CHAPTER II
LITERATURE REVIEW

2.1 Solid Waste

Due to rapid economic and population growth, along with urbanization, it is common to see many developing countries are struggling to provide a proper waste management system; a basic municipal service taken for granted by the developed world (Vidanaarachchi et al., 2006). As urbanization continues to take place, the management of solid waste is becoming a major public health and environmental concern in urban areas of many developing countries. The concern is serious, particularly in the capital cities (Ogama, 1996). A study by Zurbriigg (1999) suggested that problems and issues of MSW management are of immediate importance in many urban areas of the developing world. The main factors affecting the waste generation are population and mean living standard of the country (Daskalopoulos et al., 1998). The existence of a wide variety of processes and technologies for MSW treatment, or even the various possibilities of combining them, have given rise to the appearance of a number different structures and solutions for MSW treatment (Magrinho et al., 2006). Sanitary landfilling is one of the most challenging approaches in waste management practices. It is known as the final option method in the hierarchy of waste management, and is the method that has been adopted for MSW treatment. However, even with sanitary landfilling being the most common method of MSW management, there is no landfill gas energy recovery (Miranda & Brack, 1997). Nevertheless, there also some common problems arising from waste disposal at landfills due to the limited land resources available and the population is kept increasing (Jin et al., 2005). This would make landfills as the ultimate disposal of waste seems unattractive. Additionally, the national and international agencies are aware of the detrimental impact from an environmental point of view.

In the present situation, according to the most recent technologies, the optional solution for MSW treatment is not fully established especially in developing countries. However, waste minimization, production, prevention, reuse, recycling, recovery, and incineration, are attractive methods since there are limitations in landfilling in Thailand. Nevertheless, again, the organic fraction of waste still remains in landfills, which will definitely cause problems to the environment such as; air pollution, surface and ground water pollution. This may lead to global environmental concern; i.e., global warming and climate change from which the huge amount of gases is emitted.

2.1.1 Definition of Solid Waste

Solid wastes, as stated by Tchobanoglous et al. (1993) are all the wastes arising from human and animal activities that are normally solid and are discarded as useless or unwanted. Because of their intrinsic properties, discarded waste materials are often reusable and may be considered a resource in another setting.

Solid wastes are the inevitable by-products of man's daily activities. These are waste materials discharged and discarded as unnecessary from everyday life. These discarded materials affect the environment. Waste management problem has already become severe in many cities including Yangon City, Myanmar. This problem is compounded by the rapidly increasing amounts of wastes of complex nature and composition, which result from the growth in urban populations and the changes in their consumption patterns.

Municipal solid wastes (MSW) are all the solid wastes generated in a community except for industrial and agricultural wastes (Beede & Bloom, 1995). This may generally include the discarded durable and non-durable goods, containers and packing, food scraps, yard trimming and miscellaneous inorganic debris such as household hazardous wastes and often construction, demolition debris, sludge, ashes generated by sewage treatment plant and MSW incinerators. Municipal solid wastes, also known as urban solid wastes is generated as a result of material consumption and is classified into garbage, ashes, and rubbish.

2.1.2 Sources of Generation and Composition of Solid Wastes

Lohani (1984) stated that the generation rate of solid wastes vary from country to country and city to city depending on different factors such as geography, season of the year, economic condition of the people, characteristic of services, frequency of collection, the extent of salvaging and recycling, public attitude and regulation. Moreover, Asoka et al. (2007) mentioned that solid waste generation from organic sources includes municipal and urban wastes, animal wastes, farming wastes, horticulture wastes, domestic refuses and other agro industrial wastes.

Tchobanoglous et al. (1993) explained that the knowledge of sources and types of solid wastes, along with data on the composition and rates of generation, is the basic of design and operation of the functional elements associated with management of municipal solid waste. Municipal solid waste sources comprise all the waste produced in the community related to land use and zoning. The most important categories are residential, commercial, institutional, industrial, agricultural, construction, demolition, municipal services, and treatment plant sizes. Table 2.1 summarizes the major sources of generation and composition (type) of solid wastes.

Table 2.1 Sources of generation and composition of solid wastes

Sources	Typical facilities, activities, or locations	Types (composition) of solid wastes
Residential	Single family and multifamily detached dwellings, low-, medium, and high-rise apartments, etc.	Food, paper, cardboard, plastics, wood, glass, tin cans, aluminium, other metals, ashes, street leaves, special wastes (including bulky items, consumer electronics, hite goods, yard wastes collected separately, batteries, oil, and tires), households hazardous wastes
Commercial	Stores, restaurants, markets, office buildings, hotels, print shops, service stations, auto repair shops, etc.	Paper, cardboard, plastics, wood, food, glass, metals, special wastes (see above), hazardous wastes, etc.

Table 2.1 Sources of generation and composition of solid wastes (cont.) (Tchobanoglous et al., 1993)

Sources	Typical facilities, activities, or locations	Types (composition) of solid wastes
Institutional	Schools, hospitals, prisons, governmental centers	As above in commercial
Construction and demolition	New construction sites, road repair/renovation sites, razing of buildings, broken pavement	Wood, steel, concrete, dirt, etc
Municipal services (excluding treatment facilities)	Street cleaning, landscaping, catch basin cleaning, parks and beaches, other recreational areas	Special wastes, rubbish, street sweepings, landscape and tree trimmings, catch basin debris, general wastes from parks, beaches, and recreational areas
Municipal solid waste[1]	All of the above	All of the above
Industrial	Construction, fabrication, light and heavy manufacturing, refineries, chemical plants, power plants, demolition, etc.	Industrial process wastes, scrap materials, etc. non-industrial wastes including food wastes, rubbish, ashes, demolition, and construction wastes, special wastes, hazardous wastes
Agricultural	Field and row crops, orchards, vineyards, dairies, feedlots, farms, etc.	Spoiled food wastes, agricultural wastes, rubbish hazardous wastes

[1]The term municipal solid waste (MSW) normally is assumed to include all of the wastes generate in a community with the exception of industrial process wastes and agricultural solid wastes.

Tchobanoglous et al. (1993) also pointed out that information on the composition of solid wastes is important in evaluating equipment needs, systems, and management programs and plans. For example, if the solid wastes generated at a commercial facility consist of only paper products, the use of special processing equipment, such as shredders and balers, may be appropriate. Separate collection may also be considered if the city or collection agency is involved in a paper-products recycling program. The detail of the composition of wastes from a community is presented in Table 2.1 above. The types of water and wastewater treatment processes that are used; and these are entirely dependent on the general health of the local, state, and national economy. Table 2.2 describes the comparative data on generation and characteristics of wastes in low-income countries, middle-income countries and high-income countries.

Table 2.2 Wastes generation and characteristics based on income (Polprasert, 1996)

Details	Low-income countries[a]	Middle-income countries[b]	High-income countries
Waste amount *(kg/capita and day)*	0.4 -0.6	0.5 -0.9	0.7 -2.0
Waste density *(kg/m^3)*	250-500	170-330	100-170
Water content (%)	40-80	40-60	20-30
Composition *(% wet weight)*			
Organic	40 -85	40-60	20-30
Paper & Cardboard	1-10	15-40	15-40
Glass & Ceramics	1-10	1-10	4-10
Plastics	1-5	2-6	2-13
Dust & Ash	1-40	1-30	1-20

[a]GNP/cap year^{-1}: <US$ 360

[b]GNP/cap year^{-1}: > US$360, <US$3,500

2.1.3 Characteristic of Solid Wastes

For the effective management of solid wastes as well as to achieve the maximum benefits from the wastes, it is extremely important to have the thorough knowledge of characteristics of the wastes including physical, chemical and biological properties and transformations processes.

As outlined by Tchobanoglous et al. (1993) the physical characteristics of MSW include the specific weight, moisture content, particle size and size distribution, field capacity, and compacted wastes porosity.

Chemical properties are important to evaluate alternative processes and recovery options including energy recovery. The energy content of the wastes is one of the typical chemical characteristic with significant application (Polprasert, 1996). Typical data for energy content for the components of residential wastes are presented in table similarly, the biological properties are important in considering the organic fraction of wastes corresponding to biodegradability, production of odor, and breeding of flies. By knowing these physical, chemical and biological characteristics of wastes, one can determine the appropriate transformation processes and design the recovery methods for the wastes (Polprasert, 1996). Moreover, Chiemchaisri et al. (2007) investigated that landfill were mainly composed of plastic and foam (24.05%). Other major components were food wastes (16.8%) and paper (13.3%).

The characteristic of solid wastes of municipal solid waste in Dhaka City the C/N ratio is 16:1 for residential waste and 39:1 for commercial waste, which indicates that the waste needs some C/N ratio balancing before executing composting process (Tariq Bin Yousuf & Rahman, 2007). Which the composting potential apart from the fraction of the organic wastes depends on the chemical characteristics such as the concentration of carbon (C) and nitrogen (N) and the consequent C/N ratio. The ideal C/N ratio is about 20:1 to 25:1. A ratio higher than 30:1 may slow down the composting process and a ratio lower than 15:1 may lead to loss of nitrogen causing neither growth nor multiplication of microorganisms (Diaz et al., 1993; Yousuf, 2005).

