APPLICATION OF 3R PRINCIPLES TO SOLID WASTE MANAGEMENT ON THE ASIAN INSTITUTE OF TECHNOLOGY (AIT) CAMPUS

by

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Abstract

The research work was aimed at proposing a 3R programme at AIT to solve the current solid waste problems. The solid waste audit conducted in AIT showed that 700 tons/year of solid waste was generated and the per capita of solid waste was about 0.5 kg/day. The percentage composition of organic and inorganic solid waste was 60% and 40% respectively. The audit study also showed that 93% of the solid waste in AIT is disposed in the landfill, 4% of solid waste is recycled and 3% of solid waste is gardening waste that is composted inside the AIT campus. The chemical analysis of the solid waste at AIT showed that the carbon and nitrogen content of the waste were very high, but due to a low C/N ratio, the solid waste cannot be composted and used in the production of manure. The moisture content of the wastes was also as high as 68% that shows a high rate of organic degradation of the solid waste at AIT. Thus, the calorific value of the solid waste at AIT was also as high as 16.39 MJ/kg. The high calorific value of the solid waste at AIT indicated that the solid waste was suitable for use as RDF. The study of the formal and informal sectors in the Tha Kong Municipality showed that the amount of solid waste recycled was 44% and the amount of solid waste disposed in the landfill was 56%. The BCA showed that there was a benefit in the recycling activities in the Tha Kong Municipality. However, the BCA showed that there was no benefit in the recycling activities in AIT. The physical analysis of the solid waste showed that 25.1% of the total solid waste generated was plastic, which showed that there is a lack of awareness in solid waste management at AIT. Hence, awareness programmes in solid waste management are necessary at AIT.

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List of Abbreviations

AIT	Asian Institute of Technology
BCA	Benefit-Cost Analysis
BMA	Bangkok Metropolitan Area
C	Carbon
CH_4	Methane
Cl	Chlorine
CO	Carbon Monoxide
CO_2	Carbon Dioxide
Cu	Copper
EEM	Environmental Engineering and Management
GRO	Government Relations Office
H	Hydrogen
H_2O	Water
HCl	Hydrogen Chloride
HCS	Hauled Container Systems
HDPE	High-Density Polyethylene
LDPE	Low-Density Polyethylene
MC	Moisture Content
MJ	Million Joule
MSW	Municipal Solid Wastes
MSWM	Municipal Solid Waste Management
N	Nitrogen
NEA	National Energy Administration
NH_3	Ammonia
O	Oxygen
Pb	Lead
pH	Potential Hydrogen
PE	Polyethylene
PP	Polypropylene
PS	Polystyrene
PVC	Polyvinyl Chloride
%	Percent
3R	Reduce, Reuse, Recycle
RDF	Refuse-Derived Fuel
RWB	Recyclable Waste Buyers
S	Sulphur
SAO	Student Accomodation Office
SCS	Stationary Container Systems
SCE	School of Civil Engineering
SERD	School of Environment, Resources and Development
SET	School of Engineering Technologies
SLF	Sanitary Landfill
SO_2	Sulphur Dioxide
SO_3	Sulphur Trioxide
SOM	School of Management
SS	Suspended Solids
SWM	Solid Waste Management
SU	Student Union

TS	Total Solids
VS	Volatile Solids
USEPA	United States Environmental Protection Agency

Chapter 1

Introduction

1.1 General

The Asian Institute of Technology (AIT) located in the Pathumthani Province of Thailand, is one of the most reputed institutes in Thailand with an average population of about 3,800 (Soulalay, 2006). One of the major problems faced by AIT is the need for proper disposal of hundreds of tons of solid waste generated every year. Solid waste contains inherent valuable materials such as paper, glass, plastics, metals, rubber and textiles, etc.

The problem of solid waste management in AIT has become more and more complex with increasing environmental concern. Solid waste management is a comprehensive task that consists of the main functional elements such as:

1. Generation
2. Storage
3. Collection
4. Transportation
5. Processing, resource recovery and recycling and
6. Disposal

The major objectives of solid waste management are resource conservation and protection of the environment. Safe disposal of solid wastes at a minimum cost is very much required in this connection. Optimization of the system and eventually the total cost of solid waste management should be achieved.

1.2 Statement of the Problem

The biggest problem AIT faces is the mismanagement of the large amounts of solid waste generated. There is a lack of a proper recycling system in AIT at present. There is also an odour problem caused from the garbage bins, due to improper storage and irregular collection of wastes. This has become a nuisance to the AIT community, because of odour problems, which results in pathogens and a lot of mosquitoes in the surroundings.

There is also a problem caused by the location of the waste recycling bank located inside the campus near the Student Villages and the Student Dormitories. People often complain about the odour problems related to this. Hence, the site selection of the waste recycling bank and other disposal facilities must be taken into consideration by the Department of Infrastructure of AIT, who take care of the solid waste in AIT.

The Tha Kong Municipality has great difficulties in trying to define their actual solid waste management costs. They do not have a proper detailed cost accounting in place. When solid waste management systems based on user fees are in place, often the fees barely cover costs of collection and transport leaving practically no financial resources for the safe disposal of waste.

Therefore, the municipal authorities find it difficult to find a solution for the disposal of solid wastes. They then start looking at waste treatment methods like composting or incineration to eliminate their problems. These waste treatment methods do not eliminate the need of a disposal site. The municipal authorities have a difficult task in finding an ideal site, planning and designing a new landfill because it is a lengthy and costly affair (Zurbrügg, 2002)**.**

Hence, the need for the 3R concept arises and this can be a priority solution to this serious problem. The 3Rs are basically: Reduce, Recycle and Reuse. Recycling can provide an opportunity to recover some of these valuable substances from solid waste, particularly in the form of long-term energy and resource conservation. Recycling both conserves and uses energy, materials and products. If it conserves more than it uses, it may save materials, money and environmental degradation.

1.3 Objectives of the study

The objectives of the study are indicated as follows:

1. To conduct a solid waste audit study in AIT using a mass balance diagram.

2. To study the physical and chemical properties of solid waste collected from the various locations in the AIT campus.

3. To perform a technical feasibility study on the solid waste management of the AIT campus.

4. To study the options for solid waste reduction, reuse and recycling in the AIT campus.

1.4 Scope of the Study

The scope of the study is indicated as follows:

1. Analysis of physical components, including combustibles, non-combustibles, miscellaneous categories, moisture content and bulk density. The analysis of chemical composition (element composition such as C, H, N, S, Cl, O), constituent moisture, ash and combustible content as well as calorific values is also carried out.

2. Among the recycling materials, paper, glass, plastics and metals are evaluated for recycling and reuse processes. The market potential of secondary materials is also studied from the collection crew to the traders.

3. To determine the mass or material balance of solid wastes in AIT campus with the help of a solid waste audit study. In this way, the improvement of the existing situation of the solid waste management in AIT can be planned out.

4. The research identifies and analyzes the specific aspects of recycling activites by the formal and informal sectors in the Tha Kong municipality with respect to AIT such as:

   a) The administrative approaches such as various enterprises and market mechanisms.
   b) The quality and quantity of the recycled wastes produced by these sectors.
   c) The role of the formal and informal sectors in waste recycling.

Chapter 2

Literature Review

2.1 Solid Waste

2.1.1 Definition of Solid Waste and Function

“Waste” is a material discharged and discarded as unnecessary from each stage of daily human life activities, which leads to adverse impacts on human health and the environment. The word “waste” refers to useless, unused, unwanted, or discarded materials.

Municipal solid wastes are the wastes from residential, commercial, institutional, construction and demolition, municipal services including the wastes from treatment plant sites (e.g. sludge from wastewater treatment plants) and municipal incinerators. Industrial process wastes and agricultural wastes are excluded from MSW.

MSW compositions can be divided into three types: organic wastes (combustible wastes, plastic, wood, paper, textile, leather, rubber, etc.), inorganic wastes (non-combustible wastes, ferrous material, non-ferrous material, glass, stone, ceramic, bones, shells, etc.) and miscellaneous wastes. MSW compositions vary based on the location, season, economic condition and social life styles of a particular place.

Management can be defined as the judicious use of a means to achieve an end. “An end” is the removal of the rejected material from the material flow pattern. It was generally accepted that the cost of solid waste management was the number of dollars required to eliminate the rejected material from the material flow pattern. If this could be accomplished by dumping it in a used gravel pit, hauling it to the sea, volatilizing it into the atmosphere, or whatever, that was the minimum cost. The source of solid waste can be classified into five categories as follows:

1. Domestic/Residential Solid Waste

- Garbage, consists of results from food marketing, preparation, and consumption in relationship to residential units. It contains putrescible organic material that needs special consideration due to its nature of attracting vermin (rats and flies) and of producing very strong odours.
- Rubbish/trash consists of paper and paper products, plastics, cans, bottles, glass, metals, ceramics, dirt, dust, yard and garden wastes, and the like. Except for the yard and garden wastes, these materials are non-putrescible.
- Ash is the residue from combustion processes resulting from household activities.
- Bulking wastes include furniture, appliances, mattresses, and springs, and similar large items.

2. Commercial and Institutional Solid Waste

This category consists of the waste that originates from offices, retail stores, restaurants, schools, hospitals, and so on. Moreover, there are two additional categories, which are construction and demolition wastes, and special wastes. The former includes the materials associated with the demolition of old buildings and the construction of new buildings. The latter is the wastes that are generated by special facilities such as hospitals and research laboratories.

3. Municipal Solid Waste

This category includes the solid residues, that results from the municipal functions and services such as the street refuse, dead animals, abandoned vehicles, water and sewage plant residues, park and beach refuse, and landscape waste.

4. Industrial Solid Waste

There are two sources of the refuse generated in the industrial sites: (1) the commercial/institutional part of the plant and (2) the manufacturing process. The quantity and characteristics of the wastes from these two sources are considerably different.

5. Agricultural Residues

This residue will be indicated only in the problem of the rural areas because agriculture poses the significant and unique problems. The wastes are from confined animal feeding and crop residues.

2.1.2 Types of Solid Waste

As a basis for subsequent discussions it will be helpful to define the various types of solid wastes that are generated. It is important to be aware that the definitions of solid waste terms and the classifications vary greatly both in the literature and in the profession. Consequently, the use of published data requires considerable care, judgment, and common sense (see Figure 2.1).

2.1.3 Integrated Solid Waste Management System

Integrated solid waste management is the term applied to all of the activities associated with the management of society's waste. The basic goal of ISWM is to manage the society's waste in a manner that meets public health and environmental concerns and the public's desire to reuse and recycle waste materials. Tchobanoglous et al. (1993) suggested a classical simplified diagram showing the inter-relationship of these functional elements in a solid waste management system. The diagram of such linkage of all elements is illustrated in Figure 2.2.

Generally, the municipality is responsible for the collection and the disposal of solid wastes. Open dumping is the basic MSW disposal practice for many municipalities because there is no need to invest in engineering designs, construction facilities or in technical operations. Open dumps require a large land area for dumping MSW and for the degradation of solid wastes under natural conditions. Environmental impacts from open dumps are leachate contamination to subsurface and groundwaters, landfill gas emission (e.g. CH_4 and CO_2) and breeding of disease vectors. Some open dump sites are burned in order to reduce the amount of MSW for saving land area, resulting in air pollution. Hence, it is better to recover some of the materials, recycle and reuse them for long-term benefits in costs as well as the environment.

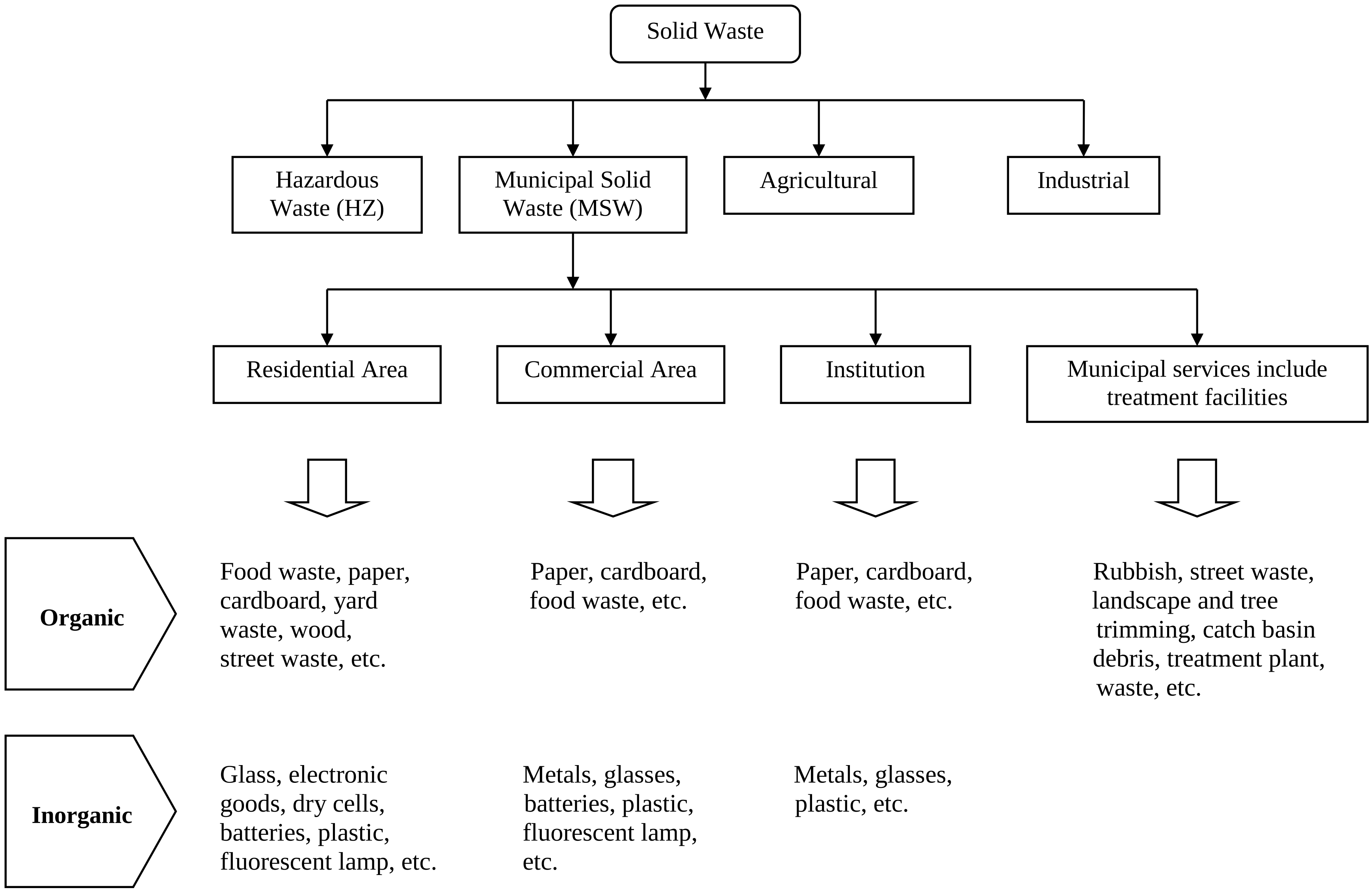


Figure 2.1 The Structure of Solid Waste Classified by Sources and Types

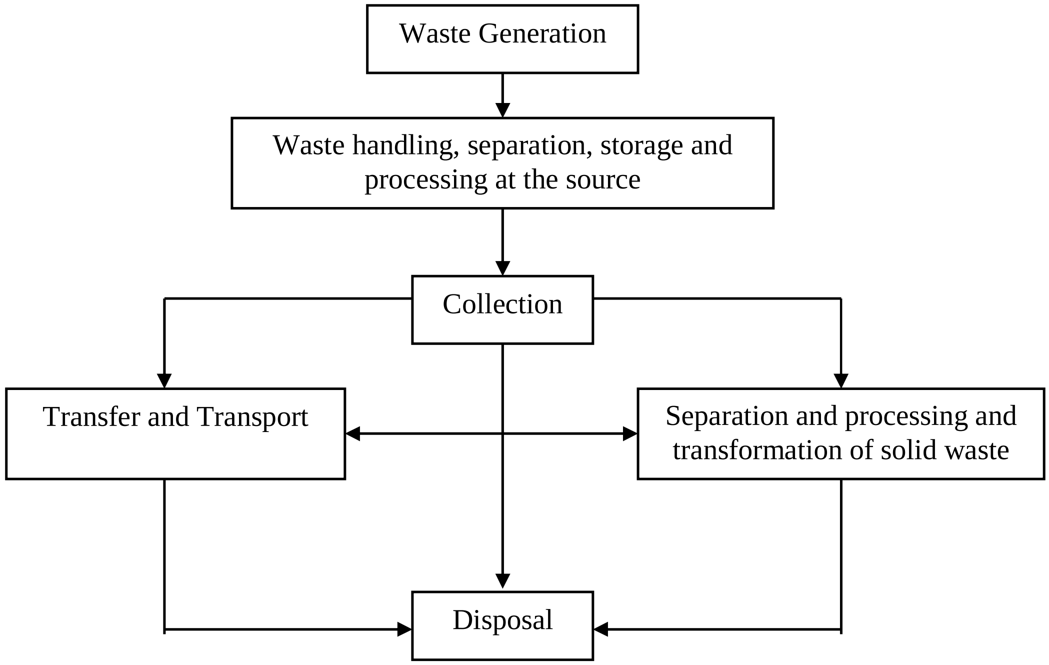


Figure 2.2 Functional Elements of Solid Waste Management Systems

2.1.4 Sources of Solid Waste

Municipal solid waste includes all the waste produced in the community except industrial and agricultural wastes. The source of waste is related to land use and zoning. The most important segments can be classified such as residential, commercial, institutional, construction, demolition, industrial, treatment plants and the agricultural sectors. A wide range of solid waste generating facilities, activities, and the locations is given in Table 2.1, where MSW is normally assumed to include all community wastes with the exception of industrial process wastes and agricultural wastes.

Plastic wastes can be a part of each type of waste sources and the quantity may vary according to the utilization. Table 2.1 shows the major sources of plastic scraps, bags, bottles etc., scattered around the environment due to mismanagement and littering.

2.2 Composition and Characteristics of Solid Waste

Generally, there are physical and chemical characteristics in municipal solid waste. Composition is the term used to describe the individual components that make up a solid waste stream and their relative distribution, usually based on percentage by weight. Knowledge of the physical and chemical composition of the solid waste is important to enable one to assess what type of disposal method is to be carried out, especially with plastics, which are originally non-biodegradable in nature. Solid waste is a heterogeneous mixture of wastes.

Table 2.1 Sources of Solid Wastes within a Community

Source	Typical facilities, activities or locations where wastes are generated	Types of solid wastes
Residential	Single family and multifamily detached dwellings, low, medium and high rise apartments, etc.	Food wastes, paper, cardboard, plastic, textile, leather, yard waste, wood, glass, tin cans, aluminium, other metals, ashes, including bulky items, consumer electronics, white goods, yard wastes collected separately, batteries, oil and tires, rubber, household hazardous wastes
Commercial	Stores, restaurants, markets, offices, buildings, hotel, print shops, service stations, auto repair shops, etc	Paper, cardboard, plastic, wood, food waste, glass, metals, hazardous wastes, etc
Institutional	Schools, restaurants, markets, offices, buildings, hotel, print shops, service stations, auto repair shops, etc	As above in commercial
Construction and Demolition	Schools, hospitals, prison, government centers, etc.	Wood, steel, concrete, dirt, plastic, etc
Municipal services (excluding treatment facilities)	Street cleaning, landscaping, catch basin, parks and beaches, other recreational areas	Special wastes, rubbish, street sweepings, landscapes, and tree trimmings, catch basin debris, general waste from parks, beaches and recreational areas
Treatment plant sites municipal solid wastes	Water, wastewater and industrial treatment processes, etc	Treatment plant wastes, principally composed of residual sludge
Municipal solid waste	All of the above	All of the above
Industrial wastes	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, and hazardous wastes
Agricultural	Field and row crops, orchards, vineyards, dairies, feedlots, farms, etc	Spoiled food wastes, agricultural wastes, rubbish and hazardous wastes

The common composition in physical characteristics are food wastes, paper, cardboard, plastics, textiles, rubber, leather, garden trimmings, wood, glass, tin cans, non-ferrous metals, ferrous metals, dirt, ashes and birches, etc. The average physical and chemical composition of the waste varies from place to place depending upon the type of waste, economy, climate, social and cultural activities etc.

Information on chemical characteristics of solid wastes is important for evaluating alternative processing and recovery processes. The most important characteristics are:

1. Proximate analysis:
   - Moisture (loss at 105^0C for one hour)
   - Volatile matter (additional loss on ignition at 950^0C)
   - Ash (residue after burning)
   - Fixed carbon (remainder)
2. Fusing point of ash
3. Ultimate analysis: percent of C (carbon), H (hydrogen), O (oxygen), N (nitrogen), S (sulphur) and ash
4. Energy Content (low and high calorific value) (Joules)

Besides the above analysis, other chemical analysis methods are also performed depending upon its requirement, such as investigating water pollution potentials for sanitary landfills and air pollution potentials for incinerator operations, chemical recovery and designing incinerators and other components.

Information on the composition of solid waste is important in evaluating alternative equipment needs, system and management programmes and plans. Information and data on the physical composition of solid wastes are important in the selection and operation of equipment facilities, in assessing the feasibility of resource and energy recovery, and in the analysis and design of disposal facilities. Physical and chemical composition of each type of waste contributes major part in designing disposal facilities because some wastes cannot be treated as compared to other wastes.

The composting method is employed mainly for disposal of organic wastes. Based on the composition, nature, the components of solid waste are categorized as organic and inorganic. The composting materials include garbage, grass, straw and paper.

2.2.1 Density

Density is defined as the mass per unit volume of any substance. Density data are often required to obtain the mass and volume of waste that must be managed. Municipal solid wastes delivered in the compaction vehicles usually vary from 120 to 280 kg/m^3. The density of solid waste is determined for transportation and other purposes. It should be noted that density values are different between compacted and un-compacted refuse.

2.2.2 Moisture Content

Moisture content usually is expressed as the percentage weight of moisture per unit weight of wet or dry material. For the wet-weight moisture content, it can be expressed as:

$$\text{Moisture content (\%)} = (a - b) \times 100/a$$

Where, a = initial weight of sample as delivered; b = weight of sample after drying

For most municipal solid wastes, the moisture content will vary from 15 to 40% depending on the composition of the wastes, season of the year, humidity and weather conditions, particularly rain.

Moisture content is important because it affects the stability of the combustion process and combustion efficiency during cold starts of an incinerator as well as for composting and other processes. For composting processes, the moisture content is maintained between 50 to 60% throughout the process for desirable conditions.

2.2.3 Volatile Solids and Ash Content

Dried samples are gradually heated to 650^0C (950^0C is also used for better results) for 2 hours in a muffle furnace and the percentage of volatile solids is calculated as follows:

$$\text{Volatile Solid (\%)} = 100 \times \text{(loss in weight)/(net dry weight)}$$

This value states the approximate percentage of organic matter present in the material. The value for percent ash is 100 minus percent solids. This value is important to determine the percent in volume reduction and ash content for incinerator design and to evaluate the efficiency of the incinerator.

2.2.4 Calorific Value

The term “heat of combustion or calorific value” refers to the amount of heat liberated per unit of the substance burned or a measure of the energy available from the fuel in a standard condition. This process involves enthalpy or heat content (H) of the system. The heat of combustion is expressed for this study in calories per gram of sample.

The heat content of various solid waste materials is important in the volume reduction process used to dispose of the waste. For example, measuring the energy balance and analyzing heat content of the solid waste before and after incineration is essential for incinerator design and disposal of the waste.

Stability of the waste product is a function of their heat content. Not all solid waste samples with similar total heat contents (enthalpies, or heat of combustion values) are similarly ignitable and combustible. The readily available heat content of a solid waste sample or its potential heat could be an important aspect in evaluating the efficiency of an incinerator or for measuring the usefulness of incinerator residue.

Potential heat is defined as the difference between the heat of combustion of a represented sample of the materials and the heat of combustion of any residue remaining after exposure to a simulated standard fire, using combustion calorimetric techniques.

Some incinerator residue and fly ash samples have negative potential heat values. Such samples are high in carbonates, which absorb heat upon decomposing (endothermic reaction). Analysts can obtain the residual heat content of the sample by deducting the potential heat in the total heat content. The residual heat content in a residue or fly ash sample is not easily obtainable and would probably exist regardless of the incinerator efficiency.

The condition for a standard fire cannot be simulated when dealing with incinerators since a combustion aid is employed for the total heat of combustion values. Solid waste is ignited and burnt to completion and can be measured by applying the same calorimetric technique except omitting the combustion aid allowing oily flash heat of ignition to ignite the sample. The approximate Btu value of solid waste can be calculated by using the following equation:

$$\text{Btu/lb} = 145.4 \times C + 620 \times (H - 1/8 \times O) + 41 \times S$$

Where C = carbon (%), H = hydrogen (%), O = oxygen (%) and S = sulphur (%).

2.3 Solid Waste Management Systems

There are six functional elements that constitute the SWM system, which are listed as follows:

- Waste generation
- Storage
- Collection
- Transfer and transport
- Reduce, reuse, recycling and recovery
- Disposal

2.3.1 Waste Generation

Waste generation includes 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 attitudes

Solid wastes from residential sources vary considerably in composition of quality. The variations depend on the economic status, ethnic composition and social habits of people living in a particular area, e.g. backyard burning of waste etc. The quantities of waste also varies with the seasons, the geographical characteristics of the land, rainfall, climate, the choice of consumer goods and the habits of the people, for e.g. what they eat, drink and the packaging/packaged material they buy.

Nowadays, in many parts of the world, plastic is the major material used in many products. Not only as a packing material but also as a means of carrying of products, plastic bags become unavoidable in everyday life. Because of many advantages that plastics have compared to others such as paper, metals, rubber, etc., the use of plastic material is increasing in every sector of civilization, resulting in the generation of plastic wastes.

2.3.2 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.

Haan (1998) suggested that in Asian countries, the various communal storage options like depots, enclosures, fixed store bins, concrete pipe sections and 200 litre drums; the last one is used frequently with reasonable success under the management of local authorities.

The following factors are considered in the on-site storage of solid waste such as:

- 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, depends 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.

2.3.3 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 systems at present are classified according to the type of operation into categories: Hauled Container Systems (HCS) and 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 stations 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 a hand cart or an animal cart. When full, the primary collection vehicle is emptied directly into a large motor vehicle.

The collection frequency depends on the characteristic of wastes, climate, container size, activities of the people, etc. Problems of plastic can also be found 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.

2.3.4 Transfer and Transportation

The definition of transfer and transport refers to the means, facilities and appurtenances used to affect the transfer of wastes from small vehicles to large vehicles, and transport them over extended distances to either processing centres 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 developing countries. A high proportion of vehicle operating time is spent on transporting wastes to the disposal sites due to traffic and road conditions and a small payload. For overcoming such a situation, transfer stations should be introduced and the decision should hinge upon economics, the total cost of collection, direct haul and disposal.

2.3.5 Reduce, Reuse, Recycling and Recovery

Different researchers have highlighted the importance of reuse and recycling. Recovery or resource recovery is the extraction of economically usable material or energy from solid wastes. Reuse is the claim of material in form and its subsequent use in the same form, for e.g. returnable bottles.

Recycling is more possible in developed countries, where settleable constituents comprise a higher fraction of collected wastes, wages are often too high to permit recovery, sorting and processing of these materials to be carried out profitably. In this case, private scavenging of solid wastes plays a vital role in the recycling process.

Fudery (1990) defined that resource recovery/recycling is different between developed and developing countries. In 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 reusing and recycling other materials, reusing and recycling of plastic materials also has benefits such as resource recovery and improvement of aesthetic qualities.

2.3.6 Processing and Treatment

Processing and treatment is a technique to improve efficiency of SWM systems and to recover resources whether it is a usable material conversion product or energy. There are various methods for treatment out of which incineration and composting are most widely used. By incineration, volume of waste to be disposed is reduced, whereas, by composting of wastes, organic soil substitutes can be recovered. Final disposal of each type of waste is one of the most important 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 a lot more complicated.

