2 LITERATURE REVIEW

2.1 Global Population Growth

Expansion of world population resulted with innovations and improvements in technology to allow the increase in productions and services to cope with the ever-increasing demand of human species (Lee and Tuljapurkar, 2008; Odum and Odum, 2006; Canadian Institute for Business and the Environment, 2001). As a consequence, the prosperous economy offers a higher standard of living to the community, indicated by the rapid increase of the world economy.

2.1.1. The impact and consequences of population expansion

The annual output of the world economy grew to $60.69 trillion in 2008, from $6.2 trillion in 1950 (Wikipedia, 2009), signified 879% increase in the duration of just 58 years or more than 15% in a decade. As a result, world energy consumption is projected to grow 2% annually until 2020. Expansion of the economy attracts urban migration which without proper management can result in environmental degradation and more pollution. The degradation of the environmental quality had been addressed over the years by scholars and scientists and were proven with various research findings (Odum and Odum, 2006; Haberl, 2006; Agamuthu *et al.*, 2004). This directly brings about undesirable side-effects to earth's natural resources and to the environment (Beede and Bloom, 1995).

While world economy improves, more than 80 countries have a per capita income lower than they were before, with less than a dollar to acquire essential needs like clean water, and food (Johannesburg Summit, 2002). This includes approximately 20% of the world poorest population that consume only 11% of global consumption while 20% of the world population of higher income group consume more than 76.6% of the global consumption (World Bank Development Indicator, 2008). The more natural resources consumed, the bigger is the waste and pollution produced.

2.2 Waste Generation Trends

The acceleration of waste generation due to world population increased (at 1.3% per annum) from 5.9 billion in 1998 to more than 6.4 billion in 2006 (U.S. Census Bureau, 2005) is a critical issue. It translated into higher level of environmental pollution with risk and health hazards to human being (Nadal *et al*., 2009; Johnson and Johnson, 1999).

2.2.1. Global Trends

Environmental degradation is closely related to resources consumption and waste generation. Municipal solid waste (MSW) generation had increased at a tremendous rate over the years particularly in developed and industrialized countries. MSW can be defined as household wastes, which include commercial waste and institutional waste that are generated according to living standards, cultural habits and other factors (Agamuthu, 2001). The population expansion is among the factors affecting higher waste production where cities i.e. 2% of the world’s land surface utilize 75% of the world resources (Scharff, 2000). The rapid increase of MSW generation is also closely related to the economic growth and increase in GDP (Troschinetz and Mihelcic, 2009; Shekdar, 2009; Odum and Odum, 2006, Agamuthu *et al*., 2004; Agamuthu, 2001) though some found that Gross Domestic Product (GDP) is inapt as an indicator of growth in civilization as it didn't address all appropriate issues (Global Exchange, 2005) including ecological impacts to the environment. The global MSW generation had surpassed 1.84 billion tonnes in 2004 and is estimated to have risen by 31.1% in 2008 (Goliath, 2004) while cities in China alone generate more than 140 million tonnes (Wang, 2000).

The trends in waste generation depend mainly on the living standard of the society that MSW issues are associated with difficulties and 'policy resistant' as compared to other environmental issues. Research findings proved that higher living standard allows higher human consumption resulting in higher waste generation capability (Odum and Odum, 2006; Agamuthu *et al*., 2004). Consumers play essential roles in the production of solid waste and yet have equally important responsibility to recycle. Many developed nation such as Denmark had realized the importance of recycling where it diverts some amount of waste from the disposal stream. Reduction of waste to be disposed off into landfills or incinerations not only work as a sound practice but also reduced occupational health problems (Nadal *et al*., 2009; Poulsen *et al*., 1995).

Waste generation rate in developed countries were reported to be much higher than that of the developing and under-develop countries. The generation of MSW in the developing nations range from 0.25 to 1.97kg per capita per day (Agamuthu, 2001). While in more developed nations, the per capita generation of MSW ranged from 1.1kg to 5.07kg (Hoorwerg and Thomas, 1999). The average per capita generation at the global scale is 1.5 kg per day and the total generation increased with population expansion. This calculated to a total global waste generation of 10.2 billion tonnes per day by the global population of 6.8 billion.

In 2001, the average waste generation in Gaborone, Botswana was 0.33 kg per capita per day, while in 1990, each American had already produced approximately 1.97 per capita/day (Bolaane and Ali, 2002). The total of 408 million tonnes of MSW generated in industrialized countries in 1990 were contributed by North America (48%), Europe (37%) and the Pacific (15%) (World Bank, 1999). MSW increased at an alarming rate in all areas within 1975 to 1990. However since 1990s, the portion of MSW generated in North America only encountered a slight increase from 47% to 48%, while it remained unchanged in the European OECD countries and decreased in the Pacific countries from 16% to 15%. This generally due to the efficient waste management system practiced and the implementation of more stringent regulation by the related countries (Wagner and Arnold, 2008; Malkow, 2004; Grodzińska-Jurczak, 2001).

USA is the single largest MSW generating country among industrialized nations with a 43.5% share, followed by Japan (12.4%), Germany (6.9%), United Kingdom (4.9%) and Italy (4.9%) which contributed a total of 73% of global waste generation (Global Exchange, 2005). Per capita MSW generation in industrialized countries averaged 480 kg/annum in 1990 after a 23% increase over the level prevailing in the mid-1970s. Table

2.1 details the MSW generated based on development of a country while Table 2.2 shows the per capita generation of MSW in 1990, in selected countries throughout the world.

Table 2.1: MSW generated and development indicator (Beigl *et al*., 2009).

National Development indicators and MSW generation	Prosperity level			
	Low	Medium	High	Very High
Gross domestic product per capita[1]	5841	11400	19418	21317
Infant mortality rate[2]	15.0	8.7	7.6	5.5
Labour force in agriculture (%)	24.0	18.7	4.8	3.2
Labour force in services (%)	44.4	52.2	59.4	66.2
Municipal solid waste (kg/cap/yr)	287	367	415	495

[1] USD Purchasing power parities at 1995 prices

[2] Per 1,000 births

Table 2.2: Municipal Solid Waste generation in selected countries for 1990.

Country	MSW Generation per capita (kg/day)	GDP per capita (US$)	Total MSW generation (million metric tons)
Low- Income Economies			
Mozambique	0.50	620	2.87
Kenya	0.50	1,120	4.42
Indonesia	0.59	2,350	38.38
Liberia	0.50	1,568	0.47
Middle- Income Economies			
Guatemala	0.50	2,920	1.68
Colombia	0.55	4,950	6.48
Romania	0.59	6,780	5.00
Poland	0.59	4,530	8.23
Bulgaria	0.59	7,900	1.90
Malaysia	0.70	5,900	4.87
Albania	0.59	4,084	0.71

Table 2.2 (cont'd)

Country	MSW Generation per capita (kg/day)	GDP per capita (US$)	Total MSW generation (million metric tons)
Upper Middle- Income Economies			
Hungary	0.73	6,190	2.82
Czechoslavakia	0.59	5,691	3.38
Gabon	0.50	4,590	0.20
Portugal	0.68	8,510	0.22
Greece	0.68	7,340	2.51
Saudi Arabia	1.09	5,691	5.93
Iraq	1.09	5,691	7.52
Oman	1.09	5,691	0.64
High- Income Economies			
Ireland	0.91	9,130	1.16
Israel	1.09	11,940	1.87
Spain	0.86	10,840	12.24
Singapore	0.86	14,920	0.94
New Zealand	1.82	13,490	2.26
Belgium	0.91	12,950	3.32
United Kingdom	1.00	14,960	20.96
Italy	0.68	14,550	14.32
Australia	1.91	16,050	11.92
Netherlands	1.18	15,200	6.42
Austria	0.59	14,750	1.66
United Arab Emirates	1.09	16,590	0.64
France	1.82	15,200	37.47
Canada	1.68	19,650	16.25
United States	1.5	21,360	136.88
Denmark	1.18	15,380	2.20
Norway	1.32	17,220	2.02
Sweden	0.91	16,000	2.86
Japan	0.91	16,950	41.02
Finland	1.09	15,620	1.99
Switzerland	1.00	21,690	2.45
Kuwait	1.09	17,406	0.84
Other low income	-	1,568	1.31
Other lower middle income	-	4,084	0.51
Other high middle income	-	5,691	1.84
Other upper income	-	17,406	8.46

Source: (Beede and Bloom, 1995, Agamuthu, 2001)

High income countries like Canada, US, and others though generated high volume of waste per capita ranging from 0.9-1.7 kg, show intermediate values in terms of the quantity of waste per unit gross domestic product (GDP) and private final consumption expenditure. Even though the generation of MSW is higher than that of middle income and low income countries, the volume of MSW stream was relatively low. Emphasis on waste separation reduces the amount of waste that requires treatment and final disposal in these developed nations (Siebenhand and Winkler, 2000). MSW generation by Portugal, Greece, Bulgaria, and Romania also has intermediate values. The high per capita MSW generating countries like Australia and New Zealand from the upper income economies, Iraq, Hungary and Malaysia from the middle income economies, as well as, Mozambique and Indonesia (low income economy), show high rates of MSW per unit of GDP and private final consumption expenditure. Japan and the largest EC countries (Germany, UK, Italy, and France) behave similarly with intermediate value for per capita and per unit GDP and private final consumption expenditure in MSW generation. In contrast to other countries, Italy, Denmark and Norway have intermediate to low level of MSW per GDP unit and high rates of MSW per private final consumption expenditure unit.

2.2.2. Regional Trends (Southeast Asia)

The Southeast Asian countries with a GNP per capita of lower than US$ 400 generates approximately 0.7 kg per capita of MSW daily (Hoornweg, 2000). In Ho Chi Minh City, approximately 3,400 tonnes of MSW were generated (Dung *et al*., 2000). The increase of GNP translated into an increase in daily waste generation from, as low as, 1.0 kg to, as high as, 5.07 kg per capita. A linear regression can be established to indicate the dependence of income level with the increase in MSW generation (Abu Qdais *et al*., 1997). In year 2000, urban areas of Asia produced approximately 760,000 million tonnes of MSW everyday and will increase by 10% annually to a daily generation of 1.8 billion tonnes in 2025 (Hoornweg, 2000). Table 2.3 indicates the waste generation rates of some Asian countries in 2000.

Table 2.3: Waste generations rates of some Asian Countries according to the Gross National Income (GNI) for 2000.

Country	**GNI**	**Waste generation (kg/per capita/day)**
Nepal	240	0.2-0.5
Cambodia	260	1.0
Lao PDR	290	0.7
Bangladesh	370	0.5
Vietnam	390	0.55
Pakistan	440	0.6-0.8
India	450	0.3-0.6
Indonesia	570	0.8-1.0
China	840	0.8
Sri Lanka	850	0.2-0.9
Philippines	1040	0.3-0.7
Thailand	2000	1.1
Malaysia	8200	1.0

GNI 2000 per capita in USD. Source : World Bank, (2000)

In 2000, most of the nations in the Asian region spent approximately US$ 25 billion per year to manage urban solid wastes, covering up to 90% of waste management in high income countries, 50-80% of waste management in middle income countries, and 30-

60% of waste management in low income countries (Hoornweg, 2000). This amount would double in 2025 if no prompt action is taken (Hoornweg, 2000). Due to the increase in cost alone, countries in Asia should focus to improve the current waste management programs. In Hong Kong, the operating cost of the waste disposal facilities was HK$ 0.9 billion in 1999 (Environmental Protection Department, 1999; Ng and Leung, 2000). However, in years to come, the per capita generation of MSW is expected to experience a slight decrease due to the strengthening of waste minimization programmes (Hoornweg, 2000). This would provide positive improvement towards the waste management system. High income countries particularly with efficient waste management system like Singapore are predicted to produce waste of approximately the same quantity (Shekdar, 2009; Hoornweg, 2000). However, among the poorer Asian countries like India, Indonesia and others, insufficient financial provision for municipals solid waste management lead to the ineffective waste management in the country and increase in waste disposal (Jindal and Harada, 2000). Study conducted in China indicated that 62% of the urban domestic waste undergone treatment and only a low percentage meet the environmental protection standards stipulated by the government (Zhang, 2000). The lack of proper waste management system leads to environmental degradation and the deterioration of human health due to pests, diseases and the unhealthy ambient.

2.2.3. National Trends

Malaysian average of waste generation started with 0.5 kg in late 1980s to more than 1.3 kg of waste in 2009 (Agamuthu *et al*, 2009). In certain cities like Kuala Lumpur and Petaling Jaya, the generation had increased to 1.5- 2.5 kg per capita (Agamuthu *et al*, 2009; EPU, 2006). The per capita generation which falls within the range of a middle income countries consists of domestic and industrial wastes. To date, Malaysians generate approximately 30,000 tonnes of waste everyday. The waste is mainly composed of putrecible waste (37%), paper (27%) and plastic (16.5%) (Fauziah *et al*., 2004). The smaller portion of the waste contained wood, rubber, metal, glass, textile and miscellaneous with the contributions of 7%, 2%, 4%, 3%, 3% and 0.5%, respectively (The Star, 2002; Fauziah and Agamuthu, 2004). MSW volume in Kuala Lumpur was 99 tonnes per day in 1970s, but has increased rapidly to 587 tonnes per day in 1990s, causing alarming situation particularly on its treatment and disposal options. The increase of the oncoming waste volume was due to the fast developments in residential and industrial sectors, with Malaysia's annual increase in solid waste category reached 2% (Agamuthu, 1999). It was also reported that the rapid development had resulted with huge volume of construction waste (Lee and Noor Zalina, 2006).

Malaysia faced serious problems due to the ever increasing amount of MSW (Agamuthu *et al*., 2004; Fauziah and Agamuthu, 2003; Choy *et al*., 2002) that solid waste is considered as one of the three major environmental problems faced by most municipalities besides water and air pollutions (World Bank, 1999). Solid waste management is defined as a discipline related to solid waste generation, storage, collection, transfer and transport, processing and disposal by taking into considerations, the environmental, economics, aesthetics and public concerns (Agamuthu, 2001). The focus on solid waste issues was not evident until late 1970s where solid waste management began with street cleaning and transporting domestic waste to disposal sites.

At the later stage, in early 1980s, the management of municipal and industrial wastes was instigated at the national level by the government. The event had lead to the implementation of waste disposal regulations i.e. Refuse Collection & Disposal By – Laws (1983), and the launch of a hazardous waste management centre (Agamuthu *et al*., 2004; Noorhajran, 1995). With the increased awareness on environmental issues among the authorities in 1990s, appropriate management of municipal and industrial solid waste had taken a high precedence with bigger financial provision. Various campaigns were launched to create awareness especially in promoting recycling activities (Saeed *et al*., 2009; Agamuthu *et al*., 2004; Fauziah and Agamuthu, 2006). The operation cost of MSW management had increasingly absorbed more and more of the total municipals' budget over the years (Agamuthu, 2001). The cost of collection and transfer of waste for disposal alone had reached up to 60% of the total income. To date, some municipalities' MSW management cost consumes more than 70% of their income (Agamuthu *et al*., 2004). Budget allocated for the preservation and maintaining a fit environment has always been specified, and without appropriate methods and technology to reduce waste for disposal, the cost of waste management of the country without doubt would increase to an unacceptable level. In 1986, Kuala Lumpur alone had to spend as much as RM 42 million to manage MSW (Fadil and Mohd. Badruddin, 2002; Fadil, 1986). The big allocation for the management obviously called in a need of a more appropriate system as the present waste management evidently is no longer 'sustainable' to the waste managers and local municipalities. An integrated waste management incorporating waste minimization, recycling and reuse should be established in order to improve the current waste management system. Currently, source separation and recycling program have been practiced formally and informally throughout the countries by various bodies (Woodard *et al*., 2006; Perrin and Barton, 2001; World Bank, 1999). Malaysian government had been implementing various strategies in solid waste management system to encourage public to participate in 3R (reduce, reuse and recycle) programs but the results have been disappointing (Fauziah and Agamuthu, 2005a). The government had targeted to increase the rate of recycling to 22% by the year 2020, to achieve higher recycling percentage and lesser waste for landfill disposal (Agamuthu *et al*., 2004). Though theoretically most waste materials can be recycled, only non-contaminated, heterogenous wastes with marketable value are recycled. This is closely related to the economic reasons where too high expenditure on the pre-sorting of viable materials would reduce the revenue obtained from recycling activities. It is very essential to take into account the economic instruments in recycling to determine the viability of the activity (Ness and Bramryd, 2001; Waite, 1995; Landreth and Rebers, 1997).

Approximately 76% of the total MSW generated in the country is collected, where 5.0% is recycled while the remaining MSW are sent to the 260 disposal sites throughout the country. Even with difficulty in searching for suitable sites for landfills, landfill disposal remains the most important waste disposal option due to the low cost of operation at RM35/tonne (USD 9.2) (Agamuthu, 2001). Currently the disposal cost via incineration is RM500/tonne (USD 132) while composting costs RM216/tonne (USD 57) (Agamuthu, 2001). The accurate waste management cost is yet to be obtained due to the insufficient of data and inconsistency of information (Agamuthu and Fauziah, 2005a). Even though many studies had been conducted to compile information and relevant data, it is still inadequate to allow an establishment of a proper management plan (Fauziah *et al*., 2005). The 2-3% increase of MSW annually requires a fast and long term solution to prevent more detrimental effects to the environment, as well as, to minimize the cost incurred in managing the waste.

Malaysian MSW, which is similar to the typical composition of waste from industrialized country, composed of approximately 72% compostable and others such as organic waste, paper, textile and wood (Fauziah *et al*., 2004; Agamuthu, 2001). Vegetables and putrescibles contribute 36.5%, followed by paper products 27.0% as indicated in Table 2.4.

Table 2.4: Typical municipal waste composition in Malaysia.

Item No.	Waste Composition	Percentage
1	Paper, cardboards, paper products	27.0
2	Vegetables and putrescibles	36.5
3	Textile and leather	3.1
4	Ferrous metals	3.0
5	Non-ferrous metals	0.9
6	Glass	3.1
7	Plastics	16.4
8	Rubber products	2.0
9	Timber products, wastes	7.0
10	Other incombustible, ceramics etc.	0.4

(Source: Agamuthu, 2001)

The waste generation increased with population expansion. Table 2.5 shows the generation of waste at particular districts and township in Peninsular Malaysia in 1990.

Table 2.5: Generation of waste at districts and township in Peninsular Malaysia in 1990.

Place studied	Population (X 1,000)	Waste collection (tonne)	Waste generation (kg/capita/day)
Town Councils			
Kuala Lumpur	920	1,187	1.29
Kuala Kangsar	60	40	0.667
Kota Setar	188	150	0.790
Penang	494	360	0.730
Seberang Perai	319	191	0.6
Taiping	151	150	0.994
Ipoh	400	216	0.540
Petaling Jaya	360	181	0.506
Kelang	242	190	0.786
Seremban	170	120	0.706
Melaka	196	90	0.459
Johor Bharu	300	300	1.0
Kota Bharu	193	100	0.517
K. Terengganu	135	80	0.593
Kuantan	188	100	0.532
Municipality	**Population (X 1,000)**	**Waste collection (tonne)**	**Waste generation (capita/day)**
Kuala Muda	180	186	0.478
Baling	18	17	0.899
Perak Tengah	13	15	1.119
Hilir Tengah	132	68	0.514
Jelebu	30	25	0.834
Tampin	46	41	0.834
Alor Gajah	143	78	0.545
Kota Tinggi	89	53	0.592
Lipis	37	12	0.327
Bachok	30	8	0.271

(Ministry of Housing and Local Government, 2003)

Proper treatment and disposal of the MSW face difficulty as issues of highly mixed composition and its complexity should be tackled as well.

2.3 Waste Characterization/Composition

The characteristic and the composition of waste play an important role in the management of the waste. Homogeneous waste normally is much easier to handle compared to heterogenous waste. Homogeneous waste such as wastewater sludge from oleochemical processing can be utilized for other usage such as compost production (Fauziah and Agamuthu, 2001). On the other hand, MSW is always heterogenous and highly mixed as it is sourced from residential, industrial and others. Table 2.6 indicates the sources and types of MSW.

Table 2.6: Sources and types of solid waste.

Source	**Typical Waste Generators**	**Types of Solid Wastes**
Residential	Single and multifamily dwellings	Food wastes, paper, cardboard, plastics, textiles, leather, yard wastes, wood, glass, metals, ashes, special wastes (e.g. bulky items, consumer electronics, white goods, batteries, oil, tires), and household hazardous wastes
Industrial	Light and heavy manufacturing, fabrication, construction sites, power and chemical plants	Housekeeping wastes, packaging, food wastes, construction and demolition materials, hazardous wastes, ashes, special wastes

Table 2.6(con'td)

Source	**Typical Waste Generators**	**Types of Solid Wastes**
Commercial	Stores, hotels, restaurants, markets, office buildings, etc	Paper, cardboard, plastics, wood, food wastes, glass, metals, special wastes, hazardous wastes
Institutional	Schools, hospitals, prisons, government centers	Same as commercial
Construction and demolition	New construction sites, road repair, renovation sites, demolition of buildings	Wood, steel, concrete, dirt, packaging waste etc.
Municipal services	Street cleaning, landscaping, parks, beaches, other recreational areas, water and wastewater treatment plants	Street sweepings, landscape and tree trimmings, general wastes from parks, beaches and other recreational areas, sludge
Process	Heavy and light manufacturing, refineries, chemical plants, power plants, mineral extraction and processing	Industrial process wastes, scrap materials, off-specification products, slag, tailings

(Source: Lee and Noor Zalina, 2006; Agamuthu *et al*., 2004; World Bank, 1999)

MSW disposed can be segregated into various types. Table 2.7 represents the classification of waste according to types.

Table 2.7: Waste classifications.

