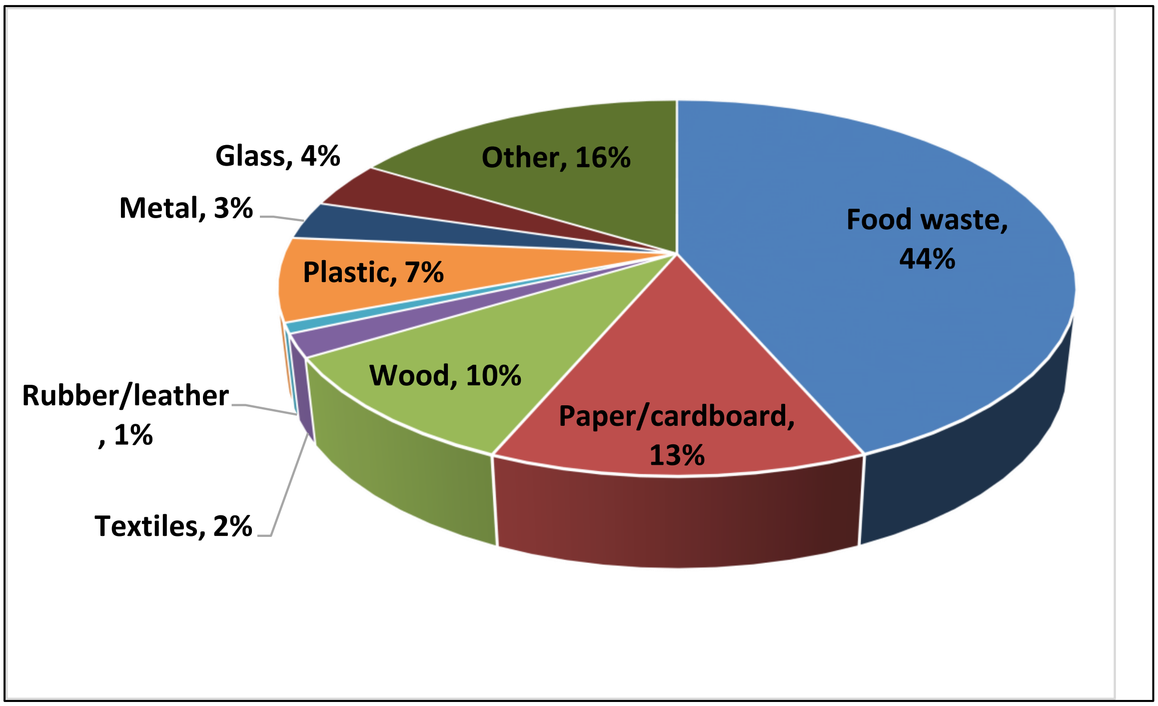


Figure 1-5: Waste composition in Southeast Asia[7]

1.2. Emissions from MSW

Apart from waste handling, reduction of emissions from the waste and its vulnerability on the neighbourhood is also a big challenge to the countries. Since the capital cost of waste management is very high, the developing countries are unable to implement an efficient solid waste management. The major GHG emissions from MSW are methane (CH_4), CO_2, NO_x and other traces of inert gases which are more harmful than the emissions from fossil fuels. The Figure 1-6 shows the type of waste collected and transported and possible emissions during the process.

[7]Waste generation, composition and management data, IPCC 2006

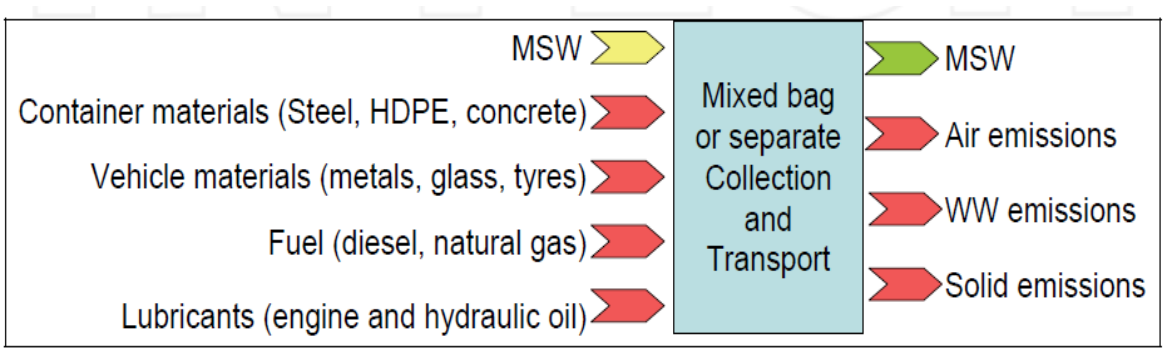


Figure 1-6: GHG emissions from collection and transport of wastes

Different wastes and waste management activities have varying impacts on energy consumption, methane emissions, and carbon storage. Recycling reduces GHG emissions by preventing methane emissions from landfills or open dumps and by preventing the consumption of energy for extracting and processing raw materials. For example, the life cycle of source of emissions and waste management process in paper industry is shown in Figure 1-7.

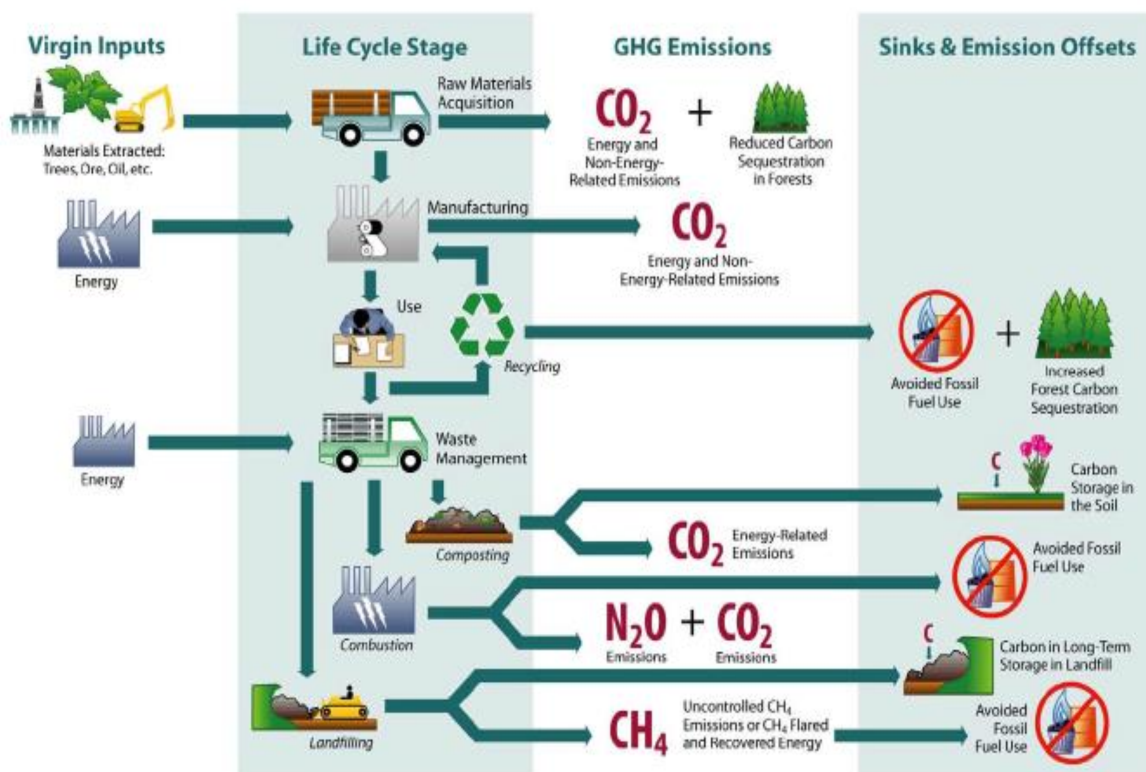


Figure 1-7: GHG emissions and waste management process in paper industry

Communities are looking for the possible ways to prevent climate change by implementing an integrated solid waste management program. Ideally MSW management should incorporate the principles of waste minimization, recycling, resource recovery as well as an integrated processing & disposal facility, leading to effective service delivery in a sustainable manner.

Management of solid waste is required at all stages from waste generation to the final disposal. An integrated solid waste management plan would consist of:

- understanding the current waste management practices
- identifying waste management needs
- setting priorities for actions required
- identifying budget needs
- coordinating with different stakeholders
- measuring progress in terms of targets achieved
- modifying priorities as the plan develops
- communicating and coordinating with the external agencies/local agencies to achieve the targets

The Figure 1-8 shows the complete schematic of the integrated solid waste management.