2.1.4 Waste Generation

Waste generation, according to Tchobanoglous et al. (1993) include those activities in which materials are identified as no longer being of value and either discarded or gathered together for disposal. The generation of waste can depend on the following factors:

- Geographic location
- Season of the year
- Frequency of collection
- Characteristic of population
- Extent of salvage and recycling
- Legislation
- Public attitude

Solid wastes from residential sources vary considerably in composition in quality. Tchobanoglous et al. (1993) found that variation depends on the economic status, ethnic composition and social habits of neighborhoods, e.g. backyard burning of waste etc. He further elaborates that quantities also vary with seasons, the opinion choice of citizens, the geographical characteristics of the land, rainfall, climate and the habits of the people e.g. what they eat, drink and the packaged material they buy. (Table 2.3) Nowadays, in many part of the world, plastic is the major packing material used in many products. Not only as a packing material but also as carrying of products, plastic bags become unavoidable in everyday life. Because of many advantages which the plastics have compare to others such as paper, metals, rubber, etc., the use of plastic material is increasing in every sector of civilization so as the generation of plastic wastes (Clayton, 1973). Moreover, Solid waste is generated from households, offices, shops, markets, restaurants, public institutions, industrial installations, water works and sewage facilities, construction and demolition sites, and agricultural activities (emissions from manure management as well as on-site burning of agricultural residues are treated in the agriculture, forestry and other land use (AFOLU) Volume). It is good practice to account for all types of solid waste when estimating waste-related emissions in the greenhouse gas inventory (IPCC, 2006).

Table 2.3 Typical values of energy content of residential MSW (Tchobanoglous et. al., 1993)

Component	Energy [a] Btu/lb	
	Range	Typical
Organic		
Food wastes	1,500-3,000	2,000
Paper	5,000-8,000	7,200
Cardboard	6,000-7,500	7,000
Plastics	12,000-16,000	14,000
Textiles	6,500-8,000	7,500
Rubber	9,000-12,000	10,000
Leather	6,500-8,500	7,500
Yard wastes	1,000-8,000	2,800
Wood	7,500-8,500	8,000
Inorganic		
Glass		
Tin cans	50-100[b]	60
Aluminium	100-500[b]	300
Other metal	-	-
Dirt, ashes, etc.	100-500[b]	300
	1,000-5,000	3,000
Municipal solid wastes	4,000-6,000	5,000

[a] As discarded basis.

[b] Energy content is from coatings, labels, and attached materials.

Note: Btu/lb x 2.326 = Kj /kg

2.1.5 Storage

Solid waste storage facilities may be classified as primary (or individual) and secondary (or communal) storage facilities. In developing countries it is essential that storage facilities be as far as possible, animal proof, insect proof and weather proof, waste able and robust enough to meet the exigencies of normal use.

Tchobanoglous et al. (1993) and Haan et al. (1998) thought that the following considered the on-site storage of solid waste include:

- Type of container to be used
- Container location
- Public health and aesthetics
- Collection methods to be used

To a large extent, the type and capacities of containers used depend on the space available for the placement of containers. There may be many types of containers such as plastic containers, metal containers, rubber containers and concrete containers. But for household and curbside waste containers, the usual form is the plastic container and the lining used for this container is also the plastic bags.

2.1.6 Collection

The frequency of collection includes not only the gathering or picking of solid waste from the sources, but also the hauling of the waste to the location where the contents of the collection vehicles are emptied. Collection system at present are classified according to the type of operation into categories: (Shamit Bringi Dev, 2007)

1) Hauled Container Systems (HCS)
2) Stationary Container Systems (SCS)

The HCS is the system in which the containers used for storage of waste are hauled to the disposal site, emptied and returned to either their original location. The SCS is the system in which the containers used for storage of waste remain at the point of generation, except for occasional short trips to the collection vehicle.

Moreover, short range transfer station may be added which divides the waste collection into two phases, primary and secondary collection. In the primary collection, house to house collection is performed by a small non-motorized vehicle, such as the handcart or animal cart. When full, primary collection vehicle is emptied directly into a large motor vehicle. The collection frequency depends on the character of waste, climate, container size, activities of the people etc. Problems of plastic can be found also in collection systems. Because plastic bags are light and able to float in air, they may be carried away by wind or other circumstances and left in the streets and environment while collecting or transferring the household and other municipal solid wastes.

2.1.7 Transfer and Transportation

According to Tchobanoglous et al. (1993) the definition of transfer and transport refers to the means, facilities and appurtenances used to affect the transfer of wastes from small vehicles to larger vehicles, and transport them over extended distances to either processing centers or to disposal sites. Transfer operations can be used successfully with almost any type of collection system.

The transport of collected waste is a major problem in the cities of developing countries. High proportion of vehicle operating time is spent on transporting waste to the disposal site due to traffic and road condition and small pay load. For overcoming such situation, transfer station should be introduced and the decision should hinge upon economics; the total cost of collection, direct haul and disposal (Shamit Bringi Dev, 2007).

2.1.8 Reduce, Reuse, Recycling and Recovery

The importance of reuse and recycling has been highlighted by different researchers. Recovery or resource recovery is the extraction of economically usable material or energy from solid wastes. Reuse is claim of material in form and its subsequent use in the same form e.g. returnable bottles (Shamit Bringi Dev, 2007).

The 3Rs in Municipal Solid Wastes are: Reduce, Reuse and Recycle. “Source reduction” is defined as the prevention of waste at its source by redesigning products or changing patterns of production and consumption. The definition refers to the reduction of either toxicity, volume, or weight of a material used in a product, the increase in the lifetime of a product, the substitution of reusable products for single use ones or the reduction in the overall consumption of goods (Lober, 1996).

“Recycling” is defined by Haan et al. (1998) as a process of transforming recovered and sorted material into intermediate materials (such as crushed glass or ground or extruded plastic) or into final products for consumer or industrial use. Waste avoidance, waste reduction, and recycling, are the principles by which the industrialized and developed countries apply when they try to reduce their high amount of refuse. Each of the processes will directly or indirectly affect the volume, weight, composition, and economy of solid waste. The recycling is more possible in the rich countries, where sellable constituents comprise higher fraction of collected waste, wages are often too high to permit recovery, sorting and processing of these materials to be carried out profitably. Private scavenging of solid waste is playing a vital role for recycling.

Reuse of a product, without alteration, to serve a purpose other than that for which it was initially intended (e.g. using old clothes as rags, refilling soft drink bottles) (Sykes, 1978; Lund, 2001).

Fudery (1990) defined the resource recovery/recycling that are different between developed and developing countries. In the developed countries, resource recovery is done mechanically and is institutionalized by the government, while in the developing countries, recycling operations are done by waste pickers or scavengers, with junk dealers, even without the encouragement and support by the government. It is noted also that most of the refuse scavenged for recycling, except paper, are non-biodegradable wastes such as plastics, glass, metal, bone, non-ferrous, ferrous materials etc. Like reuse and recycling other materials, plastic materials reuse and recycling also have the benefits of resource recovery and improvement of aesthetic qualities.

2.1.9 Processing and Treatment

Processing and treatment is a technique to improve efficiency of SWM system and to recover resources whether it's usable material conversion product or energy. There are various methods for treatment out of which incineration and compo sting are most widely used. By incineration, volume of waste to be disposed is reduced whereas by composting waste organic soil substitute can be recovered. Final disposal of each type of waste is one of the most considerable issues in MSW systems. It may be slightly easier to handle food and other non-hazardous wastes, but for hazardous and non-biodegradable wastes such as plastics, it becomes much more complicated (Shamit Bringi Dev, 2007).

2.2 Solid Waste Management

2.2.1 Solid Waste Generation and Its Characteristics in Developing Countries

Solid waste can be defined as material, which is not in liquid form, and has no value to the person who is responsible for it. The term MSW, refers to solid wastes from houses, streets and public places, shops, offices, and hospitals, which are very often the responsibility of municipal or other governmental authorities (Zurbriigg, 1999) Waste is created by human activities. However, the amount of waste generated is still depends on the socio-economic factors and the standards of living of the people. As the economic growth and the number of mega cities are rising rapidly mainly in Asia, has lead the developing countries encounter with solid waste management problems than that of the industrial countries (Zerboc, 2003). Globally, (MSW) generation on a daily basis vary significantly. Economic standing is one primary determinant of how much solid waste a city produces (World Resources Institute, 1996 cited in Zurbriigg, 2002). Table 2.4 shows waste generation rates for some selected Asian low and middle income countries.

Importantly, in the consideration of the waste management plans and treatment technology, waste composition has a significant impact on selecting the most appropriate technology. Indeed, waste composition in developing countries significantly varies with the developed nations. Although solid waste generation rates in low-income countries average from only 0.4 to 0.6 kg/person/day, as compared to 0.7 to 1.8 kg/person/day in fully industrialized countries. Many researchers (Cointreau, 1982; Blight & Mbande, 1996; Arlosoroff, 1982 cited in Zerbock, 2003) have found several common differences in the composition of solid wastes generation in developing nations as the following:

- Waste density 2-3 times greater than industrialized nations,
- Large amount of organic waste (vegetable matter, etc.),
- Large quantities of dust, dirt (street sweepings, etc),
- Smaller particle size on average than in industrialized nations.

Table 2.4 Waste generations rates of some Asian countries (Zurbriigg, 2002)

Country	Waste generation (kg/capita/day)
Nepal	0.2 -0.5
Cambodia	l.0
Lao PDR	0.7
Bangladesh	0.5
Vietnam	0.55
Pakistan	0.6 -0.8
India	0.3 -0.6
Indonesia	0.8 -l.0
China	0.8
Sri Lanka	0.2 -0.9
Philippines	0.3 -0.7
Thailand	l.1

These differences from industrialized nations must be recognized both in terms of the additional problems they present as well as the potential opportunities which arise from their waste composition. Figure 2.1 represents the typical waste generation in some selected Asia countries (Visvanathan, et al., 2004).