Waste Class	**Types**
Putrescible	Food waste
Paper	Mixed paper, newsprint, white paper, corrugated paper and magazine
Plastics	Plastic- film, hard-plastic, polystyrene, disposable diapers
Glass	Coloured glass, clear glass
Metal	Metal, tin, aluminium can, other aluminium
Organic	Textile, rubber/leather, garden waste, other organic
Others	Hazardous waste, dust/sand, other non-organic

Different type of waste retains different chemical character, density and energy content. Waste density plays a main part in waste management as it relates to the space required for disposal particularly in landfills (Sha'Ato *et al*., 2007). Waste with higher density can be more efficiently disposed than that of lower density. Plastic wastes posses big volume but very light in nature and as a result the density of plastic is low. Disposal of plastics into landfills caused poor compaction which is a tremendous disadvantage in waste cell utilization efficiency (Fauziah *et al*., 2004). While plastic presents disadvantages in compaction and landfill space, other waste types hold other detrimental effects including the emission of pollutant into the environment while some compose high energy components.

Research conducted over the years had shown that MSW generation in a country is influenced by the income level, rate of development of a country, the climate, socio-economic factor, and others (Saeed *et al.*, 2009; Fauziah and Agamuthu, 2006; Rathi, 2005; Agamuthu, 2001, Agamuthu *et al.*, 2004; Hoornweg, 2000; World Bank, 1999). Figure 2.1 illustrates the variation of waste generation and composition by affluence between high income area and low income areas.

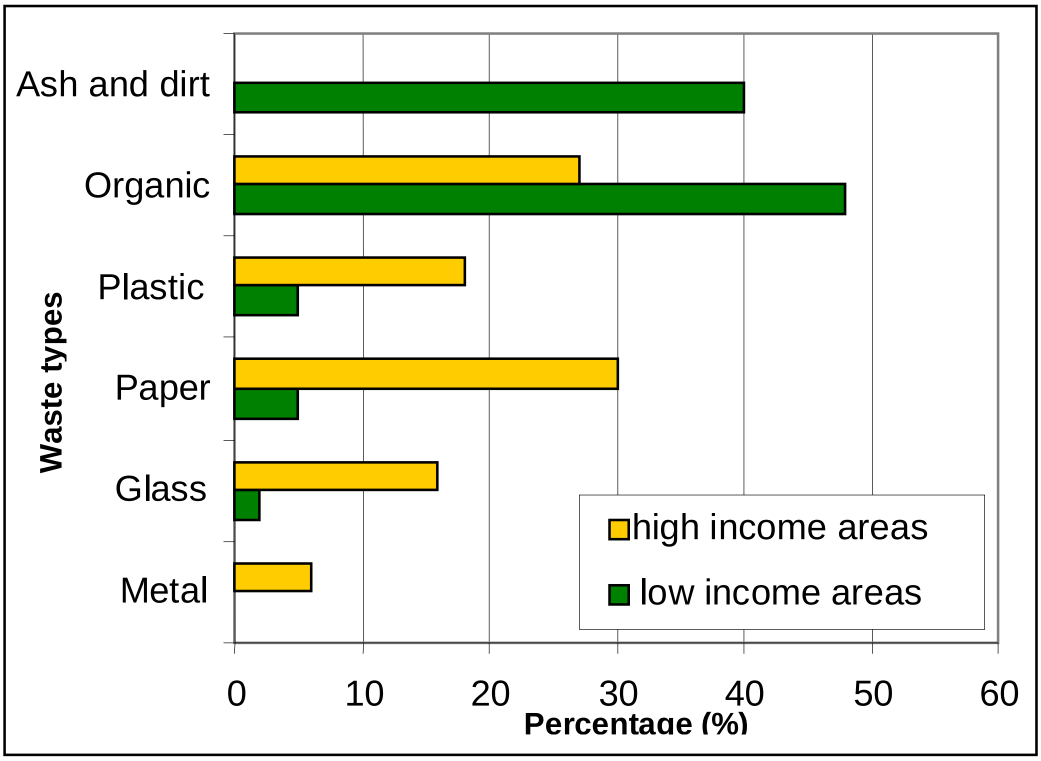


Figure 2.1: Variations in waste generation and composition by affluence between high and low income areas (adapted from World Bank, 1999).

The socio-economic life style of the community is closely related to the different trend in waste generation. The following sections discuss the trend in waste generation with regards to the level of development of a nation.

2.3.1. Scenarios in developed countries

The trend observed among the developed nations indicated that more processed waste was generated due to the hectic and busy life-style of the rich community. Even though similar types of waste such as paper, putrescibles, plastic and others are generated, the quality and quantity of the portion differ greatly. Trend from the developed nations showed that paper made up the highest portion (36%) followed closely by organic wastes and plastic wastes. Rates of paper waste generation increases with the increase in urbanization. Figure 2.2 show a typical composition of waste generated in developed countries (World Bank, 1999).

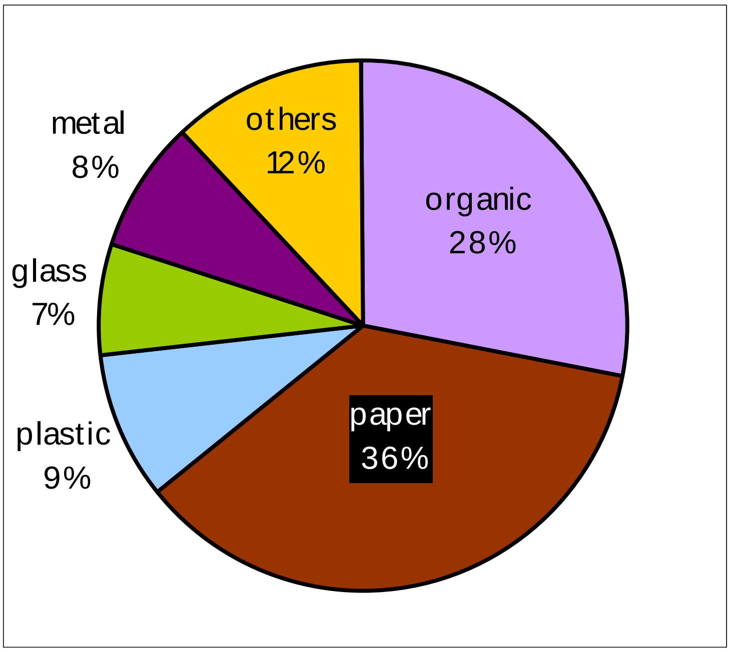


Figure 2.2: Typical waste composition in developed countries (World Bank, 1999)

The current percentages of waste composition in the developed nations will experience some slight changes in the future where higher percentage of organic and plastic wastes can be expected (Al-Salem, 2008; Demirbas, 2004; Zabaniotou and Kassidi, 2003; World

Bank, 1999). Figure 2.3 indicates the predicted waste quantities and composition for 2025.

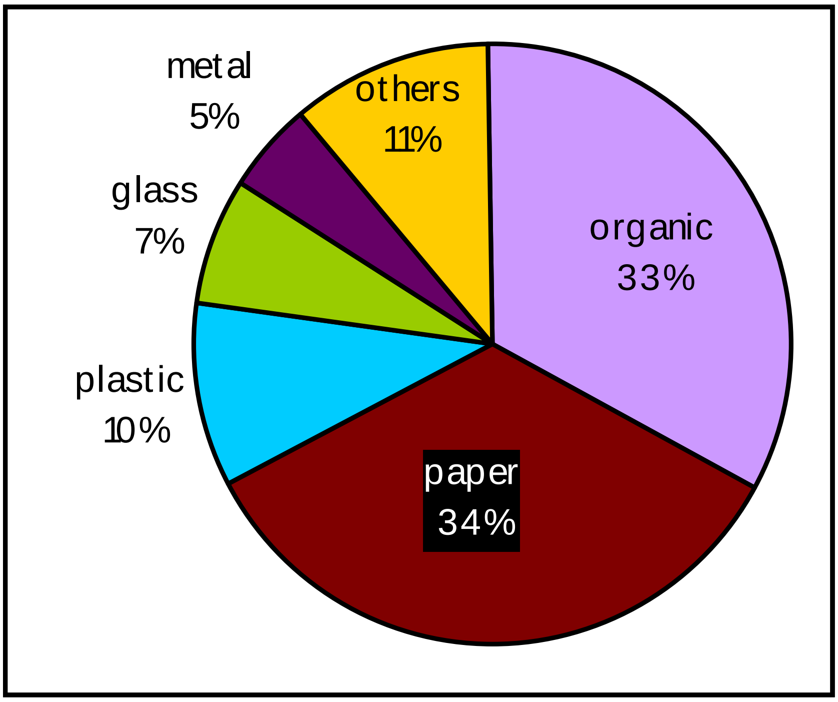


Figure 2.3: Predicted waste quantities and composition for 2025 in high income countries (World Bank, 1999).

By 2025, developed nations can be expected to dispose lower percentage of paper waste due to higher recovery for paper waste recycling (World Bank, 1999).

2.3.2. Scenarios in developing countries

The MSW generated in the developing countries contain relatively high percentage of organic waste i.e. approximately 50% of the total waste (Hao *et al*., 2008; Körner *et al*., 2008; Banar *et al*., 2009; Agamuthu *et al*., 2004). Middle-income developing countries generate paper and plastic waste at an almost equal percentage. Durability and broad range of usage caused plastic to be used widely which eventually ended up in landfills. The low cost of plastic production in the developing countries, lacked of policy and regulations related to plastic utilization, caused the use of plastic to be very wide and difficult to control (Najafi *et al.*, 2006; Zabaniotou and Kassidi, 2003; Rao, 2000) making developing countries the highest contributor of global plastic wastes. Figure 2.4 shows the percentage of waste generated by the developing countries, where plastic waste is the third largest waste type generated (World Bank, 1999).

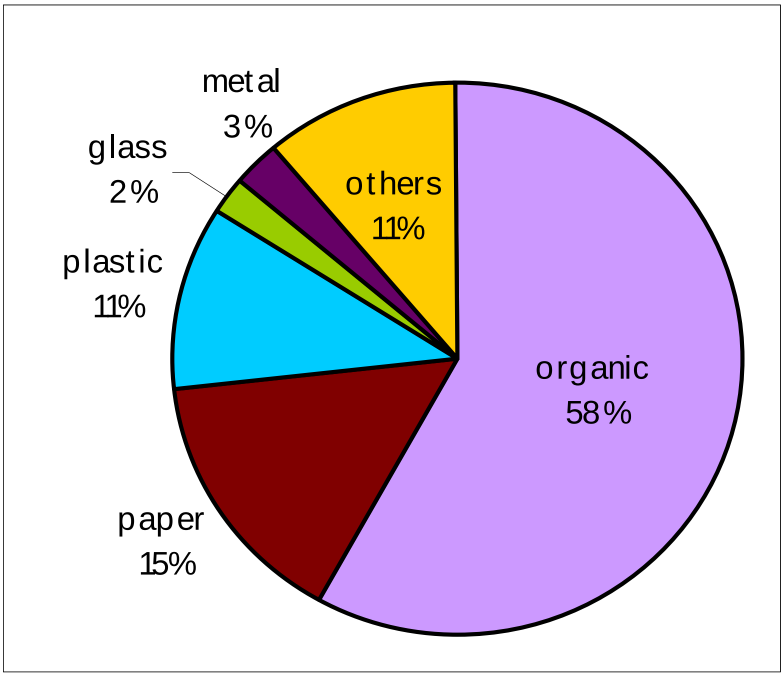


Figure 2.4: Typical waste composition in developing countries (World Bank, 1999).

In most of the developing countries, organic component is not recovered that the whole portion will be disposed off straight into landfills. The current trend is predicted to experience a slight change towards 2025, where organic portion will be slightly reduced.

Paper waste will be slightly increased while plastic waste will be reduced by 2-3%. The predicted waste composition of the developing countries is shown in Figure 2.5.

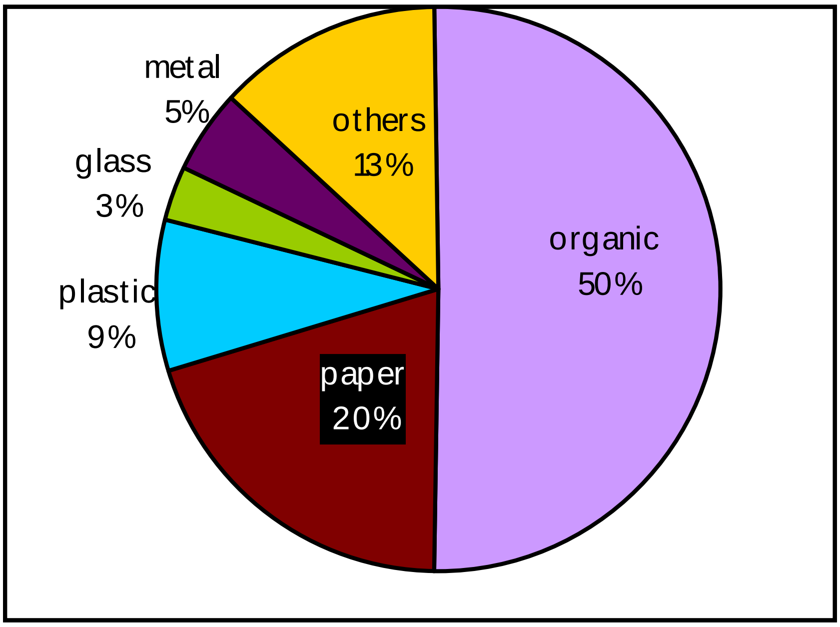


Figure 2.5: Predicted waste quantities and composition for 2025 in the developing countries (World Bank, 1999).

2.3.3. Scenarios in under-developed countries

Under-developed countries show a very interesting waste composition as the highest portion consisted of miscellaneous wastes followed by organic waste illustrated in Figure 2.6. Paper waste generation is low in line with the low urbanization in the country with a GNP lower than USD500-1000. Poverty causes majority of the people to source income from various point including wastes. Due to the high rate of source separation for recycling purpose, the recyclable materials including paper, plastic, glass and metal are very low. The remaining waste composed of other component which is non-recyclable. Indonesian MSW for example, contained 70% garbage (i.e. household refuse)

(Damanhuri and Padmi, 2000). Approximately 58% of it consisted of compostable materials indicating that different household type generates different waste composition (Damanhuri and Padmi, 2000).

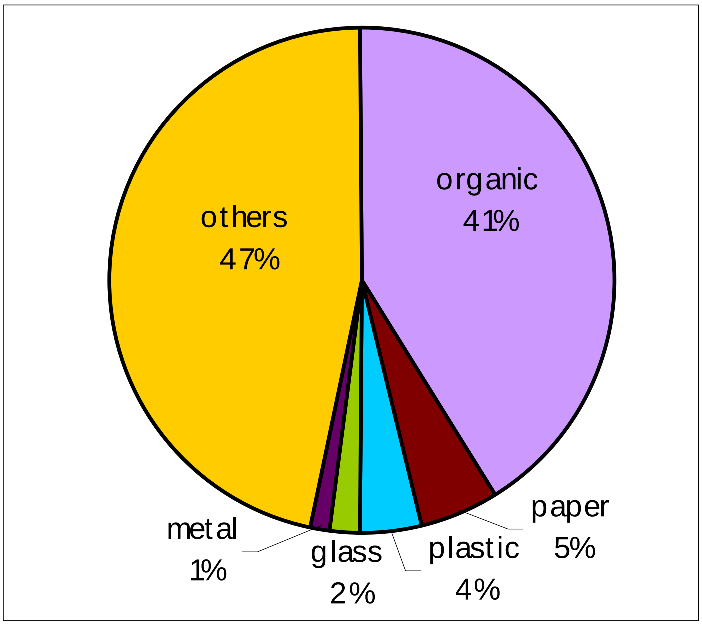


Figure 2.6: Typical waste composition in under-developed countries (World Bank, 1999).

Table 2.8 shows the waste composition among different types of household (varied by cooking and heating facilities) in Dalian, China, indicating the trend in waste composition of under-developed nation.

Table 2.8: Waste composition among different types of households in Dalian, China.

Household with different cooking and heating facilities.	Waste Content Percentage			
	Percentage	Organic	Inorganic	Other
Cooking with gas; individual heating with coal	35.3	70.1	19.3	10.6
Cooking with coal; central heating with coal	46.5	66.6	25.5	7.9
Cooking with coal; individual heating with coal	18.2	38.3	60	2.7

(Cited in World Bank, 1999)

Nevertheless, future waste composition trend is predicted to experience major changes as more areas will be developed into urban cities (Zhu *et al*., 2009). The predicted waste composition for 2025 in the low income countries can be illustrated in Figure 2.7.

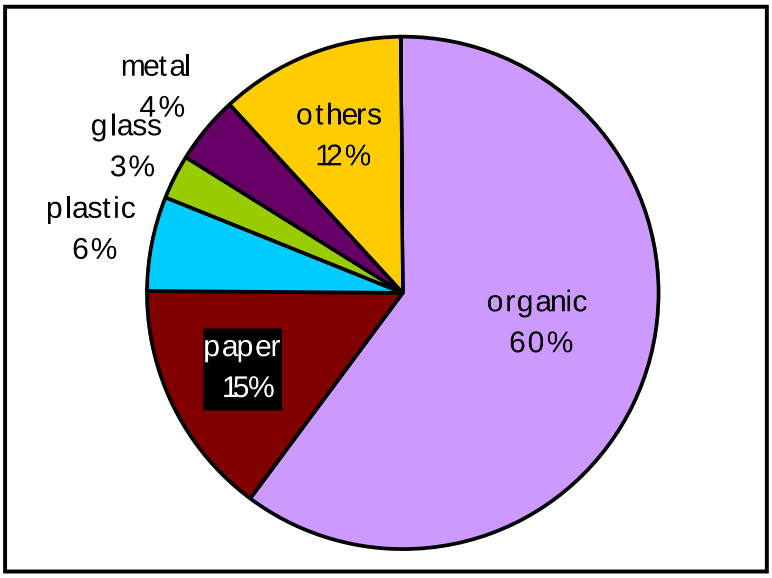


Figure 2.7: Predicted waste quantities and composition for 2025 in the low-income countries. (World Bank, 1999)

By 2025, low income nations are predicted to display the current trend of waste composition in developing countries (World Bank, 1999). The composition of organic waste is predicted to be 60% of the total waste due to the fact that traditional practice of recycling organic waste (composting, home- biogas generation etc) will be reduced in future with the improved standard of living, as being experienced by the developing countries (Shekdar, 2008). Regardless of the level of income of a country, all nation face similar problem of disposing the unwanted materials through a proper system. Following paragraphs discuss the waste disposal options in MSW management.

2.4 Waste Management Options

The ever alarming issues of the increasing rate of MSW had initiated various technology and application to manage the waste. It begins with the collection of waste from its numerous sources i.e. either from industries, residential areas, commercial zones or institutions, followed by pre-treatments prior to disposal. Among the currently practiced options are material recovery and recycling, composting, anaerobic digestion, incineration and gasification. This can be illustrated with the waste management hierarchy (Figure 2.8).

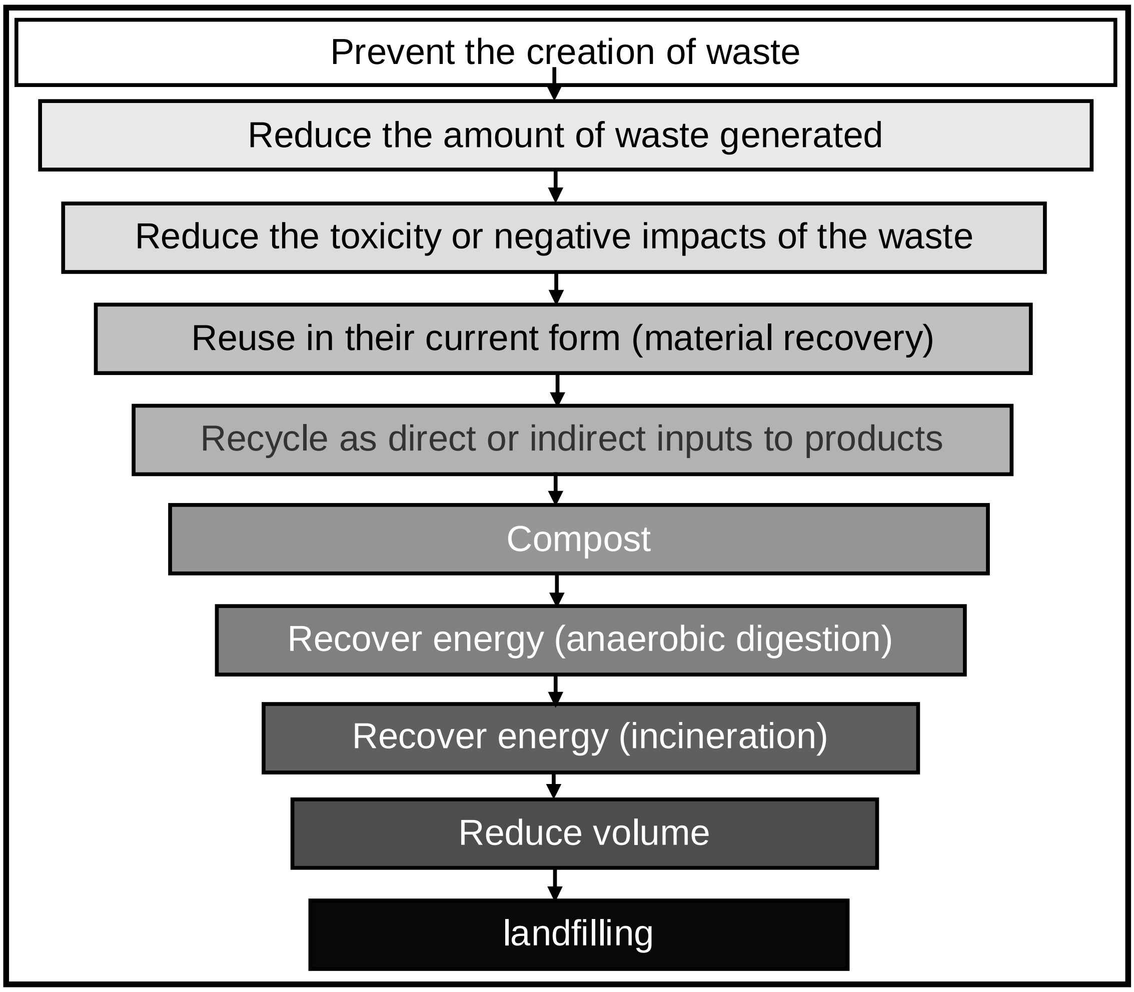


Figure 2.8: Waste management hierarchy (Adapted from Agamuthu *et al*., 2009; Tchobanoglous *et al*., 1993).