2.3.7 Disposal-Sanitary Landfill Method

A landfill is an inelegant biological reactor, in which the wastes decompose over time. It is the most significant and cheapest method for final disposal of municipal waste. It is simple to operate and can be used for land reclamation by filling the low lands with waste. Most of the world's solid wastes are disposed in the landfills, which is the main method of disposal in developing countries. Although landfilling may be the most attractive method for final disposal, non-biodegradable materials like plastics may take a very long time to degrade. Therefore, plastics may remain unchanged, while other wastes may decompose over time.

2.4 Role of the Informal and Formal Sectors in Municipal Solid Waste Management

Amin (1996) defined that the formal sectors are the enterprises, which enjoy official recognition, protection and support. The informal sector is the sector that operates in an unregistered, unregulated or casual activities, including individual and family enterprises. The term "private sector, private enterprise or private firm" can be used to refer to both formal and informal sectors.

Amin (1992) concluded that three broad approaches to define the informal sector are noticeable in which: (a) people, (b) activities, or (c) habitats are in focus.

As mentioned by Amin (1992), the informal sector is involved in the following manners:

- Through the role of mobile hawkers (good buying door-to-door)
- Through the small sector manufacturing shops
- Through the small sector manufacturing enterprises
- Through the waste pickers
- By improving casual labour to the junk-dealers in collecting, handling, sorting
- By providing labour to the local governments for its own share of garbage collection and disposal

Poerbo (1996) stated that in the informal sector approach, urban waste is viewed as an economic resource, which has multiple results such as:

- Reduction of waste
- Reduction in public expenditures for waste management
- Employment generation

Haan et al., (1998) pointed out that besides the large-scale private sector which is mostly involved in the reprocessing of waste materials into intermediate materials or products), many small-scale entrepreneurs are active in recycling. In general, the small-scale private sector consists of two groups: (1) individuals and families, performing activities which provide them with just enough income to live on, and (2) micro-scale enterprises, operating in much the same way as their larger counterparts, but not always officially registered.

Amin (2000) summarized the role of the informal sector in SWM that it is actively participating in resource recovery, recycling and reducing the amount of wastes to be finally disposed of (i.e., at transfer stations, dump sites, and landfills). The significance of the informal sector in SWM is self-developed by income-earning motivation. Its performance is not stable under market-driven mechanisms. The informal sector, however, still works in conjunction with the public and the formal private sector. Romaos and Chifos (1996) stated the role of the informal sector in SWM as shown in Table 2.2.

Informal sectors are driven to collect solid wastes because of economic constraints they face and for employment possibilities. The formal sector, on the other hand, is involved in the regular waste business and is fully legalized and registered. In Thailand, the total quantity of wastes collected at the source by the waste pickers is about 286 tons, and 5% of the garbage originates from the cities. The scavengers sell the sorted waste components to small-scale recycling shops located around the disposal sites. The quantity of materials received by these shops varies between 1 – 6 tons per day (Muttamara et al., 1994).

Table 2.2 Role of the Informal Sector in SWM

Category	**Method of Work**	**Material**
Street pickers	Recovery	Bottle caps, bottles
Itinerant hawker (announced collector)	Go from door to door	Paper material, kitchen utensils, glassware
Dealers, neighbourhood dealers or buyers	Buying	Metal, iron, steel, sheet, car spares
Small-scale entrepreneurs	Buying	Pipe material, metal-based iron, scrap
Large-scale entrepreneurs	Large-scale processing technology	Raw material, iron scraps

2.4.1 Involvement of Private Sectors

There are many different social groups involved in the waste recycling process, the householders, the street scavengers, the waste collectors, the dump site scavengers and the middle men. People engaged in waste recycling can play an important role in the existing solid waste management system of the leading educational institutes in developing countries. According to HABITAT (1992), several tens of thousands of people (up to 1 to 2% of Thailand's population) make a living in the recycling process.

Scavenging is practiced to a high degree in developing countries and scavengers perform efficiently as soon as collectors empty their loads at the disposal sites. The waste materials are picked by garbage collectors and other workers during the collection stage, the collected materials are sold to the middlemen.

Lohani (1984) indicated that existing scavenging practices provide employment for new arrivals and household incomes ranging from base survival in materials recovery. The trader who buys secondary materials from scavengers and sells to the wholesaler is known as the middleman, who further sells it to the manufacturer. The middlemen make large profits from the scavengers. If the system is controlled to avoid middlemen cheating these hard workers, organized scavenging would be a very prosperous livelihood for many people, an economic gain for the city and an achievement in the field of solid waste management.

With regard to separation of wastes at the source, taking into account the needs of the scavengers at the lowest level, would mean more employment for scavengers, reduction of costs for collection and disposal, an additional source of income to households, reduction of import of expensive raw materials from abroad, better living conditions for scavengers and elimination of illegal street scavenging. Solid waste disposal operations currently absorb 30 to 50% of municipal operating budgets and the services provided may only cover the collection of a fraction of the wastes generated.

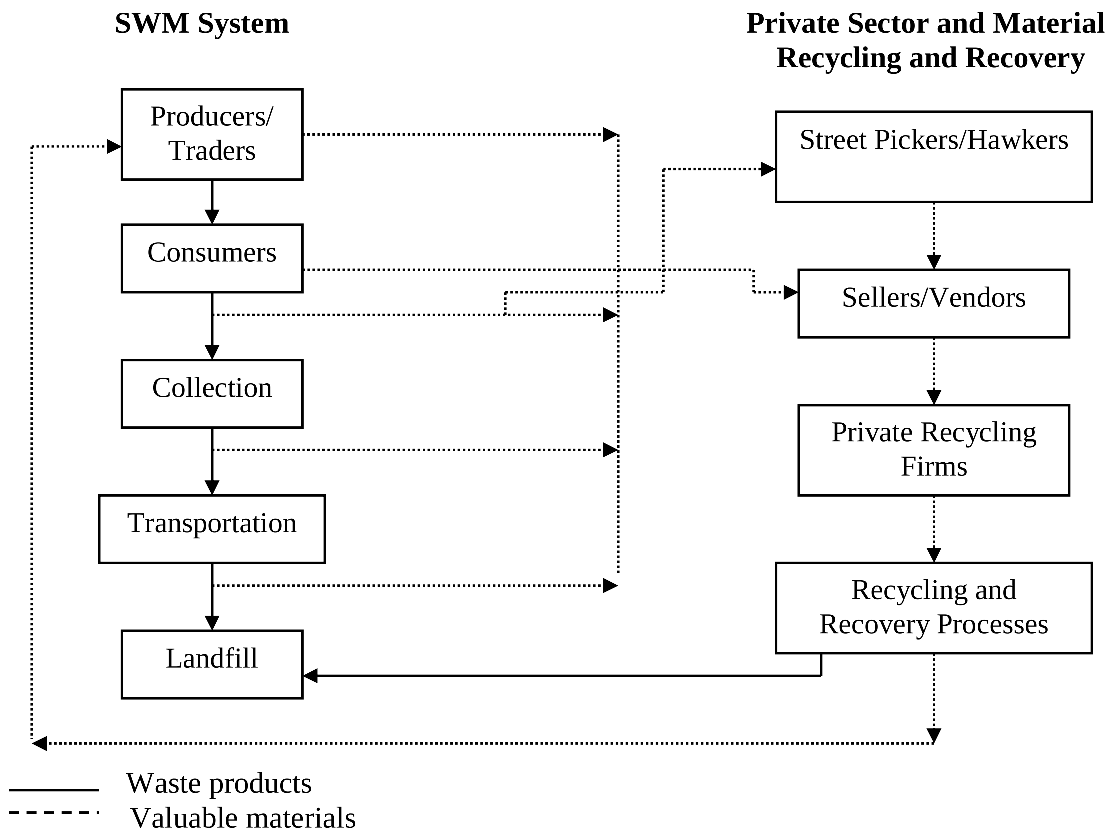


Figure 2.3 Linkage between Solid Waste Management System and the Private Sector (Suwarnarat, 1996)

2.5 Definition of the 3Rs

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 (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 term “Reuse” has been employed to convey the meaning such as, further use or to use again. For the study purpose “Recycling” is considered for utilizing one or more of the components from discarded or waste material and “Reuse” is used for further use or to use again and again of material without going into its original manufacturing process.

There are many ways of defining the meaning of reuse and recycling according to the practices and perceptions. The following are the concepts by Sykes (1978) and Lund (2001):

1. Reuse of a product, without alteration, to serve the purpose for which it was initially intended (e.g. refilling soft drink bottles).

2. 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).

3. Reprocessing of materials incorporated in a product to produce new products of the same type (e.g. using crushed glass bottles to manufacture new glass bottles).

4. Reprocessing of materials incorporated in a product to produce new products of a different type (e.g., using worn out rubber tires in the production of road surfacing material).

2.5.1 Importance and Benefits of Recycling and Reuse

"Recycle" and "Reuse" is the key element of an integrated waste management system. Recycling and reusing materials reduces the flow of materials into the solid waste stream and hence reduces the costs associated with the collection and disposal etc.

The importance and benefits of recycling and reusing are listed as follows:

- Conservation of natural resources by utilizing waste energy.
- It improves the environment from negative impacts of solid waste dumping by reducing the amount of solid wastes.
- The use of recycled materials appears to result in a reduction in energy consumption and pollution compared with the use of virgin materials.
- Benefits on public utilities such as affordable market prices for recycled materials.
- Reduces medical expenses from possible negative impact of dumping and less pollution emission.
- Helps to establish industries of secondary materials.
- Generate income to the society because of market value of waste materials.
- Facilitate employment opportunities for people in a country like scavengers, junk men, middlemen, etc.
- Reduces the amount of waste that has to be imported, by producing secondary raw materials.
- Economical development from industrial establishments, levy collection, employment generation.

2.5.2 Methods of Recycling

Recycling of materials are conducted by two means:

1) Closed loop, direct or non-sacrificial recycling.
2) Open loop, indirect or sacrificial recycling or new use.

Closed loop method: Here the material is refined back to its virginal specification, it maybe subsequently used for any purpose appropriate to that material specification. For e.g., copper maybe refined by means of electrolysis, before use in electrical applications.

Open loop method: The original materials are treated as the starting point or raw material for another manufacturing process. For e.g. contaminated copper may be used in brass extrusions (Henstock & Biddulph, 1975).

The recovery of materials from waste is very dependent on economic factors. Manufacturing costs from secondary materials are high or often higher than those from virgin materials. Only high quality materials can find a ready maker. Often artificial economic factors have to be favoured (Holmes, 1981).

2.5.3 Recycling Industries

Lohani (1984) illustrated that the recycling industries are a profitable profession. Many companies such as paper mills and glass bottle manufacturers prefer to purchase recycled materials in bulk quantities. According to the BMA (1990), the Glass Organization and paper company operate on a yearly contract for the monthly delivery of a minimum quantity of broken glass and paper. In the case of paper companies, the scrap paper delivered is known as “quota holders” because they have a quota to fulfill, i.e. they have an obligation to deliver a specified quantity monthly.

Among the reusable materials, ferrous metal, paper, glass and plastic are used for recycling processes. Paper products which account for 55% of the total waste stream, are considered as the largest “product group” in municipal solid wastes.

According to the BMA (1990), both formal and informal sections manufacture paper pulp, cardboard box and magazines from the recyclable paper. Recyclable glass or cullet constitutes about 1 – 3% of the general waste stream, which is used to manufacture plain glasses or cups.

Plastics constitute about 10 – 15% of the waste stream. Plastic increases oxidation if used with recycled material. Therefore, casual sorting is essential if these plastics are used as one of the raw materials of granulated plastics.

Pollock (1987) indicated that although metal comprises only about 2% by weight of solid wastes, its relatively high economic value can make it an important component of recycling programmes. Aluminium is the metal taken into consideration here, and the main portion of aluminium in solid wastes consists of aluminium cans, or used beverage containers. Aluminium can recycling has increased during the last few decades because of an increased demand for aluminium, and increases in energy prices (primary aluminium production is very energy-intensive).

Ferrous and non-ferrous metals are increasing in the percentage composition of solid wastes in Thailand. They are valuable resources to be recycled and cannot be treated by composting or incineration. Table 2.3 gives some of the factories using recyclable materials and their benefit/cost ratio of the production. Table 2.3 indicates that the industries with a benefit/cost ratio of 1 or more than 1 are making more profits out of the recycling process.

2.6 Environmental Options for Waste Recycling

According to HABITAT (1992), recycled materials have a lower environmental impact compared to the new products. For instance, the recycling of paper means a lesser demand for wood, which means lesser cutting of trees and a possibility for a sustainable use of the forests. The saving of resources has an important economic advantage since it saves foreign exchange and resources that are generated within the country. An added advantage of recycling is the lesser demand for energy in the production process.

Some analysts assert that more than half of the refuse can be economically recycled and reused, while achieving such high recycling rates require careful refuse handling, effective control of regulations and constant education of citizens. Pollock (1987) pointed out that some valuable resources such as refillable glass bottles, only require a thorough washing before reuse, those bottles are designed for up to 30 round trips. Aluminium and steel require more elaborate processing, but can be recycled almost indefinitely. The energy and material savings associated with recycling these products are enormous.

2.6.1 Metals

Extraction of metals from low-grade ores is expensive. It is evident that recycling will, sooner or later become necessary for most materials. Recycling of metals has a long history. Two main reasons exist for this early awareness of recycling: a) Metals by their rarity to early man, who had not yet mastered large scale extraction have always been relatively valuable compared with other materials. b) Engineering practice has in the past used solid metals, which, especially as process scrap, may easily be collected and reclaimed by simple melting. The advantage of using scrap in steel making saves energy, pollution etc. The recycling of ferrous metals is an integral part of the operations of the iron and steel industry.

Iron is a natural element usually found as an oxide. When iron is mixed with other minerals, it is called iron ore. This is reduced in a blast furnace to produce metallic iron called pig iron (so called because the moulds in which it is used to be cast are arranged around a central channel like piglets suckling a sow). Pig iron is impure and contains 3 to 4% carbon, as well as other chemicals such as manganese, phosphorus, sulphur and silicon. Some of these chemicals burn in the blast furnace to form slag, a layer of oxides on top of the molten iron. Slag is also recycled in the process.

Pig iron has two uses: a) It is cast into moulds to produce solid, heavy, often brittle objects such as manhole covers, pipes, pulleys and objects with complicated shapes such as valve bodies, cylinder blocks for engines. b) In other ways, it is used for making steel.

Sometimes iron ore undergoes a direct reduction process to produce small pellets of sponge iron. They are so called because they are porous and spongy. These too can be used for steel making, but they are unsuitable for foundry work until they have been converted in an electric arc furnace. Steel is iron with less carbon and steel making is simply the removal of the carbon by burning. This makes the steel stronger, more flexible and easier to cut than iron.

Tin cans are actually made of steel coated with a very thin layer of tin, and often with lacquer as well. They are a problem to the steel maker as the tin, which has a lower melting point, causes zones of weakness in the hot steel, leading to hot shortness and other problems. For this reason, cans are not used by steel makers, unless the tin has been removed by de-tinning. Their use is restricted to the production of low quality products such as reinforcing steel. In many places where there is a shortage of steel scrap, cans are accepted. It claims that even 50% of the cans are used for making reinforcing bars. Some steel makers prefer rusting cans for a few weeks before use.

In the original manufacture, tin is applied to the steel sheet by either of two industrial processes. The more modern is electrolytic deposition, which results in an extremely thin layer of tin (thickness of 0.0015 mm) and a weight of 0.5% to 1%. In the other process, the steel is dipped in a bath of molten tin resulting in a much thicker layer of tin by a weight of 1.5% to 7%. The three types of de-tinning processes are alkali de-tanning, alkali electrolysis and acid de-tinning.

(a) Recovery of Process

Mostly reuse and recycling of valuable metal like gold, silver, brass, bronze, etc is common in local cottage industries. However, for other metals of different stages of the waste stream like ferrous metals and some non-ferrous metals are separated in a mechanical resource recovery operation into the heavies of an air classifier. Metals are further concentrated by a succeeding treatment according to the heavies. Metals are separated from heavies in two forms: ferrous and non-ferrous metals.

Ferrous metals such as iron, steel, etc are separated by electromagnetic separators from the composting systems and incineration plants before or after incineration, some time prior to treatment. The non-magnetic fraction aluminium, copper, lead, etc maybe processed by the heavy media separation system. Methods of separating aluminium from municipal solid wastes based on electromagnetic interaction, using aluminium magnets, are being developed.

The scrap has to be collected, sorted, separated, and in many cases, physically processed before metallurgical treatment. Coarse scrap is comminuted by cutting or shredding, whereas fine material is compacted by briqueting.

(b) Manufacturing Process

Recycling maybe broadly classified as “closed loop” and “open circuit”. In the former category, the shortest route is simple collection, segregation and re-melting, the recycled metal being used for applications broadly similar to its original use. This procedure offers greater flexibility because of the contamination of the scrap.

A somewhat longer closed loop involves the addition of a refining stage in cases where the metal is contaminated, either inadvertently during service or intentionally by alloying with metallic or non-metallic additions. The open circuit method abandons the attempt to recycle to the virgin specification material, but relies on its economic feasibility on degradation to lower cost products, not themselves worth recycling. The metal, is therefore, ultimately lost to the entire system which makes the open circuit method disadvantageous (Henstock et al., 1975).

Table 2.3 Factories Using Recyclable Materials and Benefit/Cost Ratio of the Production

Factory	Waste Material Used	Benefit/Cost Ratio
East Industrial Co.	wood pulp, 600 t/m waste paper, 1200 t/m	1.260
Mai Num Paper Mill Co. Ltd.	wood paper, 70 t/m waste paper, 400 t/m	2.132
Mahachai Paper Production Co.	waste paper, 200 t/m	2.132
Mahakhun Plastic Factory	waste plastic, 1 t/d (washed), 1.2 t/d (unwashed)	1.430
Sang Charoen Plastic Factory	waste plastic, 1 t/d (unwashed), 850 kg/d (polypropylene)	1.260
Thai Glass Industry Co. Ltd.	waste glass, 3150 t/m	1.640
Glass Organization	cullet, 1800 t/m	1.577
Wongpanit Co.	glass (cullet), 4158 t/m waste paper, 4864 t/m non-ferrous metals, 594 t/m ferrous metals, 4528 t/m waste plastic, 3153 t/m	2.245 2.629 0.195 1.393 0.901

Source: Butsapak (1984)

(c) Ferrous Metals

The recycling of ferrous metals is an integral part of the operations of the iron and steel industry. The ferrous scrap like plain carbon steel, alloy steel and cast iron are recycled in the iron and steel industries by fading in different stages of its processing, depending upon scrap metals grading or quality. Mostly, home scrap is recycled in the iron foundries and steel making, casting and finishing units. The post consumer scrap or merchant scrap are mixed in blast furnaces and iron foundries.

(d) Non-Ferrous Metals

Non-ferrous metals are generally concerned with copper, aluminium, lead, zinc, etc. The recycling of these metals has many features in common. Much of these processes are also applicable to tin, nickel, titanium and precious metals. The recycling of non-ferrous metals is probably more highly developed than that of any other class of materials, the reason being the price of precious metals, tin, titanium, nickel and copper etc. The capital requirements for the physical and metallurgical processing of non-ferrous metals are lower than those for the recycling of ferrous scrap.

Non-ferrous scrap is of three types: 1) Home scrap. 2) Prompt industrial scrap (new scrap). 3) Post user scrap or old scrap. The handling of molten metal results in the formation of dross, which is difficult to recycle. Melting losses are significant in the process of non-ferrous metals.

Generated scrap is collected and analyzed for copper and aluminium. The alloy content of scraps governs its processing. It is general practice as far as possible to recover alloys as alloys. Brass mills consume large amounts of brass scrap. It has been stated that approximately 40% of the zinc in the brass product in the United States is derived from brass scrap. Lean copper alloys are also generally recovered as alloys. As a result, less than one third of the copper recovered in the United States is recovered as the pure metal. Over 90% of secondary aluminium is recovered as alloys.

Some non-ferrous scrap, for example, copper and lead scrap can be processed on either the primary or secondary production circuit. In such cases, geographic location and quality of the scrap determine which circuit is to be chosen. In the case of copper, secondary copper is fed in three points: the purest grade (No. 1 copper) to the wire bar furnace, medium grade (No.2 copper) to the anode furnace and lower grade (No. 3 copper) to the smelting circuit at the converting stage.

Kennedy (1985) indicated that aluminium is the most energy-intensive material in common use, while recycling aluminium requires only 5% as much energy as producing it from bauxite, and each recycled beverage saves the energy equivalent of a half can of gasoline. One ton of re-melted aluminium eliminates the need for 4 tons of bauxite and 700 kilograms of petroleum coke and pitch, while reducing emissions of air-polluting aluminium fluoride by 35 kilograms.

Pollock (1987) indicated that although metals comprise only about 2% by weight of solid waste, it’s relatively high economic value can make it an important component of the recycling programme (particularly aluminium, because primary aluminium production is very energy intensive).

(e) Recycling Products

To produce other possible products with the knowledge of metal work, normally domestic utensils, agricultural instruments etc are used. For ferrous and non-ferrous scrap metals, recycling is performed for the same product, sometimes lower grade products, depending on the condition of scrap metal, the value of the metal and ferrous metals used in lower grade production.

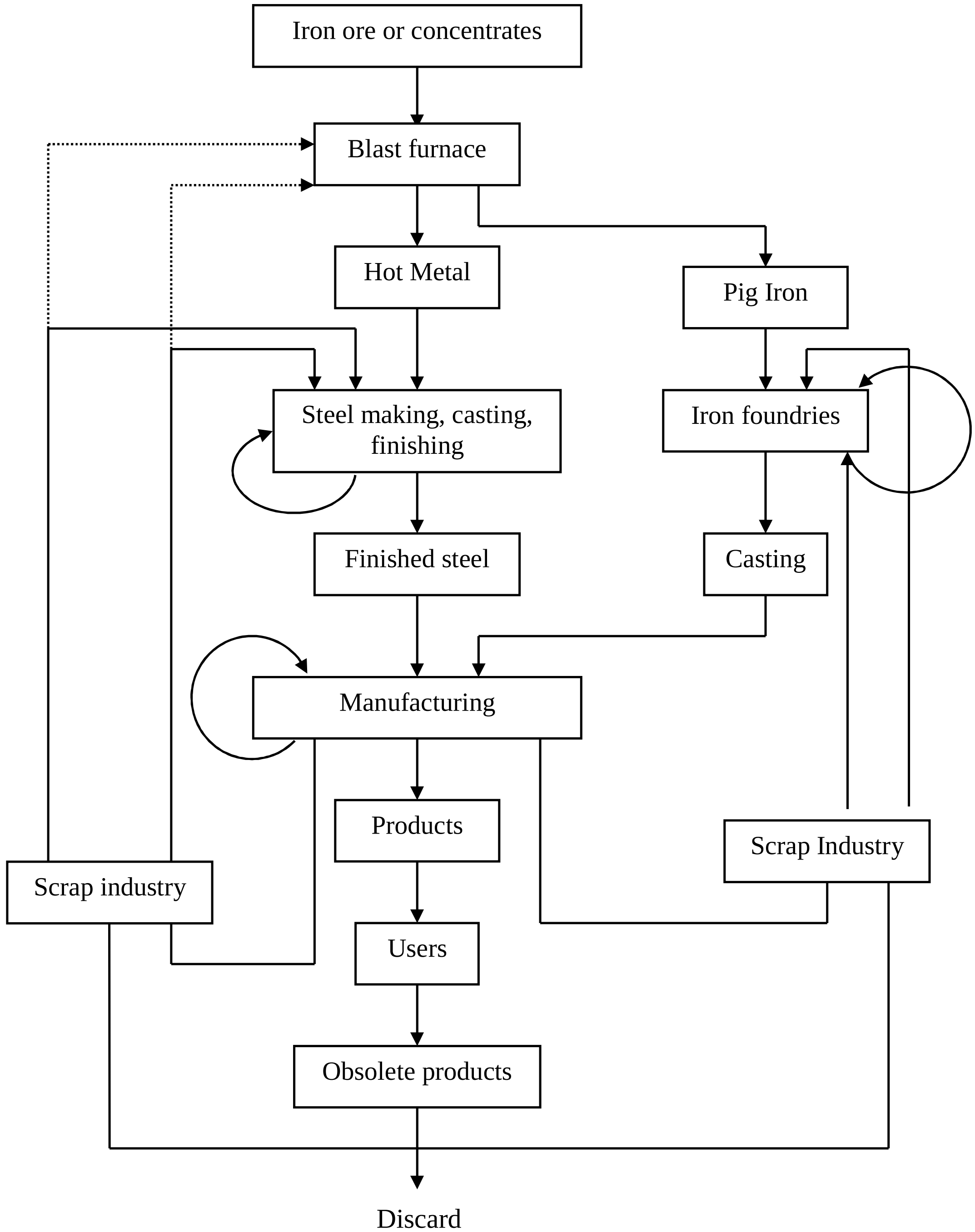


Figure 2.4 Flow Diagram of the Iron and Steel Industry

(f) Constraints to Reusing and Recycling

- In steel making plants, the contaminants from the use of scrap cannot be removed, which adversely affect the quality of steel produced.
- Scrap can cause technical difficulties by introducing impurities into the furnace.
- The melting of aluminium and the handling of the molten metal result in the formation of dross, which is difficult to recycle. Melting losses are also significant in the process of other non-ferrous metals.

2.6.2 Glass

Glass is an inorganic man-made material, it is important to remove glass for composting and other processes. The amount of glass is found in considerably large amounts in domestic waste and can be reused and recycled.

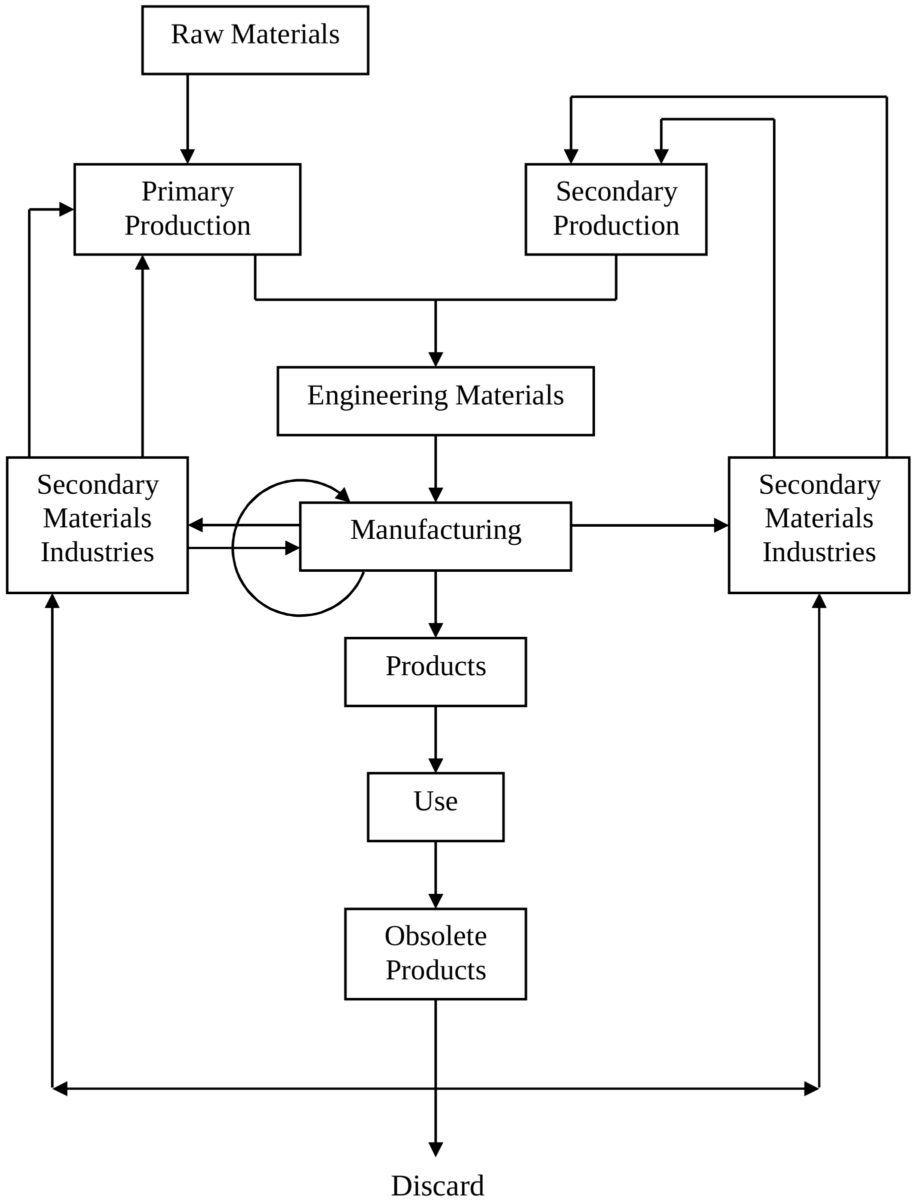


Figure 2.5 Generic Flowchart of Non-ferrous Metals

(a) Recovery Process

In the mechanical resource recovery operation, all the glass finds its way into the heavies of an air classifier. Glass is further concentrated by a succeeding treatment according to the heavies. A very effective method of concentrating glass is developed by CAL Recovery Systems (CRS).