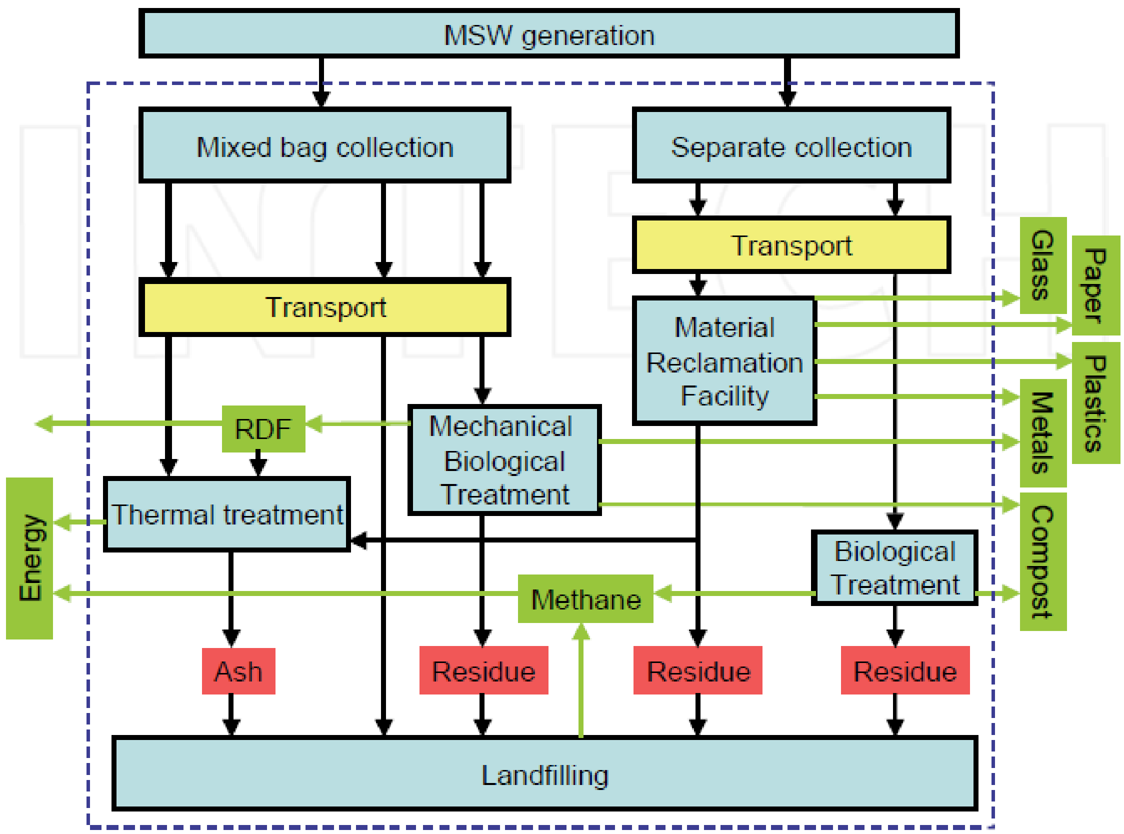


Figure 1-8: Integrated Solid Waste Management

Comparison of different technologies based on segregation requirement, land requirement, moisture content, toxicity, pollution, input & output of the technology and other limitations, etc. are explained in Appendix 1 and 2.

2. Opportunities for GHG emission reduction in MSW sector

The hierarchy of waste management insists on the reduction of waste, recycling and reusing it in the most environmental friendly way. Source reduction begins as initial phase before the waste is disposed in the dumping yard. Source reduction happens in three stages namely reduction of wastes, recycling of the sorted waste and reuse of the end products.

Due to technical and economic limitations of recycling, product design, inadequate source separation and lack of sufficient markets that can use recovered materials, most of the MSW generated ends up in landfills.

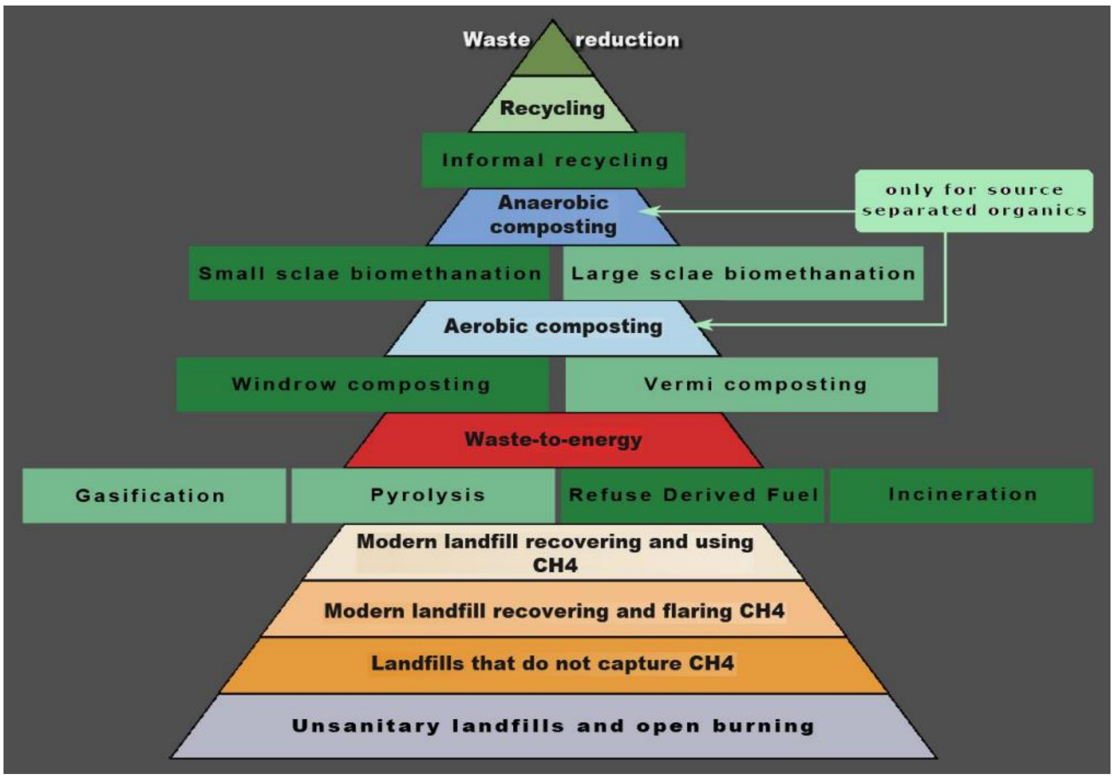


Figure 2-1: Hierarchy of waste management and their options[8]

Waste minimization and the GHG emission reduction occurs by three forms of recovery of waste namely:

- Material recovery
- Energy recovery
- Sanitary Landfill

Figure 2-2 shows the simplified form of solid waste handling and different forms of GHG emission and reduction in treatment process.

[8] http://wtert.blogspot.in/2012/03/hierarchy-of-sustainable-waste.html

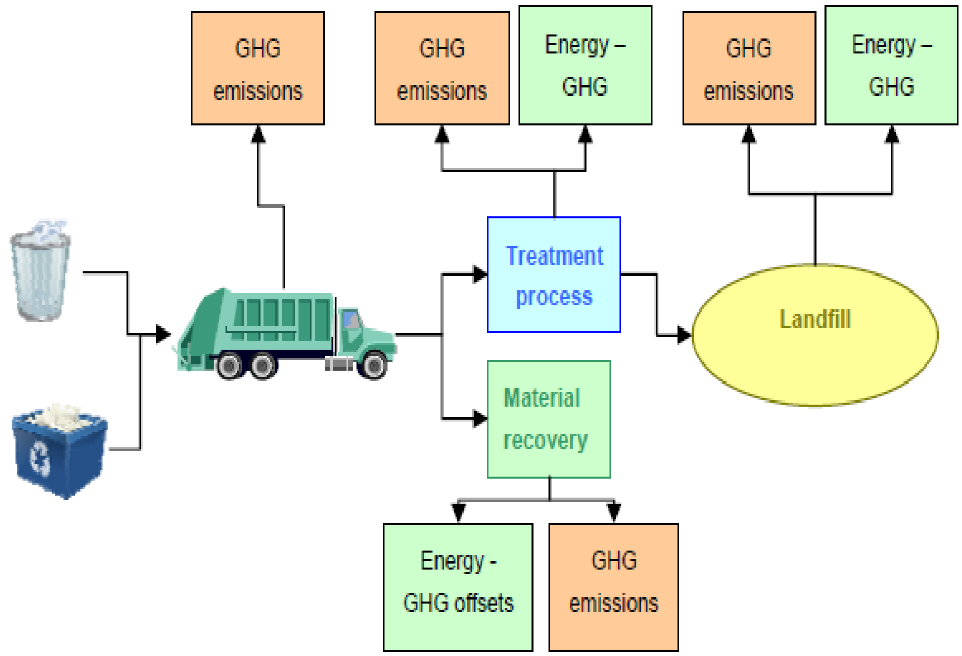


Figure 2-2: Schematic diagram of waste management and GHG emissions

2.1. Material recovery

Material recovery is the most preferable and has highest priority in the hierarchy of waste management. Material recovery can be made through two forms of treatment methods:

- Reduce, recycle and reuse
- Composting

2.1.1. Reduce, recycle and reuse (3R's)

The main objective of this 3R's concept is to reduce the amount of waste disposed into landfill. Recycling is the reprocessing of used materials and breaks materials to its main component to produce new products. Recycling is the most common and cost effective method to produce valuable materials from waste rather than virgin raw materials (such as metal, plastic, glass, electronic waste, etc.).

For example, Figure 2-3 shows the recycling of used plastics into new products which involves sorting of materials, crushing, regeneration and end products.

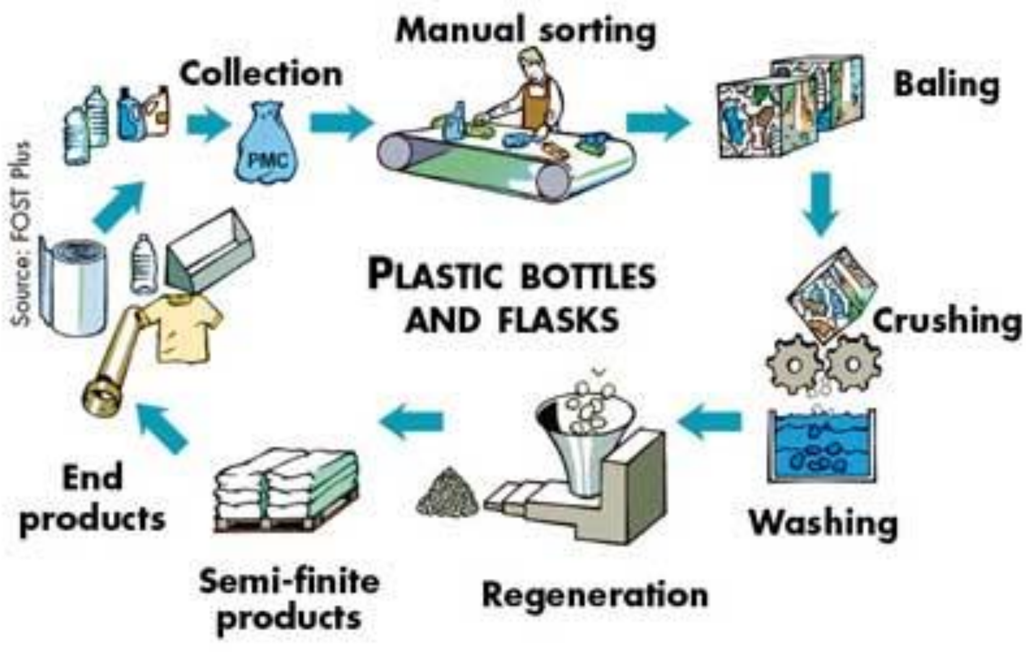


Figure 2-3: Recycling of Plastics

Advantages of 3R's concept

The value of the recycled material may vary significantly depending on the demand and uses for the end product but it has various advantages over environment protection, economic growth, etc. The following are the advantages of 3R's method;

- Reduction of waste volume
- Cost savings in collection, transport, and disposal
- Longer life span for landfills
- Reduction of adverse environmental impacts
- Reduction of raw material imports
- Job opportunities and income for the people
- Cheap products (made from recycled materials) for the poor
- Sustainable use of resources: for example, less energy consumption and thus less pollution
- Reduced amount of waste going to storage sites, resulting in a more manageable system

2.1.2. Composting

Composting is a form of waste stabilization, which requires special conditions of moisture and aeration to produce thermophilic temperatures to deactivate the pathogens in the wastes. Composting is done in two forms namely,

- Aerobic composting
- Anaerobic composting

Aerobic composting is the decomposition of organic substrates in the presence of oxygen which breakdown into carbon-di-oxide, water and heat.