The different shades of the top-down options illustrate the comparative impacts each approach has on the environment. Waste prevention is with the least impact while landfilling has the largest impact in the form of resource depletion and pollution intensity. The possibility of the waste to undergo the top options as in Figure 2.8 will prevent loss of resources via reuse, recycle and composting options. However, the hierarchy may have slight differences when it involves a low population density area, where landfilling proved to be the most convenient method of waste disposal (Barrett and Lawlor, 1997). In developed countries where organic fraction ranged between 25 to 45% make composting more viable (Hoornweg, 2000). Consecutive paragraphs discuss the detail of each option in the waste management hierarchy. One of the most important activities which should be implemented within the flow of a MSW management system after waste prevention and waste reutilization is waste recycling.

2.4.1. Recycling of Waste

Recycling of valuable materials had been practiced ever since human is forced to live with limited resources. In the 1970s and early 1980s, glass bottles was considered scarce that these bottles were collected and returned back to producers to be reused or recycled (Landreth and Rebers, 1997; Waite, 1995). However, with the advancement in technology and the possibility of tapping into alternative sources, the recycling activities began to slow down and in some cases ceased to exist. The absence of the good practice of recycling had caused certain materials to be accumulated. With too large supply of an accumulated items and the low demand, these materials were disposed off, as it lack the value its still retain. Therefore, these materials have unnecessarily turned into waste and were sent to landfill for disposal.

In recent years when the global waste generation displays a frightening increase, recycling has once more become important and necessary in order to divert the continuous large waste stream. To date, recycling plays an important role in reducing various sources of pollution, as well as, reducing the loss of resources. Currently, material which is most being recycled is paper due to deforestation and global warming issues.

The realism of the importance of recycling is more intense among the developed nations as compared to that of the developing and under-developed countries. This had caused recycling rate to be high in the developed nations while in developing countries the rate is extremely low. Even though the recycling activity among the low-income countries is found to be high, the driver influencing the situation is generally due to the lack of resources and not of environmental awareness (Agamuthu *et al.*, 2009). In most developing countries, the fluctuation of the price of recyclable materials determines the rate of recycling activities (Batool *et al.*, 2008; Pappu *et al.*,2007; Leu and Lin, 1998).

The global recycling activity extends from recycling of automotive parts, batteries, chemical and liquid waste, electronic, food waste, glass, mineral, paper, plastic, scrap materials, textile, tire and rubber, and used consumer items. Global Recycling Network had been set up to collect, sell and trade various recyclables reclaimed in MSW streams, and market it as eco-friendly products, and had been successful in achieving the objective of recycling (Global Recycling Network, 2006). Besides the utilization of recycled sources as raw materials in a manufacturing process, having it as additive also resulted better quality products as reported by Zhang *et al*. (2008).

However, not all recycling of materials bestow positive impacts to the environment. Some recycling activities are found to be detrimental to the environment and not-cost effective (White *et al*., 1995). These are among the obstacles to be solved via appropriate technology in order to improve the quality of the environment. Among the most common method of recycling particularly of organic components is bioconversion.

2.4.2. Bio-conversion

Bioconversion involves the degradation and conversion of material from a complex form to a less complex form by living organisms. While recycling convert one waste material to another useful product, bio-conversion turns waste materials into compost and methane gas that volume of waste sent to landfills is also significantly reduced (Gómez Palacios *et al*., 2002; Hellweg *et al*., 2001; Gajdoš, 1998).

Bio-conversion also allows the reduction of greenhouse gas emissions from landfills (Lou and Nair, 2009). In Tanzania, composting and anaerobic digestion have been the alternative options for MSW disposal (Mbuligwe and Kaseva, 2006; Mbuligwe and Kassenga, 2004). The most common and widely practiced bio-conversion throughout the world is composting.

2.4.2.1 Composting

Composting has been practiced as a method to convert organic wastes into useful product known as compost. Compost with all the necessary minerals can be utilized as organic fertilizer to plants which not only enhance the growth (Jakobsen, 1995) but also help to improve the soil condition and it has been used for centuries in soil and crop management (Wießner *et al*., 2009; Hargreaves *et al*., 2008; Lynch *et al*., 2006; García-Gil *et al*., 2000; Bazzoffi *et al*., 1998).

Composting has been increasingly popular as an alternative to dispose waste in these recent years as a benefiting waste recycling option (Fauziah and Agamuthu, 2009; Tejada *et al*., 2009; Lou and Nair, 2009; Gabrielle, 2005; Agamuthu *et al*., 2004; Koenig and Bari, 2000; Schenkel, 1996). Composting promotes sustainable development and reduces environmental pollution to a minimal level (Lou and Nair, 2009; Salhofer *et al*., 2008; Agamuthu and Fauziah, 2005; Rogalski, 1996). Composting technology that applied as pre-treatment of a landfill in Thailand resulted with mass reduction and improved compaction value which may double the life-span of the landfill (Ranaweera and Tränkler, 2000).

Material flow management applied in Zurich, Switzerland managed to determine the impact factors and the interaction in bio-waste conversion to organic fertilizer (Lang *et al*., 2005). In order to integrate composting option into a waste management system, it is very essential that separate collection for putrescible waste is established. This is currently practiced in central cities of Denmark, Norway, Belgium and Austria (Leroy *et* *al*., 2007; Herbst, 1996; Knut, 1996; Hauer, 1996; Nilsson, 1996). Application of composts to soils is now recognized as an effective method to improve productivity in agro-ecosystems (Erhart *et al*., 2005) and certain compensation were given to hesitated farmers in Denmark to apply these composts onto their farmland (Knudsen, 1996). A survey carried out by the Roper Organization, New York, USA (1995) reported that 96% of solid waste professionals predicted that composting will expand in future as the best option in handling solid waste. Composting is a more viable option in managing waste particularly in countries where land scarcity caused the cost of landfill to increase (Chattopadhyay *et al*., 2009; Renkow and Rubin, 1998). Compost is also applicable as Cr absorbent material from wastewater and biofilter for methane and ammonia in landfills (Hong and Park, 2005; Chan and Lin, 2006; Nikiema *et al*., 2005; Pagans *et al*., 2005; Wei *et al*., 2005). There are various methods of conducting a composting system. Each method requires certain facilities and specific factors. The most common methods are simplified as in Table 2.9.

Table 2.9: Simplified methods of composting technologies.

Composting Method	Technology
Heap method	- Suitable for area of moderate or low precipitation; areas of high rainfall requires shade. - Composting conducted in long, shallow windrow of 1.5-2.0 m high and 2.5-4.0 m wide with aerobic condition maintained manually or by forced aeration - lead to 20-50% weight loss - advantages: simple and inexpensive. - disadvantage: no control of leachate run-off and difficulty in maintaining the optimal moisture content.

Table 2.9 (cont'd)

Composting Method	Technology
Shallow compartment	- suitable for towns with moderate volume of refuse - conducted under shade or in a building similar to heap method of long windrows with aerobic condition maintained manually or by forced aeration - advantage: can control leachate with modified flooring and drainage system - disadvantage: requires space with appropriate modified flooring.
Special chamber (mechanical composting) method	- appropriate for areas with large generation of waste in specifically designed chambers - aerobic condition is maintain with intermittent or continuous turning. - advantage : ensure optimal internal condition, more rapid in obtaining thermophilic stage, minimized loss of nitrogen, optimized microbial activities, maintain proper moisture content, leachate generation is extremely low. - disadvantage: expensive equipment

(Adapted from Agamuthu, 2004)

The process involved biological decomposition of waste containing organic substances of plants or animal origin under controlled conditions to a state sufficiently stable for nuisance free storage and utilization i.e. compost (Spellman, 1997). It possess similar characteristic as humus where it requires the degradation activities of decomposers including bacteria, fungi, actinomycetes and various protozoa under an aerobic condition. Forced up-flow and down-flow aeration in a composting system was found to enhance the degradation process and shorten the composting period (Koenig and Bari, 2002; Koenig and Bari, 2000; Tiwaree, and Putdhimanee, 2000).

The quality of the compost depends on the temperature, moisture content, nutrient content, pH, particle size, oxygen supply, and others (Komilis and Tziouvaras, 2009;

Mohee and Mudhoo, 2005; Agamuthu, 2001). The peak of microbial community in the compost can be determined via the analysis of total quinone and divergence of quinone in the compost (Tang *et al.*, 2004). Composting system with additional catalyst or ‘seeding’ to promote the degradation process and shorten the composting period had been widely practiced in the past few years (Iyengar and Bhave, 2006; Chang *et al.*, 2006; Agamuthu, 1999). Moisture content of the composting materials will decrease due to evaporation during thermophilic phase (Figure 2.9).

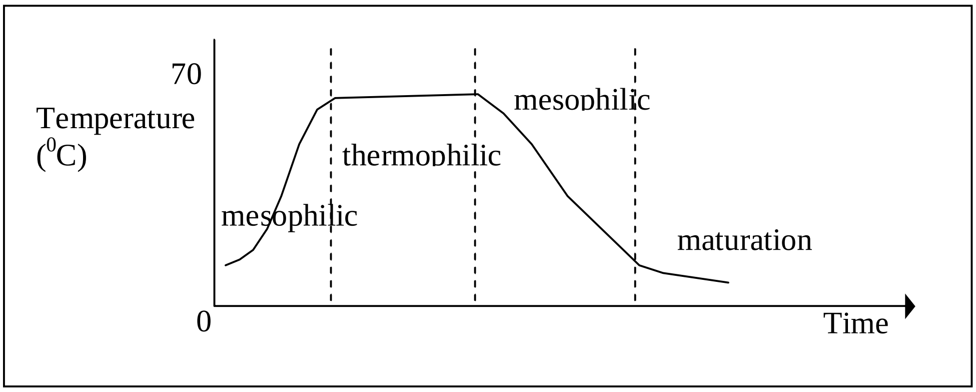


Figure 2.9: Typical Temperature Pattern of Composting System.

The composting process involves four main stages. First stage is the mesophilic stage where active breakdown of organic components occurred resulting with increase in temperature (50-55^{o}C) by the mesophilic organisms. It is followed with thermophilic stage or chemical oxidation stage where thermophilic bacteria started to grow at 54^{o}C and rising the temperature to approximately 70^{o}C (Miyatake and Iwabuchi, 2005). Dynamic successive process from mesophilic stage to thermophilic and mesophilic stage again is closely related to the temperature pattern of the composting system (Figure 2.9). The second mesophilic stage took place where temperature reduced gradually followed by the maturation stage where organic materials are completely broken down and composting organism are dying off. Organisms involved in the composting process ranged from microorganism like bacteria to macroorganism like worms as illustrated in Figure 2.10.

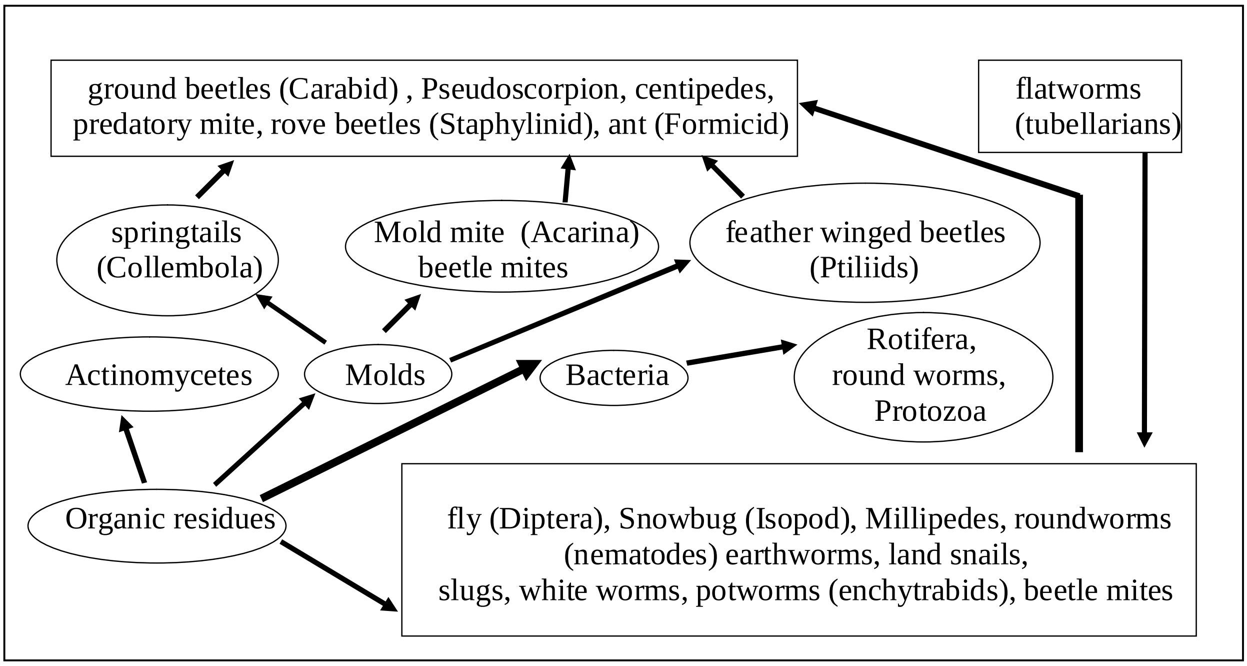


Figure 2.10: Food Web of The Compost Pile and Stages of Organisms Involved in Composting. (Adapted from: Diaz *et al.*, 1993)

Typical particle size of material used for composting ranges from 10 to 50 mm (Mohee and Mudhoo, 2005). Shredding of MSW prior to composting optimize the growth of mesophilic organisms which requires 5 -15 % of oxygen supply (Mohee and Mudhoo, 2005; Agamuthu, 2001). With optimal aerobic condition degradation of various chloro-organic compounds may also take place (Eklind *et al.*, 2004). The curing and maturation periods of the compost may take 2 weeks to a month and can be monitored with the level of dissolve organic acid or humic acid (Castaldi *et al.*, 2005; Zmora-Nahum *et al.*, 2005; Smidt and Lechner, 2005). Composting as is a biological process has its advantages and limitations (Jomier *et al.*, 1996) which can be listed as in Table 2.10.

Table 2.10: Advantages and disadvantages of composting.

Advantages	**Disadvantages**
Include few equipments	Leached out nutrient during downpour
Low operating cost	Slow rate of processing
Generates commercially profitable products	Unpredictability of a biological system
Cost effective technology	Nuisance due rodents and fly
An inexpensive and environmentally sound method.	Emitting disturbing odor

The composting technique has provides as an effective alternative in managing MSW with its wide applications (Zurbrügg *et al*., 2005). Compost may be used as a substitute for peat in preserving wetland areas or applied to plantation as soil amendment in improving the health of agricultural crops (Alvarenga *et al*., 2009; Rivero *et al*., 2005; Lynch *et al*., 2006; Crecchio *et al*., 2004). It is also being utilized as substrate for container-grown plants (Benito *et al.,* 2006; Hicklenton *et al*., 2001) and had been applied to landfill as the covering material to substitute peat and soil (Hurst *et al.,* 2005; Ingelmo *et al*., 1998; Carlsbœk and Reeh, 1996). Application of compost as landfill cover was effective in reducing the obnoxious odour released from the decomposing waste (Hurst *et al*., 2005) while the application onto land improves the soil physical properties. The commercialization of compost would require appropriate encouragement including subsidies in order to reduce the negative perception of the public on MSW compost (Danso *et al*., 2005). However, indiscriminate disposal of hazardous component such as tannery waste into the MSW stream may causes contamination to compost (Duan *et al*., 2008; Bhattacharyya *et al*., 2006). Table 2.11 shows other innovative utilizations of compost as suggested by the US EPA.

Table 2.11: Innovative Utilization of Compost (Source: US EPA, 1998).

Innovative uses of compost	**Application**
Bioremediation and pollution prevention	• Agricultural effluents, industrial residues, industrial accidents contaminate surface waters, soils, air, streams and reservoirs. • Contaminated soils, manage stormwater, control odour, degrade volatile organic compounds.
Disease control for plants and animals	• Sustainable farming systems • Agricultural plantations • Poultry industry
Erosion control, turf remediation and landscaping	• Soil amendment to alleviate soil compaction
Composting of soils contaminated by explosive	• Munitions sites particularly on explosive contaminated sites
Sites restorations	• Reforestation, wetlands restoration and habitat revitalization

Composting of MSW requires proper planning and management in order to prevent the organic component from undergoing improper degradation that become toxic and hazardous to the environment. Smaller scale of composting is also widely practiced throughout the globe where organic portion of the household waste was allowed to undergo household composting with the utilization of small-scale compost bins and others. Among other which is applicable to individual household is vermicomposting. Consecutive sections discuss the details in vermicomposting.

2.4.2.2 Vermicomposting

Vermicomposting involved the use of worms in digesting and breaking down organic component. Vermicompost is defined as the process where organic wastes are decomposed by earthworms into odour free humus-like material (Suthar, 2009). Among the species of worm used for this purpose are *Eisenia foetida*, *Lumbricus rubellus, Perionyx excavatus, Lampito mauritii, Eudrilus euginea,*and *Pheretima elongata* (Suthar, 2006; Nair *et al*., 2006; Gajalakshmi and Abbasi, 2004; Tripathi and Bhardwaj, 2004; Ghosh, 2004; Tripathi and Bhardwaj, 2004a; Agamuthu, 2004).

Eisenia foetida was found to be more adaptable to convert waste into vermicompost under the tropical condition (Tripathi and Bhardwaj, 2004). The compost produced is of higher quality with various benefits including extra advantages on pest control in soil (Yardim *et al*., 2006). Vermicompost had been proven to increase better yield in crops production (Arancon *et al*., 2005; Arancon *et al*., 2004) and some vermicompost exhibit fertilizer-cum-pesticide character with the addition of certain types of waste (Gajalakshmi and Abbasi, 2004).

Vermicompost also retains higher nutrient content including N, P, K, other minerals and higher concentration of humic acid as compared to typical compost without worm treatment (Yadav and Garg, 2009; Farrell and Jones, 2009; Kumar and Goel, 2009; Suthar, 2009; Garg *et al*., 2006). Generally, vermicomposting produces compost which carries extra benefits as compared to the conventional compost production (Table 2.12).

Table 2.12: Benefits and disadvantages of vermicomposting process. (Adapted from Suthar, 2009; Adi and Noor, 2009; Garg *et al*., 2006; Agamuthu, 2004)

Benefits	**Quality**
Particle size	Reduced to finer particle
Odour	Minimum odour due to the elimination of senescent bacterial and new colonies growth enhancement
Humus	Humus with high N content
Pathogenic microbes	Minimized or eliminated due to the activity taken place
Oxygen availability	Improve oxygen penetration with finer particle size
Minerals	Increase mineral content
Nutrient	Excretions are rich with nitrates, K, P, Ca and Mg
Disadvantages	**Quality**
Time	Slower than normal composting
Product collection	Difficult to remove the compost
Temperature	Require heavy monitoring on temperature of compost to prevent dehydration of the worms (13^0C- 35^0C)
Excess water	Requires careful monitoring to prevent the composting system from forming water clogs
Final product	Very dependent of the raw material of the composting setup.

Vermicomposting can be carried-out in a smaller scale that it is more applicable for individual household to treat kitchen and garden wastes. Other method of bioconversion of waste is anaerobic degradation.

2.4.2.3 Anaerobic Digestion

Anaerobic digestion of MSW was found to be a beneficial option which convert waste component into biogas under anaerobic condition (Augenstein *et al*., 1996) and ecologically friendly with regards to energy balance (Fricke *et al*., 2005). The first anaerobic microorganism, *Clostridium* sp. was discovered by Louis Pasteur in his study of butyric fermentation (Hughes, 1979). The sources of anaerobic digestion are paper, sewage sludge, food leftover and other non-green organics. Three principal products from anaerobic digestion process are biogas, high nutrient leachate and compost residue.

Biogas generation from anaerobic digestion process is proved to be one of the best substitutes for fossil-fuel (Demirbas and Balat, 2006). Biogas produced is a mixture of gasses consists of methane (55-65%), carbon dioxide (45-35%) and trace amount of hydrogen. Biogas production and daily leachate flow can be simulated with the use of certain model such as MODUELO and HELP (de Cortázar and Monzón, 2007; de Cortázar *et al*., 2002). Findings from Pfeffer (1979) indicated that the higher the temperature of the reactor for the anaerobic digestion process of MSW, the higher volume of gas will generate as illustrated in Figure 2.11.

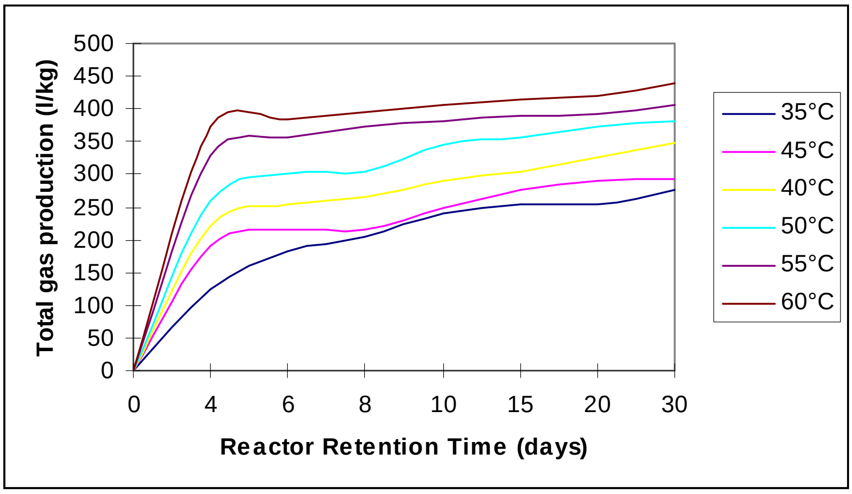


Figure 2.11: The effect of temperature and retention time on the production of gas from urban refuse (dry based) (Pfeffer, 1979).