In this system, a "stoner" inclined vibrating screen through which glass is forced, results in a material on the screen, which is fluidized. Heavier particles, mostly glass in the fluidized mass, move in one direction and the lighter particles move in the opposite direction. The heavier fraction is again subjected to the screening and fluidizing step. To meet cullet specifications two methods are mainly used: Froth Flotation and Optical Sorting (Diaz et al., 1982).

(b) Manufacturing Process

Any glass object maybe broken into cullet. The use of cullet is a long established practice in a glass container industry. Since the broken glass is virtually equivalent to original raw materials and can be re-melted many times without degradation. Raw material and glass manufacturing processes is shown as follows.

Sodium oxide is used as flux, which reduces the melting temperature of sand from 1700^0C to only about 800^0C. Calcium carbonate or limestone is used as the stabilizer to make the resulting material insoluble. These three materials (sand, sodium oxide, lime stone) mixed together in the proportion described, is known as the "batch".

Table 2.4 Glass Recovery

Less Dense Fraction	Composition (%)
Fiber	4.5
Glass	28.5
Wood	3.4
Plastic	4.6
Metal	0.5
Other	58.5
Total	100

Stoner 1 → Denser Fraction → Vibrating Screen → Stoner 2

Glass Concentrate	Composition (%)
Glass	93.8
Stones	5.6
Ferrous	0.4
Non-ferrous	0.2
Total	100

Table 2.5 Constituent of Glass

Sl No.	Component	% by weight
1	Sand (SiO_2)	72
2	Soda Ash (Na_2O)	14
3	Lime Stone ($CaCO_3$)	11
4	Alumina (Al_2O_3)	2
5	Colourants and others	1

The additives to the batch include:

- Aluminium oxide to reduce the expansion of the glass, and therefore, to prevent cracking.
- Borax (0.5%) to assist the speed of melting.
- Decolourizing agents to remove the colour, as a result of iron present in the sand.
- Colourizing agents which help to remove the small gas bubbles given off during the glass manufacturing process, the most common refining agent being arsenic oxide with sodium nitrate.
- Cullet acts as a flux, which reduces the damage to the glass furnace from the corrosive, high temperature materials and reduces the cost of materials.
- The batch materials are mixed, dried and changed into the furnace, which needs to be at about 1500^0C to melt them into tracy (an amber-coloured liquid). The tracy is passed through a refining chamber and then is made into the required shape.

(c) Recycling and Reuse Products

Waste glass is used as a flux agent in the brick manufacturing process. It lowers the required firing temperature or lowers the heating value and a shortening of the firing time, resulting in a reduction in energy requirements and manufacturing costs.

According to Tyrel et al., cited by Diaz et al. (1982), the substitute for waste glass for one half of the clay in red mixture reduces the heat required to fire the body to maturity by approximately one million kJ/Mg (million gram). With the tanned bodies, the reduction is about 900000 kJ/Mg. Conversion in terms of fuel consumption is made possible through the use of glass (i.e. a 50:50 glass-clay mixture).

In the manufacture of red bricks, a plant that produces 36 million face bricks per year, would amount to about 1.818 Mm^3 for every 100 kJ of natural gas produced per year. In the manufacture of tanned body bricks, the savings would be about 1.632 Ml of 1000 kJ gas per year. Further more, the substitute would result in a 30% increase in production of red bricks without additional kiln capacity. In the production of tanned body bricks, the increase in production would amount to 23%. The important factor to be considered for using waste glass is that no organic material should be present in the waste glass because of interference with the fluxing action of glass. The proposed maximum level for organic material is 10%. The glass must be ground to 200 mesh.

(d) Glass Polymer Composite (GPC)

Recovered crushed waste glass, when mixed with polymer at an appropriate ratio of 87% glass to 13% polymer can be used to cast glass polymer composite materials. GPC has been developed for use as a sewer pipe on a small scale. The pipe has been demonstrated to have superior compression strength and resistance to sewer acid and gases. According to Diaz et al. (1982), GPC pipes would probably be competitive with concrete and vitrified clay pipes up to 9.6 cm in diameter.

(e) Foamed Glass Insulation Panel and Glass Wool

Pulverized glass containing impurities has been used in the production of foamed glass insulation panels having densities ranging from 224 to 640 kg/m^3. Walls and doors in which foamed glass panels serve as a core material have been shown to have excellent thermal and acoustic insulation.

Glass wool is used principally for thermal insulation against heat and cold and for sound absorption. Its manufacture involves the impingement of a jet of compressed air on a stream of molten glass. Research conducted at Tuscaloosa Metallurgy Research Laboratory of the U.S. Bureau of Mines showed that glass incinerator residue could be used to make glass wool that would meet the requirements for commercial use.

The introduction of cullet results in a lowering of the temperature at which a furnace must be operated in glass production in energy consumption and a prolongation of the refractory linings of the furnace.

Diaz (1982) showed that an energy saving of 951 kJ/kg can be made by substituting cullet for primary raw material. He estimates that for a 10% increase in cullet, there would be a corresponding 2.2% decrease in fossil fuel required, a fuel saving of 4.4% and an electric energy saving of 1.1%.

According to OECD (1989) for every ton of crushed glass used in the manufacturing process, some 1.2 tons of raw materials are saved. Every 19% of cullet introduced into the furnace results in energy savings of 2 to 5%. The recent adoption of air pollution standards has led to an increase in demand for cullet by glass producers because its use reduces its emissions. Outside the glass industry, cullet is used in the manufacture of abrasives. Tiles are manufactured mixing cullet and waste ceramic products. The estimated recycling rate of glass containers was 12% within 1988 (The Society of The Plastic Industry, 1994).

(f) Constraints to Reusing and Recycling

- Cost of transportation of waste glass to the site of use.
- Lack of adequate technology for processing the waste glass to meet the rather rigid specifications for cullet.
- Glass recovered from municipal solid waste has very objectionable characteristics that must be removed or changed before the material can be used as cullet in glass manufacturing.

2.6.3 Paper

Paper and cardboard forms the second highest amount of refuse. It exists in the waste in the form of mainly writing and packaging materials. Recycling of paper is increasing day by day. Many big and small industries are found to profit from these recycling activities.

Researchers in the University of Cincinati found that un-degraded paper, food and other items well preserved after 10 years in a landfill. Paper making using virgin pulp requires as much as 300 m^3 of water for every ton of paper produced. While producing recycled paper from waste paper needs only 30 m^3 (The Society of the Plastic Industry, 1994).

The Clean Japan Centre (1987) indicated that one ton of waste paper is said to correspond to 20 standing trees. Enhancing the recovery rate of waste paper, serves not only to protect the green on the earth but also to prevent the increase of carbonic acid gas involved in mass consumption of fossil fuels, which preserves and improves the environment of the earth.

(a) Recovery of waste paper

People at the source remove the newsprint and corrugated papers prior to reaching the disposal or processing site. The mixed paper grades are removed through air classifiers. The recovered light fraction is further processed through a specially designed fiber recovery process to meet the specification of the pulp substitute. Some of these processes follow the Cal Recovery System (CRS), and other process designed by the National Center for Resource Recovery and the Black Clawson Process. The Black Clawson Process is a wet system for upgrading the fiber to paper manufacturing quality.

(b) Manufacturing Process

Papers are made from the fibers consisting of cellulose from trees and stalks, such as wheat, rice, sugarcane, etc. These plants are broken down until the fibers are loose and free of the substances that bind them. In some places, pulping of paper is done by boiling the raw material with ashes and then pounding it with a wooden mallet. The process is called pulping and the mass of fiber is no longer held together but ready to be suspended in water for making paper, known as pulp. Softwood or coniferous pulps are used for tough wrapping and packaging papers because of their long fibers, deciduous or hard wood pulps are used for printing and writing papers. There are some methods of making primary pulp from wood pulp in paper making such as mechanical and chemical pulping.

Mechanical pulping is done by pounding or grinding cellulosic material such as wood. It is used for printing newspapers. Newsprint is very weak and loses its strength altogether if wetted. It absorbs liquids and contains tiny particles of wood, which have not been reduced to fiber and are visible to the naked eye.

In chemical pulping, wood or stalks are mechanically reduced to small chips and then cooked at high pressures with certain chemicals that attack the bonds between the fibers and reduce them to pulp. The most common chemicals used are caustic soda and sodium sulphate, which produce coarse and very strong fibers known as “kraft” used for sacks and boxes to hold heavy weight. Other various sulphites such as ammonium and calcium are used to produce fine fibers used for making high quality printing and writing papers. All pulp produced is bleached to a white colour and then tinted to the required colour.

Waste papers are vigourously snared in a hydrapulper with rotating blades to separate the fiber bonded during the original paper making process. As these bonds are weaker than those of the original cellulose plant, the energy consumption is less to separate the bonds. Depending upon the quality of waste paper, further processes like bleaching etc are done and produced into secondary pulp for manufacturing papers.

Paper is made by suspending sticky fibers in water at a fiber concentration of about 0.3%. The suspension is on to an endless clot of a machine, where the water is drained and a leaf is formed. Then the leaf is dried and cut into sheets. In the past, the source of raw materials was wood, fiber, textile fiber, straw, etc (Henstock et al., 1975). Cellulose in the form of cellulosic fibers that make up paper is a renewable resource, there is a limit on the rate at which it can be renewed. The limitation is determined by the availability of appropriate land and energy for non-nutritional crop production (Diaz et al., 1982).

(c) Recycle and Reuse Products

- Paper, paperboards or other paper products are produced from reclaimed fiber.
- Can be used as a fuel in energy production.
- Can be used as a feedstock in various fermentations.
- Can be used as a bulking agent and carbon source in compost production.
- Some of the paper is reused for making paper bags, non-contact layers for moulding and preparing masks, dolls etc.
- Some of the low grades of waste paper can be used to make other products such as insulation material.
- Manufacture of asphalted roofing sheets.

(d) Constraints to Reusing and Recycling

- An important feature that distinguishes the utilization of reclaimed paper in the production of paper and paper products from the other uses is that it depends mainly on paper that has not been contaminated through entry into the solid waste stream.
- Regardless of the source with each pass from 20 to 25% of the paper fibers are rendered unsuitable for reuse in paper manufacturing because the fibers become too short.
- An important feature that distinguishes the utilization of reclaimed paper in the production of paper and paper products from virgin pulp material is that it depends mainly on paper that has not been contaminated through entry into the solid waste stream.
- Some coated papers like plastic coated cannot dissolve in water and produce pulp by a hydrapulper. In case of water-soluble coating, there will be a loss of weight in the pulp product.
- Paper recycling is a limited process, since paper can only be recycled around four times almost.
- If paper has to be produced from low-grade papers to high quality end products, more energy, chemicals and water are required. In the process, the yield is reduced and more waste is produced, creating more pollution.
- Paper produced from the pulp of reclaimed fibers is prohibited for the use of paper for food, drugs and cosmetic containers.
- Diaz et al. (1982) reports a total absence of *fecal streptococcus* and *fecal coliform* in paper rolls from mixed waste feed stocks, although the count of total bacteria ranged from 482 to 2356 organisms per square centimeters of paper.
- Swedish researchers found that there are harmful bacteria present in toilet rolls, kitchen paper and packing materials manufactured from recycled fibers.

2.6.4 Plastics

Plastics are non-biodegradable materials made of polymers. At present, plastic materials are produced from petroleum products. There are so many technologies available to produce secondary materials cheaper than virgin materials. Markets are available for its product, which means that plastic recycling industries are making large profits. Plastic materials are synthesized for special applications. Reuse of plastics is not practiced widely however.

(a) Recovery Process

At present, different kinds of plastic material is separated mainly by scavengers at different stages of the waste streams. There are different technologies that exist for separating different types of plastic, but it is not always economically realistic to use. For this reason, it is necessary in the first instance to organize recycling of plastics as far as possible on a single polymer basis in order to simplify subsequent separating operations. Poly-olefins, for example, which account for around 70% or majority of the plastics in domestic wastes can be separated from other plastics on the basis of their density (> 1 g/cm^3). Mixed waste of different polymers is generally more difficult to use.

The main criterion for separating plastic is density. A machine for this purpose was developed, known as a hydroclone. Other processes for separating polyethylene such as the sink/float method and electromagnetic separation of PVC, air classifier etc have been developed. Since many types of plastics are available in the waste stream, and many technologies are available for utilization of mixed polymers. If we have to focus on the concerns of recycling, the criteria and the requirements for these technologies to be put into place must be specified and a collection system must be set up accordingly.

(b) Manufacturing Process

Plastics are produced by the polymers present in petroleum, natural gas and coal. The word "polymer" comes from Greek meaning "many parts". Polymers are those materials whose molecules are made up of a large number of individual units known as "monomers". A monomer is a molecule with a low molecular weight able to react with other molecules of low weight to create a polymer. Synthetic polymers can be produced either by condensation of monomer molecules (with the elimination of a simple molecule, often water) or by the addition of monomer molecules containing double bonds (Jones & Chandy, 1974 cited in Barton Allan F.M., 1979).

It has been known that particular bacteria can produce a polymer with properties of plastic. Recently, the genetic material responsible for the production of plastic in the bacteria have been identified, isolated and introduced in plants. In the process, plastic is used as a storage material. The bacteria accumulate plastic as small granules, in times when plenty of food is available. But when there is a scarcity of food, it breaks down the plastic granules into energy. This is how animals accumulate body fat and seeds accumulate oils.

The gene from the bacteria has been introduced into tobacco plants and these plants are growing in experimental fields. It is a biodegradable plastic, which can be produced in farming. Another group of American researchers are developing plastics from potato. Besides potato, other starch containing crops like corn, rice, wheat etc are also being investigated. In Japan, edible wrappers for food are already being used. It is also found that polyesters can be produced from lactose.

(c) Types of Plastics

Plastics fall into two main categories: thermosetting and thermoplastics.

1. Thermosetting: Thermosetting plastics are chemically hardened plastics made of phenol formaldehyde and urea formaldehyde, polyesters and other plastics. These plastics are converted to usable materials by heating to the desired shape. These are used in electrical sockets, plastic laminates, plastic crockery, etc. Thermosetting plastics cannot be readily recycled into new plastics.

2. Thermoplastics: Thermoplastics are polyethylene (HD and LD), polypropylene, polyvinyl chloride (PVC) and polystyrene and copolymers. These plastics are converted to usable goods by suitable heating and forming, then cooling. Mostly, all packing materials are of the thermoplastic variety and used for recycling widely. The most common synthetic polymers can be represented chemically as:

$$\textbf{-(-CH}_{\mathbf{x}}\textbf{-CH}_{\mathbf{2}}\textbf{)}_{\mathbf{n}}\textbf{-}$$

where “x” can be: hydrogen in polyethylene, phenyl in polystyrene, chlorine in polyvinyl chloride and methyl in polypropylene.

Polyethylene is a fairly tough, probably the most common plastic and used in the majority of plastic bottles as well as in the form of film. Polyethylene has two forms: high density and low density. High-density polyethylene is harder and crackles in the hand if crumpled. In the production of very thin sheets such as sacks and bags or thin sheets, high-density polyethylene is stronger although these are prepared from low-density polyethylene too. Low-density polyethylene is soft and stretches more when torn. These two types are different and cannot be mixed.

Polypropylene is very similar to polyethylene and recovers its shape when deformed more readily than does polyethylene. It is generally more expensive than polyethylene. It is very strong, flexible and hard. It is used to make furniture of high durability, string and ropes, car battery cases, plumbing and to an increasing extent in packaging.

Polyvinyl chloride is used widely in shoes, plumbing, floor and wall surfaces, children’s balls and toys, hand bags, suitcases, irrigation piping. But its clarity and flexibility make it a popular substitute for packing. It is cheaper than the other plastics mentioned above. Polystyrene is also transparent, but is more rigid and despite its brittleness, has numerous applications in containers, microwaves, foam cups, toys and home appliance components. These are the various kinds of thermoplastics that can be reused.

Plastics are used in many ways and have become the material of choice because of their high serviceability and cost efficiency, requires less energy to manufacture than aluminium or non-ferrous heavy metals, save fuel through their light weight, better storage stability of food etc. Thus, plastics and plastic products are becoming substitutes for other products made of metal, paper, wood, glass etc.

(d) Category of Recycling of Plastics

Four categories of recycling are considered as follows:

1. Primary Recycling
2. Secondary Recycling
3. Tertiary Recycling
4. Quartenary Recycling

1. Primary Recycling: It can be defined as recycling of uniform, uncontaminated plastic waste produced from manufacturing plastic products. Only thermoplastics can be directly reprocessed. It can be used alone or mixed with virgin materials at various ratios. Primary recycling can be performed in the plant itself through small re-processor standard units.

2. Secondary Recycling: It can be defined as recycling by separate series of systems of operation for plastic materials such as post consumer waste recovered from the municipal waste. Post consumer wastes are obtained from returnable packages and industrial wastes which cannot be used for primary recycling, which are single wastes or mixed wastes.

3. Tertiary Recycling: It can be defined as the extraction of chemicals from plastic wastes. Some common methods of chemical extraction are pyrolysis, hydrolysis, glycolysis, etc.

4. Quaternary Recycling: Quaternary recycling or recuperation of energy can be defined as the recovery of energy from wastes. Some recovery of energy processes is by burning the waste in steam-generated incinerators and in heat exchangers, pyrolysis, hydrogenation, anaerobic digestion etc.

(e) Stages of Recycling

The process can be roughly divided into three stages as follows:

1. Prior Treatment: Removal of foreign matter classification by the type of resin, shredding, washing, dehydrating, drying and blending processes. The process to be employed depends upon the type of products to be made, quality of the plastic waste to be used.

2. Melting/Mixed Kneading: Plastic wastes after prior treatment is melted or kneaded, with the help of screw type or combined or other fading machines attached to a heat supply. Virgin plastics are mixed if necessary.

3. Moulding:

There are four moulding methods:

1. Low pressure injection moulding
2. Press moulding
3. Extrusion moulding
4. Roll moulding

(f) Recycled Products

The common materials available in markets, which are prepared from the recycled materials are:

FROM RECYCLED HDPE:

Agriculture: Drainpipes, pig and calf pans

Marine Engineering: Boat piers (lumber)

Civil Engineering: Building products, traffic cones, signs.

Household: Containers for liquid cleaning supplies and detergent containers, trash bags.

Recreational: Gardening materials, gardening furniture, landscaping

Industrial: Drums/Pails, portable toolboxes.

FROM RECYCLED PET:

Household: Soda bottles, liquid cleaners

Recreational: Skis, sailboat hulls

Industrial: Carpeting, fiberfill, building insulation, industrial packing

FROM RECYCLED POLYSTYRENE: Food packing, insulation, industrial packing

FROM RECYCLED VINYL: Industrial flooring, garden houses

FROM RECYCLED MIXED: Park benches, land skipping, plastic lumber. Some companies are testing recyclable polystyrene foam containers like cups and plates made with 50% recycled plastic.

In addition to that, significant progress is being made in the development of recycling systems for other types of plastics such as polystyrene and vinyl, as well as multi layered packing and plastic glossary sacks.

Difficulties frequently arise in maintaining constant quality owing to colour and intrinsic odour variation in recycling. Therefore, the co-extrusion and co-injection moulding process is being developed in which virgin plastic material and recyclables are combined together in layers, recyclables are used for inner parts and virgin material outside. Recent examples of products manufactured in this way include co-extruded PVC pipes (Draka-Solvay/Solvay) and detergent bottles (Procter & Gamble).

Recently, Philipino Chemical Engineering has invented an alternative to natural wood called eco-wood which can be processed from waste material such as dry leaves, rice straw, rice hulls, saw dust, plastic wastes including expanded polystyrene.

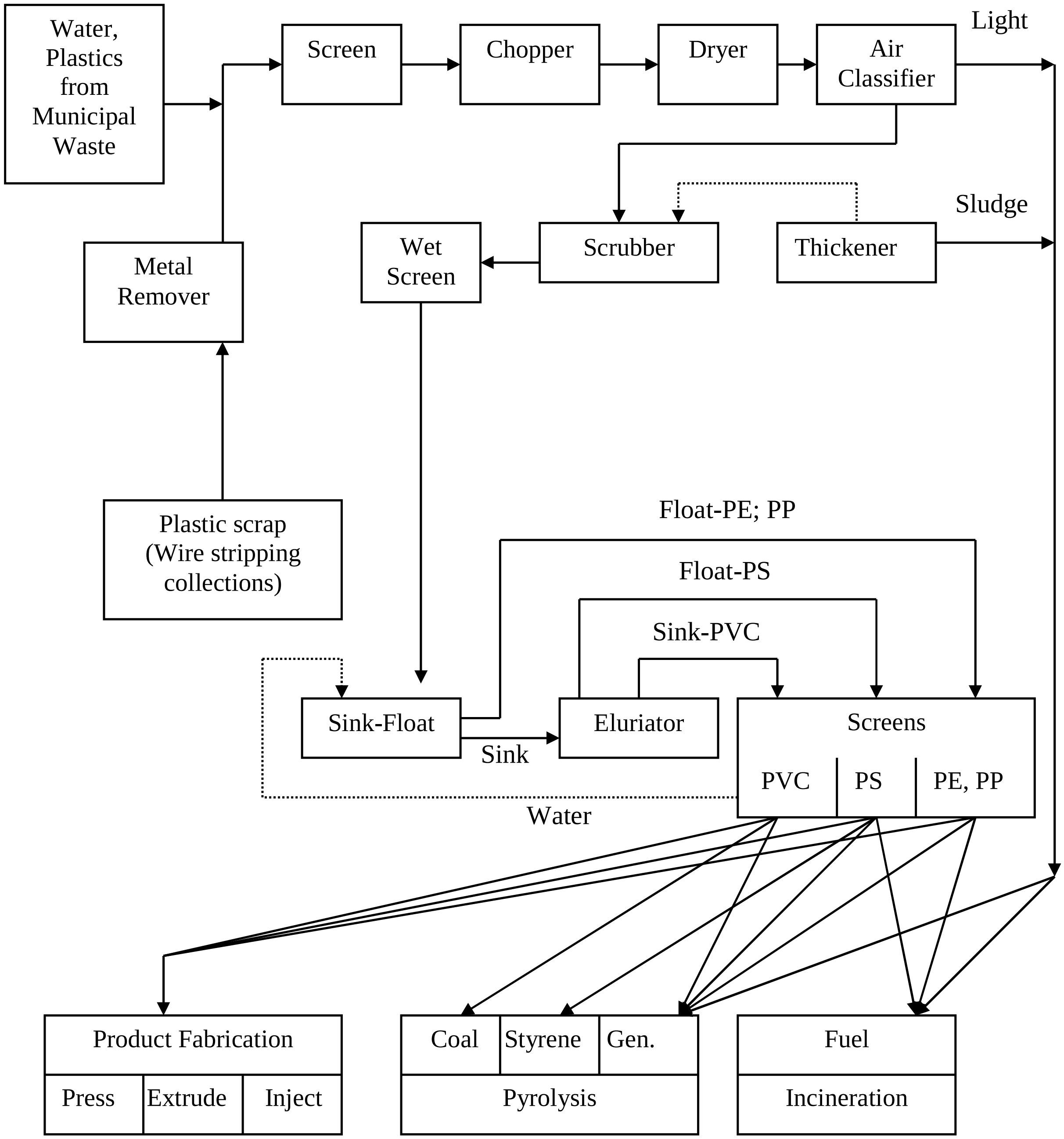


Figure 2.6 Flow Diagram of a Processing System for Reclaiming Plastic Wastes

A joint project of Hoechst AG, Adam Opel AG, and others showed that used bumpers PP-EPDM, an impact modified polypropylene when recycled with necessary upgraded plastic additives, found to be recyclable, has good properties compared with original polypropylene, enable it to be used for other automotive parts, e.g. wheel arch extensions. Bumpers and batteries are being recycled and used for applications such as wheel arches. Similar recycling systems have been developed for battery casings and fuel tanks.

(g) Constraints to Reusing and Recycling

Recycling of mixed plastic wastes from domestic refuse proves to be more difficult to perform in general. The refuse contains a variety of packaging and is generally contaminated with food and other residues. Cadmium containing waste, painted parts, affect the product quality, and so again, further step-by-step processes are required.

Plastics are materials synthesized for special applications. The more diverse the composition of the waste the greater is the deviation from original property and hence is more difficult to recycle. Any contamination by another plastic or another grade formulation means poorer quality. Recycling causes progressive deterioration each time the material is recycled.

It is relatively simple to recycle single polymer process scrap, but the recovery of single polymer post consumer waste requires close cooperation between all companies involved in the product cycle in identifying the mark and others because of difficulty to separate different types of plastic and after every cycle of the plastic materials, the original property or strength gets lowered because of oxidation in repeated use.

The Society of the Plastic Industry (SPI) has developed a voluntary coding system for plastic containers that identifies bottles and other containers by the type of materials, to assist recyclers in sorting containers by resin composition to be imprinted on the bottom of the plastic container. The code of the three-sided triangular arrow with a number in the centre and letters underneath indicate the primary resin type. The SPI coating system was introduced in April 1991.

2.7 Legislative and Organizational Options for Waste Recycling

Recycling has brought some success only in some parts of the world. Countries that have increased materials recycling have been motivated by three main factors such as: short supply of raw materials, high energy and capital costs for processing materials, and high environmental costs in materials production and disposal.

2.7.1 Constraints to Recycling

According to Muttamara et al. (1992), recycling depends on whether the original owner feels it is convenient or economically worthwhile. People performing the various steps of retrieval, sorting, recovery and reuse must receive enough benefit to compensate them for their time and effort.

Julius (1987) indicated that one way to increase recycling process is through public education programmes that stress on the benefits of recycling and by enhancing the access to scavengers of materials discarded by these populations. Cointreau et al. (1985) indicated that another way of motivating people to recycle is by showing good will towards one's neighbour, which acts as an incentive. In Sri Lanka, for example, wealthier residents actively separate coconut shells from their other wastes in order to donate these shells to their launderers who use them as char in the irons.

Cointreau (1982) mentioned that the traditional attitude towards scavengers influence whether there is an antagonistic environment for recycling. A social stigma is applied towards those who handle wastes. In order to overcome this attitude towards scavengers in Manila, Philippines, a pilot-recycling programme was established and supported by a wide-spread public information campaign. The programme trained workers and provided them with clean attractive uniforms emblazoned with the message: "pera sa basura" (money from refuse). To some extent, the social stigma towards the house-to-house scavengers appears to have lessened.

Another factor contributing to the lack of recycling is poor documentation of the full cost of safe, environmentally acceptable solid waste disposal – particularly in developing countries where unregulated open dumping prevails as the means of disposal at what appears to be little or no cost, because there is no accounting of the adverse social, environmental and health effects that occur.

2.7.2 Legislative Measures

In most developing countries, the governments have not established effective pollution control and waste management programmes that take into account country specific problems, nor have they had the capacity to adequately develop and implement standards, regulations, and charge systems. The implementation and enforcement of regulatory and economic instruments has been constrained by inadequate expertise, funds and charging systems, inadequate equipment, lack of a political will, limited public awareness and overlapping and uncoordinated institutional responsibilities. Many countries in Asia have adopted laws and regulations, which were designed in the developed countries. The problem lies in outdated existing laws and regulations on solid waste management, environmental protection and recycling of waste materials.

There are four main items of legislation concerning solid waste management in Thailand. The Public Cleansing Act fixes low fines for violators. There is the Act for the Cleanliness and Orderliness of the Country, the Bangkok Metropolitan Administration Ordinance and the Ordinance for Sanitation and Orderliness in Bangkok Metropolis. Furthermore, several laws concerning the storage and collection of waste, but no legislation exist concerning waste recycling.