Anaerobic composting is the decomposition of organic substrates in the absence of oxygen which breakdown into methane, carbon-di-oxide, organic acids and alcohol.

Figure 2-4: Large scale aerobic composting[9]

Composting process and methods is discussed in detailed in the chapters 3 and 4.

2.2. Energy recovery

Energy recovery is the method of recovery of different forms of energy from MSW. Energy recovery falls below the material recovery in waste hierarchy by the difference in recovery efficiency. For effective management of MSW, various treatment methods are adopted and tested for feasibility.

The major end products of energy recovery are methane, CO_2, heat, renewable fuel, electricity and organic manure.

Waste to Energy (WTE):

Waste to Energy is a controlled combustion process taking place in an enclosed equipment, which thermally breaks down solid waste into ash residue, electricity, heat, steam, etc. The objective of this process is to reduce the volume of MSW. Different treatment techniques of WTE are as follows;

- Pyrolysis
- Biomass combustion
- Gasification
- Reduced derived fuel

[9] Large scale composting facility in Santa Maria, California

- Incineration

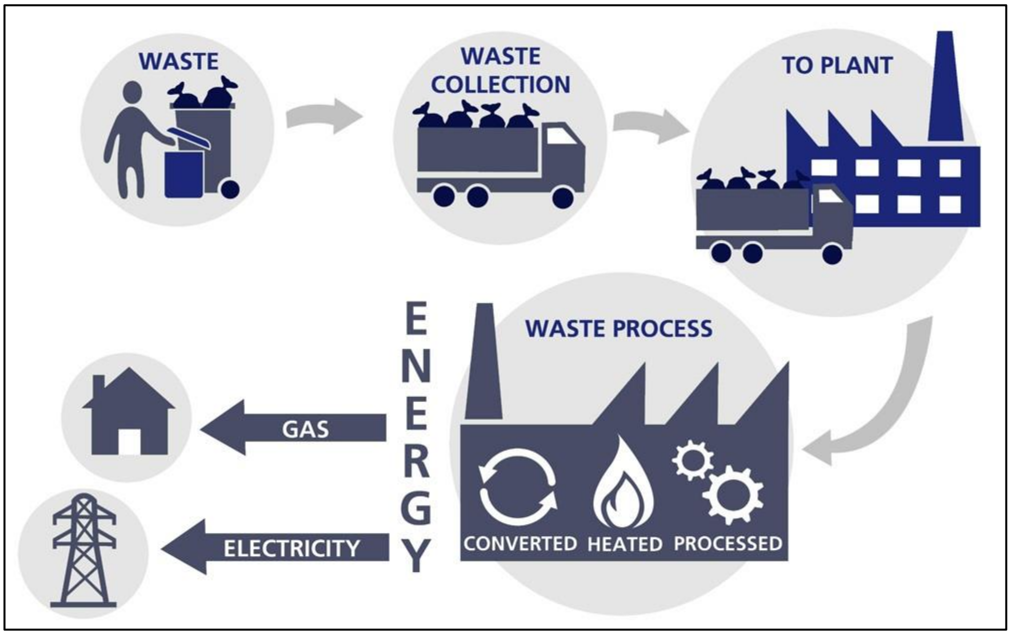


Figure 2-5: Waste to Energy Process[10]

In this report, waste to energy (WTE) is discussed in detail in chapter 5.

2.3. Sanitary landfill

Sanitary landfill is a common method of treating municipal solid waste under anaerobic condition. During treatment process, solid waste undergoes metabolic breakdown into organic materials and produces landfill gas enriched with high amount of methane. Instead of letting out gases into the atmosphere, landfill gases are recovered, purified and used to produce heat and electricity.

[10] http://www.ecomena.org/renewable-energy-from-wastes/

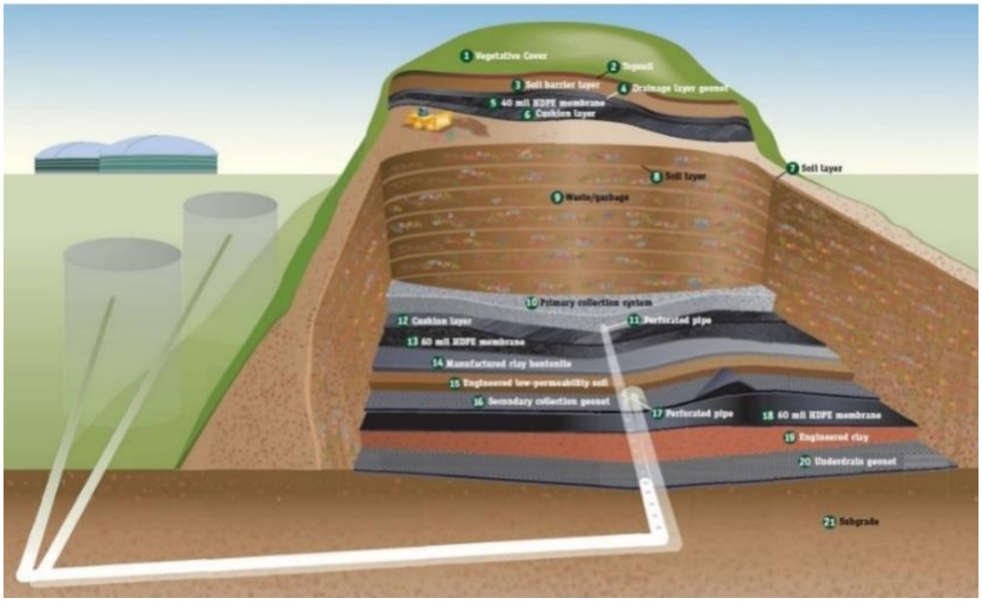


Figure 2-6: Schematic diagram of landfill site[11]

3. Aerobic Composting

Composting is the natural process of decomposition of organic matter by microorganisms under controlled conditions. Raw organic materials such as crop residues, animal wastes, food garbage, municipal solid waste, etc. are processed to yield compost as an end product. The process takes place in the presence of ample oxygen and microorganisms which break down waste in to organic matter to produce CO_2, ammonia, water and heat. The compost is highly rich in organic nutrients, causes no harm to environment and acts as a carbon pool when applied as manure for soil enrichment.

3.1. Process:

The process involves the following steps to breakdown the molecular structure of solid waste:

- Waste collection
- Contaminant separation
- Sizing and mixing
- Biological decomposition

Municipal solid waste from the household, small industries, restaurants, etc., are collected, debagged and disposed at a compost area. The waste will be sorted and separated into compostable and non-compostable materials. The compostable materials are grinded or shredded and formed as a pile. After the formation of pile, active composting materials such as bacteria, fungi, etc., which are mesophilic, acts as a catalyst for the rapid decomposition of organic materials. Turned windrow or aerated systems are used for rapid degradation. This process will take almost 8 weeks to 12 months depending upon the climatic conditions. Once these processes get completed, final screening process will take place to remove the bulk materials more than 1 to 1.25 cm.

[11] http://highacreslandfill.wm.com/Sustainability/environmental-protection.jsp

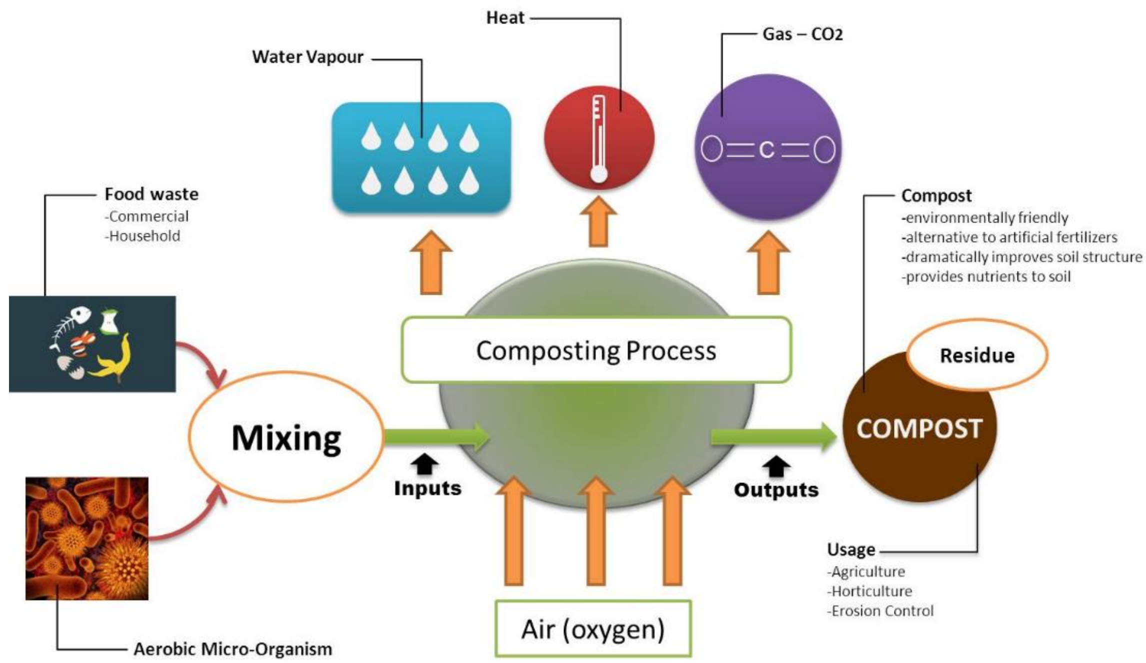


Figure 3-1: Aerobic composting process[12]

3.2. GHG mitigation

Composting is an environmental friendly waste treatment process to handle organic wastes. Although the benefits of composting are evident, GHG can be generated and emitted to the atmosphere during this process contributing to global warming.