Anaerobic digestion technology is also applicable to reduce pathogenic bacterial colonies namely *Escherichia coli*, *Salmonella* sp, *Yersinia* sp., *Listeria* sp. and others, as well as fungal growth such as *Aspergillus* sp., *Rhizomucor* sp. in various waste (Côté *et* al., 2006; Schnürer and Schnürer, 2006; Horan *et al*., 2004). The factors involved in the destruction of the pathogenic microbes included the mixing method and temperature applied (Smith *et al*., 2005). Anaerobic digestion to treat MSW can be enhance with industrial sludge, sewage sludge, swine slurries, animal fats, animal manures and others (Gómez *et al*., 2006; Côté *et al*., 2006; Fernández, *et al*., 2005, Hartmann and Ahring, 2005; Ağdağ and Sponza, 2005; Sosnowski *et al*., 2003; Callaghan *et al*., 2002; Murphy and McCarthy, 2005; Castillo *et al*., 2005; Stroot *et al*., 2001; Lund *et al*., 1996).

Though the process is found to be an advantageous method of treating waste and converting it into value-added products, it posses a few drawbacks (Fricke *et al*., 2005). Among the drawbacks are the sensitivity of the process as it is a biological process, requires pre-treatment of waste in term of particle size reduction, emission of noxious odour, requirement of air-tight vessel to work efficiently and the compost produce require further treatment including drying (White *et al*., 1995).

Studies had indicated that the pre-treatment process and addition of landfill leachate and shredded waste would enhance the biogassification process in an anaerobic digester (Sponza and Ağdağ, 2005; Bockreis and Steinberg, 2005; Nopharatana, *et al*., 1998). It is applicable to any countries despite of the climatic changes that more and more countries are harvesting biogas generated via landfill anaerobic digestion activities particularly for the conversion of electricity (Hedegaard and Jaensch, 1999). In Tanzania, biogas is expected to generate as much as 5.18 MW/day replacing the conventional energy source of wood-fuel (Mbuligwe and Kassenga, 2004). Contois models were utilized to determine the rate of waste degradation in a digester bed where volume of methane can be estimated (Vavilin *et al*., 2005). The amount of MSW input for the anaerobic digestion does not influence the efficiency of the biogas production (Gallert *et al*., 2003; Stroot *et al*., 2001). However, the increase in yield is possible with the implementation of a multi-stage anaerobic digester compared to that of the conventional method of a single stage digester (Vogt *et al*., 2002).

The subsequent step in the waste management hierarchy after anaerobic digestion is incineration. In this step, the non-organic composition of the waste will be incinerated with the purpose of generating heat and energy recovery. The consecutive paragraphs describe the function and details of incineration.

2.4.3. Incineration

Incineration plants are designed as such to serve different purpose e.g. to recover heat including for steam production and power generation. This had been practiced in early 1990s in developed nation as an effective way to convert MSW into energy (Dent and Krol, 1990; Brautlecht and Gredigk, 1998). The objectives of incinerating waste listed by Sabbas *et al*., (2003) include:

- to reduce waste volume and mass, prior to landfill disposal,
- to recover energy from waste incineration process,
- to conserve raw material for energy utilization,
- to destroy organic contaminants,

- to reduce total organic compound, which emit disturbing odour, and
- to concentrate inorganic polluting substances.

The disposal option of incinerating MSW has its advantages and disadvantages. Among them are the disadvantages and impacts on the socio-economy and environmental quality (Di Maria and Pavesi, 2005; Miranda and Hale, 1997). Table 2.13 indicates the list of advantages and disadvantages of the incineration system.

Table 2.13: Advantages and disadvantages of incineration plants.

Advantages	**Disadvantages**
• Destroys hazardous component including pathogenic substances • Cost effective in areas with land scarcity • Possible to adhere to stringent regulations stipulated by the authority • Landfill space-saving • Limited space requirement	• High capital and operating cost • Technical difficulties in operation • High moisture content in waste caused inefficiency • Low energy waste reduce energy production • Expensive installation for pollution control system and aggressive maintenance

Incineration of MSW resulted with 75% weight reduction, 60% mass reduction and 90% volume reduction (Niessen, 2000; UNEP, 1996; Oorthuys and Scharff, 1996). High moisture content reduces the burning efficiency and the volatilization of the some metallic oxides (Magrinho and Semiao, 2008; Liu *et al.*, 2009; Sharholy *et al.*, 2008; Youcai *et al.*, 2004).

Incineration is less popular in Asian countries than in Europe and USA, particularly in the slow-developing nations like Indonesia, Bangladesh, and Vietnam, with waste of low calorific value. A lower calorific value of only 3.4 – 4.6 MJ/kg or approximately 75% of those waste from Europe, has caused less efficiency in the incinerating system (Hansen *et al*., 2007; McDougall *et al*., 2000; Lucas *et al*., 2000). Data in 1991 indicated that in Shenzhen, China, only 28% of approximately 265 tonnes of waste generated daily were incinerated by which 40- 70% composed of organic materials (Pant *et al*., 2000)

In developed nations where technology and cost are not a major set-back, more incineration plants are established. For example, in 1993, approximately 125 incineration plants had been constructed in USA, which actively converts waste to energy (Wiles, 1996) while Japan had more than 167 incineration plants with a capacity of 50-150 tons /day. However, energy extraction is generally unpopular in countries with low calorific value waste. Malaysian MSW for example has a calorific value of 1,500 to 2,600 kcal/kg which would generate an estimate of 640kW/day of energy potential (Kathirvale *et al*., 2003).

Since incineration plants are more cost-effective in waste management and disposal particularly in requiring less space than landfills, countries with land scarcity found it more agreeable. Singapore, for example fully utilized incineration rather than landfilling where approximately 90% of the total wastes generated by the islanders were incinerated (UNEP, 1996). Hong Kong which generates more than 18,000 tonnes of MSW daily diverts most of the waste to incineration in order to extend the life of landfills (Rockey *et al*., 2000).

Mechanical separation of MSW in some developed countries such as The Netherlands managed to recover retrievable materials and distinctly grouped the appropriate components for incineration (Brinkmann and Oothuys, 2000). The energy harvested from MSW incineration plants is found to give a very positive impact in Sweden particularly with the reduction of fossil fuel consumption whereby the energy harvested is utilized for district heating system and electricity production (Sahlin *et al*., 2004) with various pollution preventive measures installed (Nammari *et al*., 2004).

The emission from incineration plants which includes flue gas, dioxins, HCl and poly-aromatic hydrocarbon (PAH)s was found to be hazardous and harmful to the environment that various technologies had been implemented (Wey *et al*., 2006; Rada *et al*., 2006; Caserini *et al*., 2004; Li *et al*., 2004; McKay, 2002). Air pollution control residues (APCR) as a by-product of MSW incineration consist of various hazardous compounds including polychlorinated dioxins and dibenzofurans, approximately 17 to 22% soluble salt, metallic contaminants such as Pb, Cd, Zn and Hg in oxides forms or bonded with sulphur or chloride (Rada *et al*., 2006; He *et al*., 2004; Caserini *et al*., 2004; Abanades *et* al., 2002; Pinzani *et al*., 2002; Chandler *et al*., 1997).

The release of dioxin from wet scrubber was reported to be almost proportional to time due to the 'memory effect' (Adams *et al*., 2000) and the reduction of dioxin and furans are possible by controlling CO emission with the usage of activated carbon (Lin and Chang, 2000). The counter-current sorption process using peat moss was found efficient to remove Pb from APCR (Hammy *et al*., 2005). Solidification and stabilization technique, the gasification-melting system, and chemical fixation were applied to the MSW incinerator fly ash which contains trace metals including Pb, Cd, Cu and Se prior to fly ash disposal (Geysen *et al*., 2006; Bagnoli *et al*., 2005; Kim *et al*., 2005; Yvon *et al*., 2005; Geysen *et al*., 2004; Huang and Lo, 2004; Wan *et al*., 2004; Jung *et al*., 2004; Huang and Chu, 2003). Fly ash is applicable as compact landfill liner but it is subjected to metal leaching (Palmer *et al*., 2000).

Refuse-derived fuel (RDF) Conversion

Conversion of waste into value-added products can also be achieved with the production of RDF. This option enables the utilization of source-separated MSW into energy-producing materials (Ishii *et al.*, 2003). The practice of RDF conversion has gained popularity since 1980s in the US, Europe and other parts of the world and it is now one of the main options to divert MSW from landfill (Cheng and Hu, 2010; Unnikrishnan and Singh, 2009; Marsh *et al*., 2008; Thipse *et al*., 2002; Glaub *et al*., 1984). The concept of the RDF conversion is the utilization of combustible components in the waste stream as fuel to generate energy particularly heat.

RDF products are also processed such that pallets can be stored for subsequent use (Tchobanoglous *et al*., 1993). This is achieved by ensuring that moisture content was low to prevent the microbial growth since RDF pallet may also includes organic components of the wastes. However, spontaneous ignition of RDF during storage has been reported that the initial temperature, water content and size of RDF pallets need to be monitored appropriately (Yasuhara *et al*., 2009). The viability of RDF utilization depends on the calorific value of the waste and its homogenous particle size (Galvagno *et al*., 2009; Marsh *et al*., 2008; Hernandez-Atonal *et al*., 2007). As a result, RDF processing plants should have the flexibility to respond to the ever changing quality and quantity of waste throughout the operation (Tchobanoglous *et al*., 1993).

Evaluations on the financial risk of RDF generating plant were conducted to determine the economic feasibility (Moran *et al*., 2009; Khoo, 2009; Maria and Pavesi, 2005; Caputo and Pelagagge, 2002). In most country, the generation of RDF requires the mixing of a high calorific waste such as scrap tires and plastics with the stream of household waste to achieve the prescribed heating value target (Al-Salem *et al*., 2010; Chiemchaisri *et al*., 2010; Caputo and Pelagagge, 2002). MSW mined from landfills which contained high proportion of plastic components were also feasible to be converted into RDF pallet (Chiemchaisri *et al*., 2010; Prechthai *et al*., 2008).

Another option of thermal treatment besides incineration with or without energy recovery is pyrolysis. The emissions from incineration plant, pyrolysis and other material recovery plants would still require a disposal site for its by-products. The most preferred final destination of these materials, as well as, other MSW from countries with the absence of advanced waste management technology is landfill. The consecutive sections discuss landfill option in the waste management hierarchy.

2.4.4. Landfill

Landfill is placed at the very bottom of waste management hierarchy as the last option to be considered. However, landfill remains as the ultimate disposal options since all waste material would still require a disposal site regardless of its pre-treatments. Landfill can be defined as a site where wastes are disposed off in or onto land. International Solid Waste Association (ISWA) (1992) defined landfill as "*the engineered deposit of waste onto and into land in such a way that pollution or harm to the environmental is prevented and, through restoration, land provided which may be used for another purpose*".

Landfills have always been the main methods to dispose waste particularly MSW due to the minimum maintenance requirement. However, over the years with more and more landfills becoming major source of environmental pollutions, stricter and more stringent regulations are stipulated by the authorities to curb the pollution impacts.

United States Environmental Protection Agency (EPA), for example, requires appropriate disposal of solid waste that it is compulsory for landfill managers to abide to the Resource Conservation and Recovery Act (RCRA) and subsequent EPA and State regulations (USEPA, 2000). Similar scenario was observed in the UK when the Landfill (England and Wales) Regulation 2002 came into force. Respective landfill managers must comply with the Landfill Directive where pollution impacts from landfill must be prevented or reduced to the maximum (Environmental Agency, 2006). Meanwhile in Japan, landfill managers under the Ordinance of the Ministry of Environment are subjected to comply all regulations including reserving an appropriate sum of fund for landfill maintenance (Waste Management and Public Cleansing Law, Japan, 2006). In Germany and Denmark, the disposal of untreated wastes into landfills are totally banned in order to increase the time-span of the disposal site due to the scarcity of suitable sites for landfill (Wikipedia, 2006). The Statutory order i.e. Bekendtgørelse om deponeringsanlæg BEK nr 650, of Denmark after 29 June 2001 requires landfill managers to compile and report types and amount of waste deposited, characteristic and collection of leachate and others, to relevant authorities. Similar legislations were also established in Poland which gradually improves the environmental state of the country (Malina and Bien, 2001).

Due to its low cost, waste disposal into landfills in Asia remains as an integral part of waste management in the future (Shekdar, 2009; Chong *et al*., 2005; Lucas and Shreeve, 2000). As suitable land is getting scarce, a selected land for the construction of landfill requires proper planning and efficient management in order to optimize the landuse (Davila *et al*., 2005). Zeiss and Lefsrud (1995) proposed that a siting of a landfill should include four sets of causal elements:

1. the design and operation of the facility,
2. stakeholders values, attitude, actions and belief,
3. intervention of the proponent siting, and
4. outcome and the interaction of the stakeholders.

Normally, the efficient land utilization would include the maximum waste depth of over 100 m (Ng and Leung, 1999). Also to be taken into account in designing a landfill is the ability of the landfill to attain the wastes from polluting the adjacent area (Westlake, 1997). A typical design of a landfill is illustrated in Figure 2.12.

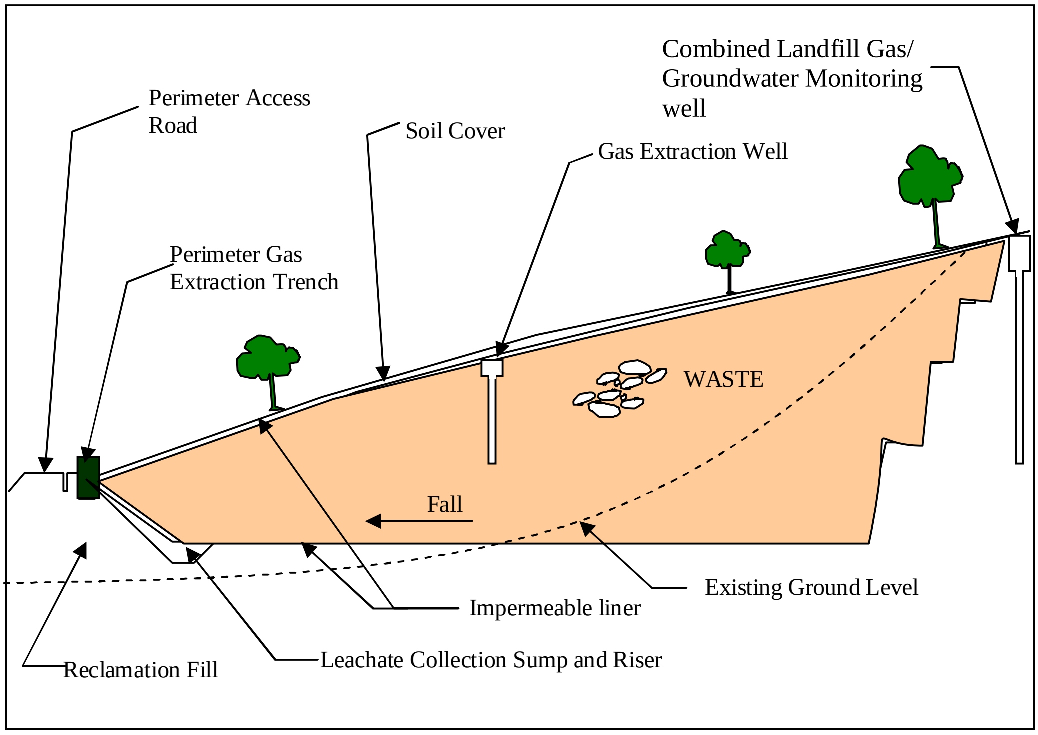


Figure 2.12: Typical section of strategic landfills (Adapted from Ng and Leung, 1999).

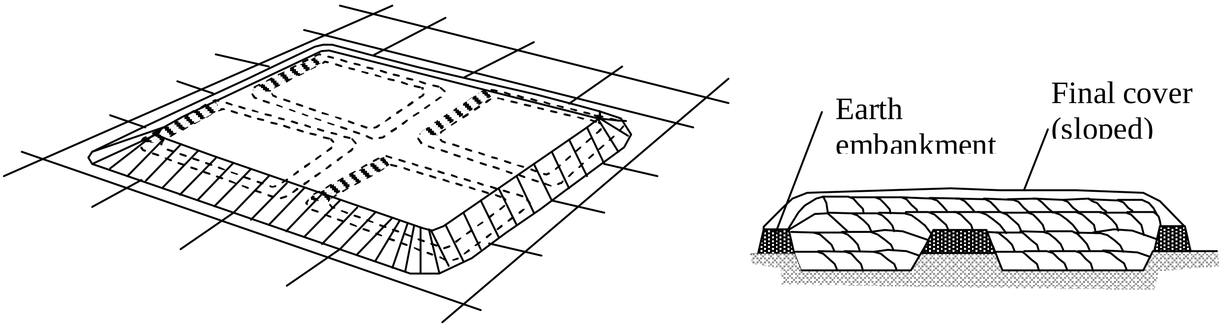
Landfills can be classified into four main classes based on the technology applied:

1. Open-dumps,
2. Controlled-dumps,
3. Sanitary landfill, and
4. Secure landfill.

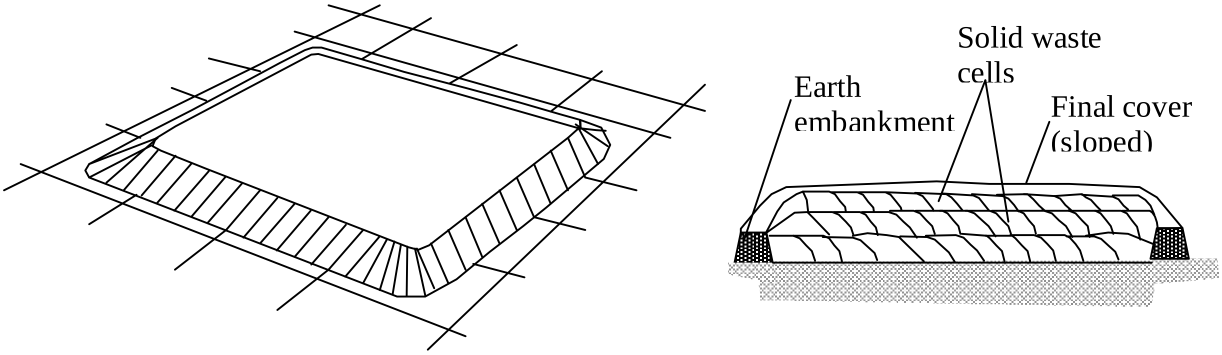
Each class of landfilling offers different output pertaining to the cost, social and the environmental risks. Planning of a landfill includes the consideration for the landfill siting, the construction, designs suitable to cater waste generated, the operation and the monitoring of the environment during the active period of the landfill and the post-closure measures.

In deciding the most suitable place for a landfill, various factors should be looked into with a multiple criteria system approach (Blight, 2005; Kontos *et al*., 2005). A site with a very low water table made it possible for a trench method of waste disposal and generally would be more cost-effective. However, if the water-table is high, it is not applicable as it might increase the risk of ground-water contamination from leachate. The most applicable method in area with high water-table is the area method where embankment or ramp is built to create waste cell and waste is disposed on the land as illustrated in Figure 2.13.

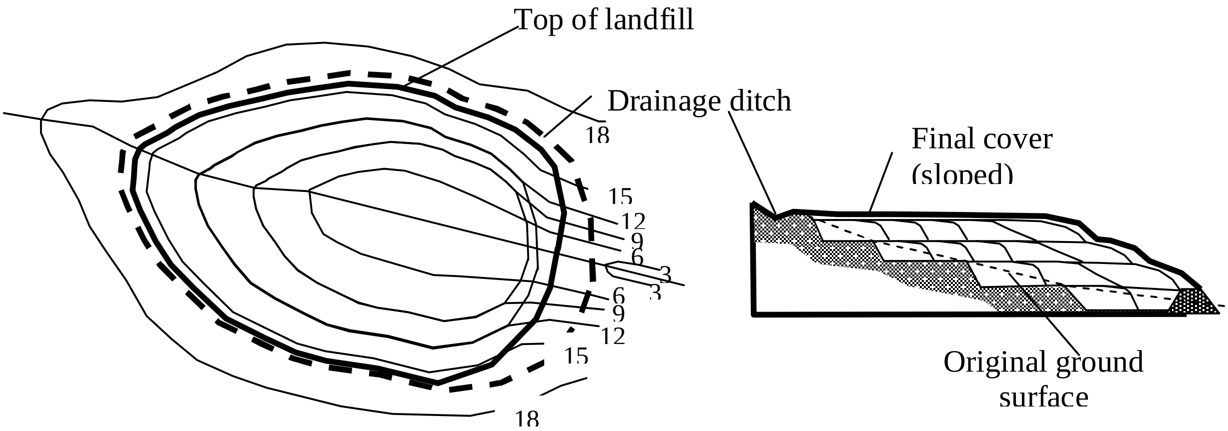
If the site selected for a landfill has a sloping geographical feature, depression method offers the most cost-effective method. While trench method generally provides cover material for the waste disposal operation, the area method would be more easily to be constructed since no excavation will take place. The advantages and disadvantages of the different types of landfill are simplified in Table 2.14 while siting guidelines related to hydro-geology proposed by UNEP (1996) is shown in Table 2.15.