2.7.3 Organizational Measures

Muttamara et al. (1992) indicated that there are several points where the wastes can be retrieved for purposes of recycling such as:

- Place of waste generation
- Place of waste pickup
- Refuse collection and transport vehicle
- Disposal site

At the source, the owner has three options:

- To deliver to the purchasing centre or sell it directly to a buyer.
- To allow others to retrieve the waste and be responsible for recycling.
- To have it collected for disposal.

In order to operate the recycling programs effectively, economic benefits should be given for the consumers. For example, in Thailand, the deposit-refund system is implemented for the items such as bottles. This system if operated for the other reusable materials could encourage recycling and prevent pollution.

2.8 Technical Options for Waste Recycling

The technological options involve the removal of a component from the waste stream and physical reprocessing into a useful product. Finally, the chemical conversion process such as pyrolysis, hydrogenation, wet oxidation and hydrolysis transform into a new product to the market.

2.8.1 Source Separation or Initial Recovery

Lohani (1982) pointed out that separation or initial recovery can be done at the source manually or through physical and mechanical means. But for it to be a success in urban areas, dedication, interest, careful planning with proper administration and cooperation from the citizens are required. People have to be educated which ultimately means a change in their daily habits. Source separation is not a "technical option" in the truest sense, but it greatly facilitates the use of subsequent conversion processes, which require sophisticated technology.

2.8.2 Composting

Lohani (1984) indicated there are several arguments that speak in favour of composting as a resource recovery option particularly suitable for developing countries, and these could be:

- Simple technology
- Process is readily adaptable to local conditions
- Only a small amount of residue is left to be disposed of
- Compost has a low toxic substance burden
- Composting meets requirement concerning hygiene
- Refuse composition is appropriate for composting

There are at least five conditions that are necessary for the successful operation of composting projects. These are:

- Suitability of wastes
- A market for the product near the compost source
- Support from government authorities, particularly those responsible for agriculture
- Price of the product which is applicable to most farmers
- Net disposal cost which can be sustained by local authorities

2.8.3 Incineration

In many developing countries, the calorific value of refuse is so low that a fuel supplement may be necessary as part of the incineration process. The high moisture content of solid wastes also needs preheating by the recovery of heat from the incinerator. This addition of auxiliary fuel or evaporating moisture during the initial stages of combustion requires the use of energy and thereby affects operating costs; pre-treatment by sorting (e.g., through source separation) to remove the non-combustible materials prior to incineration which result in higher investment costs of incineration plants.

Removing yard wastes and inorganic recyclables such as glass and metals can reduce moisture and increase the average HHV (higher heating value). In contrast, removing paper and plastics lowers the HHV and increases the moisture content. Moisture content is important because it affects the stability of the combustion process and combustion efficiency during “cold starts” of an incinerator.

2.8.4 Pyrolysis

Lohani (1984) pointed out that the pyrolysis process is self-sufficient and regenerative, the gas obtained is sufficient for heating the retort, the by-product tar-oil can be used as a substitute for furnace oil and the coke can be used as a domestic fuel.

Sunavala (1981) recommended an investigation of pyrolysis on a pilot or semi-commercial scale in the Indian cities of Kolkata, Delhi, Mumbai and Chennai. Basing his calculations on an estimated 2,000 tons/day of refuse input and burning the gas to self-sustain the reaction, 600 to 700 tons/day of coke, 70,000 to 90,000 l/day of oil, 30 tons/day of glass and 30 tons/day of metal could be obtained.

2.9 Benefit-Cost Analysis in Solid Waste Management

Field (1997) gave the definition of the Benefit-Cost Analysis (BCA) as an analytical tool used to evaluate environmental decisions. Sometimes it is used as an aid in selecting efficient policies, sometimes an agency uses it to justify what it wants to do, and sometimes officials use it to try and stop new regulations or weaken old ones. Likewise, Folmer (1995) stated that it is a method of consistent comparison between the advantages and disadvantages of a particular project.

Benefit denotes anything that increases wellbeing. Benefits of some proposed action are estimated and compared with the total costs that society would bear if that action were undertaken. Cost denotes anything causing a loss in welfare.

The purpose of the BCA is not only to compare the benefits and costs of an individual project in order to identify those with positive net benefits, but to identify the project having the highest net benefit among all feasible alternatives as well.

2.10 Waste Auditing and Waste Management

Waste auditing can be defined as a systematic, documented, periodic, and objective review, conducted by regulated entities, of facility operations and practices regulated to meeting environmental requirements (U.S. EPA, 1986).

Some purposes of waste auditing are to verify compliance with environmental requirements; to evaluate the effectiveness of in-place environmental management systems; and/or to assess risks from regulated and unregulated substances and practices. Some direct results of an auditing program include an increased environmental awareness by project employees, early detection and correction of problems and thus avoidance of environmental-agency enforcement actions, and improved management control of environmental programs.

Waste management can be used to describe several distinct processes: the elimination or reduction of waste; the recycling or reuse of waste material; the treatment or destruction of waste (physically destroying, chemically detoxifying, or otherwise rendering waste permanently harmless); and disposal of waste (depositing the material into the air, water, or land). Environmental regulations have not necessarily channeled industry efforts toward the optimum choice of waste management techniques – pollution prevention. Recycling, reuse, and treatment seem to be the industry's preferred waste minimization options, even though such methods pose more environmental risks than pollution prevention.

Chapter 3

Methodology

3.1 Introduction

This study was carried out at the Asian Institute of Technology (AIT) for a five-month period from November, 2006 to March, 2007. This chapter presents the methodological details of the application of the 3R concepts in the solid waste management practices in AIT.

3.2 Data Collection Phase

Three major processes were systematically developed which consists of data collection, data analysis, and conclusion. Figure 3.1 shows the major process of methodology including data collection, data analysis, conclusion, and recommendation. The details of each process are illustrated in the following sections. To achieve the objective of this study, not only primary data but also secondary data had to be collected in order to use such data for analysis and comparison. The consequent details were proposed to explain the methods used in each type of data. Figure 3.2 shows the comprehensive process of data collection.

3.2.1 Primary Data

In this study, solid wastes were sampled from a selected number of garbage bins in the AIT, from the different parts of the AIT campus. Samples from each point were taken from different garbage bins in the different areas of AIT one time per day for 10 days to increase the reliability of data. The sampling was done over a period of 40 days, since four samples were analyzed per day. The schedules for sampling from the different parts of AIT campus are shown in Table 3.1 below.

Table 3.1 Schedule for Sampling of Solid Wastes at AIT

Location	No. of samples	Frequency	Total
Student Dorms (A-K)	10	1 time/day	10
Student Dorms (L-S)	10	1 time/day	10
Student Dorms (T-Y)	10	1 time/day	10
Staff Quarters	10	1 time/day	10
AIT Conference Centre	10	1 time/day	10
Student Village I	10	1 time/day	10
Student Village II	10	1 time/day	10
Student Village III	10	1 time/day	10
Cafeteria Area/Mini-marts	10	1 time/day	10
Academic Buildings	10	1 time/day	10
Administrative Buildings	10	1 time/day	10
Waste Recycling Bank	10	1 time/day	10
Open Dumps	10	1 time/day	10

Five combined or mixed samples were taken from the areas in AIT mentioned above, and their physical components, bulk density were measured. A minimum sample of 100 kg was needed in order to obtain a uniform result.

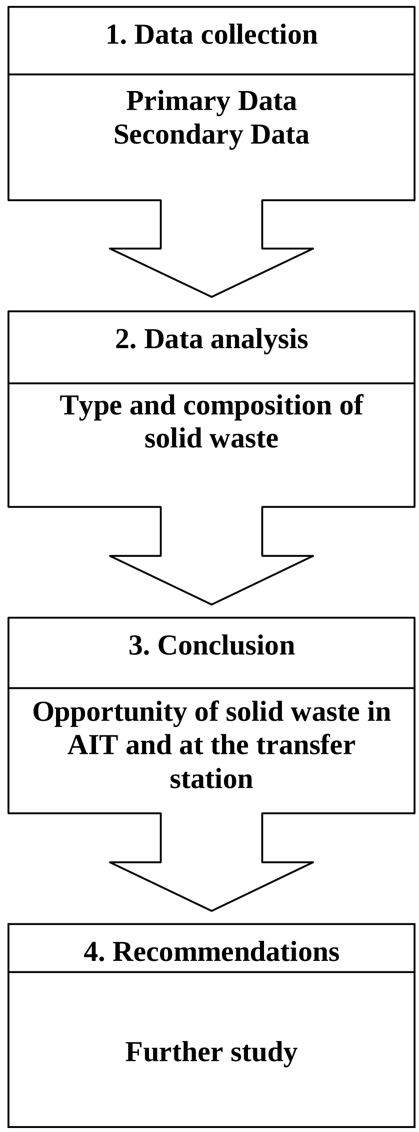


Figure 3.1 Overview of the Methodology

3.2.2 Secondary Data

The data in this research was obtained from different sources, but was mainly obtained from the research work done by various people in Thailand. All information relating to the recycling costs of solid wastes, income earned by scavengers, quantity of wastes sent to the transfer stations and recycling facilities, landfill costs, lifetime of the landfill, etc were gathered. The data consists of two types of data, which were made available from the three main sources as described as follows.

(a) Secondary Data from the Internet

The secondary data was collected from internet websites of the recycling companies that take care of the solid wastes generated by AIT. These websites have more details related to the cost of various types of solid waste. The following information can be retrieved:

- Solid wastes that can be recycled
- Cost of selling by the scavengers
- The quantity of solid waste which is sent to the recycling stations

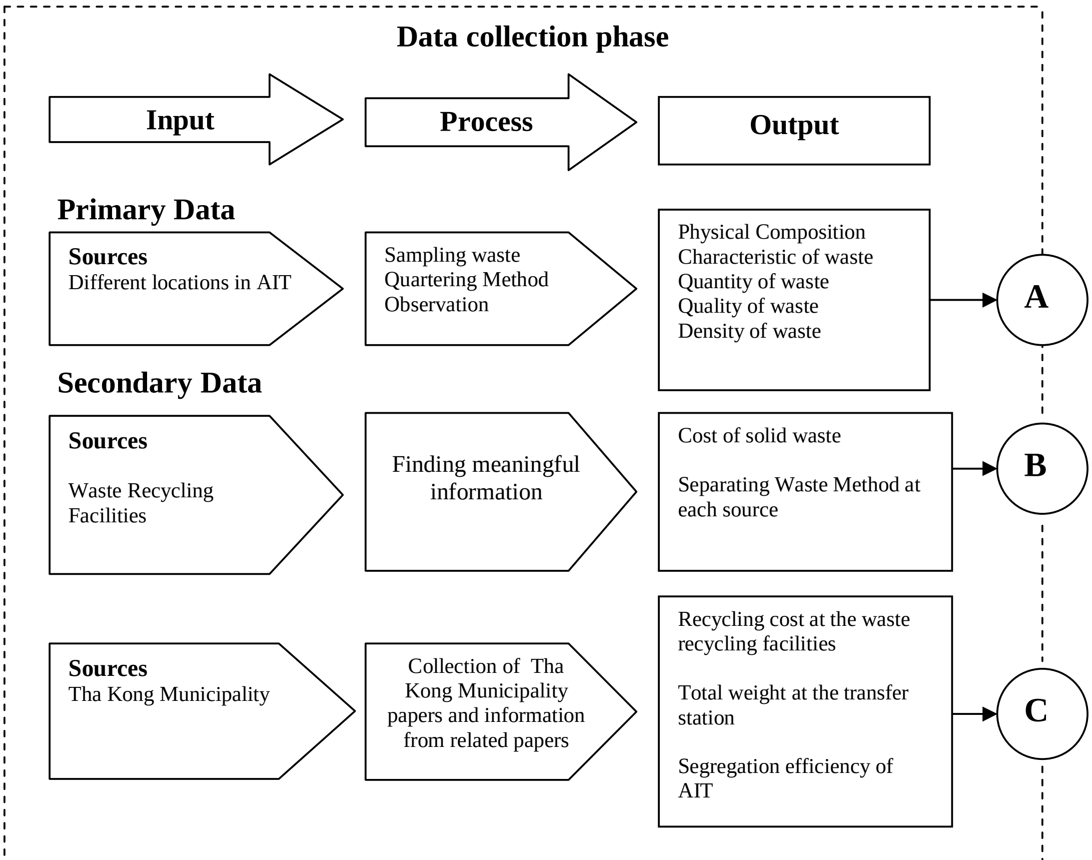


Figure 3.2 Data Collection Phase for AIT

(b) Tha Kong Municipality Data

The major concerned data needed, was related to all the costs concerned in this study. This includes for example:

- Recycling costs at the transfer station and the waste recycling facilities.
- Total weight of the solid wastes at the transfer station.
- Segregation efficiency of AIT
- Transportation costs

3.2.3 Data Analysis Phase

All the data collected was used for analysis. Primary data was used to classify the composition of the solid waste in AIT. The components found in each location in AIT were used to find opportunities of solid wastes such as recyclable and non-recyclable wastes. Then, the composition of solid wastes, both before and after separating solid wastes was used to compare costs between the two options (recycling versus without recycling). The major data needed in the study is shown as follows:

- The find the percentage composition of solid wastes generated in AIT.
- The total weight of the solid wastes produced from AIT.
- The total weight of recyclable and non-recyclable wastes from AIT.
- The saving costs made at the Tha Kong Municipality and at the transfer station.

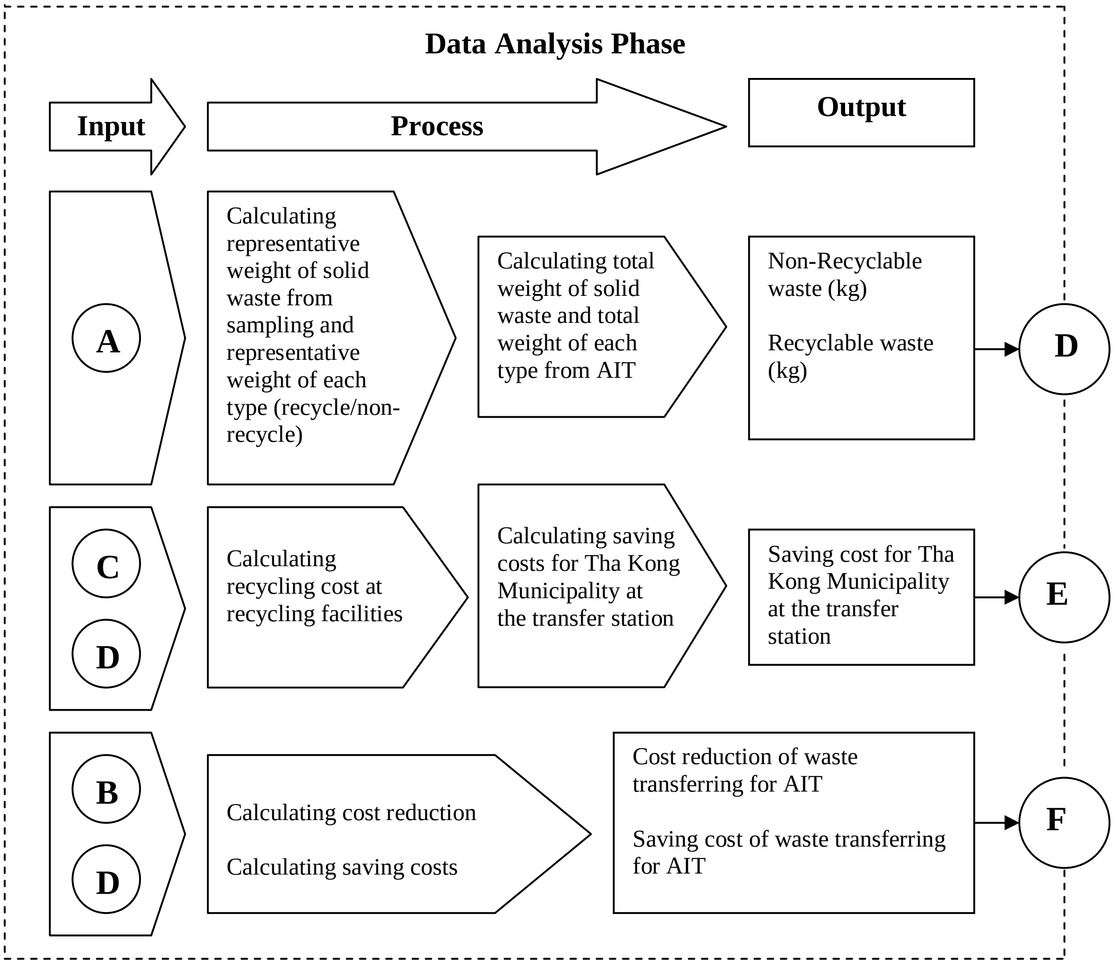


Figure 3.3 Data Analysis Phase for AIT

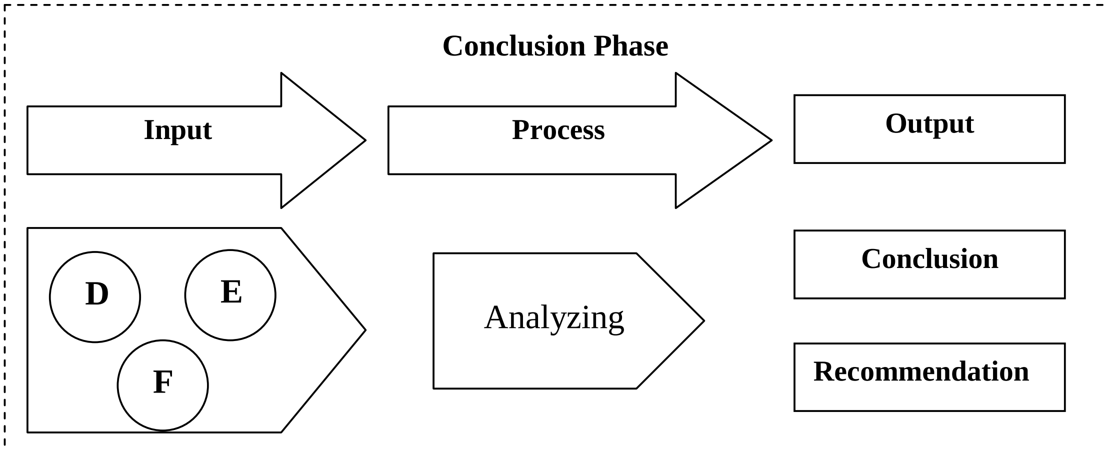


Figure 3.4 Conclusion and Recommendation Phase

3.3 Technical Feasibility Study of Solid Waste Management at AIT using Benefit-Cost Analysis

3.3.1 Data Analysis

The collected data was analyzed in both quantitative and qualitative aspects as follows:

1. Calculate the total amount of recyclables sent to the recycling firms.

2. Compare the total waste production, recyclables and amount of waste to the landfill, to show the percentage of total waste reduction from the recycling activities.

3. Calculate the expansion of the landfill's lifetime according to the waste reduction.

4. Compare the disposal and landfill operating cost with the values of recyclables.

The Figure 3.5 demonstrates the flow chart of analyzing processes as mentioned above

3.4 Solid Waste Segregations and Analysis

The different types of solid waste generated in AIT campus were studied for their composition and the possibility of extending its life cycle. Sample waste generated from different facility buildings were collected, studied and compared. The procedures are illustrated in Figure 3.6.

3.4.1 Waste Characteristics

The following parameters were obtained through the experiment:

Physical parameters:

- Physical components
- Bulk density

Chemical parameters:

- Moisture, ash and combustible content
- Chemical element analysis: C, H, N, S, Cl, O
- Calorific value

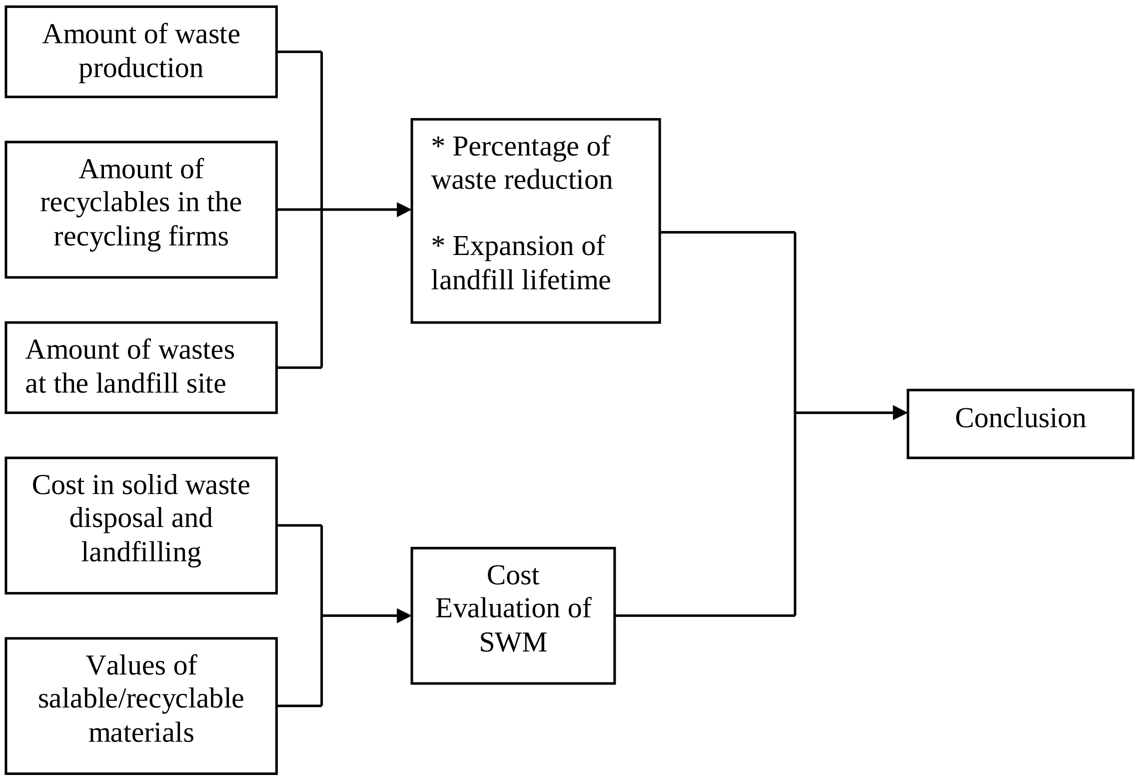


Figure 3.5 Methodology Diagram for the BCA

3.4.2 Analysis of Solid Wastes

Samples were taken from all areas of AIT campus mainly in the dry season. Four samples were collected every day, due to the detailed methods of analysis carried out. The procedure for sampling of solid waste is shown in Appendix A.1. All procedures were followed according to the methods of analysis of refuse stated by the American Public Works Association, 1970.

(a) Physical Components

Physical components are divided into three categories: 1) combustibles, 2) non-combustibles and 3) miscellaneous. Appendix A.3 shows the definition of these components. The procedure for physical classification of solid waste is presented in Appendix A.2. The weight percentages of the physical components mentioned in the Appendices were then calculated.

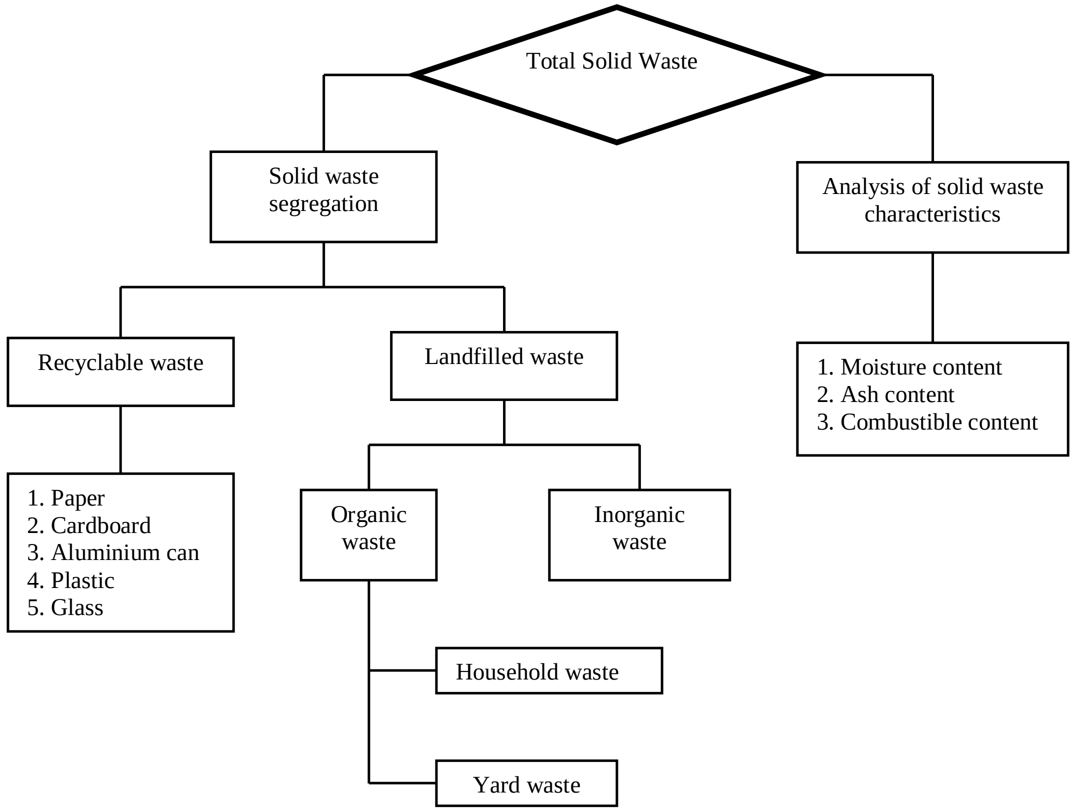


Figure 3.6 Procedures for Segregation and Analysis of Solid Waste

(b) Bulk Density Measurement

The measurement for bulk density was carried out in all the areas of AIT campus. All samples were weighed soon after collection. The procedures are outlined in Appendix A.4.

(c) Moisture Content, Ash and Combustible Contents

Moisture content of unclassified (whole) samples (about 70 g) was measured by keeping it in a constant temperature oven (105^0C) until a constant weight was attained. The dried sample after analyzing for the moisture content was burnt by flaming in the flame hood to analyze the ash and combustible contents. The procedure is given in Appendix A.6.

(d) Chemical Elements and Calorific Value Analysis

The combustible portion of the solid wastes was analyzed for carbon, hydrogen, nitrogen, sulphur, chlorine and oxygen. The chart of the chemical analysis is given in Appendix A.8. The methods for chemical analysis are presented in Appendix A.5.

For the purpose of studying the characteristics of solid waste and to review the options for solid waste recycling and reuse, the data collected was analyzed by simple statistical methods and described through tables, figures, coordinates, schematic diagrams and photographs, etc.

3.5 Solid Waste Audit Study on AIT using a Mass Balance Diagram

3.5.1 Mass Balance

A mass balance or material balance is based on the fundamental law of conservation of mass: "Mass is neither created nor destroyed". Tchobanoglous (1993) showed that the only way to determine the generation and movement of material wastes with any degree of reliability is to perform a detailed materials balance analysis for each generation source. The approach to be followed in the preparation of a material balance analysis is as follows:

- First, draw a system boundary around the unit to be studied (see Figure 3.7). The proper selection of the system boundary is important because, in many situations, it will be possible to simplify the mass balance computations.

- Second, identify all the activities that cross or occur within the boundary and effect the generation of waste.

- Third, identify the rate of waste generation associated with each of these activities.

- Fourth, using appropriate mathematical relationships, determine the quantity of waste generated, collected and stored.