The high content of biodegradable matter and inert material results in high waste density (weight to volume ratio) and high moisture content. These physical characteristics significantly influence the feasibility of certain treatment options. Systems operating well with low-density wastes such as in industrialized countries will not be suitable or reliable under such conditions. In addition, to the extra weight, abrasiveness of the inert material such as sand and stones, and the corrosiveness caused by the high water content, may cause rapid deterioration of equipment. Wastes with a high water or inert content will have low calorific value and thus, also not be suitable for incineration. (Chea Eliyan, 2007; Zurbriigg, 2002)

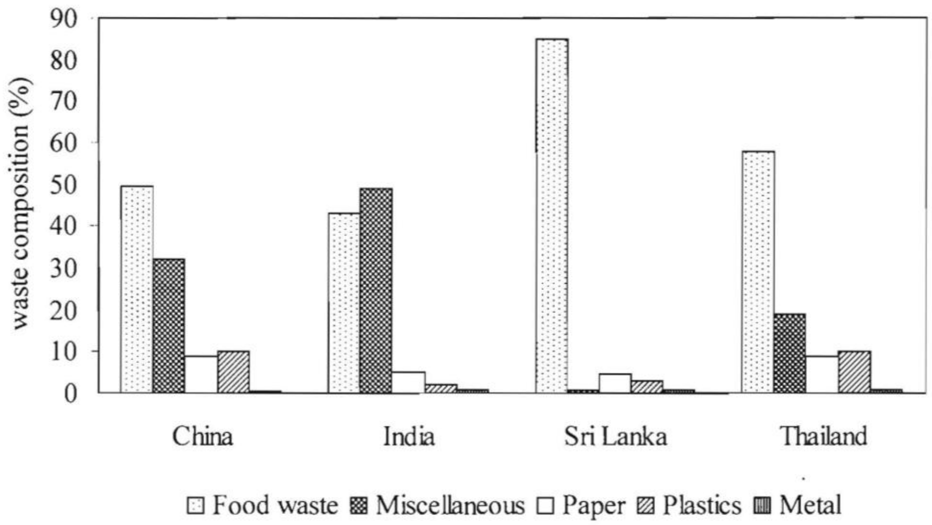

Figure 2.1 MSW composition in selected Asian countries (Visvanathan et al., 2004)

2.2.2 Potential Waste Generation Trend

The production and composition of MSW vary from one country to another and are influenced by various factors including region, climate, and extent of recycling, selection of disposal method, collection frequency, season and cultural practices. Interestingly, Visvanathan et al. (2004) reported that the generation trend situation of selected Asian country like Thailand showed the steady increase of solid waste production with time. Specifically, the annual increase of MSW generation in Thailand is depicted on Figure 2.2.

2.2.3 Current Solid Waste Management Strategies

Here, some examples of solid waste management systems encountered in low-income Asian countries are elaborated. The description does not mean to be completed, but intends to show some typical difficulties which most of municipalities are facing and elucidate what innovative solutions and approaches have been implemented. A typical waste management system in low-income Asian countries can be described by the elements: (Zurbriigg, 2002)

– Household waste generation and storage

– Reuse and recycling on household level (includes animal feed and composting)

– Primary waste collection and transport to transfer stations or community bins

– Management of the transfer stations or community bins

– Secondary collection and transport to the waste disposal site

– Waste disposal in landfills

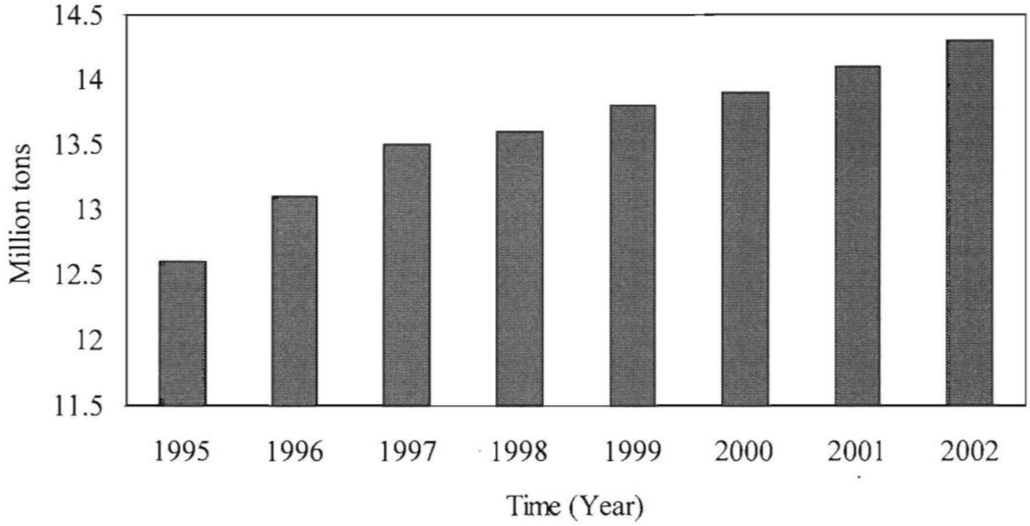

Figure 2.2 Annual MSW generation in Thailand
(Visvanathan et al., 2004)

Recovering and recycling usually takes place in all elements of the systems and is widely practiced by the informal sector "waste pickers" or by the solid waste management staff themselves for extra income. Recovered and recyclable products then enter a chain of dealers, or processing before they are finally sold to manufacturing enterprises. However, the waste management application does not match with the potential composition as the amount of organic fraction disposed to landfill will create some environmental problems.

2.2.4 Problem Associated with SWM

Open dumps, unfortunately still mostly observed in developing countries, where the waste is dumped in an uncontrolled manner, can be detrimental to the urban environment. Many governments now acknowledge the dangers to the environment and to public health derived from uncontrolled waste dumping. However, officials often think that uncontrolled waste disposal is the best that is possible. Financial and institutional constraints are one of the main reasons for inadequate disposal of waste, especially where local governments are weak or underfinanced and rapid population growth steadily continues (Kum et al., 2004). Many governments even have great difficulties in trying to define their actual SWM costs, as very often no detailed cost accounting is in place. When SWM systems based on user fees are in place (government franchise to private company), often the fees barely cover costs of collection and transportation only. Practically, there is no financial resource for safe disposal of waste. Financing this part of the solid waste management cycle is made even more difficult as most people are willing to pay for the removal of the refuse from their immediate environment but then "out of sight, out of mind" is generally not concerned with its ultimate disposal (Chea Eliyan, 2007).

Focusing of MSW management in many developing countries is on waste collection, with a lack of consideration for waste treatment or disposal. While collection would help to remove waste from the generators, collected waste is often disposed of in open dumps without concern for environmental degradation and human health impacts (Vidanaarachchi et al., 2006). Open dumping is the most economical method which is dominantly practicing except for developed countries (Visvanathan et al., 2004). Figure 2.3 shows the disposal methods practiced in selected Asia countries while Table 2.5 illustrates the disposal method in some countries in Asia and the Pacific region. Most organic materials are biodegradable and can be broken down into simpler compounds by aerobic and anaerobic microorganisms, leading to the formation of gas and leachate in landfills. Therefore, the appropriate measures are needed to control the environmental impacts, or to eliminate or minimize these impacts (El-Fadel et al., 1997). Rather than dispose such residues, after dewatering, these could be composted aerobically, but with AD without any pre-treatment, with energy recovery, seems to be a more attractive method for the treatment of the above mentioned biodegradable waste (Sharma et al., 2000).

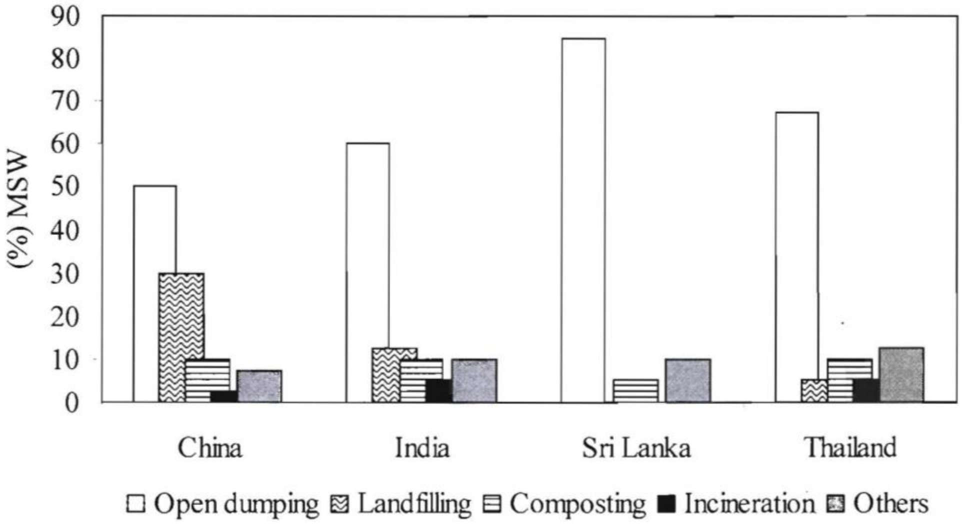

Figure 2.3 MSW disposal practiced in selected countries (Sharma, et al., 2000)

2.2.5 Pretreatment Technology Prior to Landfilling

Pretreatment fulfills the first three components of the waste hierarchy namely: reduction, reuse, recovery and disposal. As stated by SITA UK (2002), the following three criteria are considered to be fulfilled by pretreatment technologies.

– It must be a physical/ thermal/ chemical or biological process including sorting;

– It must be permanently change the characteristics of waste;

– Process must facilitate the waste's handling or recovery.