(a) trench method



(b) area or ramp method



(c) canyon/ depression

Figure 2.13: Landfilling Methods (Adapted: Tchobanoglous *et al*, 1993)

Table 2.14: Advantages and disadvantages of different types of landfill. (Adapted from UNEP, 1996)

Type	Advantages	Disadvantages
Open Dump	• Easy access • Extended lifetime • Low initial cost • Aerobic decomposition • Access to scavengers • Material recovery high	• Environmental contamination • Overuse, many noxious sites • Unsightly, need remediation • Ground and surface water contamination • Encouraged vermin, pest and vectors to diseases • Indiscriminate use • Least efficient
Controlled Dump	• Less risk of environmental contamination • Allow long-term planning • Low initial cost • Easier rainfall runoff, reduced risk • Moderate cost for maintenance • Extended lifetime due to compaction • Controlled access and use • Material recovery lower	• Less accessible • Slight environmental contamination • Decomposition slower • Higher cost of compaction • Higher cost for leachate and gas management
Sanitary Landfill	• Minimized environmental risk • Permit long-term planning • Reduce risk from leachate and gas contamination • Vector control • Extended lifetime due to compaction • Secure access with gate records • Eliminate risk to scavengers • Possible to harvest biogas	• Access requires longer siting process • High cost for construction • Slower decomposition of waste • High maintenance cost • High cost for leachate and gas management • No further material recovery activity
Secure Landfill	• Very minimal environmental risks • Allows long-term planning with accurate information • Prevent risk at site due to precautionary actions taken • Eliminate risk to scavengers • Prevent hazardous waste from contaminating the environment. • Pre-treated waste stop risk to environment i.e. no leachate etc.	• High construction cost • Minimum or almost absent of natural decomposition • High waste pre-treatment cost • High cost for maintenance • No further material recovery activity

Table 2.15: Siting guidelines related to hydro-geology (UNEP,1996; Qian *et al*., 2002).

Unsuitable sites for landfills:	Suitable sites for landfills:
• in an area with a high water table or in wetlands, • in floodplains, water-catchments areas or in areas that are close to drinking water supplies, or • areas with geological faults, unstable or areas which experience frequent seismic activity.	• Land with a layer of clay soils, • Land with an underlying bedding of igneous rock, and • cover material is available nearby.

Existing layer of clay generally is an excellent foundation in siting a landfill, as well as, the existence of igneous rock bedding (Tchobanoglous *et al*., 1993). Sand layer is unsuitable due to its high rate of water penetration. Cover material on the other hand is also necessary where daily landfill covers should be 15 to 30 cm thick (UNEP, 1996).A landfill if strategically sited in area where cover material is available nearby allows a smoother and more efficient landfill operation.

The accessibility of a landfill by waste collectors is crucial to avoid extra transportation cost incurred for waste hauling operation. Transfer station is constructed to facilitate waste collection and compaction particularly when landfill is sited outside the collection area (Wang *et al*., 2009a). Transfer station can be define as a facility where MSW undergone various pre-treatment prior to waste disposal.

Among the pre-treatments normally conducted in transfer stations are material recovery, waste compaction and others. Iron, steel, aluminum, glass and combustible matters are among the possible items to be screened and recycled in transfer station (Alter, 1983;

Kusaka and Iida, 2000). Among the most common type of transfer station is the direct load transfer station (Figure 2.14) while other include storage load transfer station and combined direct load and discharge load transfer station.

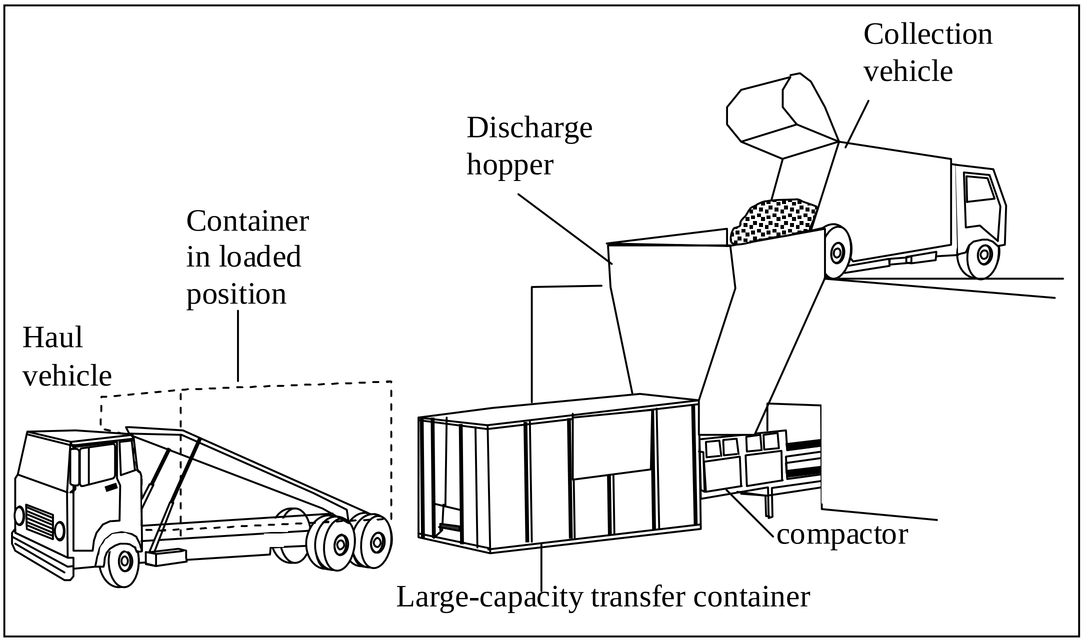


Figure 2.14: A small capacity direct load transfer station equipped with a stationary compactor (Adapted from Tchobanoglous *et al*, 1993)

Environmental advantages obtained from the establishment of transfer station are the reduction in air emission due to less vehicles transporting waste into landfill, possibility of material recovery, and reduction of leachate generation resulted from the compaction process (Wang *et al*., 2009; Tchobanoglous *et al*., 1993).

Also to be included in the decision-making of a landfill site is post closure development. Improper planning for landfill post-closure resulted with continuous risk to human and the environment (Fauziah *et al*., 2007). Conversion of closed landfill is being practiced in most part of the world including in Tunisia where a closed landfill was converted into an urban recreational park with appropriate types of plants (Zaïri et al, 2004; Rawlinson *et al*., 2004).

Landfill operations

In constructing a landfill, it is also very crucial to take into consideration its requirements. Among them are the availability of land, sufficient covering materials, fire protection materials, efficient telecommunication, utilities, sanitation and, electricity and fuel supplies (Tchobanoglous *et al*., 1993; Pavoni *et al*., 1975). Beside to isolate waste from contaminating the environment, to prevent intrusion of water from entering the waste compartment and to increase the waste degradation which is occurring naturally or engineered, landfilling is also aimed to reduce the socio-health impacts i.e. by preventing an un-becoming sight and reduction of uncomfortable stench of degrading wastes. Typical necessary operations in a landfill include unloading, spreading, compacting, and covering of waste with soil, and monitoring and evaluating the impacts to the environment. Each waste unit is called waste cell with a height of 2 to 3 m. Wastes in the cell will be spread to give a layer of waste with a thickness of 25-70 cm where compaction is then conducted. When the waste layer reached a desired height, it is covered with soil.

After a particular cell is filled to the maximum, another cell will be utilized and the active period depends greatly on the amount of waste deposited. Besides the amount of waste received, factors including compaction activity and types of waste deposited also influenced the life-span of a cell. An efficient compaction would result in the waste in the cell to have a density of 500 - 900 kg/m^3 (Tchobanoglous *et al*., 1993). Plastic wastes and vehicles tyres for example require larger space than the flexible materials that can be compressed due to their fixed structures. This creates problems to some landfills managers (Lilja and Liukkonen, 2008; Fauziah and Agamuthu, 2003). After the waste in an active cell is properly compacted, it is covered with a soil layer with 15 to 30 cm thickness daily. The final cover of a cell normally is 60 cm thick in order to encourage more compaction and to allow the utilization of the cell after a period of time. Daily covering of waste aims to control vector problem, to reduce waste from being blown away by wind, to prevent obnoxious odour, to reduce infiltration of downpour into the waste cell which resulted with leachate generation, and to promote gas generation with the presence of an anaerobic condition (Jun *et al*., 2009; Berthe *et al*., 2008; Kruempelbeck and Ehrig,1999).

Landfills operation also includes the administration activities in order to manage a smooth disposal of waste. The administration activities involved in a landfill include the release of site permits, training of staff and landfill personnel, ensuring safety and precautionary measures, maintain public relation and good reputation, monitoring pollution parameters with appropriate laboratory analysis, conducting research and development to improve the landfill further, keeping records, and disseminating information to the public and relevant authorities.

The most commonly used landfills include open dumps, controlled dumps, sanitary landfill and secure landfills. The consequent sections compare the individual landfills on the design and other requirements.

2.4.4.1 Open dumping

The simplest type of land disposal site is open dumping. Impacts from open dumps are detrimental to environment, as this particular type of landfill does not have any control and monitoring system for its leachate and gas generation making it very vulnerable to extreme pollution problems. Prior to the industrial age in 1970s, open dumps were the most common method of waste disposal as site selected would be of 'unfavoured' areas like ex-mining land, canyon, marshland and others. However, with the industrial evolution taken place, the complexity of waste generated became more evident and natural degradation was too slow to accommodate the rapid increase of waste generation. This resulted with extremely polluted area where the surrounding environment was heavily contaminated with various persistent compounds. Therefore, the awareness rose to upgrade the sites in order to have a better controlling system over the emissions. Countries like US had totally banned the use of open dumps for waste disposal as early as 1970s (USEPA, 2000).

Resource Conservation and Recovery Act (1985) defines open dumps to be "*facilities which do not comply with EPA's Criteria for Classification of SW Disposal Facilities and Practices (40 CFR 257)*" therefore regulations strictly banned its operation (USEPA, 1998). Similarly in the Philippines, Article 6, Section 37 of Republic Act 9003 had been implemented where existing open dumps were to be converted into controlled dumps by 2004 that all open dumps are banned from operating (The Manila Times, 2005).

Open dumps are still widely utilized all around the globe particularly in the poorer countries due to one major reason i.e. cost as it requires almost no initial capital investment and minimum operating cost (Ngoc and Schnitzer, 2009). However, contaminations emitted from this landfill site are tremendously damaging with Volatile Organic Carbon (VOC) emissions, a tremendous volume of PAHs, non-PAH semi-volatile organic compound and other toxic gasses, which also detrimental to human health (Lemieux *et al*., 2004). It promotes rodents and can be the breeding ground for various types of pest as reported in Guasave and Mazatlán in Mexico (Ojeda-Benítez and Beraud-Lozano, 2003). The noxious stench creates an uncomfortable living environment besides the unsightly area for neighbouring residents. A typical side effect at nearby sites would be the devalued of land pricing which play a major impact in the socio-economic aspects of the relevant community. Due to the unacceptable negative impacts to the environment, initiatives were taken even by the poor countries to establish controlled dumps through the upgrading of exiting open dumps.

2.4.4.2 Controlled dump

A controlled dump can be defined as a disposal area whereby the siting, operating, monitoring and management are planned accordingly. Siting of controlled dumps would normally take into consideration the hydro-geology aspect where risky areas will not be selected for the establishment of this facility. The capacity of waste to be received is estimated accordingly as to ensure that the facility can provide a service for a planned period of time. Controlled dumps generate less risk of environmental contaminations but without proper management, the risk is catastrophic. Inefficient management generally will cause controlled dumps to be degraded into a mere open dump.

Controlled dumps are preferred by most developing nations due to the low investment to establish these facilities. Research conducted had indicated that controlled dumps encourage and enhance the production of landfill gas as that of uncontrolled dumps (Scharff and Jacobs, 2006; Buivid *et al*., 1981; Halvadakis *et al*., 1988). Even though it requires some management of leachate, gas and drainage system, the cost incurred normally would be very much lesser than that of a sanitary landfill. This facility necessitates partial leachate and gas management, while basic infrastructure including fencing is compulsory. Controlled dumps allow more control in terms of management and landfill pollution emission with leachate treatment ponds, gas vents and others.

Many countries including Malaysia had taken the steps to upgrade their existing open dumps into controlled dumps to reduce environmental contamination in a more cost-effective method. Upgrading of open dumps include the installation of gas vent and drainage system. Normally, gas vents are incorporated at a later stage even after waste has been deposited into the cells. It involves a passive gas management system that the landfill gas produced are usually flared or released into the atmosphere.

Drainage systems installed include the constructing of perimeter drain that prevented leachate from mixing with the surface run-off. Furthermore, the operations of a controlled dump also include the compaction and covering of the waste cell. Compactions provide stability for future use as well as saving landfill space. It also indirectly encourages the anaerobic degradation and landfill gas generation as well as affecting the hydraulic conductivity and the field capacity (Renou *et al*., 2008; Jang *et al*., 2002). Compaction and main settlement of waste after 1-2 years will reduce leachate generation even though the biodegradation accelerated (Heyer *et al*., 2005; Blight, 2005). Higher biodegradation rate resulted with lower life span of the contaminants and lower cost incurred (Warith, 2002). Research also indicated that compaction of waste at the appropriate level may allow the formation of logs from combustible waste in landfill with a heating value of equivalent to coal (Li *et al*., 2001). Besides compaction, covering of waste with appropriate covering material also help to reduce leachate formation. It prevents water intrusion due to downpour into the waste cell. Over time changes in leachate composition can be predicted using Gompertz model (Őzkaya *et al*., 2006).

Material recovery is possible in controlled dumps where the risk of explosion and health hazards to scavengers had been slightly reduced. Scavenging activities can be carried out in cells where operations including spreading, compacting and covering of waste is not taking place (UNEP, 1996). Besides that, proper fence would prevent intrusion of non-authorized people from the disposal site that controlling and monitoring the sites can be more effective. Record keeping is also essential where it will provide valuable information for reference and future planning. Even though there are advantages offered by controlled dumps, sanitary landfill has proved to be the best disposal site to be considered.

2.4.4.3 Sanitary landfill

USEPA defined sanitary landfill as "*an engineered method of disposing of solid waste on land in a manner that protects the environment, by spreading the waste in thin layers, compacting it to the smallest practical volume and covering it with compacted soil by the end of each working day or at more frequent intervals if necessary*" or a disposal facility which permanently deposits and stores non-hazardous solid waste for an exceeding period of six months. ISWA (1992) defined sanitary landfill as "*a landfill disposal practice where wastes are deposited in an orderly planned manner in accordance with conditions laid down by a regulatory authority*". They are classified into three main classes by USEPA according to the permitted types of wastes to be deposited into the facilities (Table 2.16).

Table 2.16: USEPA classification of sanitary landfill.

Class	Waste type permitted
I	All non hazardous solid waste: - Municipal solid waste, bulky waste, construction and demolition waste, vegetative waste, dry industry waste, animal and food processing waste and asbestos containing waste.
II	Specific category of non hazardous waste: - Dry industrial wastes, construction and demolition waste, vegetative waste, and asbestos containing waste
III	Inert non-putrescible and non hazardous waste: - Bulky waste and vegetative waste

Landfills can be classified as conventional landfills for commingled MSW, shredded solid wastes and designated or specialized wastes (Tchobanoglous, 1993). The concepts apply in constructing a sanitary landfill is with the main aim that it will not generate any detrimental impacts to the surrounding and would be a valuable property during operation and after closure for further landuse. Post-closure plan involving landfill conversion into forest area is achievable with the planting of successful species including *Crataegus monogyna*, *Prunus spinosa*, *P. padus*, *Alnus glutinosa*, *Sorbus aucuparia*, *Acer pseudoplatanus*, *Malus sylvesteris*, *Quercus petraea* and *Fraxinus excelsior* (Rawlinson *et al*., 2004).

The essential composition of a sanitary landfill include a bottom liner system, leachate collection facilities, landfill gas monitoring system, landfill covering system and pollution treatment amenities. These elements set sanitary landfills apart from mere dumping facilities. One of the main concerns in a landfill construction is the lining system. The best selection of an area for a landfill siting is the area with existing layer of clay. Due to its fine particles, clay has a very low permeability factor and allows very minimal infiltration of water molecules. Foged and Baumann (1999) and Sheu *et al.* (1998) reported that high plasticity clay membrane which hydraulic conductivity less than 5×10^{-12} ms^{-1} offers low migration of landfill leachate through advection. However with the possibility of cracks due to desiccation, volumetric shrinkage or freezing made clay liner alone insufficient to prevent leachate migration that a lining system is necessary (Tay *et al*., 2001; Hewitt and Phillip, 1999; Miller and Lee, 1999). Figure 2.15 illustrates the schematic diagram of a typical sanitary landfill.

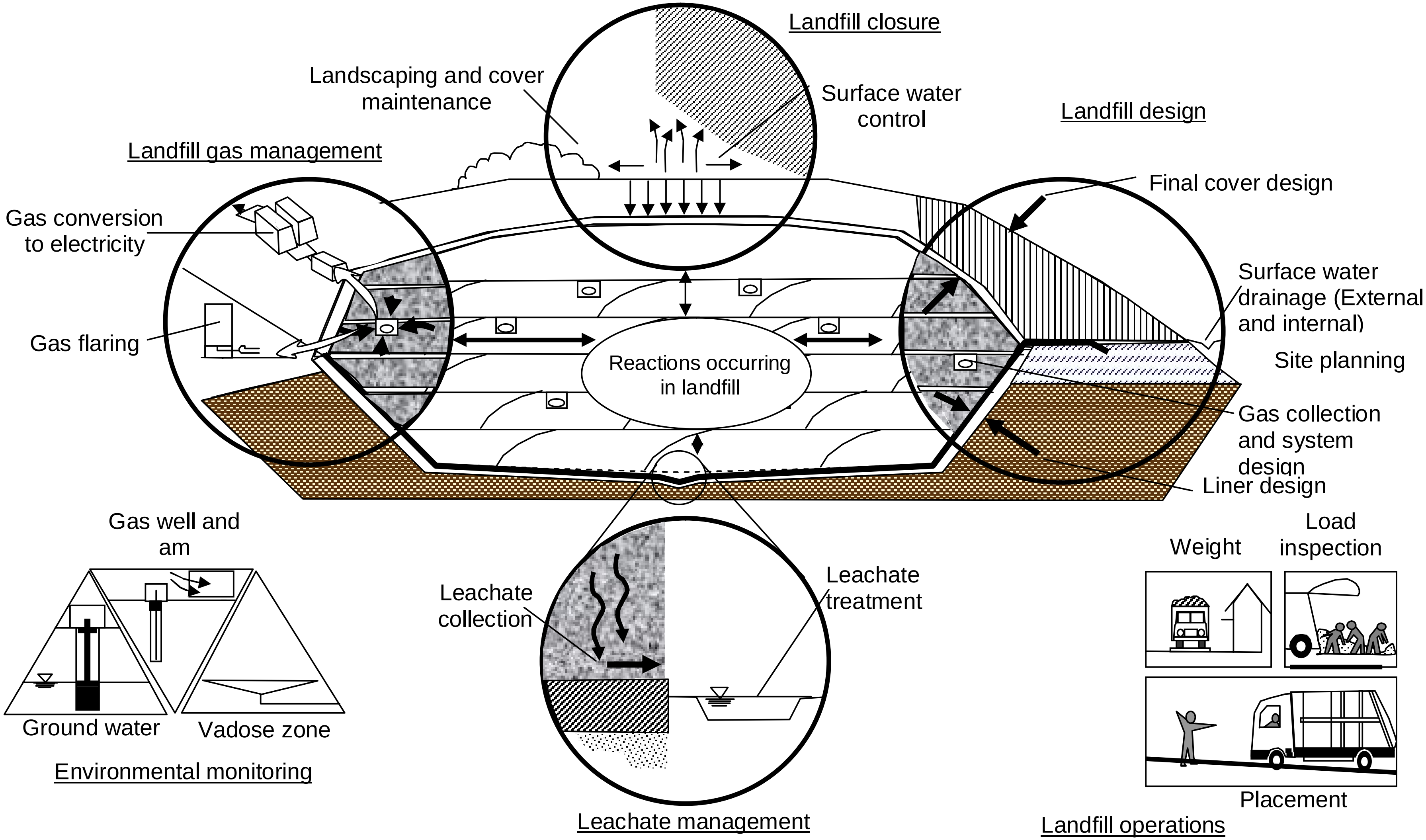


Figure 2.15: Landfill operations and processes (Adapted from Tchobanoglous *et al.*, 1993)

USEPA had banned construction of landfill that depended solely on clay liners in 1982 as it does not offer a maximum protection against leachate sipping into groundwater system. Regulations that come in force in 1991 necessitates that new landfills are to have a minimum of six layer of protection between waste layers and the groundwater system (Tammemagi, 1999). Other materials use for landfill liners are compacted crushed shales, bentonite, organoclay and composite liners (Mohamedzein *et al*., 2005; Katsumi *et al*., 2001; Lake and Rowe, 2005). Composite liner was more efficient than clay liner in terms of dispersion coefficient and retardation factor of the liner and reduction of the hydraulic conductivity (Cokca and Yilmaz, 2004; Katsumi *et al*., 2001). The self-healing feature of the geometric is very crucial to prevent leachate migration from the waste cell (Afolayan and Nwaiwu, 2005; Shi and Booth, 2005; Dillon *et al*., 2003; Rowe *et al*., 1995). The bottom liner is constructed to contain leachate within the waste cell and prevent surface and groundwater contamination.

A double lining system offer many advantages as compared to that of a single lining system. However, the construction cost of a double layer system evidently is much higher than establishing a landfill with a single lining system. High density polyethylene (HDPE) for example is very efficient as a barrier material which can accommodate certain level of stress during landfill compaction (Eith and Koerner, 1997). The installation of the lining system requires the outmost care in order to avoid punctures and non-smooth surfaces of the liners. Dessication and wrinkles of the geomembrane would cause failure in the lining system (Southen and Rowe, 2005; Koerner and Koerner, 2006; Daniel, 1993). In constructing a compacted clay liner, it is essential to consider the hydraulic conductivity, shear strength, potential for desiccation, resistance to chemical attack, interfacial friction with overlying geomembranes and the ability to deform without cracking during settlement (Qian *et al*., 2002). Figure 2.16 illustrates details of a bottom liner system which comply the USEPA requirement.