The potential GHG emission reductions in composting process are:

- Increases the overall waste volume reduction by segregating organic matter
- Contribute in reduction of emissions by 30% of ~0.3Mt of carbon in various forms from 1 million tons (Mt) of unsorted MSW13
- Enhances the recycling process
- Reduces the energy usage and fuel consumption during waste management process
- Breaks down the potential GHG gases and produce high quality manure
- Reduces the soil degradation and loss of nutrients
- Prevents from deadly diseases like dengue, typhoid, etc.
- Reduces nitrous oxide emissions and increases soil sequestration
- Prevents groundwater contamination from leachate penetration

3.3. Case study

Title of the project : Composting of Organic Content of Municipal Solid Waste in Lahore[14]

[12] http://www.renewableenergy-asia.com/Portals/0/seminar/Presentation/01-Waste%20to%20Energy.pdf

[13] http://www.worldbank.org/urban/solid_wm/erm/CWG%20folder/uwp8.pdf

[14] https://cdm.unfccc.int/Projects/DB/SGS-UKL1248265320.71/view

Location : Lahore, Pakistan

Lahore Compost Private Limited (LCL) has implemented composting plant in incremental phases over time until 1,000 tpd is achieved. The composting plant has started its operation in March 2009. The waste in this processing plant consists of 55% of organic materials. The aerobic windrow type composting is used in this process. As a first pilot phase, 300tpd of waste processing was initiated. The schematic diagram of composting process is shown in Figure 3-2.

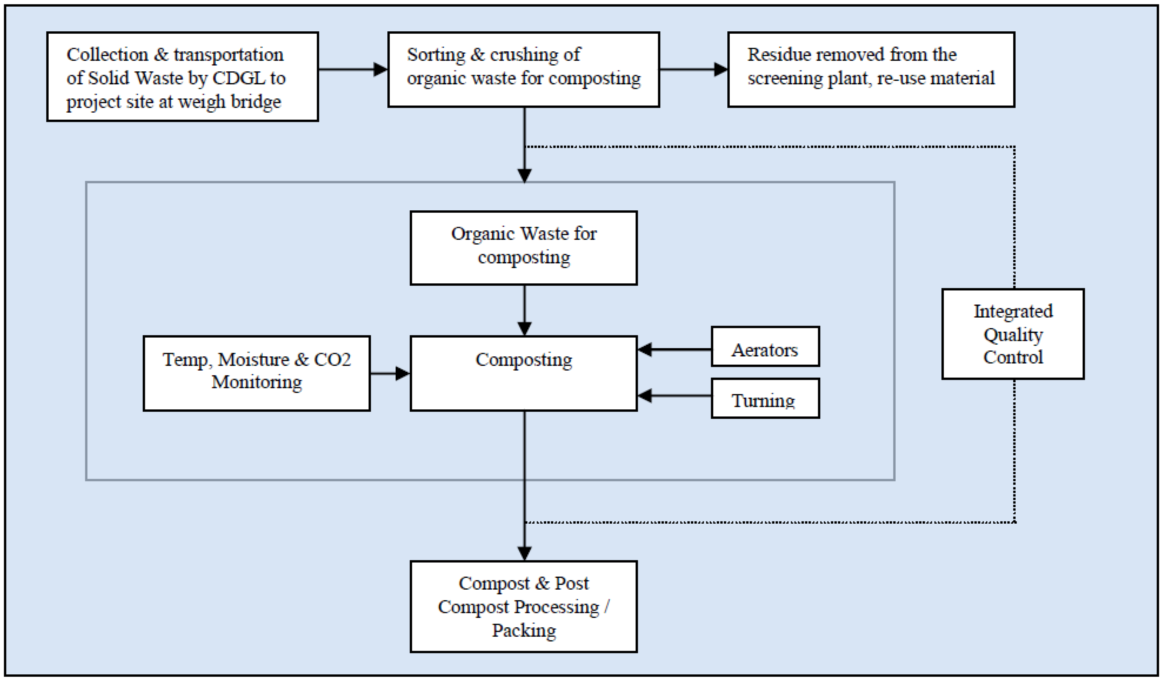


Figure 3-2: Schematic diagram of composting process

This composting process prevents uncontrolled GHG generation and emission from waste that would have been disposed-off at the open dumping yard. It reduces the waste volume and increases the life span of dumping yard. It also increases the soil fertility and water quality. The average annual CO_2 emission reduction from this plant is estimated at around 108,686 tCO_2e.

4. Anaerobic digestion

Anaerobic biodegradation of organic material proceeds in the absence of oxygen and the presence of anaerobic microorganisms. Anaerobic digestion (AD) is the consequence of a series of metabolic interactions among various groups of microorganisms. It occurs in three stages, hydrolysis/liquefaction, acidogenesis and methanogenesis. The AD is carried out in large digesters that are maintained at temperatures ranging from 30°C - 65°C and results in generation of methane (CH_4).

Methane (CH_4) is one of the primary GHG associated with the anaerobic digestion of the wastes having global warming potential of 21 times greater than CO_2. Capturing methane from an AD system is beneficial because it reduces emissions of a harmful GHG from the MSW sector.

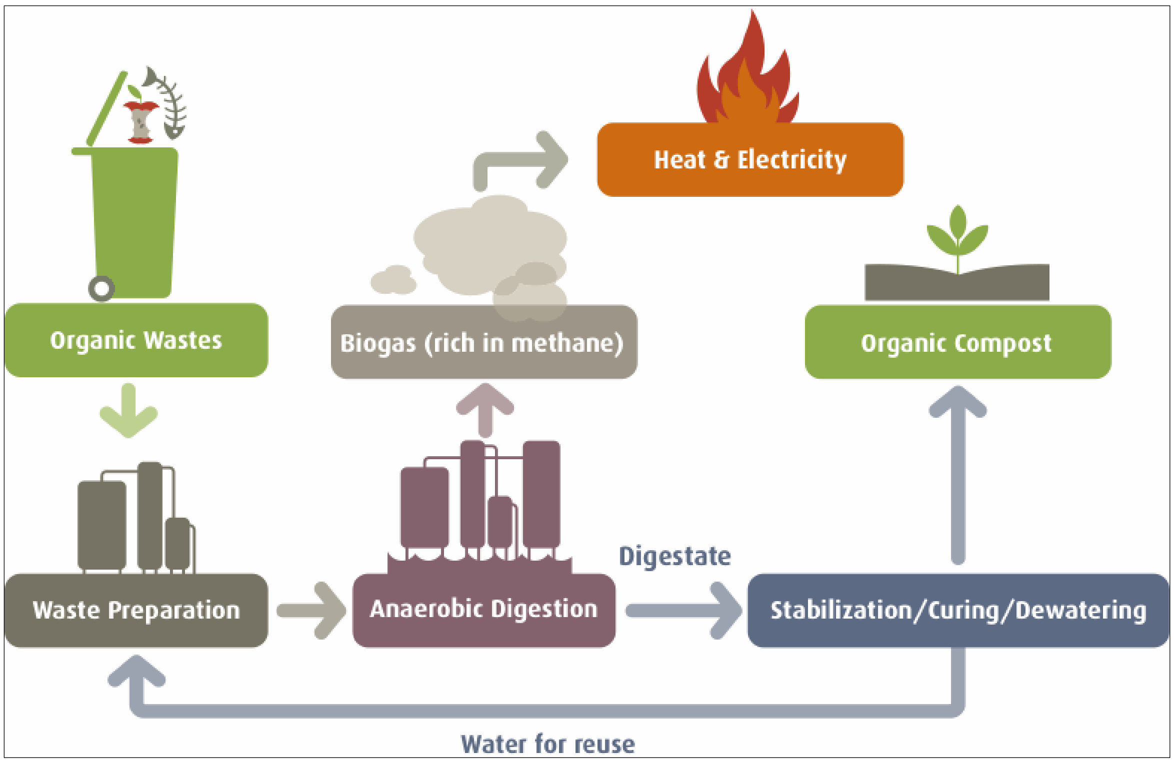


Figure 4-1: Anaerobic digestion process

The organic compound fraction of MSW in the middle income countries (like Asian countries, etc.) represents around 50 - 55%[15] of the waste composition and consists of paper, garden waste, food waste and other organic waste including plastics. The biodegradable fraction (paper, garden and food waste) accounts for 53% of waste composition. Treatment of biodegradable wastes is an important component of an integrated solid waste management strategy to reduce both the toxicity and volume of the MSW requiring final disposal in a landfill.

AD system results in the production of biogas, which can be used as a renewable energy source. Biogas consists of 60%-70% methane, 30%-40% carbon dioxide, and trace amounts of other gases (e.g., hydrogen sulfide, ammonia, hydrogen, nitrogen gas, carbon monoxide). Biogas can be explosive if exposed to air, depending on the concentration of methane in a

[15] http://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1334852610766/Chap5.pdf

confined space. The quality (i.e., heat value) and amount of biogas produced varies based on the hydraulic retention time of the AD system, the total solids content and temperature.

4.1. GHG mitigation

The potential emission reduction in the anaerobic process:

- Reduces the volume of waste to be land filled and prevents the land from degradation
- Prevents methane diffusion into the atmosphere by recovery
- Enhances the generation of heat and electricity from methane recovery
- Enhances the usage of biogas in fuel application and reduces the fossil fuel degradation
- Reduces the penetration of leachate into the ground water and improves the water quality
- Destruction of harmful pathogens in the solid wastes
- Increases the soil fertility and prevents the nitrous oxide emission
- Improves the carbon sequestration by the application of bio slurry to the land as manure

4.2. Case study

Title of the project : Biomethanation plant based on vegetable market wastes at Koyambedu whole sale market complex

Location : Chennai, Tamil Nadu

The Koyambedu Wholesale Market Complex is one of the projects evolved by the Chennai Metropolitan Development Authority (CMDA) to decongest the central business district of Chennai city and to facilitate trading of perishable items like vegetables, fruits and flowers. This Market Complex being one of the largest in Asia generates large quantity of organic wastes. About 80 tonnes of waste is generated per day and at present. CMDA has set up a waste treatment plant based on high rate biomethanation plant with electricity generation capacity of 250 kW. The Market Authorities are presently having waste collection arrangement through its sub-contractor and ten vegetable wastes are delivered at the plant site. The biogas generated is used as fuel in gas engine and the excess power generated is exported to TNEB grid. The dewatered cake is sold / used as manure by CMDA.