Based on the Environment Agency (2006); the three main methods of waste processing are chemical, biological and physical. Each of the processes comprise of many technologies as shown below:

– Biological: focusing on aerobic (with air) or anaerobic (without air) waste processing techniques.

– Chemical: studies on pyrolysis, incineration and gasification technologies.

– Physical: studies of waste processing plants that use autoclaving and thermo treatment techniques.

However, biological processes have become popular among other technologies and gained an interest in the field of waste treatment. These treatment technologies can maximize the recycling and recovery of waste components (Chea Eliyan, 2007).

2.3 Integrated Solid Waste Management System

The term Integrated Solid Waste Management applies to all of the activities associated with the management of society's wastes and aims to manage the wastes in such a way that it meets public health and environmental concerns and the public's desire to reuse and recycle waste materials (Tchobanoglous et al., 1993). Moreover, Solid Waste Management is a tool to determine the most energy-efficient, least-polluting ways to deal with the various components and items of a community's solid waste stream (Jim Stokoe & Elizabeth Teague, 1995).

Integrated solid waste management involves sustainable planning of all the functional elements that is useful for an effective and efficient waste management system. It includes the selection and application of suitable techniques, technologies, and management programs or system to achieve sustainable waste management. An integrated wastes management system includes a range of facilities, ensuring that unavoidable wastes are managed from the point of production to final treatment or disposal. It should also ensure that as much as possible is reused or turned into valuable products such as recycling and new resources, energy and composting. Figure 2.4 illustrates the overall process of an integrated solid wastes management system (Visvanathan et al., 2004).

The UNEP International Environmental Technology Centre (1996) describes the importance of viewing solid waste management from an integrated approach:

- Some problems can be solved more easily in combination with other aspects of the waste system than individually;

- Adjustments to one area of the waste system can disrupt existing practices in another area, unless the changes are made in a coordinated manner;

- Integration allows for capacity or resources to be completely used; economies of scale for equipment or management infrastructure can often only be achieved when all of the waste in a region is managed as part of a single system;

- Public, private, and informal sectors can be included in the waste management plan;

The main objective of integrated solid waste management system is to achieve the sustainability. The sustainable waste management systems are based on the "proximity principle", where waste is disposed off as near as possible to where it is produced. When that is not possible, transfer stations have to be established and transported by special purpose vehicles to its final destination (Hansenet et al., 2002).

Table 2.5 Disposal methods of MSW in Asia and Pacific region countries (UN, 2000 cited in Visvanathan et al., 2004)

Country	Disposal methods				
	Open burning	Composting	Landfilling	Incineration	Others
Japan	0	10	15	75	0
Singapore	0	0	30	70	0
Australia	0	10	80	5	5
Republic of Korea	20	5	60	5	10
Malaysia	50	10	30	5	5
Indonesia	60	15	10	2	13
Philippines	75	10	10	0	5
Vietnam	70	10	0	0	20
Pakistan	80	5	5	0	10
Bangladesh	95	0	0	0	5
Nepal	70	5	10	0	15
Mongolia	85	5	0	0	10

Tchobanoglous et al. (1993) stated that an integrated solid waste management has been evolved as a response to the regulations developed to implement various laws. A hierarchy of waste management activities has also been established by recent regulations.

Many developed countries have adopted the principles of the wastes management hierarchy in order to guide their policies on MSW management. The hierarchy lays out the preferred options for managing the waste from the point where it arises through to final disposal (IEA, 2003). As shown in Figure 2.4 (Zurbriigg, 2002), wastes avoidance followed by minimization, would clearly be at the top, as it prevents the wastes from having been managed at all. Re-using of materials followed by recycling including composting would be the next-best management option because it can return resources to commerce after the original product no longer serves its intended purpose (Kreith & Tchobanoglous, 2002). Recovery either the materials or the energy follows the next step because a great lot of materials as well as the energy can be retrieved or recovered from the wastes that otherwise would be buried and wasted. Treatment of MSW before sending it to the landfill for final disposal is another attractive strategy. Finally, disposal such as landfilling is the final resort for SWM, which is really not any better OT worse than incineration, as it too can recover energy by utilizing methane recovery technologies to develop a marketable product (UNEP, 2005).

Wastes avoidance and minimization means the reduction of wastes volume to be disposed of to the landfill or disposal sites. It can be achieved by changing the consumption behavior such as avoiding the use or consuming less packaged materials and so, which is entirely dependent on the individuals attitude and the society where they belong to but it is very difficult to change the peoples' behavior at once.

Waste minimization can be achieved through the implementation and promotion of 3R (Reduce, Reuse, Recycle) programs which includes, waste segregation at sources, waste separation at the sites so that the recycled materials such as papers, plastics, steel, metals or glass are sorted for recycling business and revenue generation. Implementation of 3R programs not respond to the problems of increasing wastes generation, but can also gain significantly from the prospects of economic progress (ADB, GES &UNEP, 2006).

Visvanathan, & Norbu T. (2006) pointed out that in most cases, people are compelled to focus more on reusing and recycling of wastes than on source reduction. Because reusing and recycling of wastes provide many benefits .both in terms of economic and environmental such as reusing of items delays or sometimes avoids that item's entry into the waste collection and disposal system. Recycling reduces reliance on virgin materials as well as reduces pollution, saves energy, mitigates global climate change, and reduces the pressures on biodiversity. In addition, source reduction, coupled with reuse, can help reduce waste handling and disposal costs by avoiding the cost of recycling, municipal composting, land filling, and combustion.

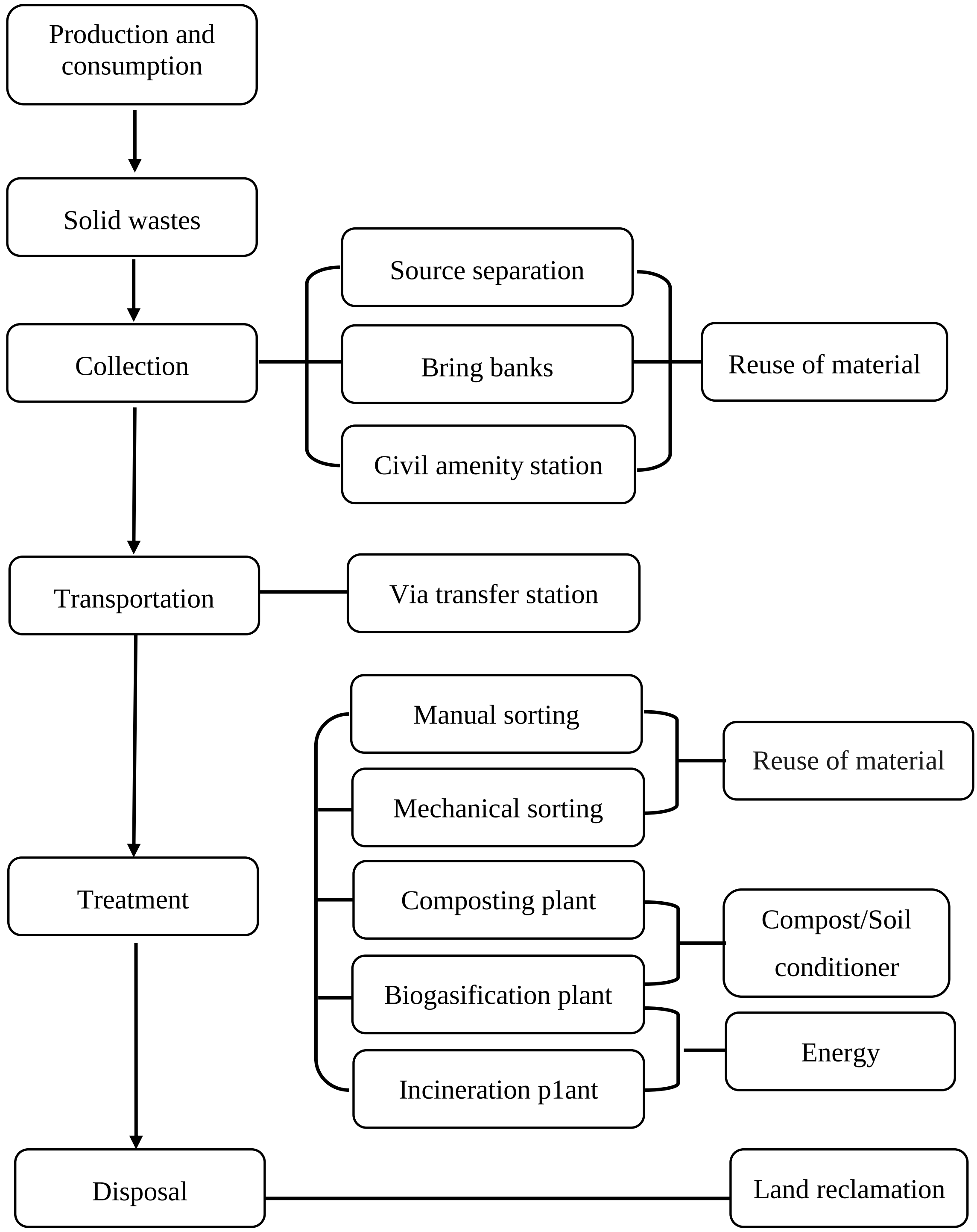

Figure 2.4 A flow diagram for integrated approach for wastes management (Zurbriigg, 2002)

Figure 2.5 Hierarchy of integrated wastes management and influencing factors (Zurbriigg, 2002)

However, significant quantities of MSW continue to be disposed off in landfill largely due to its low cost and ready availability. In landfill the biodegradable components of MSW decomposed to emit methane as well as other components such as leachate, which can cause significant environmental pollution in air and ground water, and give rise to odour (IEA, 2003) as well as demand unrestricted land resources, and of course is a growing part of the Global Climate Change (Arrow Ecology, 2005). In general, valuable resources are wasted during the disposal of wastes in landfills. For these reasons, most countries are now aiming to reduce their dependence on the use of landfill for MSW instead of which, recycling and recovery operations for MSW are increasing consequently (IEA, 2003).