The material balance can be formulated in a general word statement:

Rate of accumulation of material within the system boundary	=	Rate of flow of material into the system boundary	-	Rate of flow of material out of the system boundary	+	Rate of generation of waste material within the system boundary

A general formula for the material balance in the simplified word statement is as follows:

Accumulation = Inflow – Outflow + Generation

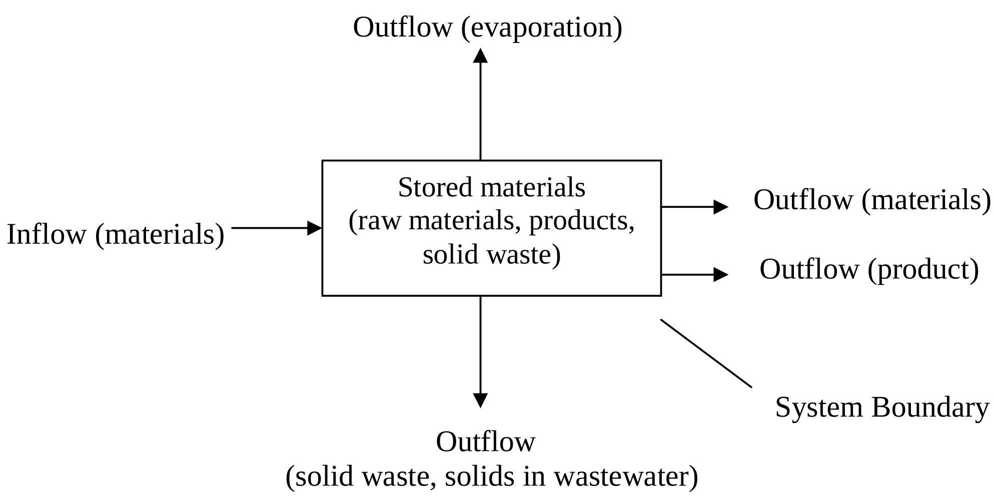


Figure 3.7 Definition Sketch for Material Balance Analysis used to Determine Waste Generation Rates

A material balance may be defined as a precise amount of the inputs and outputs of an operation. It describes a procedure for the collection and arrangement of input and output data. The procedure can be applied to derive the material balance of the processes/unit operations in the recycling activities at AIT. Figure 3.8 illustrates a set of components that need to be quantified to derive a material balance in a waste recycling facility. It notes that infrequent outputs may be as significant as continuous daily discharges.

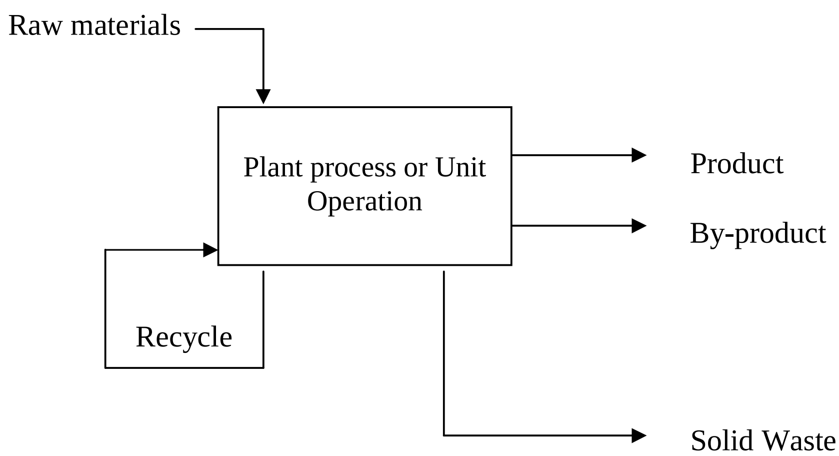


Figure 3.8 Typical Components of a Mass Balance of a Typical Recycling Facility

The mass balance for AIT campus was performed by:

- Determining the total amount of recyclable and non-recyclable wastes.
- Determining the total amount of wastes generated from AIT.
- Determining the amount of products and by-products obtained from the wastes.

Chapter 4

Results and Discussions

4.1 Solid Waste Audits

4.1.1 Solid Waste Compositions

Domestic wastes are generated mostly from the student dormitories and staff quarters, which are mainly organic in nature. Office wastes are those mainly generated from office buildings like the administrative buildings, departmental buildings, AITCC, which are mainly inorganic in nature. AIT generates about 700 tons of domestic wastes annually. The volume of solid wastes produced annually remains constant and there is a slight variation in the annual waste generation during the semester breaks, i.e., during December and June-July. Figure 4.1 below shows the monthly variation of solid wastes generated in AIT.

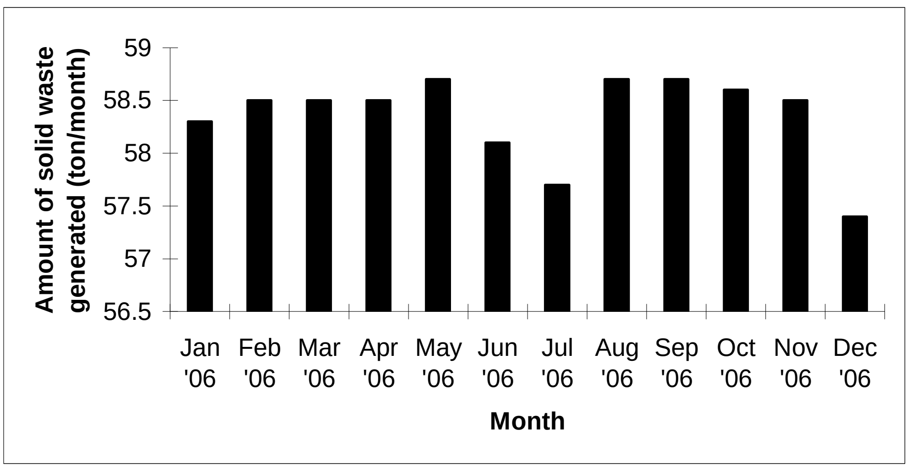


Figure 4.1 Monthly Variations in the Solid Waste Generation at AIT (The Department of Infrastructure of AIT, 2006)

The amount of waste generated per capita was about 0.5 kg/day on an average, but the wastes generated per capita cannot be determined exactly because sometimes a person will be away from AIT during the semester break and sometimes the consumption of resources can be almost negligible at times. Only in dormitoriess and student villages with cooking facilities, can there be a constant generation of organic wastes. The total amount of organic wastes generated in AIT is found to be around 1,140 kg/day and that of inorganic wastes is 760 kg/day.

The Department of Infrastructure of AIT (2006) stated that the amount of yard wastes generated in AIT is about 54 kg/day, which means it constitutes about 3% of total solid waste in AIT. The yard wastes in AIT are generally composted inside AIT itself. The Department of Infrastructure of AIT (2006) stated that 28 tons of recyclable solid waste is generated per year. This is 4% of the recyclable solid waste in AIT, which means that 93% of solid waste in AIT is sent to the landfill. Figure 4.2 below shows the distribution of solid wastes composted, recycled and disposed of in the landfill.

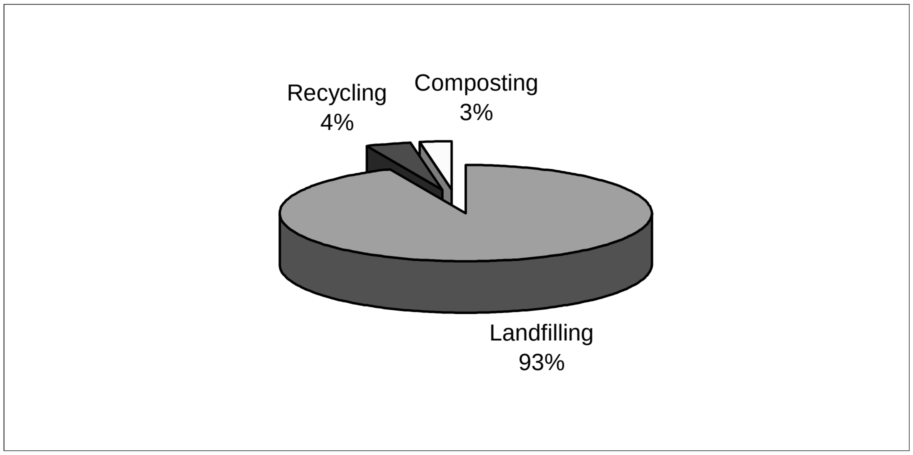


Figure 4.2 Percentage Composition of the Treatment Methods of Solid Waste at AIT (The Department of Infrastructure of AIT, 2006)

4.1.2 Recyclable Solid Wastes

The major recyclable wastes include items such as paper, foam, cans and plastic bags, which, often come from packaging material. It has also been observed that many people eat ready-made and take-home foods. The recyclable wastes are often dirty due to a combination of various kinds of solid wastes into one bin. In this case, scavengers do not want to collect these wastes, therefore, they dispose them into the landfill. This is the reason behind the high amount of wastes sent to the landfill.

The composition of recyclable wastes is shown in Figure 4.3. Every month, scavengers earn about 15,100 baht from the sales in recycling of solid wastes. It has been reported that 0.2% of the food wastes generated by the cafeterias and the AITCC is sold to vendors outside AIT as animal feed.

The remaining 3.8% is sold to industries, which reuse and recycle these solid wastes. The Solid Waste Recycling Bank located behind the football field and near the Student Village III holds 93% of the solid waste in AIT, which is eventually disposed in the Tha Kong Municipality landfill. The scavengers collect the recyclable wastes and the municipal authorities send a truck to transport the solid wastes to the landfill weekly every Friday.

Bottles are the highest in the recyclable wastes, most of them are drinking water bottles and the selling price of recycled bottles is also the highest amongst all the recyclable wastes (see Table 4.1). In AIT, 89% of the paper is generated from the offices: printed paper, copied paper, most of which are reusable. The amount of cardboard may be large on a few occasions when some office equipments or computers are bought. Glasses and cans are normally less compared to the amount of their generations, which are usually generated from residential areas. Paper usually forms the major portion of the solid waste. Waste paper can be properly collected and sent to the recycled paper industry.

4.1.3 Solid Waste Audits at Different Locations of AIT

Sources of solid waste generation have been divided into 5 categories such as AITCC, student areas, staff areas, offices (including the AIT Community School) and cafeterias, including other eating areas. The details of the solid waste are explained in Table 4.3. The major wastes are generated from the domestic areas, which comprises of 54.7% of the total solid waste generation. 60% of the solid waste in AIT is organic in nature and 18.4% of the total waste generated from office is inorganic in nature, which is mostly sent for recycling.

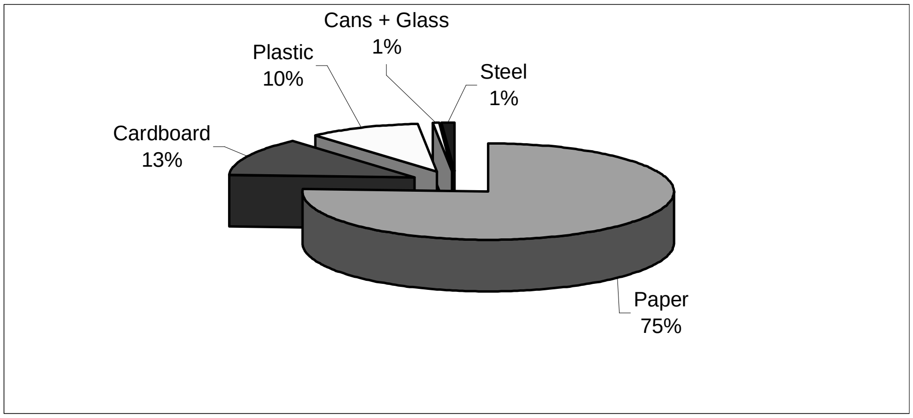


Figure 4.3 Percentage Composition of Recyclable Wastes at AIT (Modified from Soulalay, 2006)

There are a total of 68 rooms in each student dormitory and staff quarter, and each student dormitory & staff quarter generates about 20 kg/day of solid wastes. The average solid waste generation from student dormitories and staff quarters is 0.3 kg per day per capita. The inorganic component of the solid wastes from the student dormitories is as high as 195 kg/day, due to the purchasing of ready-made foods from the mini-marts, high usage of paper, plastics, printer cartridges, etc.

Table 4.1 Types and Prices of Recyclables at AIT

Type	Average Price (baht/kg)
White/Black Paper (less than 50 kg)	6.00
White/Black Paper (more than 50 kg)	7.00
Cardboard (less than 50 kg)	3.50
Cardboard (more than 50 kg)	4.00
Transparent Plastic Bottles (less than 50 kg)	13.00
Transparent Plastic Bottles (more than 50 kg)	14.00
Coloured Plastic Bottles (less than 50 kg)	17.00
Coloured Plastic Bottles (more than 50 kg)	17.00
Glass Bottles (less than 50 kg)	1.00
Glass Bottles (more than 50 kg)	1.50
Plastic Bags	8.00
Plastic Cups	10.00
Mixed Paper Pieces (less than 50 kg)	1.50
Mixed Paper Pieces (more than 50 kg)	2.00
Newspapers	4.00
Aluminium Cans (coke cans)	45.00
Aluminium Cans (coffee cans)	30.00
Steel (except stainless steel)	3.00

Source: The Department of Infrastructure of AIT, 2006

The academic buildings comprises of the faculty and staff offices, seminar halls, classrooms, computer labs, departmental labs and project offices. It is estimated that the average number of people working in these academic buildings each day is around 450. There are 4 academic buildings which comprise of students from the 4 schools: SOM, SET, SCE and SERD.

The administrative building houses the registry, the finance department, the GRO, the Department of Infrastructure, Siam Commercial Bank and the post office. There are 500 staff members and workmen in total, currently working in the administrative buildings of AIT. The total amount of solid waste generated in the offices is about 350 kg/day, which makes the average solid waste generated in offices about 0.15 kg per day per capita.

Table 4.2 Total Amount and Sales of Recyclable Wastes at AIT

No.	Items	Amount of Recyclable Wastes	
		(kg/month)	(Sales/month in baht)
1	Newspapers	95	380
2	Cardboard	300	1,200
3	Plastics	235	3,400
4	Black/White Paper	1,260	8,800
5	Mixed Paper Pieces	400	800
6	Cans	10	420
7	Steel	27	80
8	Glass	13	20
	Total	**2,340**	**15,100**

Source: Modified from Soulalay, 2006

In AIT, 50% of the solid waste generated from these offices is paper. Drinking water bottles, soft drink bottles, glass, cans and cardboard form the remaining part of the wastes. Cardboards generally originate from packaging of electronic devices such as computers, printers, scanners, hand phones, etc. All the wastes are inorganic in nature and recyclable wastes such as foam, paper, plastic bags, tissues, milk bottles, paper cups, etc., are present.

Table 4.3 Percentage Composition of Solid Waste at AIT

No.	Items	Total Garbage (kg/day)		Total Solid Waste (kg/day)	Composition of Solid Waste (%)
		Organic	Inorganic		
1	AITCC	80	20	100	5.3
2	Offices	40	310	350	18.4
3	Staff Areas	310	175	485	25.5
4	Student Areas	360	195	555	29.2
5	Cafeteria + other vendors	350	60	410	21.6
	Total	**1,140**	**760**	**1,900**	**100**
	% by weight	**60%**	**40%**	**100%**	

Source: Modified from Soulalay, 2006

4.1.4 Waste Recycling Facilities at AIT

AIT currently has a waste recycling bank (Figure 4.4) where all the solid wastes of AIT are collected and the recyclable items are sorted out. Some of the collection crew, the sweepers, clean the rooms and collect plastic bags, plastic bottles, glass bottles, waste paper according to the convenience of the tenants staying in the dormitories and quarters. The remaining part of the wastes are sent to the landfill, located in the Tha Kong Municipality.

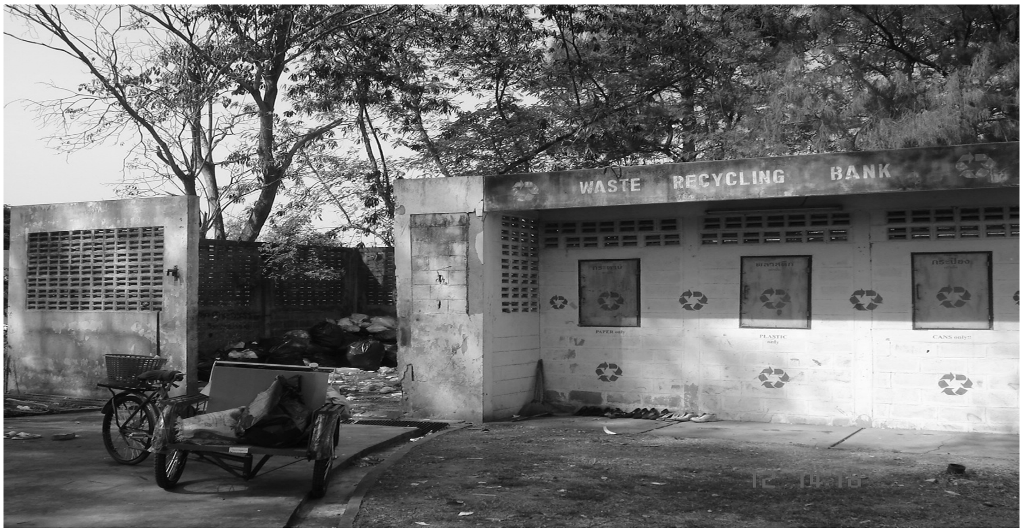


Figure 4.4 Waste Recycling Bank at AIT

Open dumps (Figure 4.5) have been observed around the SOM building, which is of grave concern to the people who visit the area. There are students conducting research work from the Food and Bioprocess Technology, Aquaculture, Agricultural Science and Engineering Programmes of SERD and the Department of Water Engineering and Management Programme of SCE. These open dumps represent the solid wastes that cannot be accommodated in the Waste Recycling Bank.

Figure 4.5 Open Dump Site Found in AIT Behind the SOM Building

It is of serious concern, especially during the rainy season and the early mornings when the moisture content of these wastes increases. As a result of which the chemical substances from these wastes leach into the soil. This can have adverse effects on the crops around the area, as well as render the soil infertile.

4.1.5 Mass Balance for Solid Waste Generation and Recycling Activities in AIT

The Department of Infrastructure of AIT (2006) reported that 19 kg/day of manure was obtained from composting of yard wastes, the amount of CH_4 and CO_2 from the landfill in the Tha Kong Municipality was estimated at 13 kg/day and 30 kg/day respectively, and that the amount of CH_4 and CO_2 generated from the composting plant in AIT was found to be 8 kg/day and 11 kg/day respectively. Based on the flow chart of the solid waste generation and the recycling activities within and outside AIT illustrated in Figure 4.6, the mass balance of the entire system can be performed.

According to the data conducted in the solid waste audit, we assume the set of variables as:

W_T = Total amount of solid wastes generated per day (kg/day) = 1900 kg/day
R = Solid wastes per day sent to recycling industries (kg/day) = 72 kg/day
C = Solid waste sent for composting in AIT (kg/day) = 54 kg/day
P = Solid By-product in composting of solid wastes (kg/day) = 19 kg/day (manure)
P_c = Gaseous By-product in composting plant in AIT (kg/day) = 19 kg/day (CO_2 + CH_4)

P_l = Gaseous By-product in landfilling of solid wastes in the Tha Kong Municipality (kg/day)
= 43 kg/day (CO_2 + CH_4)
F = Amount of solid waste sold as animal feed (kg/day) = 4 kg/day
W_l = Amount of solid wastes discharged to the landfill (kg/day)

To crosscheck the obtained data, the mass balance for the solid wastes was established. If all the obtained data are correct and all the inflows and outflows are accounted for, the input should be equal to outputs, in this case:

Input = $W_T + R$ = (1900 + 72) kg/day = 1972 kg/day
Output = $R + C + P + P_c + P_l + F + W_l$ = (72 + 54 + 19 + 19 + 43 + 4 + W_l) kg/day
= (211 + W_l) kg/day

So, the mass balance can be implemented as follows:

Input = Output

1972 kg/day = (211 + W_l) kg/day

Therefore, W_l = 1761 kg/day, which is close to the practical value of 1771 kg/day of wastes which is disposed into the Tha Kong Municipality Landfill. Figure 4.7 illustrates the mass balance for total solid waste generation in AIT. The value W_l is proof of the fact that about 93% of the total solid waste generated in AIT is disposed into the landfill.

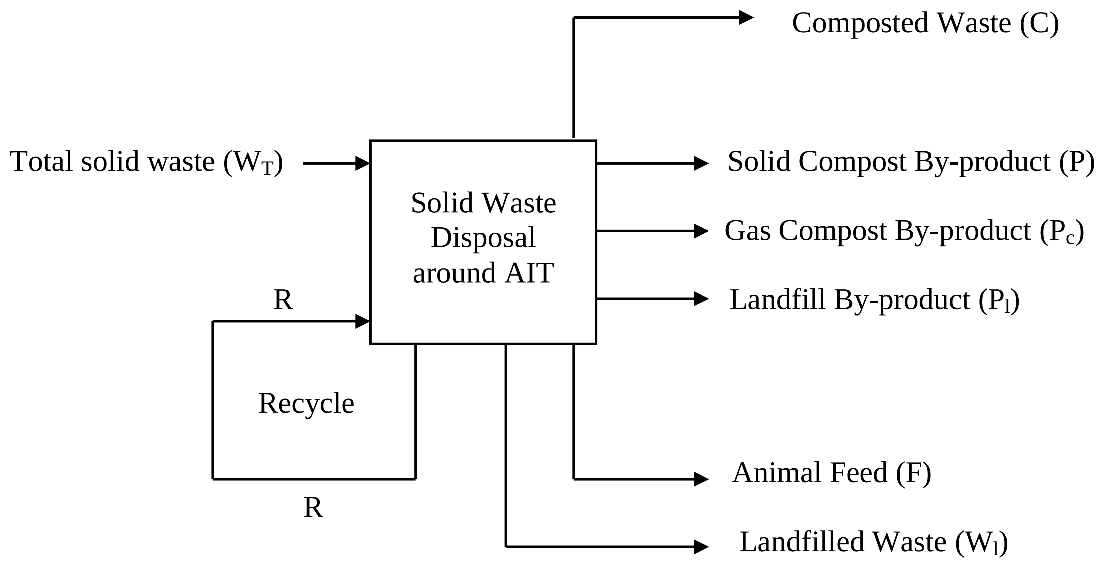


Figure 4.6 Solid Waste Generation and Disposal Component for Mass Balance at AIT

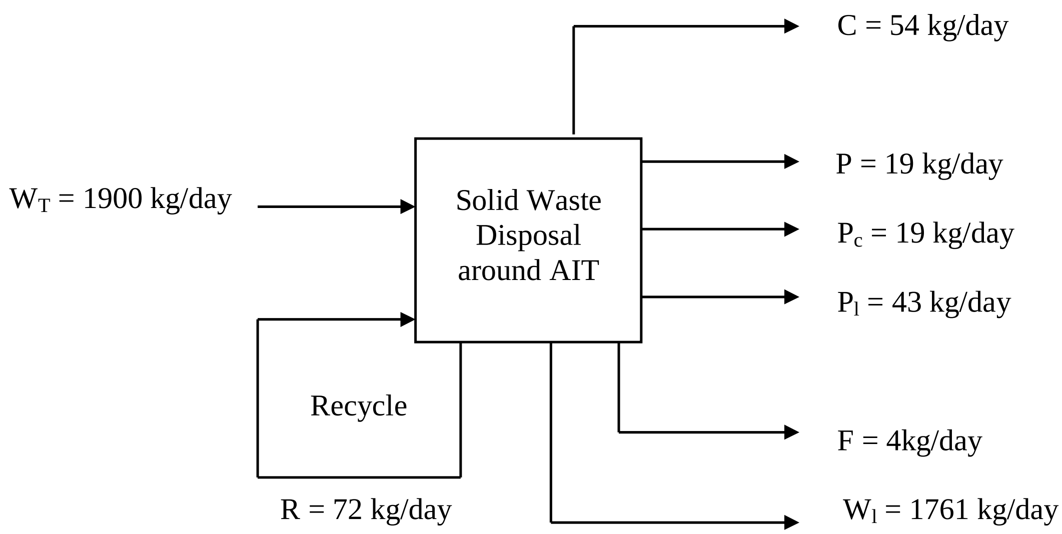


Figure 4.7 Result of Mass Balance for Solid Waste Generation and Disposal Component of AIT

4.2 Characteristics of Solid Wastes During the Study Period

One of the key problems of discussion of solid waste characteristics is related to the points of measurement. It was difficult to characterize the source of the waste bins in AIT due to the fact that they were in scattered locations and could not be classified under a specific location. For example, waste bins were located in between the academic buildings and the administrative buildings.

The other problem was the moisture content present in the solid wastes in particular sections of AIT due to plastic covers in the waste bins being wet. For example, waste bins found in the academic and administrative buildings had high moisture contents due to the fact that plastic cups with iced tea/coffee and also due to other solid food wastes present at the time of physical and chemical analysis of the solid wastes.

The physical and chemical characteristics of solid wastes analyzed from all the locations are presented in graphical form in Appendix B over the 40-day period.

4.2.1 Physical Components

Components that typically make up most of the municipal solid wastes are: food wastes, paper, cardboard, plastics, textiles, rubber, leather, garden trimmings, wood, glass, tin cans, non-ferrous metals, dirt, ashes, bricks, etc.

On the basis of physical components, the composition of food wastes was highest among all the combustible components, with an average of 59.8%. Plastics and paper ranked next (25.1% and 5.4% respectively). Leather and rubber had an overall average of 1.9%, while that of textiles was 1.6%. The least among the combustibles were grass and wood with an average composition of 0.15%. Overall, the combustibles comprised 88.5% of the total solid waste on a wet basis. The physical characteristics of the five samples are presented in Table 4.4.

Table 4.4 Physical Characteristics of Solid Waste

Component (weight % in wet basis)	First Sampling Period	Second Sampling Period	Third Sampling Period	Fourth Sampling Period	Fifth Sampling Period
1. Combustibles	93.9	93.7	94.6	93.6	93.8
Paper	4.5	4.8	6.0	5.3	6.2
Textiles	1.5	1.2	1.9	1.8	1.5
Grass & Wood	-	0.1	0.2	0.2	0.1
Leather & Rubber	2.0	2.5	2.8	1.2	1.2
Plastics	23.6	24.8	24.5	26.7	26.0
Food Wastes	62.3	60.3	59.2	58.4	58.8
2. Non-combustibles	3.65	3.4	3.4	3.5	3.5
Ferrous Metals	0.4	0.25	0.2	0.5	0.4
Non-ferrous Metals	0.35	0.15	0.2	0.3	0.2
Glass	2.9	3.0	3.0	2.7	2.8
Ceramics	-	-	-	-	0.1
3. Miscellaneous	1.8	2.1	1.5	2.1	1.9
4. Packaging Wastes	0.65	0.8	0.5	0.8	0.8
5. Total	100	100	100	100	100
6. Bulk Density (kg/m^3)	344	375	281	328	375

The metallic content (ferrous) of the solid wastes in AIT was found to be 0.35%, while the non-ferrous materials were 0.25%. Glass had the highest in terms of percentage composition of non-combustibles of about 2.9%, while ceramics was found in negligible quantities. The non-combustibles comprised 3.5% of the total solid waste in AIT. The miscellaneous materials in the municipal refuse represented 1.9% of the total solid waste in AIT.

The change in the percentage of food wastes over five weeks was due to the fact that during the first week it had rained slightly. During this period there was a partial degradation of vegetables and fruits and the moisture content of some of the samples were significantly high. However, during the second, third, fourth and fifth week, the weather was relatively dry and a lesser amount of miscellaneous components had been classified because vegetable/fruit skins and peelings could be easily identified and sorted manually.

There was a high amount of plastic cups found in the five mixed samples, which represents about 23.4% of the solid wastes in AIT. The average bulk density of the solid wastes of the five mixed samples was found to be about 341 kg/m^3. It had also been found after measuring the five samples for physical components that around 0.7% of the wastes have been found to packaging wastes such as beverage cartons, chips packages, etc. The average composition of wastes in AIT is as shown in the Figure 4.8.

There will not be any significant changes in the waste composition during the next five years in AIT. Although paper and plastic contents will increase in the future, it is expected that the amount of these wastes will not change much unless a recycling programme is inculcated in AIT. To reduce wastes in AIT, there has to be major changes in the markets in Thailand and the Governments have to introduce stringent laws in order to carry out recycling programmes efficiently.

4.2.2 Chemical Composition

The average chemical characteristics of the solid waste are presented in Tables 4.5 (a) and 4.5 (b). The moisture content in the waste recycling bank, student dormitories, student villages, staff quarters and the cafeterias was found to be higher because of the higher amount of organic wastes found. In the AITCC, academic and administrative buildings, the moisture content was slightly high because of a lot of food wastes were present. Generally, there is a high amount of paper, glass and plastic wastes found in these areas. In the open dumps, however, the moisture content was found to be slightly lower than that of the AITCC, because there were mainly inorganic wastes present there such as paper, plastics, grass and wood, ferrous and non-ferrous metals.