5. Combustion

Combustion of MSW with energy recovery in a WTE plant results in avoiding CO_2 emissions from fossil fuel use. The electricity produced by a WTE plant displaces electricity produced by an electric utility power plant. WTE facilities can be divided into three categories:

- Mass burn facility
- Modular combustion
- Refuse derived fuel (RDF).

A mass burn facility generates electricity and/or steam from the combustion of mixed MSW. Modular WTE plants generally are smaller than mass burn plants and are prefabricated off-site and assembled quickly in need. RDF plant segregates the combustible materials and compresses it into pellets of various sizes. The RDF pellets are rich in energy value and yields more heat and electricity than distorted materials. Various technologies available for waste combustion are discussed in this chapter.

5.1. Incineration

Waste incineration/combustion is the oxidation of the combustible material of the waste. The main stages of the incineration process are,

- drying and degassing
- pyrolysis and gasification
- full oxidation.

Incineration reduces the mass of waste to be disposed in open dumping. In addition, GHG emissions are avoided by offsetting the fossil fuel use, except small contribution from fossil carbon. Incineration has been widely applied in many developed countries, especially those with limited space for land filling such as Japan and many European countries.

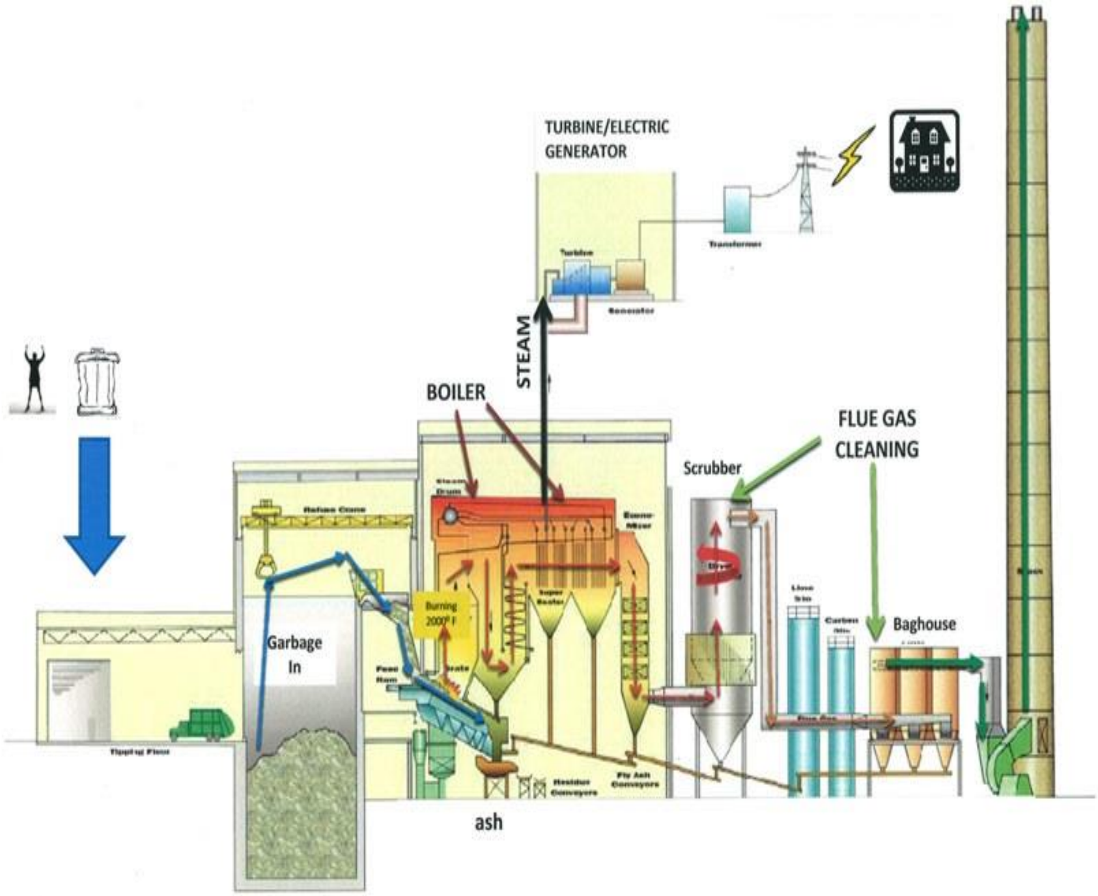


Figure 5-1: Typical incineration process

5.1.1. Refuse Derived Fuel (RDF) combustion

"Refuse Derived Fuel" refers to the processed fuel produced from the combustible fraction of the mixed municipal solid waste. The thermal reduction of solid waste through RDF combustion and power generation has been a common procedure throughout the world. There are decades of experience in construction and operating RDF combustion facilities in the United States and Europe.

By removing non-combustible material and increasing the homogeneity of the remaining combustible fraction, greater control of the combustion process can be achieved. RDF systems require less excess air than systems that require complete combustion, which increases furnace efficiency. In addition, erosion and maintenance requirement of the boiler is less when compared to the boiler used in the mass burn system.

Compared to the uncontrolled nature of unprocessed commingled MSW, RDF can be produced from the organic fraction of MSW with fair consistency to meet specifications for energy content, moisture and ash content. The recovery and sale of reusable materials from MSW can reduce landfill requirements and produce revenues for the project.

5.2. Gasification

Gasification or ''indirect combustion'' is the conversion of solid waste to fuel- or synthesis-gases through gas forming reactions. It can be defined as a partial oxidation of the waste in the presence of a controlled oxygen supply. Four distinct process that take place in the gasification process are:

- Drying of fuel
- Pyrolysis – a process in which tar and other volatiles are driven off
- Combustion
- Reduction

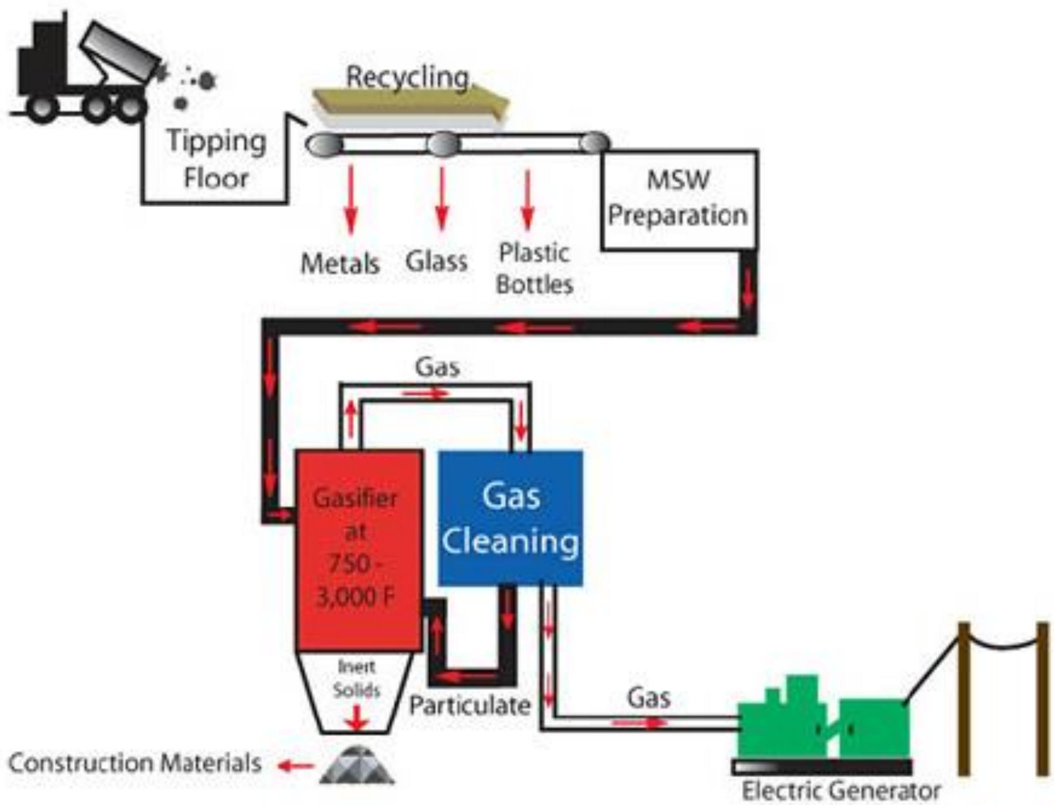


Figure 5-2: Schematic diagram of MSW gasification plant

Gasification has several potential benefits over traditional combustion of solid wastes, mainly related to the operating conditions (in particular, temperature and equivalence ratio) and the features of the specific reactor (fixed bed, fluidized bed, entrained bed, vertical shaft, moving grate furnace, rotary kiln, plasma reactor) to obtain a syngas suited for use in different applications. It can be utilized as a fuel gas that can be combusted in a conventional burner, connected to a boiler and an electricity generator.

5.3. Plasma arc gasification

It is a type of gasification which uses electric arc to produce high temperature up to 7000 ^{o}C. Plasma Gasification systems require very little maintenance and unlike traditional power plants, do not need to be shut down for weeks at a time for cleaning and maintenance while waste-streams back-up. Plasma Gasification can provide a high degree of flexibility over the longer term and it can operate at less than 100% of capacity so that there is flexibility when waste-stream declines. It does not produce hazardous bottom ash and fly ash.

But this technology is not yet proven on a commercial scale. Only very few plants operate, in Japan, using this technology[16].

5.4. Pyrolysis

Pyrolysis is the thermal degradation of carbonaceous materials at a lower temperature than gasification (450-800 ^oC), in the absence of oxygen. The products of pyrolysis are pyrolitic oils, gas and solid char. The distribution of products depends upon the temperature. Pyrolysis oil is used for (after appropriate post-treatment) liquid fuels, chemicals, adhesives, and other products. While pyrolysis of biomass continues to be developed on a relatively small scale, no commercial plants for the pyrolysis of MSW are operating today[17].