Local authority should promote source reduction in the cities since it is put at the top hierarchy of the strategy to achieve sustainable SWM. Moreover, where it is economically viable, and environmentally sound, recycling of materials is preferable to treatment for energy recovery. The experience from the countries with highly developed recycling infrastructure have shown that a significant tonnage of MSW remain after recycling to make energy recovery an environmentally justified and economically viable option-ahead of final disposal to landfill since a ton of MSW can give rise to about 600 kWh of electricity (IEA, 2003). Additionally, there are several other unseen benefits such as reduction in environmental damage, an extension of the life of existing disposal sites and a reduction on the dependency on the use of virgin materials and energy as well as reduction in costs of health care associated with poor solid waste disposal practices (Muttamara, et al., 1994; Kreith, & Tchobanoglous, 2002).

2.4 Solid Wastes Management: Policies and Strategies or Approaches

Wastes are managed through a complex system of policy and strategy, laws and regulations, as well as producers, authorities and handlers. Solid wastes management system is primarily a function of the public sector rather than the private sector, and it is difficult to measure the constraints on the public sector, especially those of political or social and natural components. However, the efficiency might be measured based on frequency of collection, types of waste collected, location from which wastes are collected and location to which the wastes are disposed of as well as the method of disposal, and of course the acceptability of the disposal systems. Additionally, the constraint of environmental factor is most important in the areas where wastes are stored or disposed of because these functions represent prolonged exposure of wastes to environment. (American Samoa, Australia, 2005)

Various policy options and strategies or approaches are being practiced for the sustainable solid wastes management in both developed and developing countries. Tchobanoglous et al. (1993), reported that policy of solid waste management, the problem usually requires some types of action by decision makers, which probably is an elected official. Therefore, to understand the nature of the planning process in this application, it is important to consider the following major issues:

– The framework in which planning activities are usually conduct;
– The effect of planning time period;
– The jurisdictional levels at which planning studies are conducted;
– The impact of alternative concepts and technologies on the planning

process;

Countries are now developing various strategies or approaches for the wastes management in the recent decade and are being implemented.

2.5 Greenhouse Gases and Climate Change

Climate change is a serious international environmental concern and the subject of much research and debate. Many, if not most, of the readers of this report will have a general understanding of the greenhouse effect and climate change. However, for those who are not familiar with the topic, a brief explanation follows.

A naturally occurring shield of "greenhouse gases" (primarily water vapor, carbon dioxide, methane, and nitrous oxide), comprising 1 to 2 percent of the Earth's atmosphere, traps radiant heat from the Earth and helps warm the planet to a comfortable, livable temperature range. Without this natural "greenhouse effect," the average temperature on Earth would be approximately 5 degrees Fahrenheit, rather than the current 60 degrees Fahrenheit

Many scientists, however, are alarmed by a significant increase in the concentration of carbon dioxide and other GHGs in the atmosphere. Since the pre-industrial era, atmospheric concentrations of carbon dioxide have increased by nearly 30 percent and methane concentrations have more than doubled. There is a growing international scientific consensus that this increase has been caused, at least in part, by human activity, primarily the burning of fossil fuels (coal, oil, and natural gas) for such activities as generating electricity and driving cars.4

Moreover, there is a growing consensus in international scientific circles that the buildup of carbon dioxide and other GHGs in the atmosphere will lead to major environmental changes such as: (l) rising sea levels (that may flood coastal and river delta communities); (2) shrinking mountain glaciers and reduced snow cover (that may diminish fresh water resources), (3) the spread of infectious diseases and increased heat-related mortality, (4) impacts to ecosystems and possible loss in biological diversity, and (5) agricultural shifts such as impacts on crop yields and productivity. Although it is difficult to reliably detect trends in climate due to natural variability, the best current predictions suggest that the rate of climate change attributable to GHGs will far exceed any natural climate changes that have occurred during the last 10,000 years.

Many of these changes appear to be occurring already. Global mean surface temperatures have already increased by about 1 degree Fahrenheit over the past century. A reduction in the Northern Hemisphere's snow cover, a decrease in Arctic sea ice, a rise in sea level, and an increase in the frequency of extreme rainfall events have all been documented.6 Such important environmental changes pose potentially significant risks to humans, social systems, and the natural world. Of course, many uncertainties remain regarding the precise timing, magnitude, and regional patterns of climate change and the extent to which mankind and nature can adapt to any changes. It is clear, however, that changes will not be easily reversed for many decades or even centuries because of the long atmospheric lifetimes of the GHGs and the inertia of the climate system.

2.5.1 The Relationship of Municipal Solid Waste to Greenhouse Gas Emissions

For many wastes, the materials that we dispose represent what is left over after a long series of steps including: (USEPA, 1998)

1) extraction and processing of raw materials
2) manufacture of products
3) transportation of materials and products to markets
4) use by consumers
5) waste management

At virtually every step along this "life cycle," the potential exists for GHG impacts. Waste management affects GHGs by affecting one or more of the following: (USEPA, 1998)

1) Energy consumption (specifically, combustion of fossil fuels) associated with making, transporting, using, and disposing the product or material that becomes a waste.

2) Non-energy-related manufacturing emissions, such as the carbon dioxide released when limestone is converted to lime (which is needed for aluminum and steel manufacturing).

3) Methane emissions from landfills where the waste is disposed.

4) Carbon sequestration, which refers to natural or man-made processes that remove carbon from the atmosphere and store it for long time periods or permanently. A store of sequestered carbon (e.g., a forest or coal deposit) is known as a carbon sink.

2.5.2 Carbon Balance Model

To address the problem of global warming, following the theme of the Kyoto Protocol, a carbon-balance model of the Earth conceptualized by Polprasert (2003) is illustrated in Figure 2.6. Beginning with the sun energy radiated to Earth at the rate of 342 Watts per square meter (W/m^2), only that average of 168 W/m^2 can touch Earth's mantle and almost half of it are used to lift the water through the processes of physical evaporation and evapotranspiration by plants. From the data of average rainfall worldwide (~1 m/y) at the surface temperature of 15°C, the energy used for water evaporation can be calculated to be equal to 78 W/m^2 (Masters M.G., 1998) or equivalent to 1.23×10^6 KJ/m^2-y for the sun radiation of 12 hours per day. Figure 2.6 indicates the circulation of carbon and water; both activated by radiated sun energy. To recognize the importance of carbon in the form of fuel, the atmospheric CO_2 is presumed to be the energy captor reacting with H_2O to form the organic compounds $(CH_2O)_n$ in the chlorophyll-catalyzed photosynthetic reaction, shown as pathway I circled in Figure 2.6. The energy stored in the freshly formed organics, as called primary producers, is transferred up to the top of pyramidal food web, along pathway 4. Most of the organic residues, left along pathway 4, are further consumed by scavengers and the remaining are washed down and exist in the water in the form of pollutant, as called Biochemical Oxygen Demand (BOD). Such the organic BOD finally finds the way, aerobically and/or anaerobically, back to inorganic carbon. Again, when both plants and consumers are dead, most of them decay and go back to the original substances (CO_2 and H_2O) with the help of the bacterial decomposition reactions. But some of them persist and accumulate underneath the Earth surface (pathway 2). The formation of petroleum following pathway 2 occurred 2 billion years ago in the Precambrian era, in which photosynthesis was abundant worldwide and the accumulation of organic carbon less than 0.1 percent (Tissot & Welte, 1984). Nowadays, the intrinsic underground deposition of carbon comes mainly from the solid waste landfilling practice. Note that there is not only one pyramid with man on the top as shown in Figure 2.7 In the real world, several and complex pyramidal food chains exist on Earth to form the integral part of carbon cycle. In the grass field of African Continent, lions and elephants are on top of the food chain, while sharks and whales are highest in the ocean. Each pyramid possesses different growth and survival rates, depending on the foundation base; that is, primary producers. In many circumstances, competition among pyramids occurs for occupying the common primary producers; for example, the shooting of wild elephant by the villagers in the upper south of Thailand. Thus, it can be concluded that the availability of primary producers is the limiting factor that governs the population of higher-level consumers, based on the energy transfer efficiency. It is fortunate that man is an omnivore, capable of consuming both plants and meat, thereby resulting in the increasing growth rates. Supposing that men were to eat only lion meat, its population would have been kept to a minimum because very much less availability of food-derived energy is left to it. Thus, we can conclude that the higher-level consumers are easily prone to extinction if they do not adapt themselves to find other food alternatives or energy sources for their living.