The ash content is generally an indicator of the amount of organic wastes present in the wastes. In the student dormitories, student villages and cafeterias, the ash content is generally found to be low because of a large amount of food and organic wastes generated. In the AITCC and the open dumps there is a higher amount of paper, glass and plastic wastes generated. In typical municipal solid wastes, the ash content is generally around 5-10% for organic wastes. Inorganic wastes generally have an ash content as high as 20-30%. (Tchobanoglous, 1993)

The ash content is also an indicator of how good the quality of the solid wastes is for use as fuels. In this case, however, the wastes that had low ash content, had a high calorific value than those with a higher ash content, as the wastes present in the above mentioned area were not purely organic wastes. The food wastes were mixed with different kinds of wastes such as paper and plastics. Hence, the calorific value of these wastes was much higher than those with mainly inorganic wastes. The wastes with a higher nitrogen and lower oxygen

content were also found to have a high calorific value, due to the high amount of nitrogenous products, methane, carbon dioxide and hydrogen sulphide generated.
The most critical environmental factor for composting is the carbon-to-nitrogen ratio (C/N ratio). The optimum range for most organic wastes is from 20 to 25 to 1. Sewage sludge has a low C/N ratio, whereas yard wastes such as leaves, and newspapers have relatively high C/N ratios. In general, all of the organic nitrogen present in most organic compounds will become available, whereas not all of the organic carbon will be biodegradable. (Tchobanoglous, 1993)

Table 4.5 (a) Chemical Characteristics of Solid Waste

Chemical Composition (weight % in dry basis)		**Student Dormitories**	**Student Villages**	**Waste Recycling Bank**	**Cafeteria/Minimart Areas**
Moisture Content		73.87	80.29	77.43	75.69
Ash Content		9.48	7.22	8.67	9.71
Combustible Content		16.65	12.49	13.90	14.60
Total		100.00	100.00	100.00	100.00
Chemical Element Composition of Solid Waste	C	22.48	22.76	22.62	22.61
	H	8.99	9.10	9.05	9.04
	N	12.49	14.76	14.26	13.74
	O	11.34	8.82	9.91	10.74
	S	1.99	2.02	2.02	2.00
	Cl	0.47	0.52	0.61	0.47
	Total	57.76	57.98	58.47	58.60
Gross Calorific Value (MJ/kg)		16.90	17.68	18.84	16.04

Table 4.5 (b) Chemical Characteristics of Solid Waste (Contd.)

Chemical Composition (weight % in dry basis)		**AITCC**	**Staff Quarters**	**Academic Buildings**	**Administrative Buildings**	**Open Dumps**
Moisture Content		62.91	77.72	60.84	48.39	58.07
Ash Content		15.64	8.51	16.04	19.72	19.24
Combustible Content		21.45	13.77	23.12	31.89	22.69
Total		100.00	100.00	100.00	100.00	100.00
Chemical Element Composition of Solid Waste	C	22.41	22.59	22.33	22.29	22.58
	H	8.96	9.03	8.93	8.92	9.00
	N	11.28	13.56	10.50	8.75	10.59
	O	15.09	9.82	16.36	19.96	16.33
	S	1.98	2.00	1.97	1.96	1.96
	Cl	0.39	0.49	0.41	0.38	0.44
	Total	60.11	57.49	60.50	62.26	60.90
Gross Calorific Value (MJ/kg)		15.81	16.65	17.05	14.35	14.23

The C/N computed on the basis of total weights of carbon and nitrogen can be quite misleading depending on the particular waste material, especially in those cases where all of the available nitrogen is biodegradable, but only a portion of organic carbon is biodegradable (e.g., lignin in waste paper). Assuming that all of the nitrogen is available, the C/N ratio for the organic fraction of MSW can vary from about 34 to 60 depending on whether it is assumed that the available carbon is partially or totally biodegradable. (Tchobanoglous, 1993)

Blending of a waste high in nitrogen (e.g., newsprint) with a waste that is high in nitrogen (e.g., yard wastes) is used to achieve optimum C/N ratios for composting. The other design factor that may affect the blending of organic fraction of municipal solid waste for composting is moisture content. The optimum moisture content for aerobic composting is in the range of 50-60%. Moisture can be adjusted by blending of components or by addition of water. When the moisture content of compost falls below 40%, the rate of composting will be slowed. (Tchobanoglous, 1993)

Manure or sludge from wastewater treatment plants can be blended to provide a near optimum C/N ratio, if the organic fraction of MSW contains significant amounts of paper or other substances rich in carbon. Materials too wet and too dry for good composting can be blended in proper proportion to achieve an optimum value of moisture content. Seeding involves the addition of a volume of microbial culture sufficiently large to effect the decomposition of the receiving material at a faster rate. (Tchobanoglous, 1993)

The average C/N ratio of solid waste at AIT is about 1.84. The C/N ratio of the solid waste samples from the open dumps was found to be 2.13, where most of the solid wastes were gardening wastes. This indicates that the solid waste is not suitable to be used in composting, and hence cannot be used as a natural fertilizer like manure. It could be used in composting after seeding, however, it maybe expensive to compost large amount of solid wastes with microbial cultures. This is due to the fact that sewage sludge has to be acquired from the Thammasat Wastewater Treatment Plant, and nutrient medium like agar has to be bought and added to the sludge and mixed with the solid wastes.

According to the European Commission (2003), if the solid waste has a calorific value of 15 MJ/kg or more, it is highly recommended for use as refuse-derived fuel (RDF). The results show that the solid wastes from the student dormitories, student villages, staff quarters and the cafeteria areas have the highest calorific value, moisture content, carbon and nitrogen. This shows that the solid wastes from these areas in the AIT campus are of great value in the manufacture of RDF.

Gases found in landfills include ammonia (NH_3), carbon dioxide (CO_2), carbon monoxide (CO), hydrogen (H_2), hydrogen sulphide (H_2S), methane (CH_4), nitrogen (N_2), and oxygen (O_2). Methane and carbon dioxide are the principal gases produced from the anaerobic decomposition of the biodegradable organic waste components in MSW. When methane is present in air in concentrations between 5 and 10%, it is explosive. Because only limited amounts of oxygen are present in a landfill when methane concentrations reach this critical level, there is little danger that the landfill will explode. However, methane mixtures in the explosive range can form if landfill gas migrates off-site and mixes with the air. (Tchobanoglous, 1993)

The hydrogen and oxygen content of the solid waste at AIT was found to be very high. The hydrogen content was found to be 9% and the oxygen content was found to be 13.35%. These values are higher than the normal hydrogen and oxygen concentrations in landfills of 0.2% and 1% respectively (Tchobanoglous, 1993).

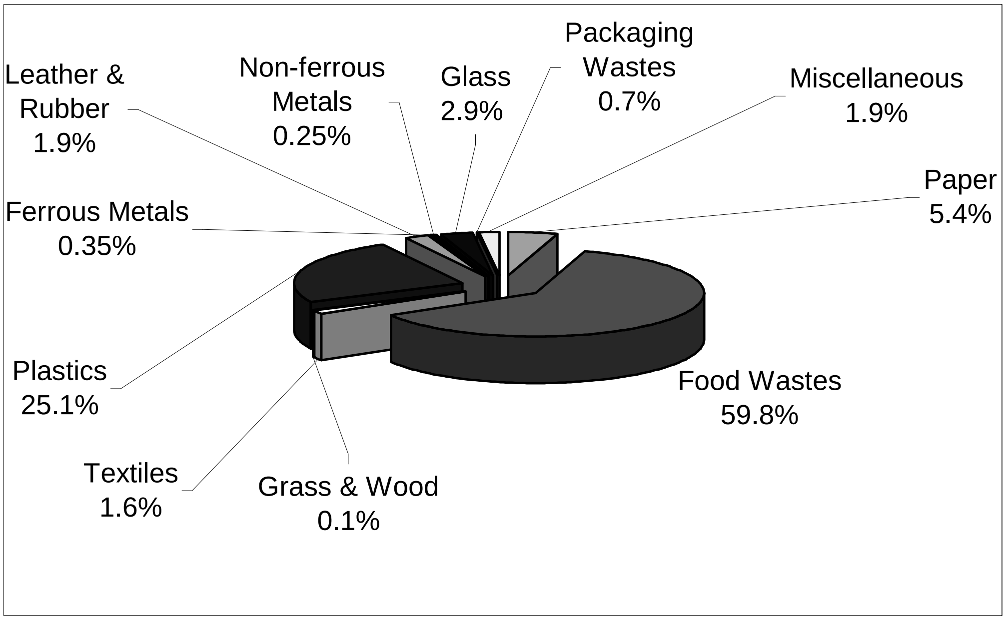


Figure 4.8 Physical Composition of Solid Waste at AIT

The solid waste from AIT which is sent to the landfill can cause explosions in the landfill due to a high hydrogen content, since the high hydrogen content indicates that high amounts of methane and hydrogen sulphide gas are present in the solid waste. The high oxygen content can initiate an explosion when it comes in contact with methane and hydrogen sulphide gas, since oxygen is a combustible gas and can start fires. (Tchobanoglous, 1993)

The high sulphur content of 1.99% indicates that high amounts of hydrogen sulphide are formed as a result of organic degradation, which results in a rotten smell of the solid waste. This is caused when wastes are mostly organic in nature and when they are kept in anaerobic conditions for a long period of time, which prevail in the closed garbage bins and the plastic bags where they are stored in the Waste Recycling Bank at AIT.

According to Tchobanoglous (1993), the chlorine content of the solid waste at AIT was analyzed due to concern of emission of chlorinated compounds during combustion.

4.2.3 Comparison of the Results of the Present Study with the Results of Tsai (1993)

A comparison of the physical and chemical composition of the study conducted by Tsai (1993) and the present study are shown in Table 4.6 and 4.7 respectively. The purpose of the comparison was done to compare the characteristics of typical municipal solid wastes in a city like Bangkok to that of the municipal solid wastes in AIT.

From Table 4.6, the physical components in the present study vary quite considerably as compared to the study conducted by Tsai (1993) in Bangkok. It was found that the amount of combustibles in AIT was much higher because of a higher amount of food wastes and plastics generated. However, in a city like Bangkok, it is found that the distribution in the composition of wastes is uniform. That can be shown due to the fact that the percentage composition of paper, textiles, grass and wood in Bangkok is much higher as compared to the composition of solid wastes in AIT.

Table 4.6 Comparison of Physical Characteristics of Solid Waste Obtained from the Present Study with the Results of Tsai (1993)

Physical Component (weight % in wet basis)	Results of Present Study	Results of Tsai (1993)
1. Combustibles	93.9	79.6
Paper	5.4	17.0
Textiles	1.6	4.7
Grass & Wood	0.1	7.0
Leather & Rubber	1.9	0.7
Plastics	25.1	15.2
Food Wastes	59.8	35.0
2.Non-combustibles	3.5	9.8
Ferrous Metals	0.35	2.1
Non-ferrous Metals	0.25	0.9
Glass	2.9	4.3
Ceramics	-	2.5
3. Miscellaneous	1.9	10.6
4. Packaging Wastes	0.7	-
5. Total	100.0	100.0
6. Bulk Density (kg/m^3)	341	341

In 1993, packaging wastes were not known to be a large threat to the environment as compared to the present day study. This study points out that the significance of these wastes with respect to the environment, in the sense that they are more toxic and hazardous as compared to the other wastes present in the environment. For a small place such as AIT, packaging wastes and food wastes represent 0.7% and 25.1% of the total solid wastes generated in AIT. The plastic waste is quite high as compared to that of Bangkok, whose population is much greater than that of AIT.

However, it was found that the non-combustible and miscellaneous wastes in Bangkok were much higher than that of AIT. This is due to the fact that the population in AIT is smaller and the people use lesser amount of canned foods, drinks and also glass bottles. The use of plastic bottles, cups, containers and bags is very high in AIT on the whole, due to the fact that most of the minimarts serve food and drinks in these plastic items.

The ceramic wastes in AIT were found to be negligible due to absence of construction wastes being dumped with the other wastes. In Bangkok, however rubble from construction sites will be found in significantly larger quantities in the solid waste stream. It is obvious that the miscellaneous items in Bangkok will be more than that of AIT due to the higher amounts of bones, shells, hair and ash found in the solid wastes.

The bulk density of the wastes, however, was found to be exactly the same in both the studies, even though a 500 kg sample of combined wastes from the open dump sites of On-Nooch and Nong-Khaem located in Bangkok, was used in the physical analysis of the solid waste. In AIT, however, a 100 kg sample of combined wastes was chosen from all the locations of AIT in order to have a sufficiently large amount of solid waste for the determination of the percentage of physical components.

Table 4.7 Comparison of Chemical Characteristics of Solid Waste Obtained from the Present Study with the Results of Tsai (1993)

Chemical Composition (weight % in dry basis)		Results of Present Study	Results of Tsai (1993)
Moisture Content		68.36	56.18
Ash Content		12.69	14.69
Combustible Content		18.95	29.13
Total		100.00	100.00
Chemical Element Composition of Solid Waste	C	22.51	15.33
	H	9.00	2.22
	N	12.21	0.51
	O	13.35	10.69
	S	1.99	0.09
	Cl	0.46	0.29
	Total	59.52	29.13
Gross Calorific Value (MJ/kg)		16.39	17.60

From the above studies, it is found that in the present study, the moisture content is high in the all the wastes in AIT. This is due to the fact that the plastic bags kept inside the bag are wet because plastic cups filled with liquids such as coffee, tea and water formed as a result of melting of ice cubes placed inside them. There is also a lot of food wastes found from almost all sections of AIT, since many people consume food within the academic and administrative buildings.

In Bangkok, however, the volume of wastes is larger and there is a lesser organic fraction in the wastes as shown in the analysis of physical components by Tsai. Hence, the moisture content is lesser in the solid wastes analyzed in Bangkok. These wastes had high amounts of paper, rubber, leather, textiles, bones and ceramics, which contributed to a high ash content in the solid wastes, and therefore, a higher average calorific value as compared to the wastes found in AIT.

The chemical element composition of solid wastes was also high in AIT due to the high rate of anaerobic decomposition of the solid wastes from the garbage bins from the student dormitories, student villages, cafeterias, waste recycling bank and the staff quarters. The high amounts of elemental carbon, hydrogen, oxygen, nitrogen and sulphur show that high amounts of carbon dioxide, methane, hydrogen sulphide, nitrates, nitrites and urea are present in the solid waste.

The elemental compositions are much greater than those found in Bangkok and shows that the solid wastes in AIT have good potential in the manufacture of RDF. The only difference lies in the fact that the C/N ratio of the solid waste in Bangkok was as high as 30 and is suitable for use in composting, as compared to the solid waste in AIT which was found unsuitable for use in composting. The hydrogen content and the oxygen content of the solid waste at Bangkok was found to be in optimum amounts, whereas, the hydrogen and oxygen content of solid waste at AIT was found to be very high.

The sulphur content of the solid waste at AIT was much higher than that of the sample analyzed from Bangkok. The chlorine content of the solid waste at AIT, however was a little higher than the solid waste at Bangkok, and indicates that the solid waste at AIT can be more hazardous due to emission of chlorinated compounds during combustion, in the manufacture of RDF.

4.3 Potential for Reduction, Reuse and Recycling of Solid Waste at AIT

4.3.1 Source Reduction and Segregation of Solid Wastes

It is found that there is a large use of packaged and ready-made foods on campus. This means that there is a high use of plastic packaging. There is also a high amount of plastic cups and packaging materials generated from the bakeries, cafeterias on campus. From primary data obtained during the analysis of solid wastes, it has been found the percentage of plastic and packaging wastes was found to be 25.1% and 0.7% respectively. This is a very high amount of solid wastes generated by an institute with a small population of 3,800.

In Thailand, people are not aware of the fact that plastics cannot be easily recycled and are not educated well in environmental ethics and management. Stringent rules such as manufacturing a smaller amount of plastic bags can only come into play, only and only if the Government authorities realize that plastic is difficult to recycle in general.

It is difficult to prevent the use of plastic items in Thailand, because there are many marketing issues related to it. For example, enforcing stringent laws in AIT regarding the use of plastic items could hamper the business of coffee shops, bakery shops and minimarts, which originate from Bangkok. This would mean revamping the entire solid waste management process in Thailand, and it is only possible using the top-down approach. The top-down approach signifies the actions taken by the higher authorities in the Government of Thailand to improve the environment of the Thai citizens.

Future Park in the Rangsit area in Thailand has a system in which dry wastes are separated from the wet wastes as shown in Figure 4.9. It is an easy, simple and cost-effective way to segregate wastes, reduce the amount of wastes reaching the landfill and will encourage more recycling, and reuse of thrown away items, like glass bottles containing soft drinks, juices, milk etc.

The word “Reduce” can also be used to describe the process in which the load of solid wastes on the landfill can be reduced substantially. There can be a reduction in volume of the wastes by purchasing items, which are compact in nature and can be torn, crushed or folded after use. This decreases the cost of transportation, by reducing the number of visits made by the municipal authorities to the landfill or the recycling facilities.

A good example is that of beverage cartons made of six layers of packaging. This is known as brick packaging and is the most compact form of packaging and is packed in the form of a tetrahedron, which is popularly known as a “tetrapak”. Hence, a famous worldwide food packaging and processing company decided to take the name Tetra Pak, based on the terminology used in the packaging of these foods.

Waste segregation is being practiced in many areas of Bangkok, as well as in schools and universities such as Chulangkorn, Thammasat and Kasetsart Universities. The Thai Government has taken initiatives by using different coloured waste bins for disposing various kinds of wastes. For example, plastic bottles, cups are put into a yellow waste bins and food wastes are put into a blue waste bins, and paper items are put in green waste bins as shown in the Figure 4.10.

Figure 4.9 The Recycling Programme Employed in Future Park

Figure 4.10 Garbage Bins of Different Colours for Different Kinds of Waste (Visvanathan et al., 2004)

4.3.2 Opportunities for the Application of 3R Principles at AIT

Solid waste management has to be concentrated more around the cafeteria/minimart areas as well as the student dormitories and staff quarters. Cardboard paper cups that are easier to manufacture and recycle, as compared to plastic cups should be used. Food products should be bought from the shops that sell more of these paper cups. Wastage of food as far in the cafeteria areas should be avoided as far as possible, which can also help to reduce the load of wastes in the landfills and open dumps. The use of plastic spoons, plates or any such items should also be avoided in the cafeteria areas as far as possible.

Plastic bags should be avoided as far as possible, unless a large amount of items have to be transported. Plastic bags with single items such as coke cans, tetra pak cartons and throwing these items along with these bags should be avoided completely. Plastic bags should be reused again for carrying a large number of items. Jute bags or carry bags owned by individuals can be used to carry a large number of items at the groceries, shops and minimarts as a substitute for plastic bags. Disposing of food and organic matter in plastic bags should be completely avoided. The use of separate garbage bins to segregate dry and wet wastes is a much better practice. Dry wastes consist mainly of paper, cardboard and plastics, and wet waste generally consist of food wastes such as vegetable, fruit peels, meat pieces and bones.

Small amounts of paper should be used, and the space available on paper should also be used as far as possible. As soon as the paper loses its value, the paper should be given to the collection crew. Even old plastic bottles should be given away as soon as de-colouration of the bottle is noticed (i.e., when a transparent bottle starts looking yellowish in colour). Plastic cups and plastic bags that are used must not be thrown thoughtlessly into the garbage bins. These items must be kept with people until the collection crew come to AIT to collect wastes and during the cleaning of dormitories, the cleaning staff from the SAO should collect these recyclable items. They can also be reused for eating, drinking and for storing utensils in the dormitories and should be given away to the collection crew when they are rendered useless after a long period of time (say one year).

4.3.3 Site Selection of Recycling Facilities at AIT

The waste recycling bank should be located away from the inhabitants in AIT. In this way, the effect of the bad odour will be diluted by the winds and it is far away from the densely populated areas of AIT. The economic and “convenience” aspects should also be seriously considered The more convenient method would be to improve the conditions of the existing waste recycling bank. This would still allow solid wastes to be transported easily because of its close proximity with all the places located at the centre of AIT. The disadvantage of this process is that there is a reduction of space in the waste-recycling bank, which is already unable to accommodate the huge quantities of solid wastes in AIT.

Deodourizers such as sodium or potassium carbonate can be used as minor ingredient of a make-up formulation, but as a major one, and, optionally, when the formulation is a powder, is combined with a significant proportion of drying agent. This provides a stock formulation from which an extremely efficient deodourizing aqueous spray composition, particularly an aerosol spray composition can be made.

Taking all these factors into consideration, shifting the waste recycling facility to a different location would be better because the facility can be increased in size and the environmental degradation can be reduced quite considerably. This would enable the administration to build a larger waste recycling bank that would accommodate the large amount of solid wastes generated at present.

The latter method of improving the conditions in the existing waste recycling bank and applying de-odourizers would not be economically viable. There will be no significant improvement in the conditions around the waste recycling bank, since there is a high rate of organic degradation due to the heat and humidity in the surrounding atmosphere. Application of chemicals itself can cause further environmental degradation around the area, more than what is already occurring at present.

4.3.4 Provision of Awareness and Participation Programmes in Solid Waste Management at AIT

The importance of inculcating an awareness or educational programme in SWM at AIT lies in making the higher authorities in AIT such as the faculty and staff aware of the problems posed by solid wastes in general. This can be achieved by holding weekly lectures by students, staff and professors from the Environmental Engineering and Management Programme for all the people staying in AIT. People should be educated about the different types of wastes generated in AIT, how they are disposed of, which wastes are easy and difficult to recycle and how they can be recycled.

The Student Union (SU) should be in contact regularly with the Faculty and Staff from the Department of Environmental Engineering and Management in AIT. Therefore, both the Student Union and the Environmental Engineering and Management Programme can work together with The Department of Infrastructure of AIT to arrive at a solution to the problem.

Interest, however, has to be created within AIT regarding solid waste management issues. People must understand the importance and benefits of recycling and how it can be applied to their daily lives, otherwise there will be a lack of interest in participating in such activities. In this regard, the SU should hold weekly open forums or brain storming sessions for the students to openly speak about the problems caused by the garbage in AIT. This will create more awareness and would motivate people to take action and solve the problem.

The SU should also provide incentives in order to encourage student participation in these activities. For example, the Student Union runs the Snack Bar in AIT that serves food to many people within AIT. The people responsible for running the Snack Bar should be made to realize the importance of such a programme and should participate in it. In this way, the people running the Snack Bar will be encouraged to give the students discounts on their meals with the help of the SU.

Participation in solid waste management programmes can be initiated in AIT by introducing institute-wide courses on Campus Eco-Sanitation, which will make it very interesting for the students in the sense that it will not count on their grade sheet. There is no pressure when it comes to educating students this way, because they will not feel that they are memorizing information before an examination. However, the students, staff and faculty in the Environmental Engineering and Management Programme should lead by example by practicing good environmental ethics in solid waste management, in order to motivate people studying in other departments to practice the same. The students of AIT should also be provided with assistantships to assist in Eco-Sanitation projects within AIT and in other technical institutes within and outside Thailand.

The participation programme should stress on reduction of wastes at the source itself. However, it is important to segregate the different types of wastes in different types of bins. For example, general wastes and recyclable wastes should be placed in different coloured bins. This would be an important strategy to cultivate interest in packaging industries like Tetra Pak to initiate a beverage carton recycling programme at AIT.

4.3.5 Formalization of the Solid Waste Management System at AIT

AIT should look to privatize the solid waste collection system if it has to start a recycling programme, but at the same time have a public-private partnership with the Tha Kong municipal authorities. AIT can formalize the system by making it privatized in such a manner in which AIT earns some money out of selling the recyclables to these scavengers. The scavengers in turn can sell these recyclables to the recycling firms, franchises and junk shops. This will in turn benefit both AIT and the scavengers.

As explained in Section 4.9, AIT can further profit if it recycles an additional 44% of the total solid waste generated which amounts to 181,200 baht per month. Assuming that 49% of the solid waste in AIT is sent to the Tha Kong Municipality Landfill, the yearly cost of landfill disposal of solid wastes from AIT would amount to 589,040 baht. This is would account for a yearly saving of 528,940 baht, which is a 50% reduction in the costs of disposing the solid waste of AIT, and would be very beneficial to the Tha Kong Municipality on the whole.

A cost accounting system should be implemented by the Tha Kong Municipality, especially for AIT, to keep a record of the disposal costs of the solid wastes into the Tha Kong Municipality Landfill. Installation of a cost system for solid waste management system can aid the Mayor of the Tha Kong Municipality, in controlling the costs and performance of the operations, and also in planning for the future. This would help in decreasing the costs of solid waste disposal in the landfill as well.

4.4 Solid Waste Recycling Systems in the Tha Kong Municipality

4.4.1 Parties Involved in Recycling Activities

Achieving success in recycling is not the task of one party, but the whole society. In AIT and the Tha Kong Municipality, people know that they can earn money by selling recyclables sorted out off their discarded materials. Therefore, the Tha Kong Municipality has the important role to promote these activities, as well as the promotion of awareness of the people.

There are three main groups of parties involved in the recycling activities in the Tha Kong Municipality, which are (1) Formal and Informal recycling firms, (2) Communities, and (3) The Municipality Office. The structure and interaction of all groups is demonstrated in Figure 4.12.

4.4.2 Types and Prices of Recyclables

Recyclables for trading in the Tha Kong Municipality are divided into various types, however, they can be grouped into six categories, and several grades of materials in each category are given the different prices, depending on their quality.

These six categories of materials and their sub-categories are:

1. Paper and Cardboard
    - Newspaper
    - White newspaper

- Brown cardboard
- Coloured paper
- Pound paper
- Notebook paper
- Computer paper

2. Glass
   - White glass
   - Coloured glass
   - Bottles

3. Ferrous Metal
   - Hard Steel
   - Cut Steel
   - Thin steel
   - Melted steel
   - Sling

4. Non-ferrous Metal (Metal Scraps)
   - Thin layer aluminium
   - Aluminium cans
   - Copper wire
   - Stainless steel
   - Brass
   - Aluminium work
   - Lead

5. Plastic
   - PET bottles
   - HDPE: detergent containers
   - Polystyrene: food packaging, insulation
   - Vinyl: floor cleaners
   - Mixed Plastics

6. Miscellaneous
   - Coconut meat
   - Coconut shell
   - Candles
   - PVC boots
   - Cloth rags
   - Electronic scraps
   - Used car and motorcycle batteries
   - Mattresses

Prices of recyclables are varied depending on the market mechanisms, as the theory of demand and supply, and the competition of the market. The price of the main trading materials, however, varies according to the quality of the materials. The materials that are of the highest selling price are the scrap metals due to the variation of the quality of scraps. The material that can be sold at a very high price is aluminium, which is of the highest quality. The prices of the recyclables are shown in Table 4.8.

Table 4.8 Types and Prices of Recyclables at the Tha Kong Municipality

Type	Price (baht/kg)	Average Price (baht/kg)
Newspaper	2.70-4.00	3.35
Paper and Cardboard	1.00-2.70	1.85
Glass Bottles	0.40-1.60	1.00
Aluminium cans	30.00-44.00	37.00
Plastic	3.00-4.00	3.50
PVC boots and flippers	7.00-8.00	7.50
Used car batteries	6.00-7.00	6.50
Metal scraps (Cu, Pb, Brass, etc.)	17.00-50.00	33.50
Crushed coconut meat	1.50-1.70	1.60
Coconut meat	3.50-4.40	3.95
Steel (except stainless steel)	1.50-5.00	3.25

Source: Pichonsajja, 2002

4.4.3 Private Sectors Activities

Kebekus et al. (2000) mentioned that the recycling sector is strictly a private-enterprise activity, with the recyclable materials spanning a broad spectrum from paper, cardboard and glass (breakage and bottles) to plastic (bottles, pipes, bags, etc.), rubber and various metals (iron, steel, copper, aluminium, etc.). Indeed, even such things as coconut meat (as a sort of oil), mattresses, electronic scraps, cloth rags, etc. is recycled. Thus, the recycling sector in the Tha Kong Municipality constitutes a complex diversity of inter-related actors as shown in Figure 4.13. Both the municipalities and private recycling enterprises promote the separation and collection of recyclables.