5.5. GHG mitigation

WTE is the pre-eminent method of waste disposal in Europe and Asia because of its ability to reduce the volume of waste, generation of valuable energy, and the reduction of GHG emissions.

The potential emission reduction through combustion technologies are:

- Avoids methane emission from open MSW landfills
- Avoids CO_2 emission from fossil fuel power plants
- Reduces the quantity of fossil fuel destruction
- Reduces the volume of MSW disposal and enriches the land quality
- Minimizes the release of other GHG gases into the atmosphere
- Reduces CO_2 indirectly by the reduction of quantity of heavy metals and other materials to be processed
- Permanently removes significant quantities of mercury from the environment.
- Prevents groundwater contamination
- Avoids new landfill construction for MSW

5.6. Case study

Case study on Incineration

Title of the project : Nanhai MSW Incineration II Project[18]

Location : Guangdong Province, P.R. China

Nanhai MSW Incineration II project is a joint venture project to treat 1,500 tons of MSW per day. This project adopts combustion technology using incinerators. The project started its test operation in 2011. The project composed of 3 x 500 tons per day MSW combustion production lines coupled with 3 mechanical grate incinerators. For power generation, 2 x 15MW steam turbines and 2 x 20MW generators are installed at the site. The project is estimated to generate 168,655 MWh electricity per year, of which 80% will be exported to South China Power Grid (SCPG).

[16] http://www.itigroup.co/uploads/files/59_Comparative_WTE-Technologies-Mar-_2014.pdf

[17] http://www.itigroup.co/uploads/files/59_Comparative_WTE-Technologies-Mar-_2014.pdf

[18] http://cdm.unfccc.int/Projects/DB/Germanischer1317298382.09/view

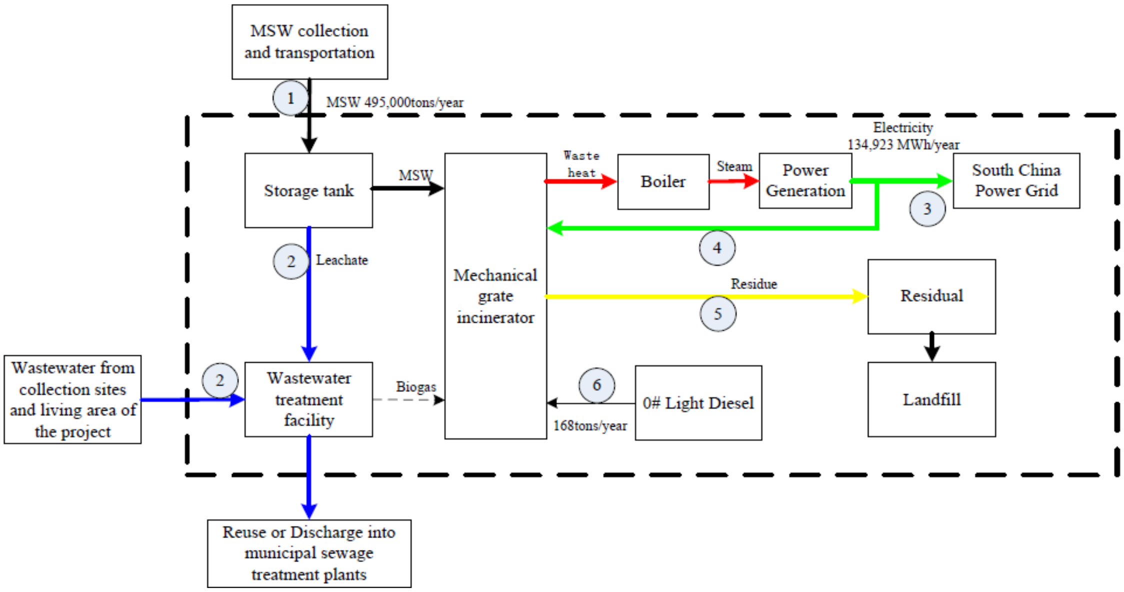


Figure 5-3: Schematic of MSW incineration process

The estimated annual average emission reductions will be 183,530 tCO_2e. The project's contribution to mitigate global warming is in the form of control of methane direct release to atmosphere from uncontrolled landfills, methane recovery and methane destruction with end output of electricity and heat. It reduces the amount of waste disposed-off and increases the lifetime of landfills.

Case study on Gasification

Gasification for large scale MSW treatment has not been carried out at commercial scale yet. There is one project - Municipal Solid Waste to Energy Project by Western Power Company (Pvt.) Ltd[19] from Srilanka registered in CDM for MSW gasification. However, any progress on its implementation is not known.

[19] http://cdm.unfccc.int/Projects/DB/TUEV-RHEIN1356188121.92/view

6. Landfill

Landfill is a site for the disposal of MSW by burying it under the ground. It is an oldest and common method currently in operation in most of the world countries. Landfills are used for transfer of waste, storage and processing of waste using waste management techniques.

Landfill can be of the following types:

- Sanitary landfill/bioreactor landfill/engineered sanitary landfill – Mixed waste with landfill gas (LFG) recovery, leachate collection system and storm water management system
- Secured MSW landfill – Inert waste without landfill gas recovery
- Monofills – Only one kind of waste

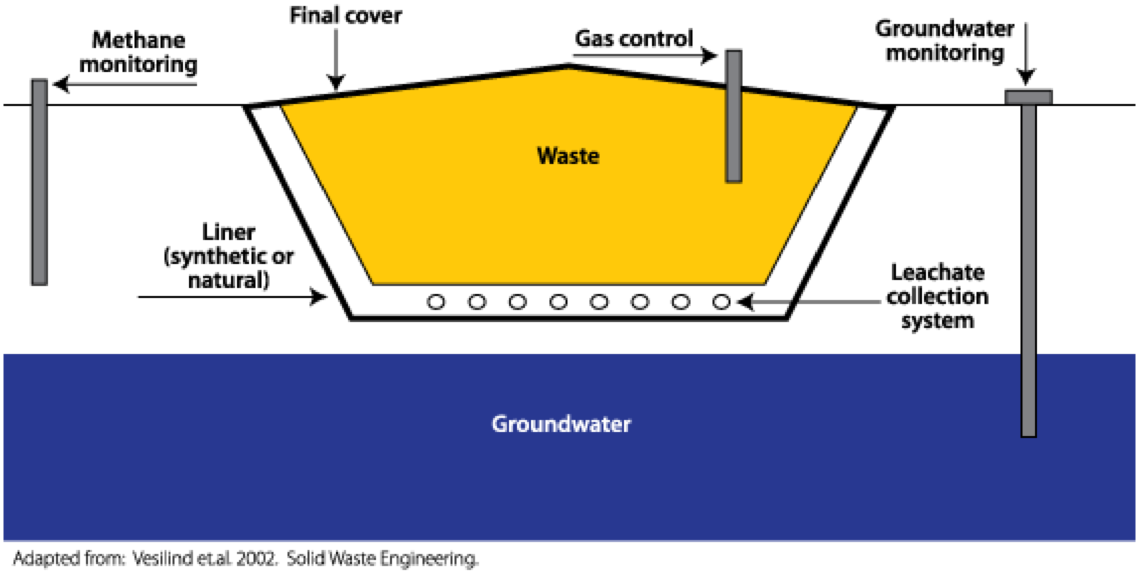


Figure 6-1: Typical engineered landfill with LFG recovery

Over the course of years, landfills have evolved from the open dumps to the highly engineered facilities designed to isolate waste from the environment. Moisture content optimized with leachate recirculation is found to be the most critical factor affecting MSW biodegradation in landfills.

Within the landfill ecosystems, biological, chemical and physical processes promote the biodegradation of organic wastes in the MSW. The sanitary landfills usually include environmental barriers such as landfill liners, covers, etc.

6.1. Available control technologies for GHG emissions

The available control technologies are divided into three categories: (i) LFG collection efficiency improvement, (ii) LFG control devices and (iii) increase of CH_4 oxidization. Large landfills with emissions exceeding 50 Mega grams (Mg) or more are required to control and/or treat LFG to significantly reduce the amount of toxic air pollutants released. It helps in the reduction of greenhouse gas direct release into the atmosphere.

6.1.1. LFG collection efficiency improvement

Collection efficiency is contingent upon landfill design, its operation and maintenance. Gas collection efficiency can be improved by implementing gas well, surface monitoring, leak identification and repair techniques.

There are two types of LFG collection systems, active and passive. Passive systems rely on the natural pressure gradient between the waste mass and the atmosphere to move gas to collection systems. Active systems use mechanical blowers or compressors to create a vacuum that optimizes LFG collection.

Higher collection efficiencies may be achieved at landfills with well-maintained and operated collection systems, a liner under the waste, and a cover consisting of a geomembrane and a thick layer of clay. Landfills with final geomembrane covers have higher collection efficiencies. Changing the final cover material can improve gas collection efficiency and reduce LFG emissions.

6.1.2. LFG destruction methods

After collection, LFG may be used as gas fuel or as an energy source to generate heat and electricity. Combustion of LFG is the most common method used to reduce the volatility, global warming potential and hazards associated with LFG. Combustion of LFG also reduces odours and other hazards associated with LFG emissions.

LFG combustion methods include,

- Destruction devices (e.g., flares)
- Electricity generation units (e.g., reciprocating engines, gas turbines)
- Energy recovery technologies (e.g., boilers).

- **Flares**

Flaring is the most common method used. Flaring process combusts the collected gas completely and does not recover energy. Controlling LFG emissions by flares is technically feasible for most of the landfills. The capital and maintenance costs associated with flares are relatively low compared to other combustion technologies. Two different types of flares are available,

- Open flares
- Enclosed flares.

- **Electricity generation**

Internal combustion engines are the most widely used technology for the conversion of LFG to electricity. Advantages of this technology include:

- Low capital cost
- High efficiency
- Adaptability to variations in the gas output of landfills.

Micro turbines can be used instead of internal combustion engines for LFG energy conversion. This technology generally works best for small scale recovery projects that supply electricity to the landfill or to its proximity. Micro turbine units have capacities ranging between 30 and 250 kW works well with LFG flow rates of 350 cfm at 50% CH_4 (EPA, 2010d). Sufficient LFG treatment is generally required for micro turbines and involves the removal of moisture and other contaminants (EPA, 2010c).