In order to obtain numerical figures of the substantial amounts involved with the photosynthesis and so on, the change of the reaction enthalpy can be calculated, using the chemical thermodynamic data (Stumm & Morgan, 1996) as follows.

$$CO_2(g) + H_2O(g) \leftrightarrow CH_2O(g) + O_2(g) \qquad (2.1)$$

$$\Delta H_f^o; \quad -393.5 \quad -241.8 \qquad -116.0 \qquad 0 \qquad \text{KJ/mol.}$$

$$\Delta H^o = (-116.0+0) - (-393.5-241.8)$$

$$= +519.3 \text{ KJ/mol.}$$

Since ΔH^o value is positive, the reaction is endothermic, thereby absorbing the energy content and forming the organic carbon at the proportion of 43.3 KJ/g C. We can observe this phenomenon in the paddy field or forest that its evening temperature is much lower than that in town and in the morning, the air moisture is cooled enough to be foggy. Whereas, in town with fewer trees but more combustion from running motor vehicles, hot condition persists both day and night, as is commonly called "heat dome". If a land area is fully covered with plants that are ready to react photosynthetically, the maximum quantity of carbon fixation can be calculated.

$$CO_2 \text{ fixed} = (1.23 \times 10^6 \text{ KJ/m}^2\text{-y})/(43.3 \text{ KJ/g C}) \quad (2.2)$$
$$= 28.4 \times 10^3 \text{ g C/m}^2\text{-y}$$

Meanwhile, from the reactions (1), the product O2 is generated at the maximum rate of 75.8 Kg O_2 per square meter per year. It is, then, used by all aerobic, heterotrophic consumers, including man, in respiration to get the energy and produce CO_2 back to the atmosphere, following the reverse of reaction (1) or pathway 5 shown in Figure 2.6. Pathway 3 did not exist until the invention of machinery in the age of industrial revolution. Fortunately, man can eat only the freshly formed organics, not the 2-billion-year-old rotten ones, to fill their stomach; in contrast, such the extremely old organics are highly toxic and may cause death, if ingested. Fossil fuels can be used just to facilitate man's activities only by running non-life engines and so on.

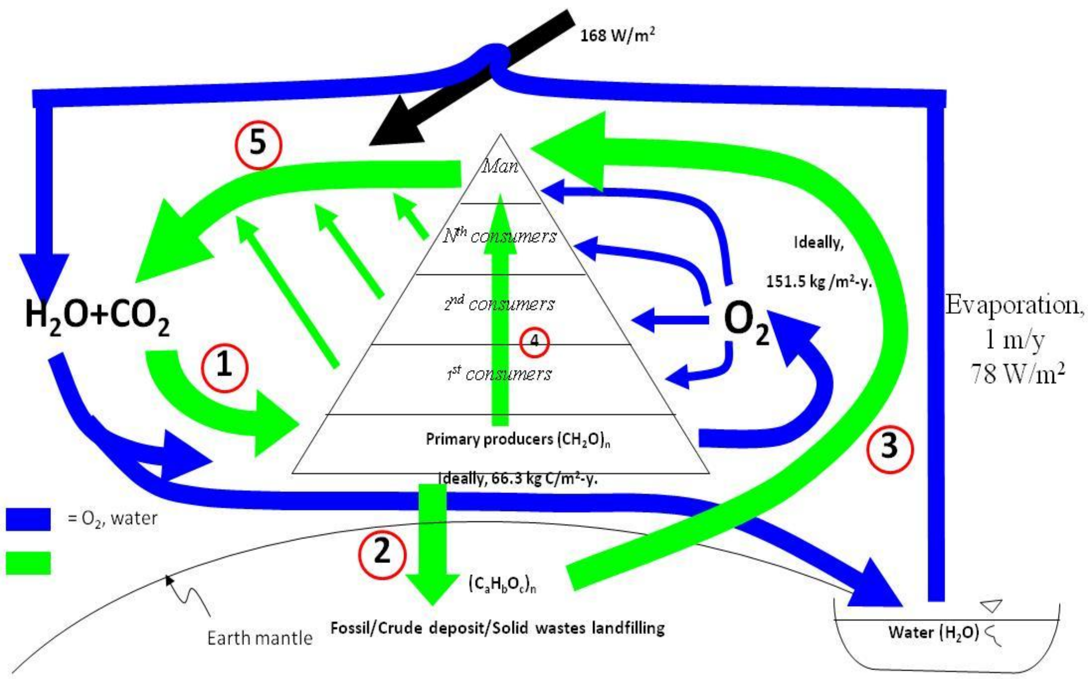

Figure 2.6 A carbon-balance model of the globe

(Polprasert, 2003)

The carbon-balance model as shown in Figure 2.6 depicts the major activities of carbon interchange between Earth's atmosphere and lithosphere. Such the activities can be categorized further as follows.

(1) Fixation

– Permanent fixation: Forest area and solid waste landfilling.

– Temporary fixation: Agricultural area with monoculture or low biodiversity.

(2) Emission

– Food consumption of all aerobic heterotrophic organisms.

– Use of fossil fuels for industries and transportation.

It is perceptible that nowadays, the amount of carbon emission has outgrown that of fixation since the age of industrial revolution because fossil fuels are dug up to use as energy to facilitate almost all urban activities. Figure 2.6 adapts the global carbon-balance model to fit a real situation of Thailand's territory. The country's area can be divided into two significant areas (1) forest area and (2) urban and agricultural area that contain different sorts of human use value. Forest, including rain forest and mangrove, serves as a fertility bank for man's future need. Rain forest is a spongy buffer system that absorbs not only energy radiated from the sun, but also a large quantity of rain water in the wet season and, later on, gradually release it for use in the dry season. Moreover, it represents the maximum level of biodiversity complex prevailing on Earth, as well. Meanwhile, mangrove can greatly retard a big wave, like disastrous tsunami, and serve as a very important basic foundation of a food web for most coastal sea organisms. From a bird-eyed view, it is all right to take urban into account of agricultural area as the majority of people's settlement is in the form of villages scattering all over the Kingdom. The agricultural area is definitely the place to produce food for man's living. The amount in excess of national consumption is exported in exchange for the imported crude of more than 90 percent of total requirement. Such the crude is used as energy to run almost all industries and businesses so as to build the economic growth as commonly called Gross Domestic Product (GDP) and prosperity for the sake of the country's forest resource.

Now let's consider two extreme conditions of a country with and without forest area. When the forest area is diminishing, the land would turn into a grass field with a lack of biodiversity, but a great risk to severe flood and drought occurring all year round. On the opposite side, the country cannot be fully afforested because the agricultural area is required to produce food sufficiently to feed the national population. As shown in Figure 2.7, the country's urban and agricultural area can be taken neither to the limit of nor beyond the Kingdom's territory, overlapping those of neighboring countries. Hence comes to the point where an ideal equilibrium condition exists between the environment, man, and economics; the following statement is recommended: "The country's forest area must be maintained (or even afforested more) as much and long as possibly by implementing agriculture just enough to feed people of the country. If a higher economic prosperity is desired. it should be done by building it up ourselves (and/or less importing) and/or exporting only value-added goods and services." To achieve the desired economic prosperity, Thailand cannot follow all the footsteps of other developed countries with plenty of underground resources. The more import of crude and hi-tech machinery in exchange for the export of agricultural products, the higher risk is leading to the country's economic collapse. But there are a number of ways it can pursue to help alleviating the global wanning without jeopardizing the equilibrium of Environment-Ecology-Economics (3E). Not only energy-saving measures, but also waste minimization, recovery and recycling programs are additional alternatives for the country to fully carry out so as to get along with the "3E" equilibrium approach (Bishop & Paul, 2000; Misra, 1996; Polprasert, 1996; Kirkwood & Longley, 1995).

In most tropical countries, like Thailand, products of photosynthesis serve as not only food, but also as important key economic drivers in every market, both local and international. Apart from the forest areas, agricultural lands in Fig. 2.8 are grouped, based on types of photosynthetic products, into three - lands for the production of staple food (rice grain), non-staple food (fresh fruits, cassava, and sugarcane), and non food (palm fruit and Para rubber). The amounts of products in excess of domestic consumption are exported in exchange for the imported crude oil and machinery from abroad. Such imported fossil energy is used mostly by both industrial sectors and domestic households in urban areas. Therefore, understanding the CBM would enhance the public’s participation in reducing carbon emissions, thereby leading to a win-win approach - not only mitigating the global warming problem, but also saving more foreign currency from reduced crude oil import.

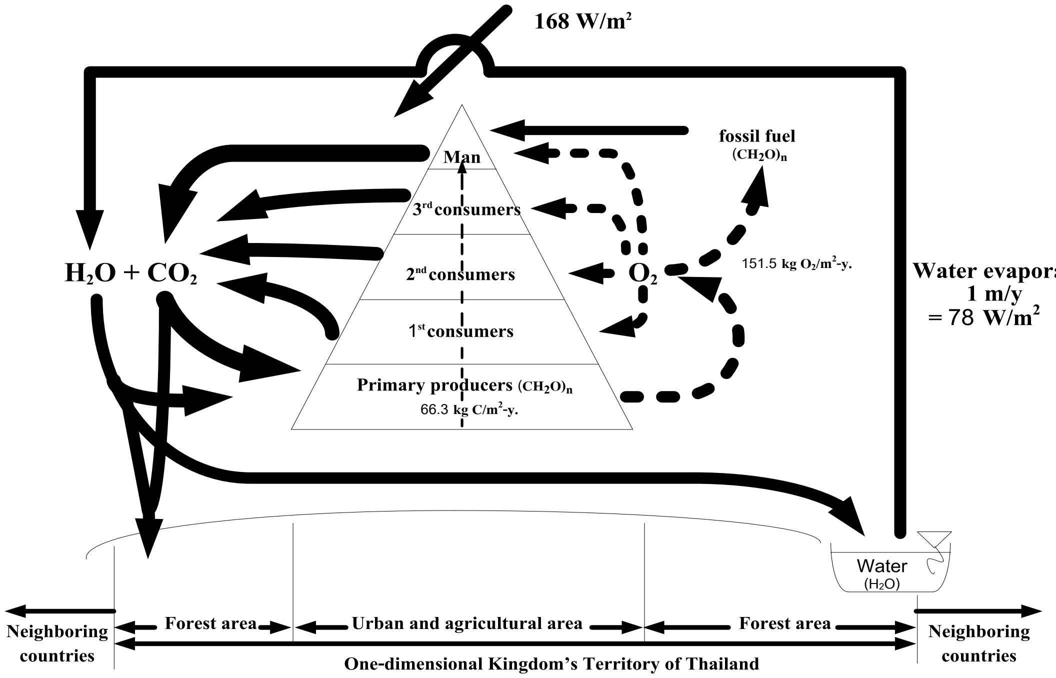

Figure 2.7 A carbon-balance model of Thailand

(Polprasert, 2003)