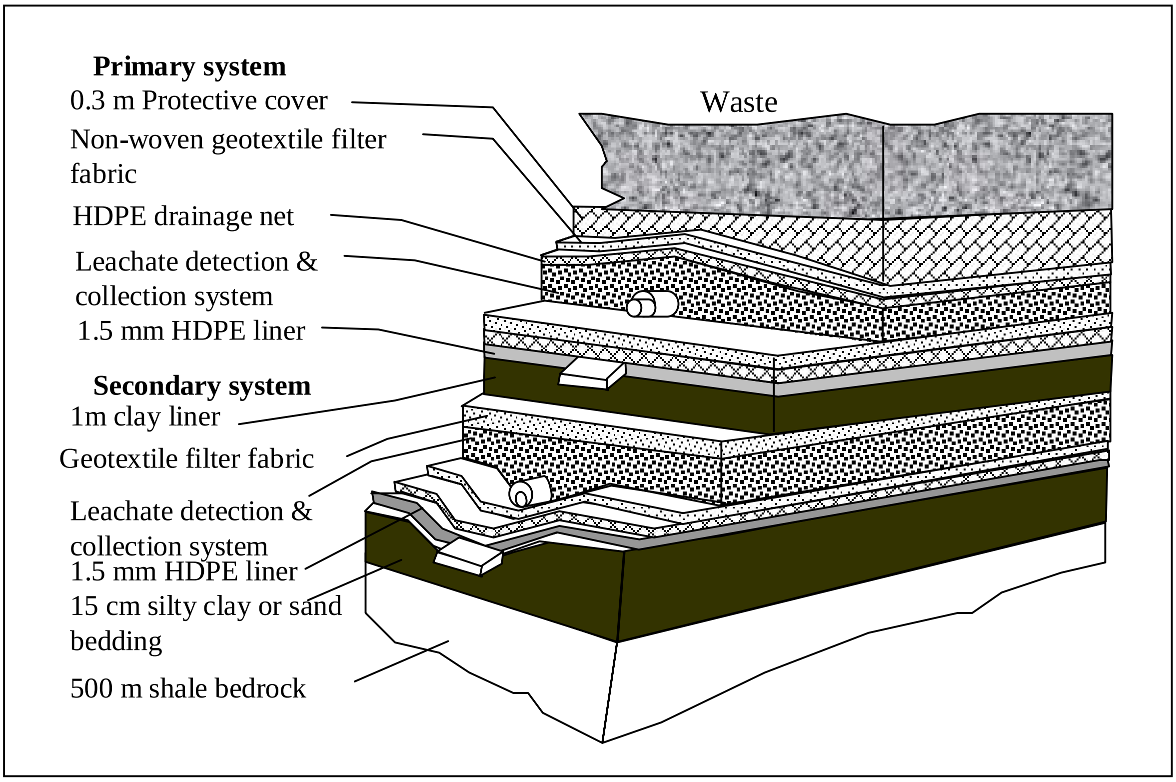


Figure 2.16: Details of a bottom liner system of a modern sanitary landfill (Adapted from ECDC Environmental)

Textures of the geomembrane affect the shear strength where higher strength geomembrane can accommodate bigger friction (Zabielska-Adamska, 2006). Besides geomembrane, other geosynthetic liners applicable as landfill lining system includes geosynthetic clay liners, geonets, geotextile and goegrids (Qian *et al*., 2002). Table 2.17

compares the advantages and disadvantages between a single liner and a double lining system of a landfill.

Table 2.17: Comparison between a single lining and a double lining system (Adapted from Qian *et al.*, 2002).

	Single Liner	Double Liner
Risks of Leakage	High risk if lining system fails due to various reasons. Contamination risk is high i.e. to ground water system	Very low risk. Even if the primary liner fails, secondary liner would prevent contamination to ground water system.
Detection of leakage	Later detection since post-construction leak detection is through the downstream monitoring wells.	Sooner since a leak detection layer is present that leachate quantity can be monitored.
Leakage control	Low due to direct escape of leachate into layers below.	High with secondary liners to collect the leachate for treatment purposes.
Cost Incurred	Lower cost	Higher cost
Environmental safety and security	Generally better	Superior environmental protection
Compliance to regulation imposed by local authorities	Some may comply but other may not particularly with more stringent local authorities.	Comply with the most severe regulation.

Use of bentonite in landfill liner was found capable to enhance attenuation of ammonium in leachate (Pivato and Raga, 2006). While organoclay has higher capability to retard the transportation of phenolic compounds as compared to that of conventional soil liner, natural zeolites which can be applied as the substitute of clay liner reduces the base liner thickness exhibit low permeability effect, efficient chemical filter and high cation exchange capacity (Tuncan *et al*., 2003; Lo and Mak, 1998; Kayabali, 1997). It was reported that the retention of transmissivity of geotextile decrease at high pH (pH 12 and above) (Jeon, 2006).

These liners are essential in preventing environmental contamination emitted by the products of landfill. Bentonite-sand liners and geotextile were found to display the lowest hydraulic conductivity (Agamuthu *et al*., 2009a; Wareham *et al*., 1998). The failure of these liners would prove detrimental to the environment due to leachate contamination and risk of explosion from landfill gas. The consecutive sections discuss the pollution impact emitted from landfill activities.

2.5 Landfill Pollution Impacts

The impact of MSW landfill on the community is always negative, causing concern and fear not only about gas explosion and odour from such landfills (Hassan *et al*., 2000) but also pollution to water resources due landfill leachate contamination (Laner *et al*., 2009; Fauziah *et al*., 2005; Roy, 1997). Therefore, it is very essential that appropriate monitoring is conducted to determine the risk of contamination to the environment. Ray *et al*. (2005) reported that MSW disposal workers of Okhla Landfill, India experienced health problems which ranged from respiratory problems, inflammation of air ways, lung weakening and others. Leachate toxicity can be greatly affected by the concentration of ammonia present (Pivato and Gaspari, 2005). Exposure to leachate contaminations were reported to induce damages to bone marrow and DNA that resulted with genetoxic effects in mammals (Sang and Li, 2005; Tewari *et al*., 2005). Five elements including surface water, ground water, atmosphere, soil and health should be taken into consideration in deriving the environmental- landfill indexes which define the intensity of pollution from various landfill emissions. (Table 2.18).

Table 2.18: Variables affecting the five elements of Environmental-Landfill Indexes (Adapted from Calvo *et al*., (2005) and Ham (2000).

Parameters	Variables
All elements	Compaction, waste and organic matter types Age, cover material Control of leachate Operationality Final cover
Surface water	Inclination to the surface beds Permeability of surrounding strata Surface water in the surroundings Surface drainage systems, rainfall Landfill lining system Release point location in surface run Release point location in floodwater storage volume
Ground water	Aquifer characteristics Surface drainage system, rainfall Landfill lining system Fault Release-point location in surface run Release-point location in floodwater storage volume
Atmosphere	Rainfall, gas control, paths
Soil	Waste slope, gas control, landfill lining system Release-point location in surface run Release-point location in floodwater storage volume
Health	Gas control, environmental control Distance to population, distance to infrastructure Available equipment

The consecutive sections discuss the risk of landfill contaminations to the land, aquatic and atmospheric environment.

2.5.1. Land pollutions

The presence of metals in wastes or landfill soils is very common due to the miscellaneous mixture of the waste received. Among the reported metals included Cr, Fe, Al, Cd, Cu, Ni, Pb and Zn (Jain *et al*., 2005; Ho and Qiao, 1998). Other pollutants include persistent components and endocrine disrupting chemical like polychlorobiphenyls (PCBs) and bisphenol A, nonylphenol, butyl benzylphalate (BBT) and others (Behnisch, 2001; Aresta *et al*, 2003). Also found in landfill contaminated soils are xenobiotic compounds like dialkyl phthalates which is a by-product of components due to the microbial activity taken place in landfill (González-Vila *et al*., 1995) and mercury traces and volatile acid compounds in soil surrounding the landfill (de la Rosa *et al*., 2006). The heterogeneous composition of waste from the variety of sources particularly of putrecible waste encouraged microbial degradation that without proper treatment would cause the spreading of diseases and pests and instability of soil that the post-use of ex-landfill area becomes a difficult task. A dynamic analysis Model of Organic Compounds in Landfill (MOCLA) has been introduced to evaluate the behaviour and routes of the compounds in landfills (Kjeldsen, 2004). Besides land pollutants, landfills also generate landfill gas which will be discussed in the following sections.

2.5.2. Air pollution

One of the by-products generated by landfills is landfill gasses. Landfill gas production from MSW organic components at 26^{0}C for 240 days was 0.661 m^3/kg volatile solid (Rao *et al.*, 2005). Krzystek *et al.* (2001) reported that putrescibles undergoing continuous aerobic and anaerobic degradation with 33% recirculation of processed load at a resident time of 8-16 hours would generates a similar organic load as that of 72-96 hours process. This resulted in the production of methane and other landfill gasses including CO_2 and others. Table 2.19 list the typical composition of MSW landfill gas.

Table 2.19: Typical composition of MSW landfill gas (Adapted from Tchobanoglous *et al.*, 1993).

Component	**Percentage (dry volume basis)**
Methane	45-60
Carbon dioxide	40-60
Nitrogen	2-5
Oxygen	0.1-1.0
Sulphides, disulphides, mercaptans, etc	0-1.0
Ammonia	0.1-1.0
Hydrogen	0-0.2
Carbon monoxide	0-0.2
Trace constituents	0.01-0.6

Gasses produce from landfill have a high heating value of 2,048- 14,894 kJ/m^3 (Tchobanoglous *et al.*, 1993). The rate of landfill gas generation varies with the waste composition disposed into the landfill, the age of the landfill, the present of landfill liners, compaction of the waste, moisture content and others (Christophersen *et al.*, 2001). Studies indicated that the gasses are produced in five sequential phases.

During phase I, putrescible waste was rapidly decomposed in an aerobic environment within the waste layers. At this stage, oxygen generally is converted to CO_2 causing the oxygen level to reduce simultaneously with nitrogen concentration. Phase II involves a transition phase where remaining oxygen is used continuously and finally diminished. The conversion of nitrogen prolong since the concentration of this particular gas is normally much higher than other gasses such as oxygen. The generation of CO_2 increases and the acidogenic phase is initiated. The gas generation phases are illustrated in Figure 2.17.

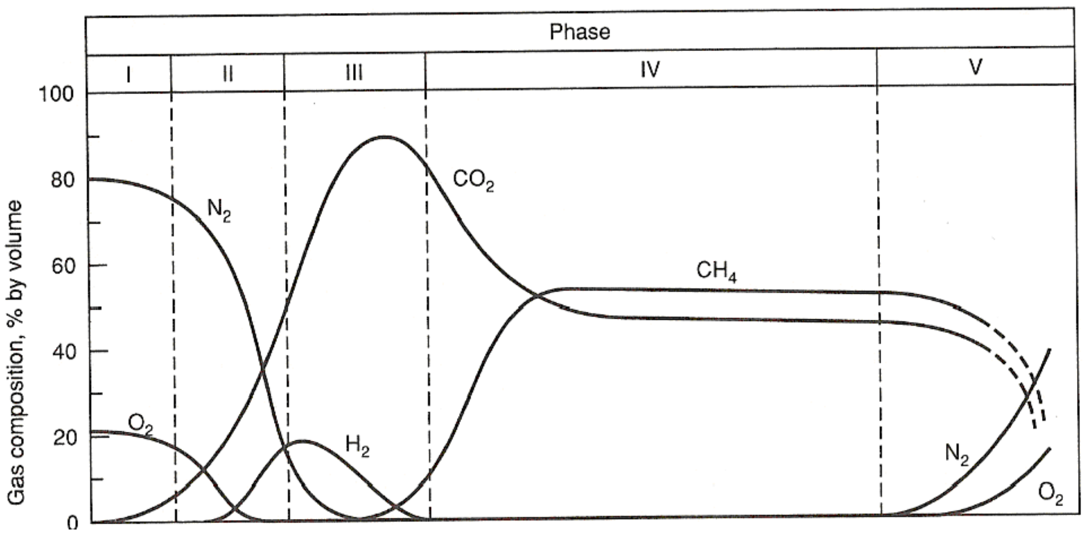


Figure 2.17: Phases in the generation of landfill gasses (I =initial adjustment, II= transition phase, III= acid phase, IV= methane fermentation, and V= maturation phase) (Tchobanoglous *et al*., 1993).

Acidogenic phase occurs in phase III where complex organic components are converted into organic acids by the acidogenic microorganisms. At this phase, the concentration of CO_2 continues to increase while hydrogen reduces. The next stage of phase IV is the period where hydrogen gas and organic acids are converted into methane and CO_2. The whole conversion process takes place in an anaerobic condition by the methanogenic microorganism. During this methanogenic fermentation stage, CO_2 utilization occurs at a reverse rate of methane formation. The final phase involved during the degradation of organic component in landfill cells is the maturation phase. At this stage, the organic elements present in the waste had been completely converted into CO_2 and methane. The remaining constituents include organic compounds that undergo a very slow degradation. Wastes that did not decomposed like paints, solvents, pesticides and adhesives contain several organic components that allow degradation to produce non methane organic gasses (EPA, 1999). The complete conversion of organic disposed into landfill gas can be presented by the following equation:

$$C_aH_bO_cN_d + \left(\frac{4a - b - 2c - 3d}{4}\right) H_2O$$

$$\rightarrow \left(\frac{4a - b - 2c - 3d}{8}\right) CH_4 + \left(\frac{4a - b + 2c + 3d}{8}\right) CO_2 + dNH_3$$

Equation 2.1: Complete chemical conversion of organic compound into landfill gases.

Other polluting emission includes methylated mercury compound which posing risk of air contamination without proper treatment facilities (Lindberg *et al.*, 2005; Kim and Kim, 2002). Therefore many countries had implemented stringent regulations such as Interim Internal Technical Guidance for Best Practice Flaring of Landfill Gas in United Kingdom (Baker *et al.*, 2000).

Landfill gas harvesting has begun as early as 1970 (Alter and Dunn, 1980; Augenstein *et al.*, 1996) and is still favoured as an alternative energy though the harvesting operation cost had been reported to increase considerably (Moulden, 2000). Landfill gas can be harvested using vertical gas extraction system as proposed by Cheung (2000) and up to 82% for domestic utilization (Rodriguez-Iglesias *et al*., 1999) that more studies have been conducted to benefit from this 'cheap source' (Bove and Lunghi, 2005; Desideri *et al*., 2003; Harder and Freeman, 1996). Numerous countries in Europe had been converting biogas into electricity including Sweden, Denmark, Italy and many more as a requirement to comply regulation stipulated by EU (Zamorano *et al*., 2007). It is reported that approximately 1.6 X 10^8 kWh/yr of electricity were harvested from waste while substitution with biogas for vehicles resulting with 85% reduction of greenhouse gasses emission as required in Kyoto Protocol in 1997 (Tsai, 2006; Murphy *et al*., 2004; Van herle *et al*., 2004). Chen *et al*. (2003) had established that with a depth of gas well exceeding 90% of the landfill depth, flow rate of landfill gas is 77% higher than that of well less than 50% of the landfill depth. Extraction of landfill gas can accelerate the emission of gas to more than 80% (Yedla and Parikh, 2002; Park and Shin, 2001). Methane emission rate ranged from 2.2 to more than 10,000 mg CH_4/m^2 day through various types of landfill cover with 4-50% undergone oxidation process (Spokas *et al*., 2005). A new landfill design and system for landfill gas control was proposed by Popov (2005) which has the ability to reduce and prevent gas leaking. Improvement on landfill gas collection system in Groton, Connecticut in the United State had managed to increase the heating value to more than 31% (Spiegel and Preston, 2003).

Methane which is the main component in landfill gas presents risk of explosion and contamination to the surrounding ambient. At a concentration of 5-15 % in the air, methane can be very explosive (Agamuthu, 2001; Tchobanoglous *et al*., 1993) and the generation differs with temperature in the waste cells (Clemens *et al*., 2006). Therefore, it's presence in landfill without proper extraction generates potential deep-seated fire or explosions (Ng and Leung, 1999; Bae *et al*., 1998). However, due to the limited oxygen content in landfill, the possibility of explosion is slightly reduced. An active landfill generates 6.5 billion m^3 of landfill gas, while between 3 to 45 years, as much as 17,600 m^3/h of landfill gasses will be generated with a peak value of 32,000 m^3/h during its 16^{th} year (Chan and Fan, 2000). Nashua landfill in New Hampshire in United State for instance, generates approximately 16.7×10^6 m^3 of methane annually (Czepiel *et al*, 2003). The emission of methane emanates simultaneously as much as 1.7 ton of carbon dioxide per ton of household waste (Ngnikam *et al*., 2001). While methane is explosive, other trace gasses even at a very low quantity can be detrimental to human health due to their toxicity (Deipser and Stegmann, 1997).

Studies reported that landfill gas generation may last at least three decades after its closure before the emission is finally cease (Ritzkowski *et al*., 2006). The generation of landfill gas can be simulated based on a kinetic equation or numerical modelling to determine the quantity and period of emission (Meraz *et al*., 2004; Findikakis *et al*., 1988).

Landfill gas migrates horizontally and vertically in the waste cell (Scheutz and Kjeldsen, 2001). The migration is uncontrollable with the absence of proper lining and gas piping system. These gasses would escape through any opening and pores between waste layers to the atmosphere. There is a risk of explosion if these gasses particularly methane is trapped between the waste layers and post-excavation of the landfill took place. The mixing of trapped methane with oxygen in the atmosphere would cause catastrophic explosion. Numerous cases including in Loscoe, UK and in Ümraniye-Hekimbaşi, Turkey were reported to cause loss of life and properties due to landfill explosion (Kocasoy and Curi, 1995; Collin, 1991; McOmber and Moore, 1981; Parker, 1981; Shafer *et al*., 1984; Raybould and Anderson, 1987). Pollution preventive measures are installed within the flaring facilities of a landfill to avoid unnecessary pollution emission to the atmosphere. Methylated mercury component in landfill gas can be totally destroyed with the flaring operation (Lindberg *et al*., 2005). The most common applications are landfill aeration and biofilters. Aeration to landfill enhanced oxidation of more than 46% of methane which would be released through the gas vent (Gebert and Groengroeft, 2006). Aeration of landfill in the remediation of landfill emission will accelerate the biological processes and stabilized the organic material (Prantl *et al*., 2005; Read *et al*., 2001; Huber-Humer and Lechner, 2001; Read *et al*., 2001a). It also enhances waste degradation and improve settling rate which would resulted with longer extension of landfill service (Read *et al*., 2001a). When landfill gas has been fully extracted from a landfill, landfill aeration would be applied to control the remaining emission which is not cost-effective for harvesting (Ritzkowski *et al*., 2006). *In-situ* aeration also was proved to accelerate the degradation of the waste in landfills (Prantl *et al*., 2005).

Methane oxidation with the utilization of bio-filter manages to remove methane at 80gh^{-1} m^{-3} at restricted or limited oxygen supply under the influence of temperature, methane influx and the flow rate (Gebert and Grőngrőft, 2005). Methane is oxidized when allowed to flow through fine grained compost or other suitable microbes-rich materials over a period of time (Agamuthu *et al*., 2009a; Haubrichs and Widmann, 2006). Among the most active methanotroph bacteria that oxidize methane are *Methylobacter* sp. and *Methylosystis* sp. representing Type I and Type II, respectively (Stralis-Pavese *et al*., 2006). These bacteria are dominant on the top layer of the landfill soil cover and in the roots of the plants growing over the waste cell (Stralis-Pavese *et al*., 2006). It was reported that Type I methanotrops actively convert methane at a lower temperature ranging at 5 to 10^{o}C while Type II methanotrophs activities accelerates at 20^{o}C indicated the effect of temperature on methanotrops populations in landfills (Bőrjesson *et al*., 2004). Nikiema *et al*. (2005) reported that inorganic filter bed was found to oxidize methane to CO_2 at a higher rate than that of organic filter bed as it generates lower volume of biomass particularly of *Methylocystis parvus*. However, present of exopolymer substances will inhibit rapid methane oxidation process in landfill due to its clogging nature of the soil pores which restricted the gas diffusion (Streese and Stegmann, 2003; Hilger *et al*., 2000). It has been reported that various kind of organic components are also degraded during the process of methane oxidation, particularly, components with halogenated combinations (Scheutz and Kjeldsen, 2001). Other than gasses, landfill also emits leachate which contaminates surface water and groundwater. The consecutive sections discuss water contamination risk due to leachate from landfills.

2.5.3. Water pollutions

Improper waste management particularly from landfills imposed pollution hazard to the water resource due to leachate contamination (Laner *et al*., 2009; Fauziah and Agamuthu, 2005a; The Urban Governance Initiative, 2003; Tchobanoglous *et al*., 1993). Some studies reported that waste disposal into uncontrolled landfill affected the surrounding ambient including the groundwater (Mangimbulude *et al*., 2009; De Waele 2004). In Hoogey Maey, Flander in Belgium, metallic ions corroded from metallic constituents had reacted with other elements in the waste cell to produce various types of toxic pollutants including phosphine which was released to the environment (Roels and Verstraete, 2004). Raw leachate from Hong Kong landfills for example, contains high concentration of ammonia at 2,000 to 5,500 mg/l (Ng and Leung, 1999), which pose risk of ammonia contamination. A high level of phthalic acid esters, pentachlorophenol and many other endocrine-disrupting chemicals were reported to leach from plastics and biocide respectively into the groundwater and the aquatic environment (Asakura and Matsuto, 2009; Koshy *et al*., 2008; Pohland *et al*., 1998; Bauer *et al*., 1998). A recent study in Linggi Drainage Basin indicated that the rivers and ponds nearby landfills were highly polluted affecting the nearby residents with headache, loss of appetite, vomiting and diarrhea (Tan *et al*., 2002).