4.5 Organization of Waste Management Activities in the Tha Kong Municipality

4.5.1 Municipal Solid Waste Collection, Treatment and Disposal

(a) Waste Collection: In all the provinces in Thailand, collection trucks and their crews collect wastes on a daily basis, once a day, even two times partly. Large containers are provided in the high incidence level of wastes such as supermarkets, hotels, schools, hospitals, etc. The Municipality provides two types of waste bins, which are 60 and 240 litre plastic bins. Besides, the plastic waste bins provided by the municipality, waste bins in any place could be oil drums, buckets, cardboard boxes, or anything else that could serve as the same function. The collection times are different in different places, in which people have to put their bins in front of their house at the scheduled collection time. There are 46 collection crews, 19 truck drivers and four types of collection trucks are used for solid waste collection, as shown in Table 4.9.

(b) Waste Disposal: The sanitary landfill of the Tha Kong Municipality is located beside the Tha Kong Municipal Office on Paholyothin Road, which is about 2 kilometers from AIT. The area of the landfill measures about 288,000 m^2. The dumping site is divided into two phases: the first phase with an area of 72,000 m^2, and the second phase with an area of 80,000 m^2. The first phase is divided into four cells with the area of 124 × 143 × 2 m^3, and is currently in use now. The solid waste disposal cost is 900 baht/ton. The cost is inclusive of the operation and maintenance cost, land cost, machine cost, labour cost, construction cost, and other miscellaneous costs. The cost that the municipality employed in the solid waste management in the year 2006 is shown in Table 4.10.

Table 4.9 Waste Collection Vehicles at the Tha Kong Municipality

Types of Vehicles	Capacity (m^3)	Quantity
Regular garbage trucks	10.22 8.76	2 2
Slide Loaders (Open side truck)	10.95	9
Slide Loaders (Pick-up)	3.50	4
Compactor Trucks	10.95	8

Source: Pichonsajja (2002)

4.5.2 Weight and Composition of Solid Waste

The population of the Pathumthani Province in the year 2006 was estimated to be about 772,000 and that of the Tha Kong Municipality was found to be 78,600 (GeoHive, 2006). The wastes are sent to the sanitary landfill beside the Tha Kong Municipal Office. The quantity of solid wastes from 2002 to 2006 is shown in Table 4.11 and the composition of solid wastes is shown in Figure 4.11.

Table 4.10 Cost of Solid Waste Disposal at the Tha Kong Municipality

Cost Detail	**Costs (Baht)**
Mechanical Engineering and Maintenance Section	
Salary and Wages	2,209,240.00
Food for over-time working	446,950.00
Fuel Cost	1,766,430.00
Maintenance Cost	325,300.00
Vehicle Spares Cost	287,250.00
Disposal Cost	23,116,500.00
Total	***28,151,670.00***
Division of Public Health and Environment	
Salary	935,520.00
Permanent Wages	2,363,320.00
Temporary Wages	6,056,355.00
Food for over-time working	635,420.00
Fuel Cost	7,357,630.00
Maintenance Cost	803,180.00
Vehicle Spares Cost	883,695.00
Total	***15,957,660.00***
Grand Total	**44,109,330.00**

Source: Modified from Pichonsajja (2002)

The amount of solid waste generated in the present year 2006 in the landfill alone, was found to be about 26,200 tons/year. The amount of solid waste remaining in the landfill after waste segregation by scavengers at the landfill was found to be 25,685 tons/year. The disposal cost of the landfill is calculated depending upon the wastes remaining in the landfill after all the wastes have been segregated.

Table 4.11 Weight of Solid Waste at the Tha Kong Municipality

Year	Average Weight (tons)
2002	24,100
2003	24,625
2004	25,150
2005	25,675
2006	26,200

Source: Modified from Pichonsajja, 2002

4.6 Recycling Firms

According to the activities of the recycling firms, it can be referred that both formal and informal recycling firms act as the recyclers. They collect scrap materials for sorting, processing and transport to the manufacturers. Technically, the manufacturers often state that this business is not the recyclers' since they do not complete the loop of turning scrap materials into end products.

Nevertheless, they take the first step in material diverting from the waste stream and they are widely visible and easier to reach from the communities as well. Therefore, they are generally called "Recyclers". The recycling firms buy and collect the recyclables from their customers who are households, organizations, tricyclists, collection crews and other business firms from solid waste transfer stations such as Wangnoi. Then, they sort the recyclables into several categories and store for selling to the middlemen or manufacturers.

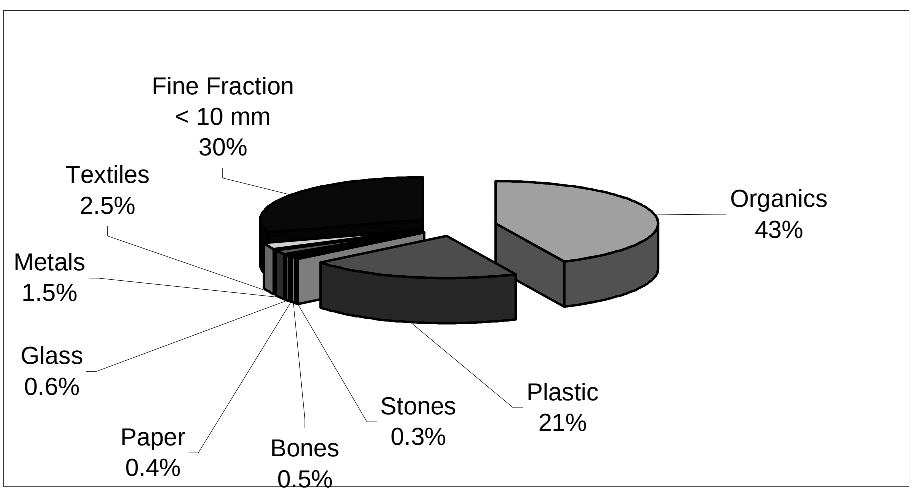


Figure 4.11 Waste Composition of the Tha Kong Municipality (Pichonsajja, 2002)

The common machine in the recycling firms is the baler. It is simply a bundling system in which recyclables made from plastic, paper and cardboard are compressed. The final product is densely packed in a cube-shape, and then tied with a wire. The balers are different in each shop due to their needs. However, Lund (2000), expressed that each baler encompasses three parts: (1) feed hopper, the area where recyclables are fed, (2) rams, the flat surfaces which compress the materials, and (3) baling chamber or the compression chamber, where bale compression takes place.

Wongpanit, the largest recycling firm in Thailand, has organized the obvious activities in recycling within the community. Besides running the business, the company joins the community's participation promoting programme, which has been launched in Phitsanulok and many provinces in Thailand, including Bangkok. The programme's objective is to preserve the environment and manage waste problems in the municipality. One of the activities in the programme is the formation of a second hand product market.

The market is arranged weekly for trading and purchasing second hand and discarded materials. Another joint activity is training for safe handling and handling of household reusable items. This is the direct transaction between the company and the Tha Kong Municipality. Waste collection trucks transport the wastes they have collected to the company, while the Municipality engages in selling of various handicrafts, produced from the use of reusable components programme of the company. (Chantarakiri and Vithal, 2002)

The aim of the programme is to reduce the amount of solid waste by 90-95% by four steps:

1. Sorting out the valuable or recyclable wastes at the source itself. Public participation is the best way to promote the recycling program in the municipality and at AIT. Many recycling activities are held in several communities such as recycling activities in the school by the cooperation of the school and the community, which is operated by the youth in the community.

2. Allow the tricyclists to sort wastes from the Municipality's waste bins around the city. The tricyclists are given the opportunity to take care of their environment, and at the same time, they have the chance to do their work. They are given the license for waste sorting and also they are the volunteers for environmental protection. The Municipality provides them training in the sanitary waste sorting, and free-of-charge health care service for them.

3. Allow the collection crews to sort the wastes out, while they are collecting wastes.

4. Allow the scavengers to sort the wastes out at the landfill.

The Municipality cooperates with the private recycling firms in the city for the market mechanism in waste recycling.

4.6.1 Recycling Firms as the Formal Sector

Accordong to Pichonsajja (2002), the recycling firms in the area of the Tha Kong Municipality can be expressed in three categories as follows:

1. Family business junk shops: The recycling business structure in the Pathumthani Province is mostly run as the family business. This is so-called due to one or more family members, who do some or all activities in the business. The family members that are not the shopkeepers, who only do the managing task, however, they weigh the goods, and being the cashier, clerk, and accountant, or even do the workers' task sometimes. These establishments have been in this business at least two generations for around 20-40 years.

2. Junk shops in the form of companies: Wongpanit Company Limited, the only one recycling firm that is in the form of a company in the study area. It is very well known since the twenty years of establishment and the activities that it does with the communities. However, at the first time of establishment, Wongpanit ran its business as the family business, then, it has expanded the business as the company and located some branches around the city. After the first step of expansion, Wongpanit decided to sell its franchise. There are people from the municipality, the province and also other provinces who are interested in the business by the franchise customers of the shop brand.

3. Franchise junk shops: These types of firms use the brand Wongpanit, but the shops are managed by the shop-owners. They have basically been officially registered few years ago after the expansion of the Wongpanit Company. They can buy and sell their goods anywhere, however, most of their goods are sold to the Wongpanit Head Plant. The shop-owners were trained from the head plant for the methods of sorting, handling and storage of the recyclables. The franchises are included in the Wongpanit Network for waste recycling; the shop-owners, who were trained, will be asked to be trainers in other Wongpanit training programmes.

4.6.2 Recycling Firms as the Informal Sector

Pichonsajja (2002) stated that informal recycling firms are in the form of unregistered junk shops. They are small shops managed by members of the communities and the recyclable materials found there are mostly plastic, glass and paper. The amount of recyclables are not high, some shops sell them to the Wongpanit branches near their area, however, some sell them to the pick-up traders who come to buy at the source.

4.6.3 Sources and Quantities of Input Recyclable Materials

Generally, the recyclable materials are from households, small shops, and tricyclists all over the city. However, there are some specific sources such as the large-scale supermarkets, military area, and the municipal collecting trucks. Recyclable materials from these specific sources has their different destinations, recyclables from the supermarkets and the municipal collecting trucks are sent to the Wongpanit company, while those from the military area are sent to the plastic and scrap metal shops. Recyclable materials from the households or the communities are present in the form of salable materials from the waste banks in some communities. The market prices of recyclable materials are shown in Table 4.12. In order to indicate the economic value of those discarded materials, Table 4.12 shows values of them as well.

Table 4.12 Values of Recyclable Materials in the Market

Categories	Amount (tons/year)	Average Price (baht/kg)	Net price (Million baht/year)
Paper and Cardboard	4,335	3.35	14.52
Glass	3,710	1.85	6.86
Non-Ferrous Metal	535	30.50	16.32
Ferrous Metal	4,040	3.25	13.13
Plastic	2,810	3.50	9.83
Total	15,430		60.66

Source: Modified from Pichonsajja (2002)

Since the Wongpanit Company calculated the amount of ferrous and non-ferrous metal together, therefore, the graph in Figure 4.14 shows a small amount of non-ferrous metal. In spite of this, the percentage graph was carried out to show the portion of each category

(Figure 4.15). Ferrous and non-ferrous metals have taken the highest portion in recycling with 30%, whilst others are in nearly the same portion.

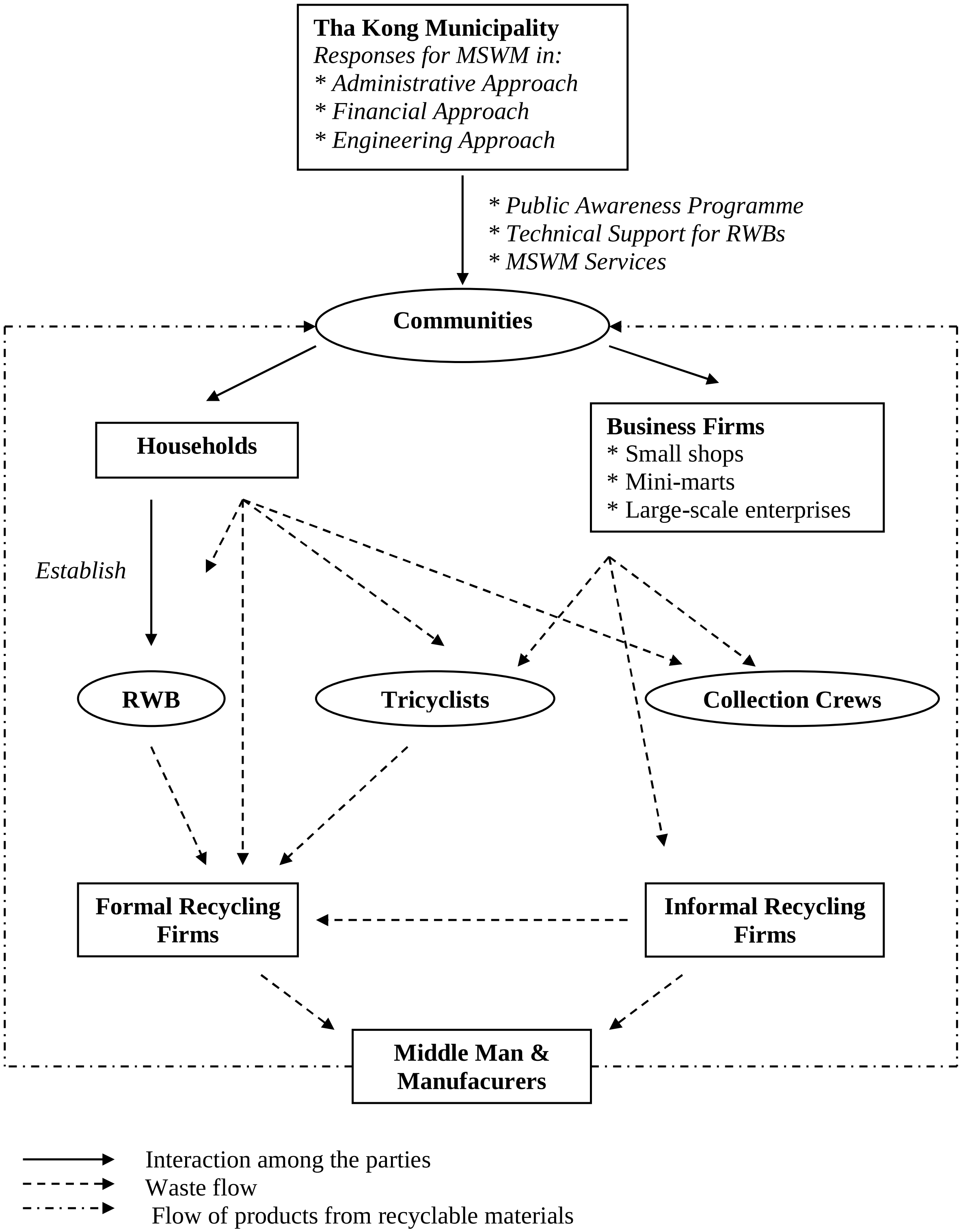


Figure 4.12 Structure and Interaction of Parties Involved in Recycling Activities in the Tha Kong Municipality and AIT

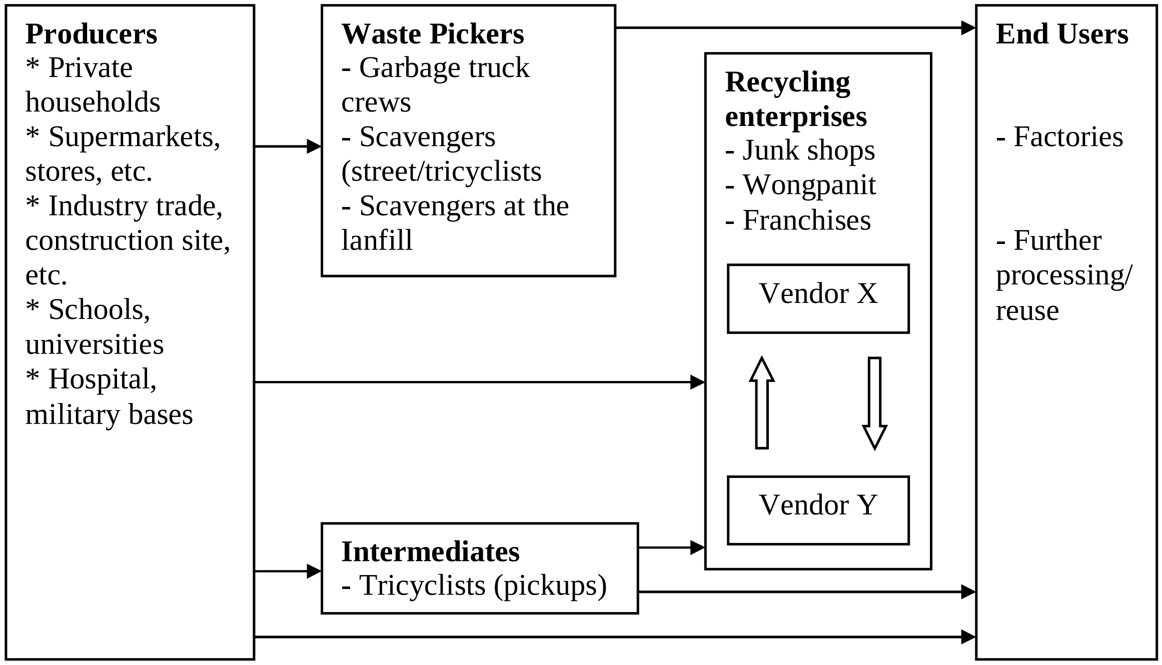


Figure 4.13 Schematic Diagram of the Tha Kong Recycling Sector (Modified from Kebekus et al., 2000)

4.7 Other Informal Sectors Involved in Recycling Activities

4.7.1 Tricyclists, Pick-up Traders and Street Scavengers

There are around 220 tricyclists, pick-up traders and street scavengers who are registered by the Tha Kong Municipality, and are given training by the Municipality in waste separation, as well as health care service, which is provided by the Medical Welfare section. However, all of the registered traders work as the main source of income, some of them do it as part-time work, and some work full-time since they believe that the Municipality can provide them with incentives. (Pichonsajja, 2002)

Their ages are around thirty to sixty five years old and are educated at the school level and for 90% of them, this work is their main source of income. These traders and scavengers start their days in the morning, they travel along their routes, collect all kind of salable materials, go to the junk shops when their tricycles are full. Those who do this work for their main source of income, sell their recyclables everyday, even if it fetches them a small amount of money, since their basic needs in life are food, clothing and shelter. Most of them sell their recyclable materials to the same shop every time they want to sell a solid waste item. (Pichonsajja, 2006)

Pichonsajja (2002) stated that the average income of the tricyclists and the scavengers are around 100-500 baht per day, and varies by the amount of recyclables collected each day. They have their own zone of buying or waste sorting due the limitations their vehicles possess, which are manual tricycles, motor tricycles and sometimes also due to physical exertion caused by walking long distances. On the other hand, the pick-up traders have more chances to buy more recyclables in their wider area, as they have the better vehicles and can earn more. The daily quantities of recyclables sold by tricyclists, pick-up traders and scavengers to the recycling firms in the Tha Kong Municipality are shown in Figures 4.16 and 4.17.

Pichonsajja (2002) found that the tricyclists and scavengers rarely use safety equipments, such as boots and gloves, even though some of them were trained by the municipal office to use such equipments. Most of them gave the reason that they were uncomfortable working with these safety equipments.

Pichonsajja (2006) stated that the problems faced by the tricyclists and scavengers were:

- Unstable prices of the recyclables due to the market mechanisms.
- Decreasing of recyclables since the households collect and sell by themselves.
- Protesting from some people in some communities or villages because people are afraid that they maybe thieves.

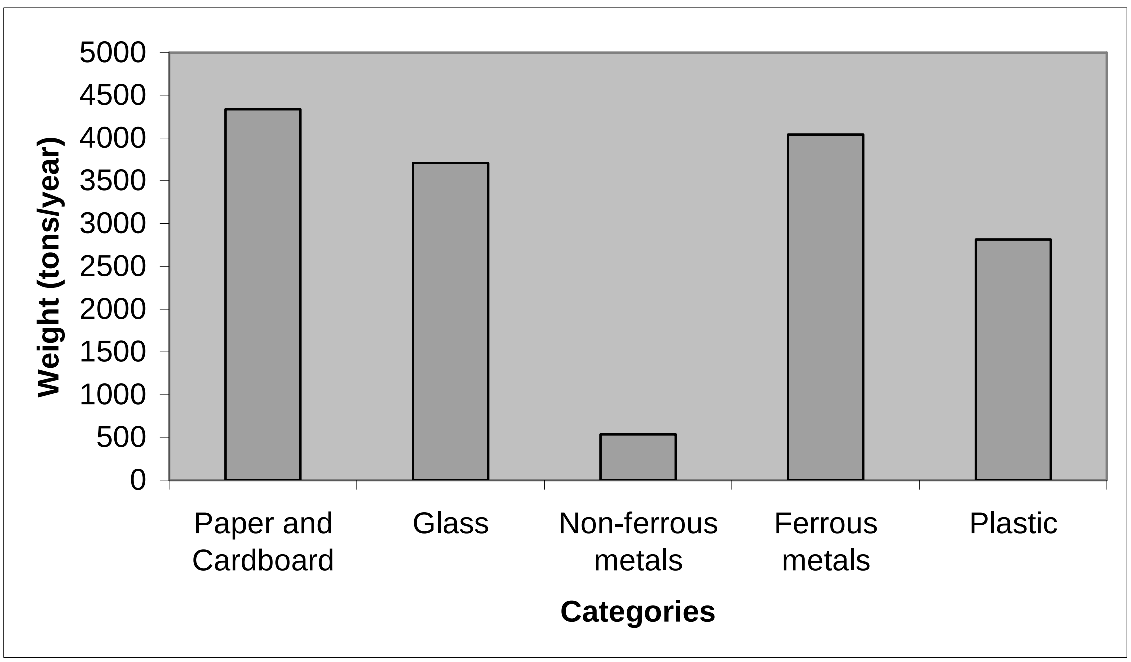


Figure 4.14 Quantities of Recyclables Measured at the Recycling Firms in the Tha Kong Municipality (Modified from Pichonsajja, 2002)

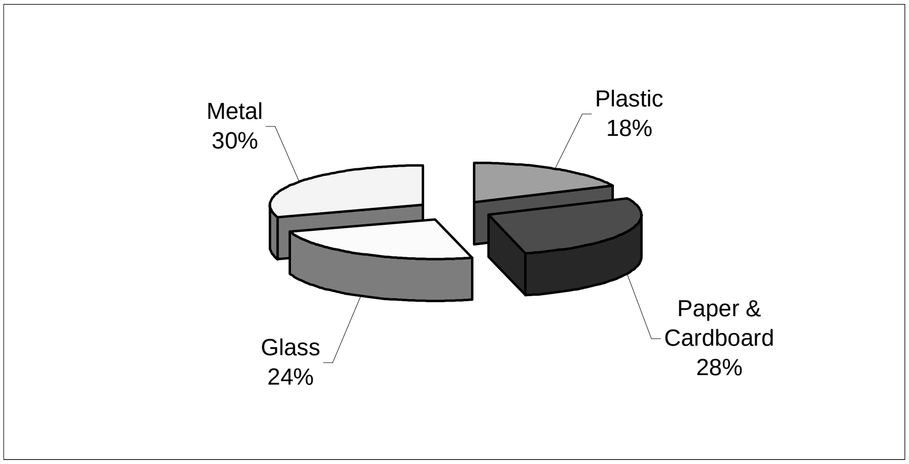


Figure 4.15 Percentage by Weight of Recyclables Measured at the Recycling Firm in the Tha Kong Municipality (Pichonsajja, 2002)

4.7.2 Collection Crews

For the collection crews, waste separation for recycling in one way to increase their incomes. The Wongpanit Company is the place where the collecting trucks have to drop the wastes for separation. This is due to the contact between the municipality office and the company. There is a corner at the plant for dropping wastes from the trucks, the collection crews have to separate the wastes by themselves. Nevertheless, the company provides the disinfectant spraying at the separating point for the collection trucks. (Pichonsajja, 2002)

The profits from selling recyclable materials will be shared between one driver and three crews. The trucks will collect wastes two times a day and earn about 800 baht per truck from selling the materials. Different types of recyclables were separated from the solid wastes by collection crews, and the quantities were estimated on a daily basis as shown in Table 4.13.

The quantities of recyclable materials sold on a daily basis by the tricyclists, pick-up traders and street scavengers at the recycling firms from the roadsides and from households are shown in Figure 4.16 and Figure 4.17 respectively. It is noticed that there is a difference between the quantities of ferrous and non-ferrous metals. The order in the rank of recyclable categories sorted out by the tricyclists group and the collection crew group is different, and the recyclables are sorted out according to the value of the material. (Pichonsajja, 2002)

4.7.3 Sanitary Landfill (SLF) Scavengers

There are about 30 registered scavengers working for the Tha Kong Municipality, however, some of them do not come for separation of wastes at the landfill. Most of the scavengers working at the landfill were farmers, construction labourers or street scavengers, before becoming scavengers at the landfill. They are from the same area near the landfill site, and work as promised to the Lord Mayor of the Tha Kong Municipality, that they would separate wastes if the landfill is located within the municipality. The first group of scavengers has worked here since the start of the operation of the landfill. They work mostly as family teams with 2-3 people in a team. Each family earns 5,000-6,000 baht per month, however, in the first year of operation, they could earn about 10,000 baht per month. (Pichonsajja, 2002)

The quantities of recyclables have been decreasing since the Municipality allowed the tricyclists and the collection crew to separate the wastes. Furthermore, the usage of the compactor trucks also affects the quality of some recyclables such as glass, which are broken while compacting and hence difficult to separate. The percentage of each category of recyclable materials sorted out at the SLF is shown in Figure 4.18, while Figures 4.19 and 4.20 show the quantities of recyclables sorted out at the SLF, based on the sale of the recyclables at one particular time (see Appendix D for details). The buyers will come to buy at the landfill site once a week during the weekend. The categories and prices of the recyclables are shown in Table 4.14. There are some kinds of recyclables that will be separated as requested from the buyers such as compact discs (1 baht/kg), instant noodle envelopes (0.1 baht/envelope), videocassettes and other packaging items.

Table 4.13 Quantities of Recyclables Sorted by the Collection Crews

Categories	Weight (kg)
Aluminium	468
Battery	54
Used Candles	94
Cardboard	4,240
Coconut Meat	6
Copper	40
Glass	18,956
Lead	11
Paper	17,406
Plastic	7,060
PVC Boots	196
Steel	2,918

Source: Modified from Pichonsajja, 2002

The scavengers at the landfill are not allowed to separate wastes from the supermarkets and hospitals, as other scavengers coming in trucks perform those operations. The hygienic condition at the landfill is not good since there is not enough pesticide to kill the flies. Therefore, there are a lot of flies around the landfill, and the scavengers around the landfill are susceptible to diseases like typhoid. The scavengers working in the landfill area are not given the necessary vaccination to become resistant to such diseases. (Pichonsajja, 2002)

Glass, includes red, white, and bottles, is found in large quantities after separation. At the same time, other containers such as plastic and paper containers are also found to be large quantities after separation. It can be mentioned that these kinds of containers are to be discarded by the consumers easily. The percentage of non-ferrous metals such as steel and aluminium cans were found to be quite low as compared to the ferrous metals, and were sorted out before being discarded.