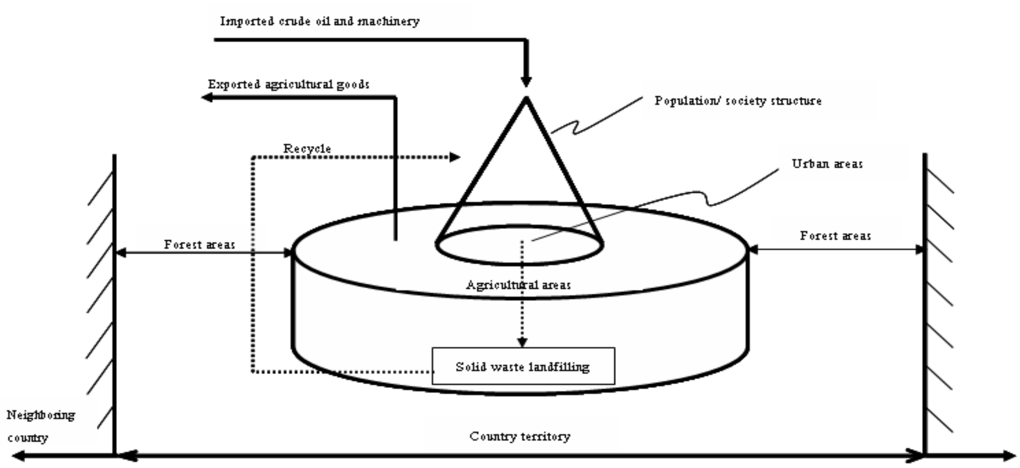

Figure 2.8 The Carbon balance model

(Polprasert, 1996)

The Natural Carbon Balance

Carbon continually exchanges within a closed system consisting of the atmosphere,oceans, biosphere, and landmass. There are short-and long-term cycles at work.

Short-Term Cycles:

Carbon is exchanged rapidly between plants and animals through respiration and photosynthesis, and through gas exchange between the oceans and the atmosphere.

Long-Term Cycle:

Over millions of years, carbon in the air is combined with water to form weak acids that very slowly dissolve rocks. This carbon is carried to the oceans where some forms coral reefs and shells. These sediments may be moved deep into the Earth by drifting continents and eventually released into the atmosphere by volcanoes.

The Earth maintains a natural carbon balance. When concentrations of carbon dioxide (CO_2) are upset, the system gradually returns to its natural state through the processes shown here. These natural processes work slowly, compared to the rapid rate at which humans are moving carbon into the atmosphere by burning fossil fuels. Natural carbon removal can't keep pace, so the concentration of CO_2 in the atmosphere is increasing.

2.5.3 Carbon Equivalence of Fuel

Lal (2004) used data from literature to convert into carbon equivalence (CE) by using emission factors for a wide range of fuel sources. Although conversion coefficients vary within a fuel source (e.g., different type of coal have different conversion coefficient), an average value was used for implication. Similarly, diverse energy units used in the literature were converted to CE using the conversion factors given in Table 2.6.

Table 2.6 Carbon equivalence of fuel

Fuel sources	Unit kg C per	Value	
		West, T. O. & Marland, G. (2002)	Lal R. (2004)
Diesel	kg	0.94	0.94
Gasoline	kg	0.93	0.85
LPG	kg	-	0.63

2.5.4 Carbon Equivalence of Electricity

Carbon dioxide emission was calculated from energy cooperation consumption such as coal, water, natural gas, and diesel fuel. Table 2.7 shows the carbon equivalence from the studies in different countries.

Table 2.7 Carbon equivalence of electricity

Sources	Emission value	
	kg CO_2/kWh	kg CE/kWh
EGAT (2009), combine	0.5800	0.1580
Lal R. (2004), combine	-	0.0725
US. Average (DOE and EPA, 1999), combine	0.6082	0.1659
Hinchiranan S.(2009)	0.5057	0.1379

2.6 Methane Emission from Solid Waste Management

CH_4 emission potential was estimated by following two methods: the method proposed by the IPCC and the LandGEM proposed by the U.S. Environmental Protection Agency (EPA). The results obtained from these methods were compared to the results obtained from the disposal sites using the closed flux chamber technique.

2.6.1 Determination of Methane Emission Potential by IPCC Method

This method proposed by the IPCC for estimation of CH_4 emission from disposal sites uses equation (3) for the calculation.The estimate depends on the category of the waste, degradable organic carbon (OC) fraction, and CH_4 gas in the landfill (IPCC ,1996). In the estimation of CH_4 emission potential from the sites using IPCC as the default method, the fraction of biodegradable OC and biodegradable OC readily available for degradation were assumed at 0.12 and 0.77, respectively. CH_4 content in landfill gas was assumed to be 0.55. The fraction of CH_4 that is oxidized to CO_2 was not taken into account, thus the oxidation factor (OX) was assumed to be zero. Solid waste available for anaerobic degradation and CH_4 generation were assumed to be half (50%) of the value used for landfills because the conditions in the landfill are more anaerobic compared with open dumps due to the presence of a top barrier cover that provides favorable conditions for CH_4 production (Chiemchaisri & Visvanathan, 2008).

$$CH_4 \text{ emission (Gg/yr)} = (MSW_T * MSW_F * MCF * MCF * DOC * DOC_F * F * 16/12 – R * (1\text{-}OX) \quad (2.3)$$

where MSW_T = Total amount of waste generated (Gg/year)

MSW_F = Fraction of waste being disposed

MCF = Correction factor of waste fraction that generates methane gas for sanitary landfill and 0.5 for open dumping)

DOC = Fraction of biodegradable organic carbon

DOC_F = Fraction of biodegradable organic carbon that is readily available for degradation

F = Fraction of methane in biogas

OX = Fraction of methane gas that is oxidized to carbon dioxide

2.6.2 Determination of Methane Emission by Landfill Gas Emission Model (LandGEM)

The United State Environmental Protection Agency (EPA) has developed a program called Landfill Gas Emission Model (LandGEM) for the estimation of methane from degradation of solid wastes in the waste disposal site with time (EPA, 1998). The model is based on first-order decay reaction in waste biodegradation and methane generation as shown in Equation 2.4

$$Q = LoR (e\text{-}kc – e\text{-}kt) \quad (2.4)$$

Where Q = Volume of methane gas produced in current year (m^3/year)

Lo = Potential of methane production from solid wastes (m^3/ton)

R = Receiving rate of solid wastes during site operation (ton/year)

k = first-order decay rate constant ($year^{-1}$)

c = Time period from the closure of waste disposal site to present year (year)

t = Time period from the opening of waste disposal site to present year (year)

2.6.3 Determination of Methane Emission Rate by Close Flux Chamber Method

Actual methane emission rate from waste disposal sites was measured in the field using close flux chamber method. The methane flux can then be computed using the following equation 2.5 (Chiemchaisri & Visvanathan, 2008)

$$J = (V/A)dC/dt \tag{2.5}$$

Where J = Methane Flux from the waste disposal site ($mol/m^2.h$)

V = Volume of chamber (m^3)

A = Covered area of chamber (m^2)

dC/dt = Increasing rate of methane gas in chamber ($mol/m^3.h$)

2.7 Waste-to-Energy Strategy

Anaerobic digestion: Anaerobic digestion is one of the most suitable waste-to-energy technologies in which biodegradable portion of the wastes i.e. organic matter is treated anaerobically or degraded through bacterial action in the absence of oxygen so that the organic matter is broken down into CH_4 and CO_2 known as biogas. For this the organic material is placed in large airtight tanks known as digesters, and operated under certain conditions to produce biogas and is captured and burnt directly in thermal applications to generate heat and electricity (Agamuthu & Hansen, 2007). The remaining non-biodegradable wastes are then disposed of at sanitary landfills if they are safe enough or non-hazardous. This technology is complicated compared to aerobic composting. However, it can contribute a lot to reduce the wastes load to be disposed of at the sanitary landfills as well as to reduce methane emission as there is high opportunity of methane recovery. In addition, it also removes the odor and minimizes the pollution potential of the wastes.

Composting: In this strategy, the organic wastes can be biologically treated in a composting plant in which aerobic bacteria and other microorganisms decompose the organic matter in the wastes into sanitary, nuisance-free, and a humus like material known as compost, which is used as soil conditioner. The composting process requires carefully segregated wastes to avoid glass, plastics and heavy metal residues in the end product. Sites range from small community-based composting units to large centralized plants and windrow composting. In addition, it also produces biogas, which can be converted to electricity.

Incineration/gasification: The combustible portion of the wastes is incinerated to produce heat for the production of electricity. This is another appropriate waste-to-energy technology. Thus produced electricity is used in factories. From this technology, fuel gases and refuse derived fuel (RDF) can also be generated as byproducts. Figure 2.9 illustrates the numerous conversion routes for MSW to energy.