While landfill gas emission continues for a decade, leachate generation is believed to be continuously generated even for many hundreds more years after landfill closure (Jones *et al*., 2005; Blight, 2005). The quality and the quantity of leachate during the first two years of landfill operation vary with the characteristics of the waste received and disposed in the landfill cell (Wang *et al*., 2009a). It was reported that disposal of mechanical- biologically treated waste material generates lesser gas and leachate than components without any pre-treatment (Lorber *et al*., 2000). The amount of precipitation that seeps into the waste cell also affected the leachate generation. The concentration of heavy metal in leachate depends on the age of the landfill that higher level of this pollutants were generated during the acidogenic phase, when the waste undergone aerobic degradations (Ziyang *et al*., 2009; Fan *et al*., 2006; Wang *et al*., 2005; Al-Yaqout and Hamoda, 2003; Reinhart and Grosh, 1998). Leachate has the tendency to cause lipid peroxidation and alter oxidative status in brain and liver cells of mice, as well as, causing cytogenetic damage to the root tips of *Hordeum vulgare* (Li *et al*., 2005; Sang *et al*., 2005). Shrive *et al*. (1990) reported that leachate irrigation to sugar maple had caused irregularity to the sapling. Leachate was also reported to display its acute toxicity to some bacteria, freshwater rotifer and crustaceans, as well as, containing a significant number of microbes including coliform bacteria (Isidori *et al*., 2003; Banerjee and Biswas, 2000). *Bacillus subtilis* rec-assay had been utilized in detecting genetoxic substances in landfill leachate (Takigami *et al*., 2002).

Leachate is defined as "*liquid which seeps through a landfill and, by so doing, extracts substances, including contaminants, from the deposited waste, and may result in hazardous substances entering surface water, groundwater, or soil*" (ISWA, 1992). Tchobanoglous *et al*. (1993) defines leachate as "*liquid that has percolated through solid waste and has extracted dissolved or suspended material*" while USEPA's definition of leachate is "*any liquid including any suspended components in the liquid that has* *percolated through or drained from hazardous waste*". Generally, leachate is the polluting liquid originated from the combination of precipitation and water released from waste degradation by microbial activities in landfill, which contains various dissolved contaminants. Rapid absorption resulted with the present of pollutants emitted from the run-off path and stream on sediment surfaces (Gonçalves *et al*., 2004).

Leachate often contains high concentrations of various pollutants namely organic matter and inorganic ions including heavy metals (Øygard *et al*., 2005; Øygard *et al*., 2004; Jensen *et al*., 1999; Agamuthu, 1999). Among the pollutants present in MSW leachate is the endocrine disrupting chemical (EDCs) and PCDD/DF (Choi and Lee, 2005; Asakura *et al*., 2004). The pollutants originated mainly from the degradation process occurring in waste cell when microorganisms interact with the waste. The microbial breakdown of the waste begins with the most readily degradables including putrescibles and other organic wastes. Once the putrescible component of waste had been exhausted, the microbial degradation will commence with more complex organic components including textile, wood and such. It has been reported that leachate consist of dissolved organic matter, inorganic macro-components, xenobiotic organic compounds and heavy metals including B, Cr, As and Cu that commonly applied to treat wood (Baysal *et al*., 2005; Jambeck *et al*., 2006; Kjeldsen *et al*., 2002; Baun, *et al*., 2004). The generation of various organic acids and other microbial by-products effectively dilute ionic metals from cans and other metallic waste into the liquid phase causing the present of metallic ions in landfill leachate. Typical characteristics of leachate are shown in Table 2.20.

Table 2.20: Leachate characteristics from selected landfills (Agamuthu, 1999; Tchobanoglous *et al*., 1993)

Parameter	Units	Hong Kong	South-east Asia	South Africa	UK	USA	Malaysia
pH	-	7.4-8.6	6.0-8.4	7.5-8.3	7.4-8.5	4.5-7.5	7.6-8.84
COD	mg/l	650-2,800	1,600-13,000	1,400-6,000	2,600-8,500	3,000-60,000	1724-7038
BOD_5	mg/l	45-400	-	300-700	90-3,000	2,000-30,000	1120-1800
Total Organic carbon	mg/l	-	400-10,000	-	400-3,400	1,500-20,000	1610-2890
Ammoniacal-N	mg/l	1,200-3,000	1,200-3,000	900-3,000	1,100-2,500	10-800	1.88-32.00
Cl	mg/l	500-3,000	2,500-6,300	1,200-4,000	1,700-5,200	200-3,000	1625-3200
Alkalinity ($CaCO_3$)	mg/l	3,000-12,000	8,000-40,000	3,000-12,000	7,000-17,000	1,000-10,000	1540-9000
Conductivity	µS/cm	14,000-30,000	14,000-42,000	10,000-30,000	14,000-30,000	-	8.64-33.50
Nitrate-N	mg/l	<0.1-22	<1-12	<0.1-1.3	<0.3-2	5-40	-
Nitrite-N	mg/l	<0.1-3.6	<1-2	<0.1-1.4	<0.1-2	-	-
Sulphate	mg/l	-	<5-1,200	<0.6-400	<5-150	50-1,000	18.5-110
Phosphate	mg/l	3-125	2-50	1-25	4-20	5-100	6-11
Na	mg/l	200-2,100	1,500-3,000	800-2,500	1,700-4,000	200-3,500	2616-5660
Mg	mg/l	18-50	60-500	75-400	17-150	50-1,500	41-105
K	mg/l	357-1,200	1,000-3,000	550-1600	750-1,700	200-1,000	719-1818
Ca	mg/l	20-45	50-3,000	50-200	40-420	200-3,000	47-177
Cr	µg/l	-	200-2,500	80-300	40-2,200	-	0.24-0.94
Mn	µg/l	-	250-17,500	12-900	70-2,200	-	-
Fe	µg/l	5,000-9,000	1,000-20,000	2,500-20,000	3,000-72,000	50-1,200	3.6-15.7
Ni	µg/l	-	400-1,500	80-120	150-3,000	-	0.13-0.95
Cu	µg/l	-	<50-400	<50	20-80	-	0.05-0.49
Zn	µg/l	200-2,200	150-1,500	30-200	30-330	-	1.0-5.4
Cd	µg/l	-	<50	<1-10	<10-20	-	0.0001-0.23
Pb	µg/l	-	<300-1,000	<4-56	<40-600	-	0-5.37

Ward *et al*. (2005) reported that the high strength leachate displayed complex metal binding effects due to the presence of site-specific characteristics of the waste in the landfill. Depending upon the nature of these formations and in the absence of a leachate treatment system, leachate has been associated with contamination of aquifers underlying landfills which prompted extensive investigations over the past four decades (Bou-Zeid and El-Fadel, 2004; El Fadel *et al*., 1997).

Robert *et al*. (1975) reported of virus survival in landfill leachate indicating the risk of viral contamination to drinking water if leachate comes into contact with water resources. Studies conducted indicated that Malaysian landfill leachate has high COD of 1250 to 6660 mg/l and BOD readings of 120 to 1990 mg/l and exceptionally high concentrations of K, Na and Cl, that pretreatment is required prior to biological treatment (Fauziah *et al*., 2005a; Agamuthu, 1999). Analysis on leachate collected from one landfill in Malaysia i.e. Kelana Jaya Landfill in 1996 revealed high concentration of Fe, Mn, As, and Cr, from the disposal of 1.57 million m^3 of MSW, which exceeded the Malaysian Environmental Quality Regulation Standard A levels (Agamuthu *et* al., 2007; Trischler und Partner GmbH, 1996).

The concentration of heavy metals in leachate is higher during the acidogenic phase of waste degradation due to the generation of acids in aerobic conditions (Mohd. Suffian *et al*., 2002; Reinhart and Grosh, 1998). Conversion of organic matters to organic acids indicates the highest stage of oxidation and further conversion breaks the chains into carbon dioxide and water (Sawyer and McCarty, 1978).

Dissolved organic matter in MSW landfill leachate displayed high tendency in absorbing phthalic acid esters, a ‘priority pollutants’ listed by U.S. EPA (Bauer *et al*., 1998; Reinhart and Grosh, 1998; Keith and Telliard, 1979). Since leachate contamination poses very high pollution risk to the surface and groundwater system, it is essential that it undergoes an appropriate treatment system so that the release does not create detrimental effects to the environment. Subsequent sections discuss the treatment options commonly applied for landfill leachate.

2.6 Landfill Leachate Treatment System

Various treatments had been conducted to tackle the contaminating factor of leachate including application of UV and H_2O_2 photoreactor, ultrasound wave treatment, vegetative filtration, reactive media filtration or constructed wetland (Kietlińska and Renman, 2005; Neczaj *et al*., 2005; Shu *et al*., 2005; Duggan, 2005; Rosenqvist and Ness, 2004; Robinson and Barr, 1998; Robinson *et al*., 1999; Bulc *et al*., 1997). Generally, series of treatment which integrate physical, chemical and biological treatments resulted with higher efficiency in removing the pollutants (Kurniawan *et al*., 2005; Tchobanoglous *et al*., 1993). Due to the heterogenous nature of the leachate, physical, chemical and biological treatments are effective in removing certain types of pollutants such as BOD, COD, total solid, metallic ions, ammonia and others (He *et al*., 2006; Mæhlum, 1995; Kjeldsen and Christiansen, 1984). Application of probabilistic approach with leaching model can be used to determine the efficiency of a treatment process (Takigami *et al*., 2002).

Sequence Batch Reactor (SBR) is effective in removing pollutants from low strength landfill leachate, as well as, high strength leachate (Fisher and Fell, 1998; Fisher and Fell, 2006). Leachate quality can also be improved with the application of MSW and incineration residues into landfill cells (Radetski *et al*., 2004; Gau and Chow, 1998). Treatment required for landfill leachate must take into consideration the following factors (adapted from Qasim and Chiang,1994):

1. leachate characteristics with the organic and inorganic compounds,
2. hazardous nature of the presence of organic and inorganic toxic components,
3. sensitivity of the discharge alternatives and the impact once effluent is being released,
4. extensiveness of the treatment,
5. availability and applicability of treatment technologies,
6. operational needs and maintenance, and
7. cost of treatment system.

Among the most commonly established treatment system is the physical treatment system which generally offers various advantages. The following section describes the details in physical treatment system of landfill leachate.

2.6.1. Physical treatment system

The physical treatment system for landfill leachate involves the use of physical characteristic whereby these physical parameters are modified accordingly to create an optimum environment for treatment process. Table 2.21 lists the commonly applied physical process for leachate treatment.

Table 2.21: Physical process applicable for leachate treatment (Bila *et al*., 2005; Tchobanoglous *et al*., 1993; Qasim and Ching, 1994)

Process	**Description**
Natural evaporation	Evaporation of liquid phase leaving solids to be disposed of easily.
Air stripping	Countercurrent flow of air and liquid in stripping stack to remove ammonia, VOC and other gasses.
Sedimentation	Removal of particles settled due to gravitational pull as sediments.
Membrane processes	Removal of dissolved solid through ultrafiltration, electrodialysis or reverse osmosis techniques.
Filtration	Removal of solid through a filter bed.
Equalization	In-line or off-line tanks equalized the mass loading and flow of leachate.
Screening	Removal of debris which are floating or suspending with a screen.
Flocculation	Fine particles are amassed involving stirring in a gentle motion.
Floatation	Removal of floating solid with fine bubbles introduced into the system.

Each process has advantages and its own drawbacks. The following section discusses the detail of each physical process with the advantages and disadvantages.

2.6.1.1 Natural evaporation

Natural evaporation is among the simplest method in wastewater treatment. Natural evaporation took place in a collection pond which takes into account the surrounding humidity, climate, temperature, and the velocity of the wind with the purpose to concentrate the wastewater. The convenience of this method is that it requires no extra energy input other than the natural heat generated by the sun which is very cost-effective in a hot and warm climate and it allows the recovery of residues (Qasim and Ching, 1994). However, it requires large areas as bigger surface area offers higher level of evaporation. This option may not be the most desired in treating leachate as the process only reduces the amount of leachate but not the contamination level (Tchobanoglous *et* *al.*, 1993. Other disadvantages include the risk of percolation and groundwater contamination.

2.6.1.2 Air stripping

The aim of incorporating air stripping into a wastewater treatment system is to remove volatile compound including volatile organic compounds (VOCs) and ammonia. Air stripping applied in Komurcuoda landfill, Turkey and in Hong Kong landfills managed to removed 94-98% of ammoniacal nitrogen from the leachate (Calli *et al.*, 2005; Li *et al.*, 1999). Air stripping improved the removal of ammoniacal-N particularly if the pH is greater than pH 10 (Kargi and Pamukoglu, 2004). Marttinen *et al.* (2002) reported that at pH 11, the ammoniacal-N removal reached 64% even at a low temperature (6^{o}C). It was also reported that the introduction of air stripping regardless of the air volume into leachate treatment system had effectively reduces the COD level to below 50 mg/L (Bloor and Banks, 2005). Air stripping can also be implemented as the pre-pretreatment of a biological system with extreme pH adjustment to pH 12 which effectively reduce the level of COD and ammoniacal-N to a level more treatable for a biological system (Uygur and Kargi, 2004; Kargi and Pamukoglu, 2003). However, due to the alteration to high pH, calcium carbonate will be accumulated on the walls of the stripping tower causing major disadvantage to this operational system.

2.6.1.3 Sedimentation

Gravity plays an important role in the sedimentation process. This treatment option is applied to reduce suspended solid and turbidity in the leachate where particles are allowed to settle to the bottom of the pond. In order to enhance the sedimentation process, various additives may be added to cause the particulates in leachate to clump or flock together and settle at a much faster rate. The sedimentation method is generally cheap and economical in treating leachate with high turbidity and high suspended solid (Qasim and Ching, 1994). However, this process requires suitable ponds to optimize the sedimentation.

2.6.1.4 Reverse osmosis

The process involves forced permeation of wastewater at 10,000 kN/m^2 through a semipermeable membrane, which resulted with the preclusion of foreign molecules from water, to produce high quality water (Qasim and Ching, 1994). The application requires regular removal of brine for further treatment post to reverse osmosis stage. The major drawback of this option is the high cost incurred to produce high force, high cost of semipermeable membrane, maintenance of the system within pH 4.0-7.5 to prevent scale formation, and constant removal of certain particles and ion to prevent inefficiency in the semipermeable membrane (Qasim and Ching, 1994). However, the advantage of producing high-quality water made this option applicable in treating leachate in certain countries.

2.6.1.5 Filtration

The main objective in applying this method is to remove suspended particle from wastewater and commonly applied as the pretreatment to a more advance treatment. It involves the passing of wastewater or leachate through a filtering medium which will separate the larger solid particles from the filtered liquid phase by gravity or forced pressure. The cost of the filtering medium plays an important aspect and among the materials normally used as filtering medium are crushed charcoal, sand, pebbles, earth and others. Dini *et al*. (2000) reported that the use of cockle shells as filtering media can remove COD and ammoniacal- N to a certain extent. Zeolite as filtering media has high adsorption capacity that may remove Pb from the leachate system (Kaya and Durukan, 2004). Though this method is generally simple, economical and requires minimal operational maintenance, this treatment system may not remove or reduce the level of dissolved contaminants.

2.6.1.6 Mechanical filtration

Mechanical filtration is the utilization of a certain type of material as the filtering medium where wastewater is forced through the medium to decant the solid from the liquid phase. The most common materials used as the medium in a mechanical filtration system are diatomaceous earth, fused glass, ceramic, sand grain, activated carbon, limestone and others. Activated carbon and limestone can be used to remove iron from leachate but limestone is far more economical (Mohd. Suffian, 2002). The main drawback of this filtration system is that it requires pretreatment of the wastewater to prevent clogging of the filtering medium. Other filtration type which has similar level of efficiency in removing colloidal particles in wastewater is membrane filtration.

2.6.1.7 Membrane filtration

Membrane filtration system is generally built densely to allow larger membrane surface contained in a minimum volume which include tubular membrane and, plate and frame membrane. The selection of a membrane filtration system incorporates the cost, packing density, backwash operation, clogging risk and others (Qasim and Ching, 1994). The advantages of this option are non-conditional requirement of specific temperature allowing high temperature wastewater treatment, low requirement of energy, simple operational procedures, possible utilization over a long period of time with the manageable both dead-end flows and cross-flow. The disadvantage of this filtration system is that it is costly. In general a physical treatment system is normally applied as the pre-treatment of a more elaborate system which includes chemical and biological treatment systems.

2.6.2 Chemical treatment system

Chemical treatment requires the application of chemical additives which will enhance the treatment process of a system. Due to the low cost associated, physical treatment is always selected and implemented as the pre-treatment in wastewater treatment system prior to chemical treatment. Among the available chemical treatment are activated carbon application, coagulation and flocculation, combination of filtration and sedimentation, and others. Each exhibits the advantages and the disadvantages of its application. Table 2.22 lists the chemical treatment commonly applied in treating landfill leachate.

Table 2.22: Chemical treatment system applicable to treat leachate (Tatsi *et al*., 2003; Sletten *et al*., 1995; Qasim and Ching, 1994).

Types of system	Action involved
Coagulation	Colloidal particles are coalesced with the addition of coagulants.
Precipitation	Chemical reaction reduces the solubility of certain pollutants.
Gas transfer	Addition or removing gasses through mixing and air diffusion.
Chemical oxidation	Addition of oxidizing chemicals to enhance oxidation process of pollutants.
Chemical reduction	Addition of reducing chemicals to enhance the reduction process of the pollutants.
Disinfection	Removal of pathogenic microorganisms with ultraviolet lights or oxidizing agents.
Ion exchange	Removal of inorganic and minerals with ion exchange process.
Carbon adsorption	Reduction of various pollutants from wastewater through the adsorption onto carbon particles.

Jar test has been applied in determining the best combination of coagulant and flocculants at the most optimum pH and temperature (Bes-Piá *et al*., 2002). The most common additives in coagulation and flocculation system are activated carbon, ferric chloride, alum and others. Consecutive paragraphs describe the application of various additives in the chemical system in order to treat leachate.

2.6.2.1 Carbon adsorption

Activated carbon, which undergone carbonization and activation process is normally used for the carbon adsorption treatment as it posses macropores with more than 500 Å diameter and micropores of 10-500 Å diameter (Faust and Aly, 1999). Among the factors that affect the adsorption ability of an activated carbon are the nature of the adsorbent that includes surface area and pore structure, particle size, and chemistry of the surface. Other factors include the nature of the adsorbate, effect of foreign ions, effects of temperature, and effects of pH (Faust and Aly, 1999).

2.6.2.2 Flocculation

Flocculation is the process whereby destabilized particles were agglomerates into microfloc and later into larger floccules when flocculants were added. Floccules formed from this process will be removed physically from the system. The agglomerates formed during flocculation trapped suitable polluting entities from wastewater which can be removed from the wastewater system. Flocculants used for the wastewater treatment include inorganic polymers, synthetic flocculants and natural polymers (Qasim and Ching, 1994). Table 2.23 indicates the examples of coagulant and flocculants used in treating wastewater.

Table 2.23: Coagulants and flocculants in chemical treatment of wastewater (Qasim and Ching, 1994).

Type of reagents	**Examples**	**Application in water treatment**
Inorganic coagulants	Aluminium salts	Surface water clarification
	Aluminium polymers	Wastewater treatment
		Surface water clarification
	Iron salts	Removal of phosphates
	Other inorganic coagulants	Algicide
		Water with organic matter
		To ignite sea water coagulation
Natural flocculants	Inorganic flocculants	Cold water
	Organic flocculants (natural polymers)	With ferric salts
		With aluminium salts

Different flocculants resulted with different pollutant removal efficiency while factor controlling the formation of agglomerates are pH, temperature, concentration and others. Some flocculants were found to work efficiently at a higher pH while others work better in acidic condition (Qasim and Ching, 1994).

2.6.2.3 Coagulation

Coagulation process involves the destabilization of colloidal particles when a coagulant was added into the wastewater system. The coagulation process generally followed the kinetic process in Smoluchowski equation and the earliest practice of coagulation in treating water was during the Egyptian era where crushed almond was utilized (Faust and Aly, 1999). Table 2.24 lists the properties of some common coagulants.

Table 2.24: Properties of some common coagulants (Faust and Aly, 1999).

Common Name	**Formula**	**Equivalent Weight**	**pH at 1%**	**Availability (%)**
Alum	$Al_2(SO_4)_3.14H_2O$	114	3.4	Lump – 17 Al_2O_3 Liquid – 8.5 Al_2O_3
Ferric Sulfate	$Fe_2(SO_4)_3.3H_2O$	51.5	3-4	Granular – 18.5 Fe
Lime	$Ca(OH)_2$	40	12	Lump – as CaO Powder – 93-95 Slurry – 15-20
Copperas	$FeSO_4.7H_2O$	139	3-4	Granular – 20 Fe
Ferric Chloride	$FeCl_3.6H_2O$	91	3-4	Lump – 20 Fe Liquid – 20 Fe
Sodium Aluminate	$Na_2Al_2O_4$	100	11-12	Flake – 46 Al_2O_3 Liquid – 2.6 Al_2O_3
Aluminum Chloride	$AlCl_3$	44	-	Liquid

The concept of coagulation is mainly to allow the formation of bonds between the colloid present in the wastewater system with the coagulants whereby the pollutants may be successfully removed from the aqueous system. The rate of the bonding in the system depends on various factors including type of coagulant, coagulant dosage, pH, mixing effects, temperature, turbidity, presence of foreign ion (neutralized effects), electrophoretic mobility, and colour concentration. The presence of unwanted elements within the system would suppress the kinetics of the coagulation process which resulted with the deterioration in the pollutant removal efficiency. In most cases where chemical treatment is insufficient to remove the pollutant from the wastewater or landfill leachate, further treatment such as biological treatment is very essential. The following paragraphs discuss the biological treatment applied in leachate treatment system.

2.6.3 Biological treatment system

The concept in biological treatment system is the provision of leachate as the medium or environment for the growth of microorganism with pollutants as the possible source of nutrient. It includes the requirement of nutrient and oxygen, effect of temperature, and food to microorganism ratio (Arceivala, 1981). The degradation of organic loads from leachate will reduce the pollutant intensity and eventually become absent of contaminants (Koenig and Liu, 2002). It can be grouped into an aerobic system that occurs with the present of oxygen and an anaerobic system which takes place without oxygen. The details of leachate treatment option available are discussed further in the following paragraphs.