- **Cogeneration**

Cogeneration is known as combined heat and power (CHP) to generate heat and electricity from LFG. The thermal energy recovered is usually in the form of steam or hot water that can be used for on-site heating, cooling, or process needs. Cogeneration systems are typically more efficient and often more cost effective than separate systems for heat and power (EPA, 2008b). Combustion technologies generally suitable for CHP include internal combustion engines, gas turbines, and micro turbines. There are also boiler/steam turbine applications where LFG is combusted in large boilers for steam generation that is then used by turbines to create electricity (EPA, 2010c). The CH_4 control efficiency for cogeneration is directly linked to the electricity generation unit combusting LFG.

- **Direct use**

Landfill gas may be used to offset traditional fuel sources such as natural gas, coal, and fuel oil used for various applications. Direct use of LFG is primarily limited to facilities within 5 miles of a landfill. Direct use applications for landfills include:

- Boilers (LFG used solely or co-fired with other fuels)
- Direct thermal technologies (e.g. dryers, heaters, kilns)
- Leachate evaporation

6.1.3. Leachate treatment

Leachates are defined as the aqueous effluent generated as a consequence of rainwater percolation through wastes, biochemical processes in waste's cells and the inherent water content of wastes themselves. Leachates may contain large amounts of organic matter, ammonia-nitrogen, heavy metals, and chlorinated organic and inorganic salts. Technologies used for leachate treatment can be classified into four major groups: (a) leachate transfer: recycling, marooning and combined treatment with domestic sewage, (b) biodegradation: aerobic and anaerobic processes, (c) chemical and physical methods: chemical oxidation, adsorption, chemical precipitation, coagulation/flocculation, sedimentation/flotation and air stripping and (d) membrane filtration: micro filtration, ultra-filtration, Nano filtration and reverse osmosis.

Each of the aforementioned alternatives presents its own advantages and disadvantages. The combination of biological and physical–chemical processes is being considered as the most appropriate technology for manipulation and management of high strength effluents.[20]

6.2. GHG mitigation

The potential GHG mitigation through landfill technologies are:

- Avoids methane emissions from open landfills and helps in reducing global warming
- Offsets the use of fossil fuels and helps in reducing the CO_2 emissions
- Reduces the health risk of surrounding environment by eliminating hazardous pollutants
- Prevents leachate penetration and improves the water quality
- Reduces the landfill odors by combustion of LFG

[20] http://www.s217021060.onlinehome.fr/pdf-2011/Renou4.pdf

6.3. Case study

Title of the project : Bangkok Kamphaeng Saen East: Landfill Gas to Electricity Project[21]

Location : Kamphaeng Saen District, Nakhon Pathom Province, Thailand

The project is implemented to extract, capture and utilize the landfill gas to generate electricity. The electricity generated is exported to Thailand grid. The project has been set up to have LFG collection system, LFG generators and flaring system.

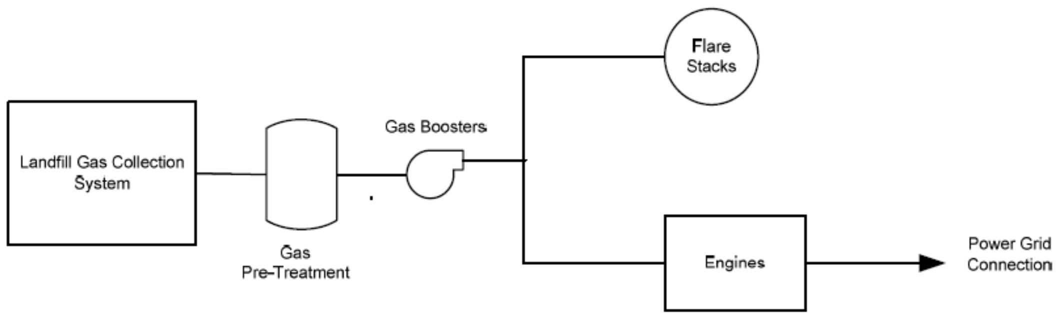


Figure 6-2: Schematic diagram of LFG utilization

4 LFG generators are installed with a cumulative capacity of 8MW and 3 enclosed flares of capacity 2,000 Nm^3/hr each. Approximately 50 – 60% of LFG is methane, which is a highly combustible gas that can be utilized in spark ignition engines to produce electricity. Methane that cannot be used for power generation is destroyed in enclosed flares. The project activity results in the reduction of CH_4emission from decomposition of waste at the landfill site and reduction CO_2 emissions from fossil fuel. The annual average GHG emission reduction of the project is 273,081 tCO_2e.

[21]https://cdm.unfccc.int/Projects/DB/SGS-UKL1267631662.24/view

7. Climate change friendly waste management selection

Greenhouse gas (GHG) emissions from waste management contribute significantly to global climate change issues. Open dumping and land filling are the third largest anthropogenic methane emission sources (IPCC, 2007). Worldwide, CH4 emissions from the waste sector contribute to approximately 18% of the global anthropogenic CH4 emissions (Scheutz et al., 2009).

A Life Cycle Assessment (LCA) approach is suggested for selecting the right waste management method. LCA is a methodical approach for quantifying GHG emissions considering all phases of the lifecycle such as transportation, operation (pre-processing, treatment) and disposal. It enables identification of issues of concern and possible policies for effective mitigation, considering the direct and indirect impacts associated with a specified waste management method.

All the waste treatment methods emit GHGs during waste transportation, operation and waste degradation. Similarly, each waste disposal method has potential for avoiding GHGs. The approach in choosing the climate change friendly method is to compare the emissions estimated against the emissions avoided and choose the method the results in the maximum net avoided emission benefits. The emission mainly occurs during two stages of waste management – (i) waste collection, processing and transport and (ii) waste disposal (composting/land filling).

The general steps in choosing the climate change friendly waste management method is discussed below.

7.1. Step 01: Identification of waste source, its composition and quantity

Identifying the waste source, quantity and its type helps to understand the nature of waste and estimate its potential for generating emissions. GHG emissions are generated mainly from biodegradable wastes such as food wastes, vegetable wastes, tree trimmings, human waste, manure, sewage sludge, slaughterhouse waste, etc. Non-biodegradable wastes such as metals, rubbers, glass, ceramics, construction site waste, etc., do not result in GHG emissions.

- High biodegradable waste composition – high potential for GHG emissions
- High non-biodegradable waste composition – low potential for GHG emissions

7.2. Step 02: Estimation of emission generated during waste collection, processing and transport

Putrescible wastes (food waste, animal waste, manure, night soil, etc.) degrade at a faster rate and can generate emissions even within few hours of its generation and collection in waste containers. Fossil fuel consumed during waste collection operation is a significant contributor to GHG emissions. Higher the waste quantity and larger the waste collection range (distance between collection points and disposal site), higher will be the emissions generated. Use of electricity at waste segregation and material recovery plants is also an emission source. Other emission sources include lubricants, engine oils, etc., from such waste recovery plant operations. Thus, the energy consumption and emission generation must be estimated at each stage of the waste management method.

The estimations to be done at this stage are:

- Self-degradation of bio-degradable/putrescible wastes

- Fossil fuel use during waste transport
- Electricity use at waste segregation and material recovery plants
- Inherent waste generation and related emissions at waste management facilities

7.3. Step 03: Estimation of emissions generated during waste disposal

In this step, each waste disposal option shall be analyzed with respect to GHG emissions due that disposal method along with other considerations of waste composition, investment needed, conformity to local site and environmental safeguard requirements.

In composting, microorganisms consume the organic matter and release heat and carbon dioxide (CO_2). In combustion process (waste to power and incineration), both carbon dioxide and nitrous oxide are released. Nitrous oxide is around 300 times more harmful GHG than carbon dioxide, but makes up only a small percentage of the total emissions. Land filling is the most common waste disposal practice and results in the release of methane from the anaerobic decomposition of organic materials.

It is also noted here that the operation and maintenance of the waste disposal site also consumes some energy and thus contributes to emission generation. Accordingly, the estimation of following emissions can be done in each waste disposal options:

- Composting – CO_2 emissions
- Combustion – CO_2 + NO_x emissions
- Land filling – CH_4 emissions
- Emissions from operation and maintenance of the waste disposal site

7.4. Step 04: Estimation of avoided emissions during waste disposal

By choosing the combination of appropriate technologies, a significant amount of material/energy from wastes can be recovered along with reducing the amount of waste sent for disposal at the landfill. Recovered materials and energy can be used to replace the production of the equivalent amount of materials and energy from raw materials and conventional processes. Therefore, the GHG emissions that would otherwise occur from extraction of raw materials and conventional processes can be reduced.

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

In combustion process, such as waste to power and incineration, energy released during combustion can be harnessed and used to power other processes, which results in an offset of GHG emissions from a reduction in fossil fuel use. In addition, combustion diverts waste from land filling and reducing the amount of methane that would be produced.

In landfill process, methane produced is also a source of energy. The methane generated can be captured and used for heating or power generation. In addition, many materials in landfills do not decompose fully and the carbon that remains is sequestered in the landfill and is not released into the atmosphere.

Thus, the following estimations can be done w.r.t. avoided emissions from different waste disposal options:

- Energy recovered from incineration and avoided use of fossil fuels elsewhere in the energy system

GHG Emission Reduction Potential in SWM

- Avoided emissions associated with producing materials from primary resources
- Avoided emissions associated with the use of any inorganic fertilizers
- Amount of carbon sequestered during the landfill

7.5. Step 05: Selection of appropriate technology mix

The net GHG reduction is the difference of GHG emissions avoided and emissions generated from the overall waste management process. Based on these evaluations along with other parameters such as investment needed, conformity to local site and environmental safeguard requirements, etc., the appropriate waste disposal technology mix with maximum net GHG reduction can be selected. For example, a combination of waste segregation, composting, recycling and engineered landfill will provide a best approach as the emissions will be avoided in each stage and the final waste quantity sent for landfill will be reduced substantially.

The following figure provides the overall approach in estimating net GHG emission benefits from the overall waste management method.