Landfill gas-to-energy: Disposal of wastes to a landfill is the final resort when no other wastes management option is available. In many countries, disposal of wastes to landfill continues to be the pre-dominant wastes management option. In Southeast Asian region, where in most cases leachate and landfill gas treatment is not in place and aftercare considerations are if at all neglected, dumping of wastes in a non-engineered landfill (or open dumping in many places) is the only option for final waste disposal (Ranaweera et al, 2001) and are the ultimate repository of a city's MSW after all other MSWM options have been exercised (Centre for Environmental Studies, 2002).

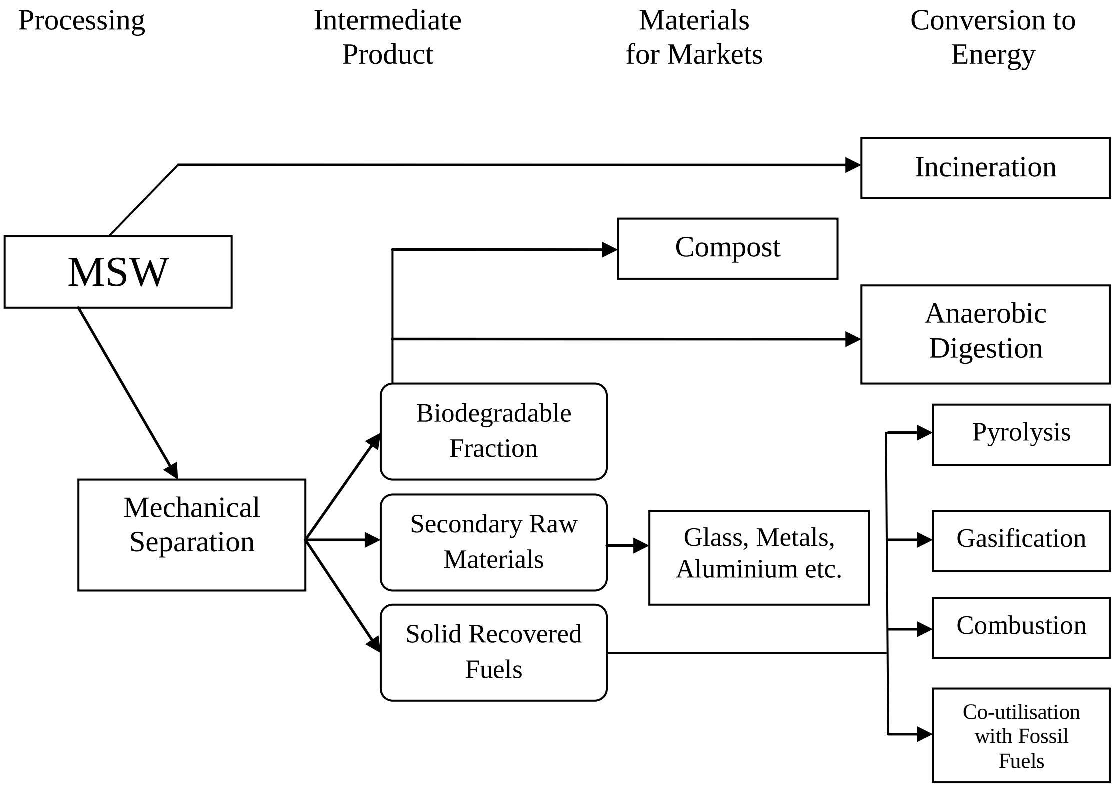

Figure 2.9 Pathways for MSW treatment for recovery and recycling processes (IEA, 2003)

Landfills are designed to be anaerobic, meaning that once waste has been dumped, very little air remains below the surface. Landfill gas is generated as a byproduct of the digestion of organic materials by organisms that thrive in these anaerobic conditions. Food, waste, paper, grass, and other organic matter is readily digested and turned into landfill gas, which is 50% methane (Californians Against Waste, 2006).

Gases found in landfill include ammonia (NH_3), carbon dioxide (CO_2), carbon monoxide (CO), hydrogen (H_2), hydrogen sulfide (H_2S), methane (CH_4), nitrogen (N_2), and oxygen (O_2). Methane and carbon dioxide are the major principal gases produced from anaerobic decomposition of the biodegradable organic waste components in municipal solid waste. Typically landfill gas is composed of 45-60% CH_4 and 40-50% CO_2 (Chomsurin, 1997). These gases are the byproducts of various types of reactions undertaking inside the landfills. Among all, the most important reaction is the one that involves the organic MSW, which leads to the evolution of methane under anaerobic condition (Equation 2.6).

$$\text{Organic matter} + H_20 \xrightarrow{\text{bacteria}} \underset{\text{(Organic matter)}}{\text{Biodegraded}} + CH_4 + CO_2 + \text{Other gases} \qquad (2.6)$$

Landfill gas is highly flammable and posed a risk of explosion if not properly managed and play a vital role in increasing global warming problem if exposed freely in the atmosphere. But it can be a very good resource if managed and utilized properly such as production of electricity and biogas fuel i.e. landfill gas-to-energy.

Methane (often called as landfill gas) can be recovered from existing as well as future landfills, since organic materials in dumps and landfills continue to emit CH_4 for 10-30 years or more. Frequently more than half of the CH_4 can be recovered and used for heat or electricity generation, a practice already common in many countries. Thus obtained landfill gas can be purified and injected into a natural gas pipeline or distribution system. In some countries such as Brazil, purified landfill gas has been used to provide power for a fleet of garbage trucks and taxicabs (IPCC, 1996).

For the generation of electricity from landfill gas, methane is combusted in generators and a bulk of electricity is produced, which can be sold to electricity grid or utilized on-site for various purposes such as operating leachate treatment facility; and running lights and fans in maintenance workshops. The excess gas can be flared. Flaring is needed during the periods of engine maintenance or low demand for electricity (EcoSecurities, 2004). A typical flow chart for landfill gas-to-energy, which has been applying in Brazil is presented in Figure 2.10.

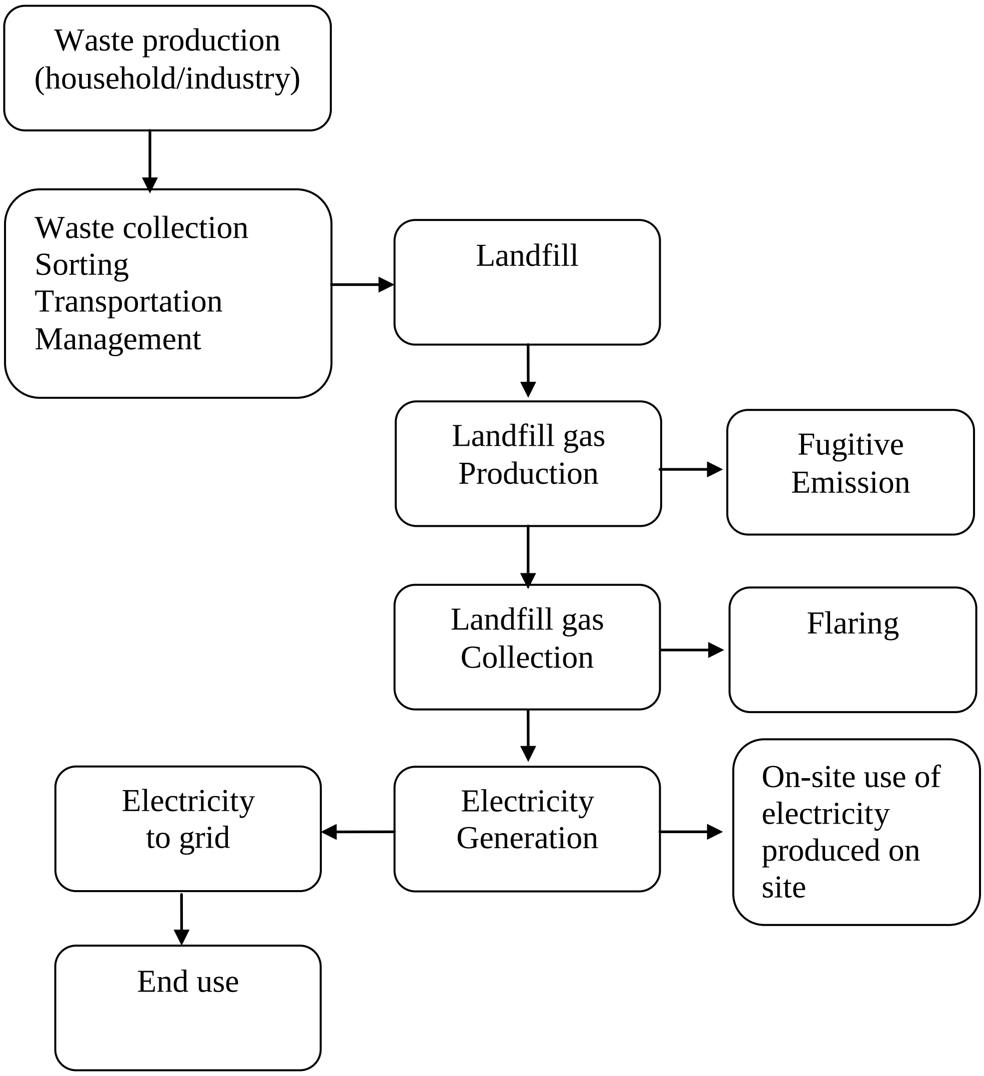

Figure 2.10 Flow chart for landfill gas-to-energy project (Ecosecurities, 2004)