2.6.3.1 Aerobic system

Aerobic system is very popular in treating landfill leachate as it allows the degradation of organic compounds to CO_2, H_2O and biomass. Oxygen becomes the electron acceptor in the metabolism of the microorganisms. Various application are available in treating landfill leachate which include activated sludge, waste stabilization pond, aerated lagoon, trickling filter and rotating biological contactor (de Morais and Zamora, 2005; Liu and Koenig, 2002; Koenig and Liu, 1996; Qasim and Chiang, 1994). Each application has its own advantage and disadvantages based on the reaction within the system.

a. Activated sludge

In an activated sludge system, the sludge becomes the media that supply microorganism into the treatment system. Microorganisms were thoroughly mixed with the organic component allowing the growth of the microbes with sufficient oxygen via agitation. The factors influencing the efficiency of this treatment are the quantity and quality of leachate fed into the system, temperature, nutrients availability, pH, leachate retention time and others. Failure of the activated sludge treatment option is commonly due to the presence of toxic components in the leachate (Qasim and Chiang, 1994).

b. Waste stabilization pond

While activated sludge process introduces microorganism into the treatment system, waste stabilization pond allows natural degradation to occur. This is one of the most economic methods as it allows the wastewater to be decomposed over a period of time with minimum maintenance cost. Autotrophs and heterotrophs organisms decompose the organic fractions in the system while some solids that settle to the bottom of the basin decompose anaerobically (Koenig and Liu, 2001; Koenig and Liu, 1996; Qasim and Chiang, 1994). This system is only applicable to low volume leachate as it requires a long period of retention time and recalcitrant element component should always be absent.

c. Aerated lagoon

Aerated lagoons were generally similar to the waste stabilization pond except that artificial aeration was included to enhance aerobic degradation of the leachate (Mehmood *et al.*, 2009; Qasim and Chiang, 1994). As compared to that of the activated sludge system, the aerated lagoons allow the growth of natural microorganism at a longer retention period. Sludge is not re-circulated into the system as practiced in the activated sludge process but certain microbial cocktails including microbes isolated from soil may be introduced into the system to enhance biodegradations (Ding *et al.*, 2001).

d. Trickling filter

Trickling filter operates where wastewater is trickled through the air to absorb oxygen and flows through a media covered with microbial growth. The pollutants will be decomposed via the microbial metabolism in the media. The main drawback of this system is the short contact period between the wastewater and the microbes that removal efficiency is not very high. The energy requirement is generally low as compared to that of activated sludge system that two-stages of trickling filter is normally applied to increase pollutants removal efficiency (Qasim and Chiang, 1994).

Bauer *et al*. (1998) reported that phthalic acids esters (PAEs) leached from plastic waste in the waste cell can be hydrolyzed by microorganism, which break the side chain in the aerobic condition. However, it is inefficient in destroying it totally. Leachate recirculation was found to be able to convert pentachlorophenol (PCP) and other organic compounds to less toxic components through reductive or oxidative processes to produce better quality leachate (Őzkaya *et al*., 2005; Yu and Markku, 2004; O'Keefe and Chynoweth, 2000; Pohland *et al*., 1998).

Walsh *et al*. (2002) reported that several microorganisms are involved in landfill leachate degradation process which includes *Methylamicrobium* sp. that oxidize ammonium, A*lcaligenes* sp. that conducting heterotrophic nitrification and *Proteobacteria* sp. that nitrifies ammonium. Others are *Thiobacillus denitrificans* and *Candida aquaetextoris* (Koenig and Liu, 2001). Table 2.25 simplifies the advantages and disadvantages of various aerobic treatment processes.

Table 2.25: Advantages and disadvantages of aerobic treatment system.

System	Advantages	Disadvantages
Activated sludge	-Capable to remove almost all organic compounds - short retention time (< 1 day) - low solid formation in waste stream	- high energy consumption - toxic contaminant cause failure to the whole system - require feeding of additional nutrient if leachate is of low quality
Waste stabilization pond	- capable to remove most contaminants - produce generally high quality effluent - minimum energy requirement	- long retention period - requires large area
Aerated lagoon	- short retention time - low energy demand - high organic loading	- high construction and maintenance cost
Trickling filter	- low energy consumption - low biomass formation	- low contact time - low removal efficiency - low organic loading
Rotating biological contactor	- low power demand - greater process stability - high organic loading - high removal efficiency	- requires clarifier - high construction cost.

Since the aerobic system has its drawbacks, most leachate treatment facilities are also equipped with other treatment system namely the anaerobic system in order to increase the pollutant removal efficiency. The consecutive sections discuss the application of anaerobic degradation of leachate or wastewater treatment system.

2.6.3.2 Anaerobic system

Anaerobic degradation involves a simultaneous reaction of several groups of microorganism in a complex biological reaction without oxygen as the electron acceptor. While aeration system resulted with the conversion of organic materials into CO_2, H_2O

and biomass, anaerobic degradation produced biogas mainly methane and CO_2. The process takes place in two main phases, namely acid phase and methanogenic phase.

In the acid phase, the complexities of the organic compounds were reduced. Acid-forming microbes will degrade the organic to organic acids such as acetic acids, butyric acid and others that reduce pH value. Then, methanogenic phase takes place when methane forming microbes convert volatile organic acids to methane and CO_2. In most developed countries, methane is harvested for energy conversion that landfills are converted into 'an anaerobic digester' to enhance higher production of methane via leachate recirculation and pollutant removal (Marañón *et al*., 2005; Chan *et al*., 2002). Recirculation of leachate is only applicable in sanitary landfills with appropriate lining systems to prevent aquifer and groundwater contamination (Berge *et al*., 2006). Leachate recirculation will promote anaerobic degradation of the organic components in the leachate and the waste (Wang *et al*., 2005; Őzkaya *et al*., 2005; Morris *et al*., 2003; Rodriguez-Iglesias *et al*., 1999). Factors which influence the anaerobic digestion include the capacity of the digester, temperature (mesophilic and thermophilic), sludge characteristics and pH (Qasim and Chiang, 1994). It was reported that an anaerobic digester system can remove approximately 80% COD (Calli *et al*., 2006; Sierra-Alvarez *et al*., 2005). The performance of an anaerobic digester can be enhanced with the utilization of straw bed as the high-solid stratified bed digester (Svensson *et al*., 2006).

The implementation of an effective leachate treatment facility in a country requires the appropriate amount of expenditure, as well as, the appropriate technology. This is possible when necessary waste management system is in place. The establishment of an effective waste management system however depends not only on waste managers, and the local authorities but also the public. Public plays a major role in the success of a waste management system in a country. Consecutive sections discuss the issue of public participation in waste management system.

2.7 Public Participation

Public plays an important role in the waste management system that it is crucial that this group of people understand the essential aspects of their involvement. The main concerns in public participation are public attitudes and socio-economic factors.

2.7.2 Public attitude

Public attitude towards environmental issues is closely related to the level of education received. In most cases, highly educated groups were easier to understand the necessities of certain action as compared to the less educated groups (Irina and Chamhuri, 2004). Various studies indicated that there are significant differences between the attitudes of the public in developed nations and in developing countries (Vesilind *et al.*, 2002; Goulder, 1995). Parochialism attitude is mainly observed in developing countries resulted with no significant changes over a newly proposed system as in Indonesia (Firman, 2009). The following paragraphs discuss the attitudes of public in different countries.

2.7.1.1 Attitude of public in developed nations

In early 1970s, public participation in environmental issues was very minimal throughout the globe (Vesilind *et al.*, 2002). However, awareness and concern among public in developed nations had improved gradually together with the positive actions implemented by the governments to improve the environmental state. Among the nations that experienced the changes in attitudes are US and Denmark (Fourie, 2006; Fourie, 2004; Subramanian, 2000; Goulder, 1995; Rimberg, 1975).

High pollution problem emerged from the industrial sector creates the awareness among the public where they begun to be actively involved in environmental and waste management issues. Transparency is very much stressed that the public are always aware of the events occurring within their vicinity. This had been practiced by many of the developed countries in Europe including Denmark, Sweden and the Netherlands as regulated in Article 5 of the Report of the Fourth Ministerial Conference on Environment for Europe (1998) (Malina and Bien, 2001; Kocasoy, 2001). Therefore, public of these nations displays positive public attitudes. This becomes evident with the high public participation in recycling activities. Recycling of MSW in most states in US is mandatory allowing the higher rate of recycling (Louis and Shih, 2005; Tilman and Sandhu, 1998). In Japan, public participation particularly in source separation begun as early as 1979s when incineration became the main waste disposal option and needs to reduce waste became crucial (Matsuto, 2004). However, despite the awareness on environmental issues, waste managers in Japan were still being opposed by the public when a new landfill site is proposed due to the negative image carried by landfills (Matsuto *et al*., 2004). That indicated that one-off education is insufficient but a continuous program would proved beneficial to improve environmental awareness and positive public participation (Kuraš and Mikoláš, 2001).

2.7.1.2 Attitude of public in developing nations

The solid waste management in the developing nations is slightly less efficient than those observed in developed countries like Denmark and Sweden. While developed nations managed to provide services to almost the whole of the populations, developing countries are still trying to cover more than 60% of the nations waste management services (Bolaane and Ali, 2002; Bolaane, 2006; World Bank, 1999). Research conducted in Benin, Nigeria indicated that approximately 3/5 or 60% of the population does not received waste collection services (Ogu, 2000) while in Latin America and the Caribbean, waste collection system covers only 70% of the total waste generated by the populations (Hernandez *et al*., 1999). This happened with the too rapid urbanization or mega-urbanization that municipalities found that waste management is not inline with technology and affordability (Firman, 2009; Fauziah *et al*., 2004).

Survey conducted in South Africa indicated that there is an interest among the public to have proper and more appropriate waste management system with high willingness to pay for a good system (Korfmacher, 1997). In Malaysia, similar attitudes were observed where significant group of the public (98%) are willing to abide government ruling regarding environment as a public participation towards environmental improvement and efficient waste management (Fauziah and Agamuthu, 2006; Irra, 1999). Public participation was found to be effective in increasing the efficiency of a waste management system (Muller *et al*., 2002), however, this is still lacking in most developing countries where parochialism attitude exists.

Main drawback is the negative attitude where the “don’t care” and “not my business” concepts are strongly embedded among the people. Therefore, educations play a major role as to change these concepts to “co-ownership perspective”. Public may respond better if their finances are directly involved. For example, the implementation of Pay As You Throw (PAYT) system was found to work positively towards the reduction of MSW disposal to landfills as consumers tend to reduce their waste in order to minimize the cost of their disposal fees (Karagiannidis *et al*., 2008; Miranda and Aldy, 1998). Other method employed to reduce the generation of waste as well as to improve the recycling rate is the taxing of virgin material (Bruvoll, 1998).

Vigorous campaigns and workshops are also important to improve the knowledge of the public on environment-related issues (Saeed *et al*, 2009). The main target of the activities is to create co-ownership of the environment among the public that this attitude will encourage them to participate in promoting better environmental behaviour. However, due to lack of positive attitudes in certain developing nations, incentives such as the ability to generate income to recycler were necessary to promote the recycling activities as in the case of Dar es Salaam City, Tanzania (Kaseva and Gupta, 1996). In order to establish a proper recycling system, it is crucial to institute an appropriate waste management system involving an efficient collection and disposal of MSW (Gupta *et al*., 1998) that the success of a system does not totally depended on the public alone.

2.7.2 Socio-economic factors

Besides the attitudes of the public, the socio-economic factor is also crucial in influencing the effectiveness of an implemented waste management system (Lake *et al*., 1996). In

Germany for example, the high awareness among the public and the politicians made a selected waste management option a success (Schulze, 2000). In low income countries, insufficient financial sources become the main constraint towards efficient waste management (Ashok and Shekdar, 2009; Zhang, 2000; Muttamara *et al.*, 1994). In some cases where public having learnt to live with the existing degraded environment together with low ability to generate income, willingness to pay was found to be in-convenient to manage waste (Karagiannidis *et al*., 2008; Garrod and Willis, 1998).

Report indicated that economic improvement may improve waste management with the aid of legal regulations (Vogel, 2000). Successful implementations are the Packaging Ordinance in Germany and Austrian Waste Management Act in Austria which improved the packaging recycling rate and eliminate packaging waste from the waste stream (Fahrbach, 2000; Stiglitz, 2000). Economic policies on environmental practices will elevate the increase in environmental awareness and environmental quality of a country (Sathiendrakumar, 2000). Implementation of price-based policies such as deposits or refunds, advanced disposal fees and recycling subsidies were also able to encourage participation in waste reduction programs (Palmer *et al*., 1997; Wilson, 2000). It was reported that awareness can be increased among the stakeholders of a waste management system by highlighting the opportunities to be gained from the implementation of a specific system (Lucas and Shreeve, 2000). Taiwan's MSW diversion (90%) to 36 waste-to-energy facilities compensates residents involved with free refuse collection and disposal services, and improved and unique architectural landscapes (Chang- Shya and Hurdle, 2000).

The “carrot or stick” concept is proven to be very effective in most developing nations. Also, appropriate laws and regulation is very essential to ensure that the system can be managed accordingly (Nie *et al*., 2000). Taxes are one of the tools used to protect the environment via controlling the collection and disposal, as well as other relevant waste management system (Goulder, 1995). Taxing of virgin material has been implemented with the purpose to manage the ever increasing generation of waste via the reduction in labour taxation and increase in virgin material taxation (Bruvoll, 1998).

The implementation of the so called green taxes have been used as a waste management tool for a number of years and one such tax in the UK is Landfill tax, which increases year on year (Bye, 2002; Turner *et al*., 1998). The waste management in Hong Kong was reported to experience drastic improvement with the implementation of Waste Reduction Framework Plan where reduction rate exceeded 38% in 1998 (Chan and Lai, 2000). However, it is also very important that sufficient studies were conducted that the improvement of a waste management system can be made possible. Various methods and tools can be utilized to gather information and data. The following paragraphs discuss the tools and concept in waste management system.

2.8 Tools in Waste Management System

A solid waste management system should also be self-sustained to generate sufficient income in order to cover the cost of maintenance and future improvement (Streeter and Martin, 2000; Streeter and Martin, 2000a). Feasibility analysis should be conducted in order to predict the future revenue and cost to be faced by waste managers (Streeter and

Martin, 2000a). One of the methods to ensure an effective waste management system is via privatization. It was reported that privatization of waste management system in Bahrain and Hong Kong was proved necessary in order to prevent ineffective management by the authority where full authorization is given to the rightful company to manage and improve it (Al Sayigh, 2000; Ng and Leung, 2000).

In order to determine the most cost-effective and the most efficient practice in waste management system, the impacts on the environment should also be taken into account. The external cost of landfill in Hong Kong in late 1990s was found to be larger than the cost incurred for its operation, capital and maintenance (Chung and Poon, 1997).

Main drawbacks in improving existing waste management are the lack of basic data and information failure (Powell, 2001, Daskalopoulos *et al.*, 1998). Therefore, it is essential that consistent and reliable data can be collected to provide basic information for further improvement of an existing system or to design a new system (Chong, 2003; Bozzo *et al.*, 2001). This can be accomplished with the use of various tools introduced in designing and managing the waste system. Among the factors involved in designing an effective waste management system are economy and environment. Figure 2.18 illustrates the factors involved in designing an effective waste management system.

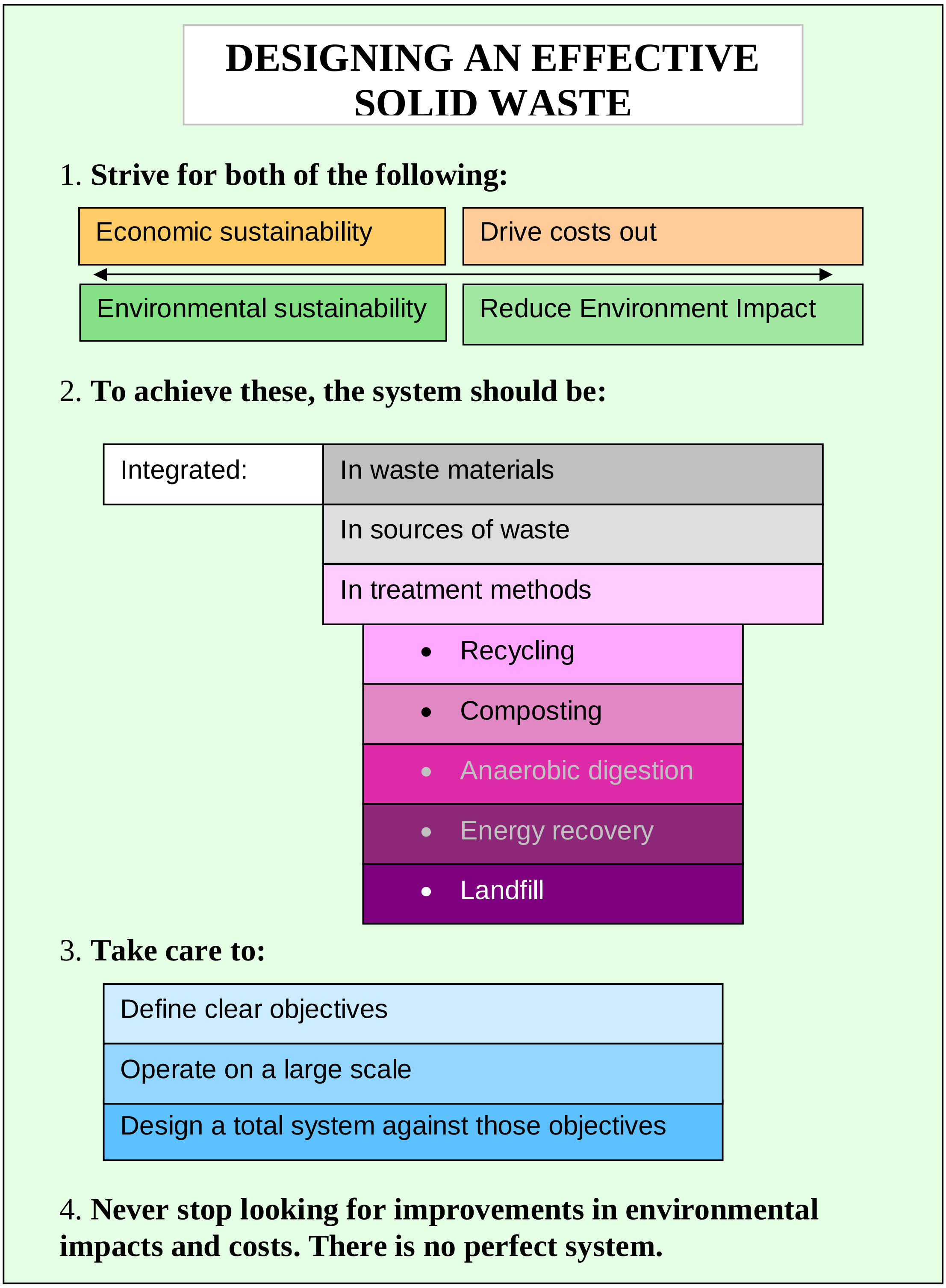


Figure 2.18: Components involved in designing an effective solid waste management system (Adapted from White *et al*., 1995).

Figure 2.18 illustrates that an integrated system is crucial where clear objectives, operation scale and appropriate design are factors to consider in achieving a sustainable solid waste management system (White *et al*., 1995).

2.8.1 General tools in waste management system

There are a variety of tools implemented to analyze and evaluate the efficiency of a management system. It ranges from a simple tool of taxing, or correlating gross domestic production (GDP) with waste generation to a more complex model such as life-cycle-analysis (LCA) (White *et al*., 1995). LCA is applied by USEPA in order to determine the relative benefits of all options in waste management system in the U.S. (Reinhart, 2004). A regional waste management planning of an area can be optimized in order to predict the efficiency of a management strategy and to aid the decision making through simulation (Babendreier and Castleton, 2005; Costi *et al*., 2004; Abou Najm and El-Fadel, 2004). Related total consumer expenditure with waste generation has been developed in producing highly-accurate predictions of individual MSW generation (Daskalopoulos *et al*., 1998).

Other than that, to evaluate the effectiveness of an existing waste management system, models were applied to predict future outcomes. Consecutive paragraphs detail the concept and application of models in waste management system.

2.8.2 Modelling in waste management system

Various models were introduced in waste management system with the capability to analyze or evaluate or predicts future outcomes. LCA is necessary as a tool in evaluating environmental load generated from an activity or a product by means of identification and quantification of energy and material utilized, generation of waste emitted to the environment and the impacts (Finnveden *et al*., 1995; Powell *et al*., 1996; McDougall *et al*., 2000). Beside LCA, geographic information system (GIS) and GreenPro 1 are also applied in waste management in order to determine the most appropriate and cost-effective management system (Skordilis, 2004; Ghose *et al*., 2005; Shmelev and Powell, 2005; Khan *et al*., 2002). Other tools include commercially available software such as SWPlan and others (Fauziah and Agamuthu, 2006a). Risk modelling is applied to access risks on municipal landfills (Chilton and Chilton, 1992).

A simulation of a scenario with the implementation of taxes on virgin resources can also be derived from McKibbin-Sachs Global model. Bruvoll (1998) reported its positive outcome which would offer potential improvements to the current waste management systems. Even though various mathematical models had been developed, the validity of the simulation may not reflect the actual outcome (Bozbey and Guler, 2005). Various validation study were conducted particularly in assisting the development and evaluation of a model and among them was the establishment of prototype decision support system as reported by Barlishen and Baetz (1996). The test not only would determine the accuracy of a particular model but also allow identifying the most appropriate. Other methods of evaluating waste management options include the utilization of 'a variety of weighing' application or percentage weight on relevant criteria (Powell, 1996). Therefore, it is essential that all factors are considered that an appropriate waste management system may be established to improve the current system or to replace faulty one. This will ensure that effectiveness of the selected waste management system benefits the waste managers and other relevant stakeholder economically and environmentally.