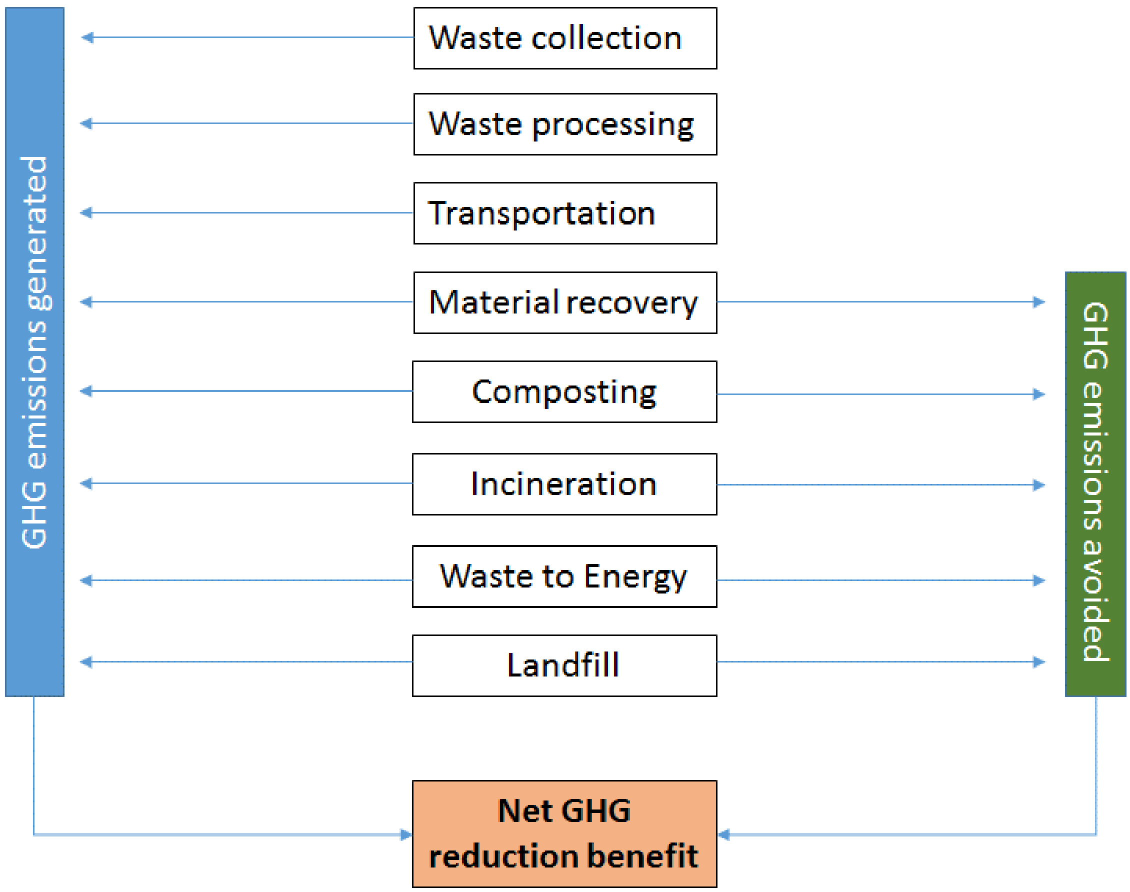


Figure 7-1: Approach in estimating net GHG reduction

Appendix 1: Comparison of WTE technologies

Item	Aerobic composti	Anaerobic Digestion	Incineration	Gasification	Sanitary Landfill
Segregation requirement	Very high	Very High	Low	High	Low
Potential for direct energy recovery	No	No	Yes	Yes	Moderate
Overall efficiency in case of a small setup	High	High	Low	Moderate	Low
Efficiency in case of high moisture	High	High	Very low	Low	Moderate to High
Land requirement	High	Low to Moderate	Low	Moderate	Moderate in case of bioreactor landfill because, at least in theory, the land filled material can be removed once the contamination potential from the landfill is negligible and same site can be reused.
Ability to tackle bio-medical and low-hazard waste	No	No	Yes	Yes (to some extent)	No

GHG Emission Reduction Potential in SWM

Item	Aerobic composti	Anaerobic Digestion	Incineration	Gasification	Sanitary Landfill
Concerns for toxicity of product	-	-	High	-	Low
Leachate Pollution	High, if not routed properly for treatment	Moderate to high in case effluent is not properly treated or utilized	None	None	Moderate to high depending upon the leachate recycling and control systems
Concern for Atmospheric Pollution	Moderate	Low	High (not easy to control)	Moderate (easy to control)	Low
Capital Investment	High	High	High	unknown	High

Appendix 2: Parameters and constraints of WTE technologies

Technology	Parameters	Limitations	Benefits	Environmental concerns
Aerobic composting	Segregation of organics from MSW Quantity of organic matter Moisture content Market demand Location of the facility	Receiving of unsegregated waste No yield consistency (varying compost quality) Slow process Sound marketing arrangements are required Sensitive process – requires good segregation and maintenance Limited acceptance by the farmers and sometimes even by the city parks and gardens department	Reduces volume of organic waste fraction of MSW by 50 to 75 % Stabilizes organic fraction of MSW Potential usable product as output Potential of co-composting operations with other waste streams Reduces organic waste to landfill thereby reducing the production of leachate and gases from landfill Highly useful product for crop improvement Value addition to waste resource Sustainable approach	The final product which is used as manure in fields can contaminate the soil if not tested for toxic elements before sale. Emissions of Particulate matter when moving/handling the waste Odour problems
Anaerobic digestion	Moisture Content Organic/Volatile matter C/N ratio Segregation of Organic	Higher capital costs Not suitable for wastes containing less biodegradable	Completes natural cycle of carbon Recovery of energy & production of fully stabilized organic manure Control / Reduction	Gas handling Fire & safety measures Proper operation of drying beds

Technology	Parameters	Limitations	Benefits	Environmental concerns
	waste Quantity of organic matter Market demand	matter Non-availability of segregated waste in the municipality Lack of financial resources with ULB's and municipal corporations Requires waste segregation for improving digestion efficiency	of GHG emissions like Methane Complete destruction of Pathogens through anaerobic digestion - No transmission of disease through vectors Only pre-processing rejects - No post-processing rejects Reduced burden on Landfills Conversion efficiency: 60 to 70 % Clean combustion, compact burning, high thermal efficiency and good degree of control Environment friendly because of firewood savings and reduction in CO_2 emissions Can be done on a small scale Generation of gaseous fuel Free from odor, fly menace, visible pollution Production of biogas and high grade soil conditioner Very low power requirement unlike aerobic composting, where sieving and	Leachate collection & treatment from sludge drying beds

Technology	Parameters	Limitations	Benefits	Environmental concerns
			turning of waste pile for supply of oxygen is necessary Modular construction of plant and closed treatment needs less land area	
Refuse Derived Fuel (RDF)	Segregation of Organics from MSW Quantity of organic matter Moisture content Market demand Location of the facility	Competitive with large mass burn plants Requires secure markets for fuel Processing involves high electrical power consumption and maintenance Space requirement for fuel production Can cause damage to boilers and pipe work than other fuels	RDF can be processed to half the calorific value of coal Lower level of heavy metals in RDF RDF can be co-fired with other fuels in a variety of industrial boilers Process is self-sustaining with value addition Resource recovery for economic gain Low risk technology Low cost option for MSW treatment and processing.	Air pollution from emission of smaller quantities of organics, particulates, and metals Water pollution from leachate
Incineration	Calorific value Moisture content Organic/volatile matter Fixed carbon Total Inerts	Excessive moisture and inert content in waste affects net energy recovery; Auxiliary fuel support may be necessary to sustain combustion; High capital and O&M costs.	Achieves maximum volume reduction Incineration is a standard hygienic operation compared to open burning. Heat generated can be utilized for production of steam / hot water / electricity – revenue generation	Emissions - particulates, SO_x and NO_x emissions, chlorinated compounds, ranging from HCl to organo-compounds such as dioxins, and heavy metals Toxic metals

Technology	Parameters	Limitations	Benefits	Environmental concerns
		Most wastes which can safely be burned (i.e. vegetation, cardboard, paper) may be more useful if recovered for mulching and soil improvement. Residual ash and metal waste require disposal. Overall efficiency is low for small power stations Indian MSW has low calorific value; hence supplementary fuel is required for combustion and hence high fuel costs	Less land is required and minimal burden on landfills Most suitable for high calorific value waste Relatively noiseless and odorless Thermal energy recovery for direct heating or power generation Can be located within city limits, reducing cost of waste transportation	may concentrate in ash; Fumes from low temperature incineration of mixed municipal refuse. These fumes will contain a number of toxic compounds, e.g. from burning of chlorinated plastics, solvents etc. These could be a hazard to people living and working in close proximity and are generally undesirable in the environment. Care and strict management of the waste to be burned in order to minimize contamination with undesirable waste types

GHG Emission Reduction Potential in SWM

Technology	Parameters	Limitations	Benefits	Environmental concerns
Gasification	Calorific Value Organic/Volatile matter Segregation of Organic waste Quantity of organic matter Market demand Moisture Content Fixed Carbon Total Inerts	Economic performance - Costlier Requires very rapid heat transfer	Converts larger fraction of organics into a fuel gas Clean way to handle fuel feed stocks that have many impurities	Air emissions
Landfill	Quantities of existing and future waste Waste characterization Waste segregation Waste collection and transportation Site selection/location Leachate estimates Potential for methane gas Lining for Landfill Quantity of new waste in case of existing landfills	Land area requirement Significant transportation costs to the landfill site Utilization of methane may not be feasible for remote sites; Cost of pre-treatment to upgrade the gas may be high; Lack of financial resources with municipal corporations/urban local Bodies. Lack of conducive policy guidelines from State Governments in respect of allotment of land, supply of garbage and power	The gas produced can be utilized for power generation or as domestic fuel for direct thermal applications Reduced GHG emissions	Greatly polluted surface runoff during rainfall Soil and ground water aquifers may get contaminated by polluted leachate in the absence of proper leachate collection and treatment system Spontaneous ignition due to possible methane concentrations In case of inefficient gas recovery process yielding from total amount of gas actually generated, GHG gases may escape to the atmosphere

Technology	Parameters	Limitations	Benefits	Environmental concerns
		purchase / evacuation facilities, etc.		