Table 4.14 Prices of Recyclables at the Tha Kong Municipality Landfill Site

Categories	Prices	Remarks
White plastic bags	2.00/kg	
Black plastic bags	1.00/kg	
Pesticide bottles	0.80/bottle	2 bottles/kg
Red Glass	0.30/kg	
White Glass	0.50/kg	
M-100 bottles	0.90/kg	
Fish sauce bottles	1.10/bottles	
Flat liquor bottles	0.50/bottles	5 bottles/kg
Sponsor bottles	0.50/bottles	5 bottles/kg
Mixed plastic	4.00/kg	
PET bottles	3.00/kg	10 bottles/kg
Drinking water bottles	8.00/kg	
Pound paper	3.00/kg	
Mixed paper	1.00/kg	
Cardboard	2.40/kg	
Aluminium cans	34.00/kg	
Steel	3-3.90/kg	
Copper	49.00/kg	
Cable	3.00/kg	
PVC Shoes	5.00/kg	

Source: Pichonsajja (2002)

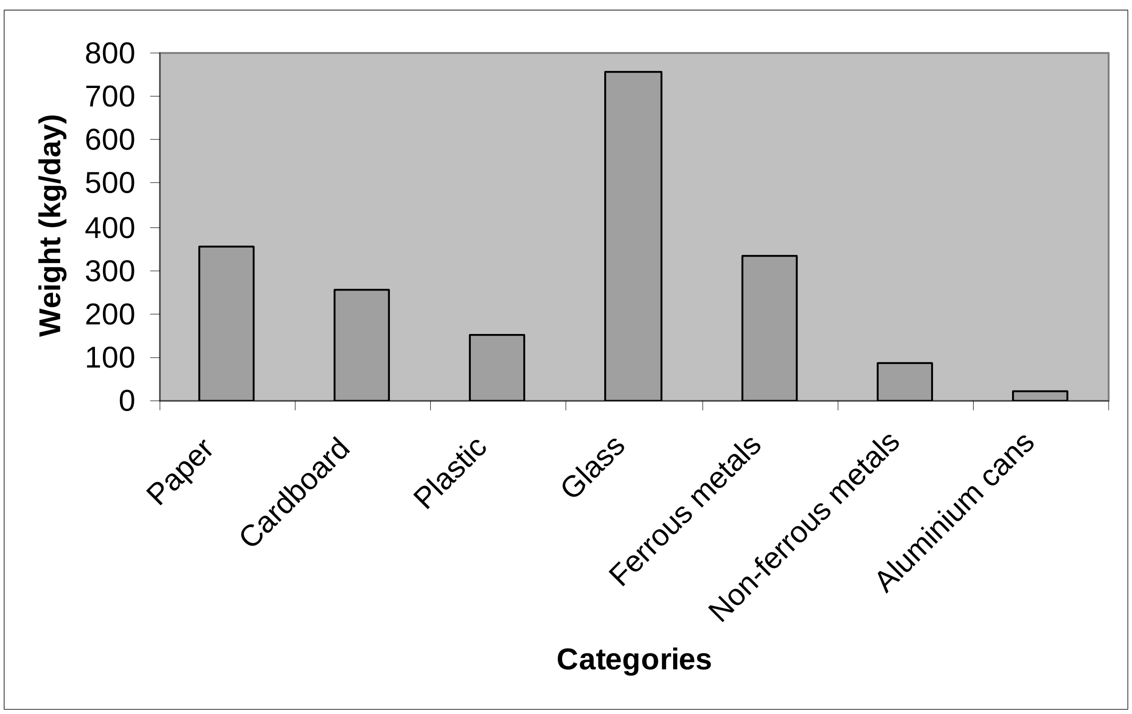


Figure 4.16 Quantities of Recyclables Collected at the Roadsides by Tricyclists, Pick-up Traders and Street Scavengers at the Recycling Firms (Modified from Pichonsajja, 2002)

Nevertheless, an obvious percentage of the plastic bags that seemed to be low in terms of the overall weight of recyclables. In fact, plastic bags are the main problem in SLF, since they are found in large quantities and the difficulty to dispose especially the shopping plastic bags. This kind of material is not sorted for selling, because there are no benefits obtained from recycling such materials. (Pichonsajja, 2002)

4.8 Roles of the Formal and Informal Sectors

The formal sector comprises of the registered recycling firms, who are the buyers of recyclables in the Tha Kong Municipality. They are the ends of the recycling pathway, where most of the salable materials in the city are sold. However, some part of the materials is sold to the outsider pick-ups that buy the recyclables at the shop at the outskirts of the municipality. Some of these formal sectors have launched the activities with the Tha Kong Municipality, and the communities. It could be mentioned that the Wongpanit Company, a famous recycling firm, has been the influencing factor in the recycling activities in the municipality. There are other famous and long-established recycling firms that have been recognized well. (Pichonsajja, 2002)

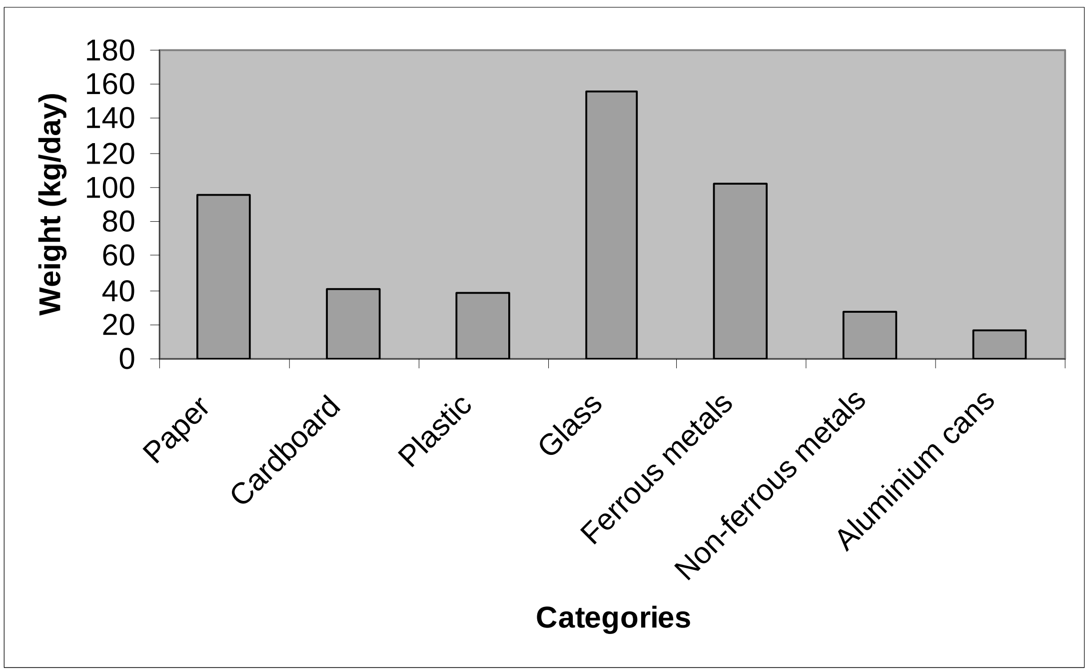


Figure 4.17 Quantities of Recyclables Collected at the Households by Tricyclists and Pick-up Traders at the Recycling Firms (Modified from Pichonsajja, 2002)

On the other hand, the unregistered recycling firms are also the buyers, but not the ends of the pathway. Since their businesses are smaller, some are only the purchasing points, they sell their recyclables to the registered recycling firms and the outsider pick-up traders. Nevertheless, these firms are located in the communities. They provide more chance to people in the communities to reach the recycling activities. (Pichonsajja, 2002)

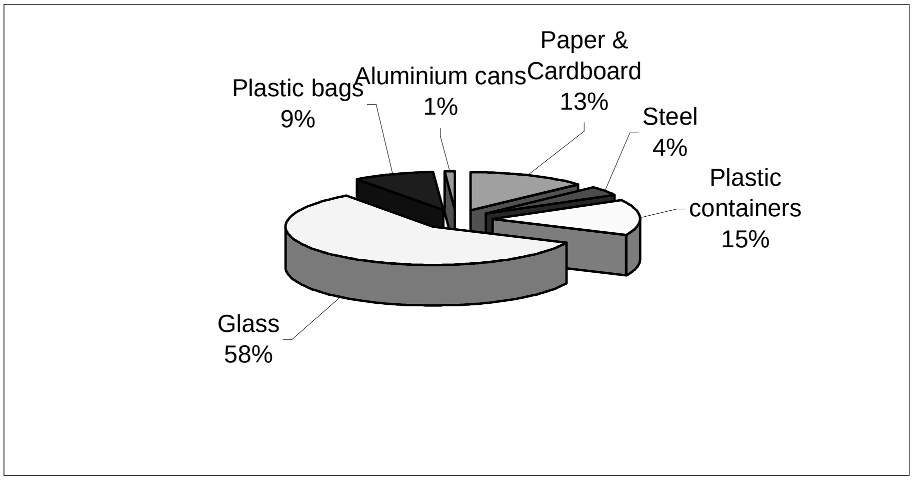


Figure 4.18 Percentage by Weight of Recyclable Materials Sorted at the SLF (Pichonsajja, 2002)

The informal recycling parties: the tricyclists, collection crews, pick-up traders and street scavengers are those who collect the recyclable materials from households, shops and organizations around the city, mostly for their primary source of income. They take an important part in the recycling activities due to the performance of the recyclable quantities they collect in one year compared to the numbers from households and landfill scavengers. Figure 4.21 shows the percentage by weight of recyclables collected by the groups of (1) tricyclists, pick-up traders and street scavengers from roadsides, (2) collection crews from Wongpanit, (3) SLF scavengers and (4) tricyclists and pick-up traders from individual households. (Pichonsajja, 2002)

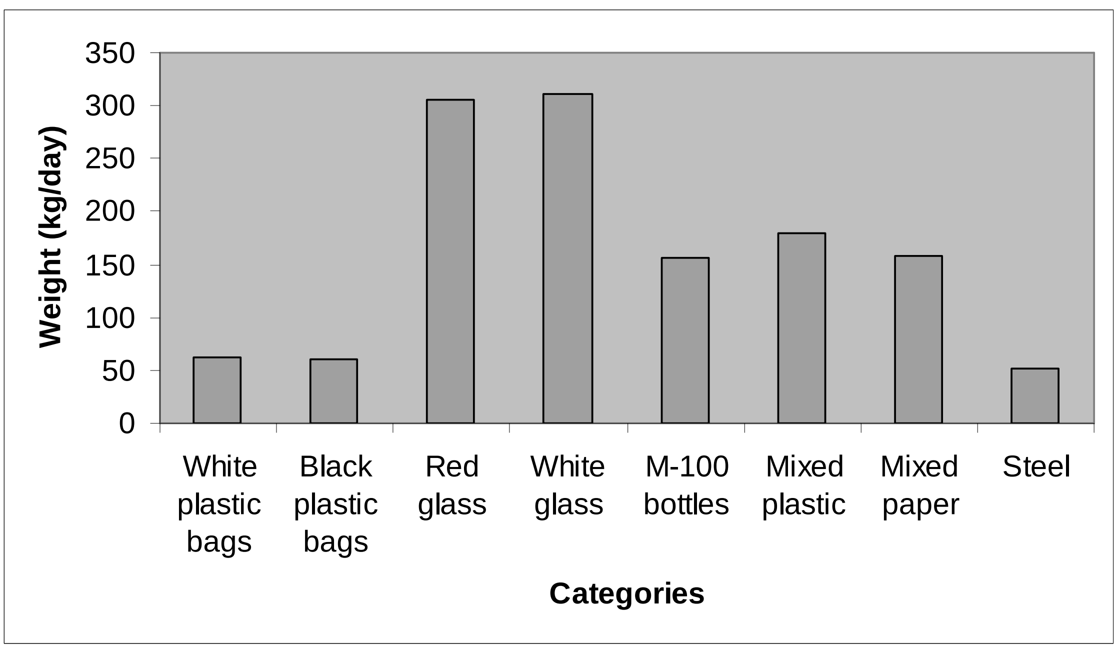


Figure 4.19 Quantities of Recyclable Materials Sorted at the SLF Based on One Time of Selling: Large Portion (Modified from Pichonsajja, 2002)

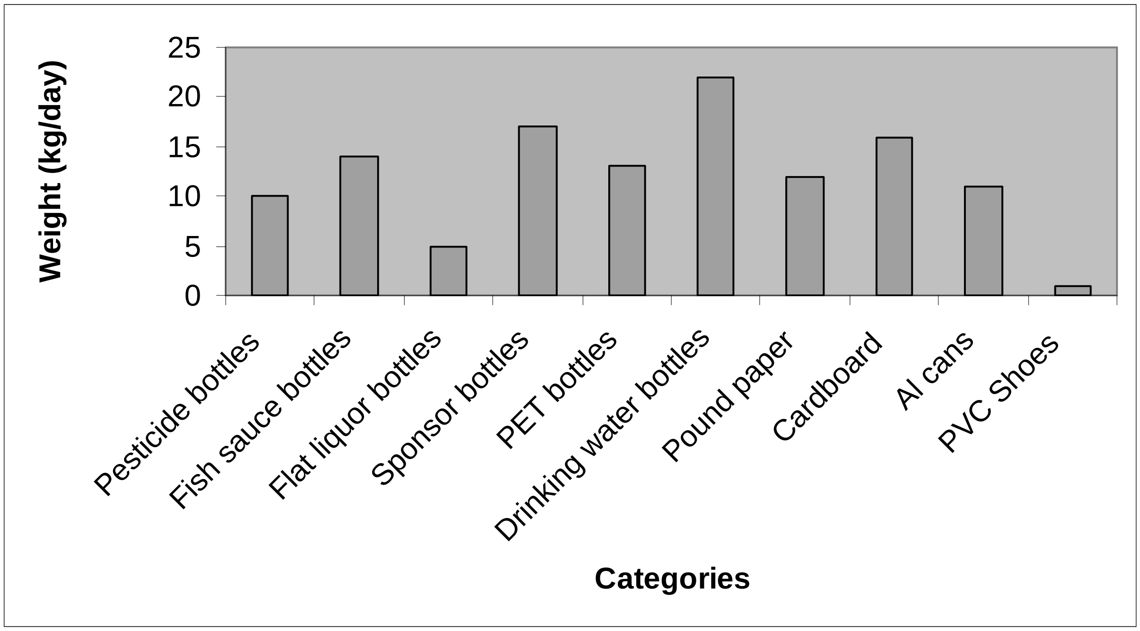


Figure 4.20 Quantities of Recyclable Materials Sorted at the SLF Based on One Time of Selling: Small Portion (Modified from Pichonsajja, 2002)

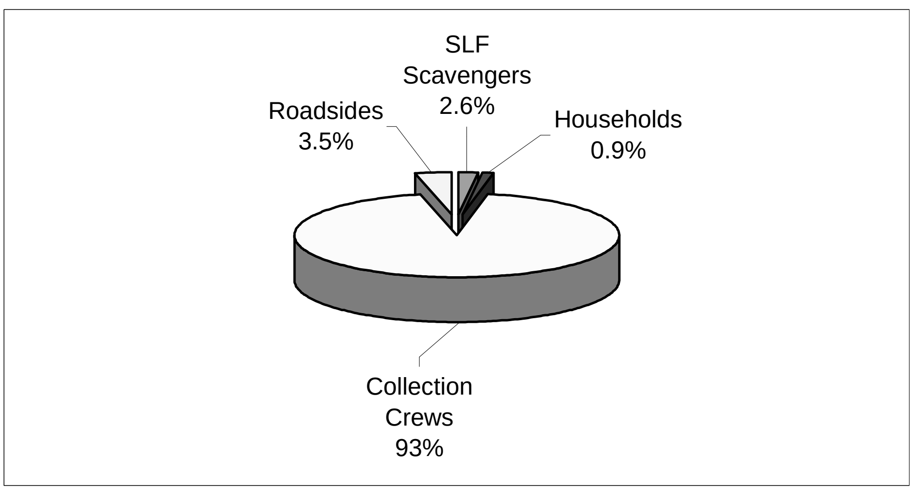


Figure 4.21 Percentage by Weight of Recyclables Collected by Formal and Informal Parties (Modified from Pichonsajja, 2002)

The Sanitary Landfill (SLF) scavengers play their role as the final separators at the landfill site before dumping of wastes. They recover 2.5% of the total amount of recyclables from the total amount of solid waste transported to the landfill. However, their recyclables are in lower amounts as compared to those collected by other parties. (Pichonsajja, 2002)

Figure 4.22 shows the percentage by weight of salable and non-salable materials (wastes) that was collected from the data collection process during the study. The recycling activities by the sectors have the efficiency of 44% separated salable materials from the overall quantities of materials produced in the study area. Nevertheless, the pathway of recyclables is from landfill scavengers, households, crews and tricyclists' group to the junk shops, whereas, there is some portion of recyclables that the shops buy from other parties such as large-scale supermarkets, organizations, and so on. (Pichonsajja, 2002)

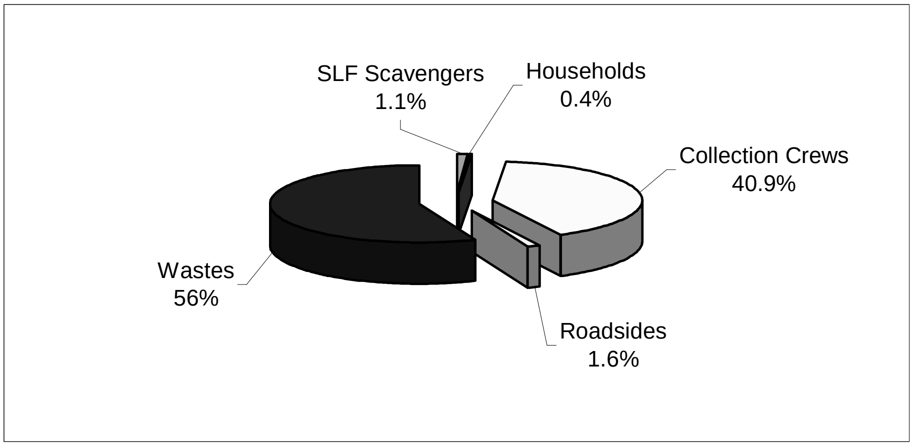


Figure 4.22 Percentage by Weight of Salable and Non-Salable Materials in the Tha Kong Municipality (Modified from Pichonsajja, 2002)

4.9 Cost Evaluation of Solid Waste Management at the Tha Kong Municipality and AIT

The costs involved in solid waste management at the Tha Kong Municipality are given in Table 4.10. However, the average solid waste management cost is 1,720 baht/ton of wastes. The cost excludes cost of land for the landfill site and cost of vehicles. From the study, the total amount of salable and non-salable materials in the area of the Tha Kong Municipality is shown in Table 4.15. The per capita waste generation in the Tha Kong Municipality was found to be 1.6 kg/day.

The recycling activities can reduce 44% of solid waste from Tha Kong and AIT going to the landfill. Therefore, the lifetime of the landfill would be expanded more or less by 44%. The higher the quantities of wastes, higher will be the cost of management. Hence, the total cost in solid waste management with and without the recycling activities is shown in Table 4.16.

Table 4.15 Quantities of Salable and Non-Salable Materials from Involved Parties

Categories	Weight (ton/year)
Salable Materials	
SLF Scavengers	515
Households	175
Collection Crews	18,780
Roadsides	715
Non-Salable Materials	
Landfill	25,685
Total	**45,870**

Source: Modified from Pichonsajja, 2002

As implied from the Benefit-Cost Ratio, the value of recyclables was compared with the cost of waste management, based on the weight of the materials and the wastes. The Benefit-Cost Ratio of the recycling activities in the Tha Kong Municipality was found to be 1.03. It could be referred that the recycling activities gave the benefit in the solid waste management system of the Tha Kong Municipality as explained in Section 2.5.3 (see Chapter 2).

From Table 4.2, it has been shown that the value of recyclables in AIT was found to be 15,100 baht. Comparing it with the recycling costs to a downscaled population of 3,800 in the Tha Kong Municipality, the cost of recycling was found to be 2.84 million baht/year. Hence, for AIT the Benefit-Cost ratio was found to be 0.005. This value is found to be lower that that of the Tha Kong Municipality on the whole, as the quantity of solid waste in the Tha Kong is much higher. (See Appendix D for Calculations)

Table 4.16 Total Costs of Solid Waste Management at the Tha Kong Municipality with and without Recycling Activities

Amount of Materials (ton/year)	Cost (million baht)
With Recycling Activities: 20,185	58,809, 460.00
Without Recycling Activities: 25,685	44,109,330.00

Source: Modified from Pichonsajja, 2002

There is a difference in the composition of wastes in Tha Kong and AIT. AIT has more food wastes and paper wastes, but in terms of plastics, AIT is almost similar to Tha Kong. Hence, the recycling potential in Tha Kong is better than AIT. But AIT has a high amount of plastic and paper wastes as found in the analysis of physical characteristics of the solid wastes as explained in Section 4.2 of this Chapter. Hence, action has to be taken to recycle those wastes, in order to reduce the amount of wastes in AIT reaching the landfill.

Chapter 5

Conclusions and Recommendations

5.1 Conclusions

The following conclusions can be derived from the study:

- The solid waste audit study in AIT revealed that 93% of the solid wastes in AIT is disposed in the Tha Kong Municipality Landfill, 4% of the solid waste is recycled and 3% of the solid waste which is gardening waste is composted.
- The percentage composition of organic wastes and inorganic wastes in AIT are 60% and 40% respectively. Food waste is found in to be the highest in AIT due to the large number of domestic quarters present.
- Open dumps are present in the vicinity of the institute that poses an enormous threat to the environment.
- The BCA showed that there was no benefit as far as recycling activities in AIT is concerned. However, the recycling activities at the Tha Kong Municipality showed benefits.
- The amount of plastic wastes in AIT is 25.1% of the total solid waste generated, which is quite high for a technical institute with a small population of 3,800.
- Packaging wastes constitute 0.7% of the total solid waste generated in AIT, and hence needs to be considered seriously.
- There is a lack awareness of solid waste management practices in AIT, and the need for an awareness programme is strongly recommended.
- The chemical analysis showed that the solid waste of AIT contained high amounts of carbon and nitrogen, but due to a low C/N ratio, the solid waste cannot be composted and converted to manure.
- The elemental analysis of hydrogen and oxygen showed that the solid waste at AIT can pose problems in the solid waste disposal into the Tha Kong Municipality Landfill.
- The chlorine content of the solid waste was very high and can prove to be a hazard during the manufacture of RDF.
- The solid waste in AIT can be used in the production of RDF since it has an average calorific value of 16.39 kJ/kg.
- The moisture content and the sulphur content of the solid waste was as high as 68% and 1.99% respectively, which indicates a high rate of organic degradation of the solid waste in AIT.
- The study shows that scavengers earn 15,100 baht per month, and AIT does not earn any income from recycling activities.
- The study showed that AIT is responsible for contributing to 1,117,980 baht per year of the Tha Kong Municipality total yearly cost of 44,109,330 baht in solid waste disposal.
- It is of utmost importance that a 3R programme needs to be implemented in the near future at AIT.

5.2 Recommendations

(a) Options for Solid Waste Reduction, Reuse and Recycling at AIT

- Use of paper items instead of plastic items in cafeteria/minimart areas.
- Wastage of food should be avoided as far as possible in cafeteria/minimart areas.
- Plastic items should be used to a minimum extent.
- Plastic items should be reused until they are rendered useless.
- Paper items should be utilized completely until they are rendered useless.
- Food should not be disposed in plastic bags.
- Segregation of different types of wastes in different types of bins should be practiced.

(b) Site Selection of the Waste Recycling Bank at AIT

- The waste recycling bank should be merged with the open dump behind the SOM building.
- The conditions in the existing waste recycling facility can be improved by providing standard types of waste bins used in AIT, instead of plastic bags normally used to store the wastes.
- De-odourizers such as sodium or potassium carbonate can be used along with certain other amphoteric compounds.

(c) Provision of Awareness and Participation Programmes in Solid Waste Management at AIT

- Hold weekly lectures by students, staff and faculty from the Environmental Engineering and Management Programme for all the people staying in AIT.
- The SU should be in contact regularly with the administration of AIT.
- The SU should hold weekly open forums or brain storming sessions to solve the solid waste management problems at AIT.
- Institute-wide courses should be introduced on Campus Eco-Sanitation for the students at AIT.
- The students of AIT should be provided with assistantships.
- The SU should provide incentives in order to encourage student participation in these activities.

(d) Formalization of the Solid Waste Management System at AIT

- AIT should look to privatize the solid waste collection system by having a public-private partnership with the authorities of the Tha Kong Municipality.
- AIT can formalize the system by making it privatized in such a manner in which AIT earns money out of selling the recyclables to scavengers.
- A cost accounting system for the solid waste management system in AIT should be implemented.

References

Amin, A.T.M.N. & Parera, L. (1996). Accomodating the Informal Sector: A Strategy for Urban Environmental Management. *Environmental Management, 46*, 3-15.

Amin, A.T.M.N. (2005). Enriching Planning Education with Economic and Financial Insights: A Personal Account of an Economist Working in the Urban Planning and Environmental Management Field. *8th International Conference of Asian Planning Schools Association*, 11th-14th September 2005.

American Public Works Association (1970). *Municipal Refuse Disposal*. Institute for Solid Wastes of American Public Works Association, Chicago.

Barton, A.F.M. (1979). *Resource Recovery and Recycling*. A Wiley-Interscience Publication, John Wiley & Sons, New York. ISBN: 0-01-37135-3.

BMA (1990). *Statistical Profile of BMA, 1990*. Department of Policy and Planning of the Bangkok Metropolitan Administration.

Butsapak, S. (1984). *Engineering and Socio-economic Aspects of Municipal Solid Waste Recycling*. Asian Institute of Technology, Bangkok, Thailand. AIT Research Report No. EV-84-2.

Canter, L.W. (1996). *Environmental Impact Assessment*. McGraw-Hill, Second Addition, Singapore. ISBN: 0-07-114103-0.

Chantakari, R. and Vithal, G. (2002). *Wongpanit Garbage Management System and Somchai Wongcharoen*. Rattanasuwan Printing Press, Phitsanulok, Thailand.

Clean Japan Centre (1987). *The Role of Resource Recycling.* Retrieved: September 19, 2006: http://www.sprigerlink.com/index/777H4672UP844616.pdf.

Cointreau, S.J. et al. (1982). *Solid Waste Management Study for Colombo, Sri Lanka*. Report to the National Water Supply and Drainage Board, Mount Lavinia, Sri Lanka.

Cointreau, S.J., Gunnerson, C.G., Huls, J.M. & Sildman, N.N. (1985). *Integrated Resource Recovery, Recycling from Municipal Refuse: A State-of-the-Art Review and Annotated Bibliography*. UNDP.

Diaz, L.F., Savage, George, M. & Golueke, C.G. (1982). *Resource Recovery from Municipal Solid Wastes*. CRC Press Ink, Florida. ISBN: 0-02-98754-1.

European Commission (2003). *Refuse Derived Fuel, Current Practice and Perspectives: Final Report, July 2003.* Directorate General Environment, European Commission.

Folmer, H., Gabel, H.L. & Opschoor, J.B. (1995). *Principle of environmental and resource economics: a guide for students and decision makers.* Edward Edgar Publishing Ltd., UK. ISBN: 0-23-409945-3.

Fudery, C. (1990). *Social Experts of Solid Recovery in Asian Cities*. BKK Environmental Sanitation Information Centre, AIT.

GeoHive (2006). *Population of Thailand and the Respective Administrative Units.* Retrieved: March 12, 2007: http://www.geohive.com/cntry/thailand.aspx.

HABITAT (1992). Promotion of Waste Recycling and Reuse in Developing Countries. *Seminar organized by HABITAT*, Bangkok, 3rd September, 1992.

Haan, C.H., Coad, A. & Lardinois, I. (1998). Municipal Solid Waste Management: Involving Micro- and Small Scale Enterprises, Guideline for Municipal Managers. *International Training Centre of the ILO*, SKAT, WASTE.

Henstock, M.F. (1974). *The Recycling Aid: Disposal of Solid Waste*. Pergamon Press, Oxford, New York. ISBN: 0-08-32715-9

Henstock, M.E. & Biddulph, M.W. (1975). *Solid Waste as a Resource*. University of Nottingham. Pergamon Press, Oxford, New York. ISBN: 0-02-76011-0

Hill, C.W.L., and Jones, G.R. (2001). *Strategic Management: An Integrated Approach*. Houghton Mifflin Publishing Co., 2001. ISBN: 0-08-54295-7.

Holt, C.A. (1999). Teaching Economics with Classroom Experiments: A Symposium. *Southern Economic Journal*, *65*, 603-610.

Julius, D.S. (1987), *Urban Waste as an Economic Good*. In: Pacey, A. (Ed) Sanitation in Developing Countries, John Wiley and Sons, The Gersham Press, UK. ISBN: 0-02-40192-2.

Kekebus, F., Janikowski, G., and Dilewski, G. (2000). *Study on the Feasibility of a Mechanical-biological Residual Waste Treatment Plant in Phitsanulok, Thailand*. Retrieved: December 23, 2006: http://etg.ufmg.br/~gustavo/geotecniaaplicada/p12.pdf.

Kennedy, J.S. (1985). *Energy and the Primary Aluminium Industry*. International Trade Administration, U.S. Department of Commerce, Washington D.C.

Lober, D.J. (1996). Municipal Solid Waste Policy and Public Participation in Household Source Reduction. *Waste Management and Research*, *14*, 125-143.

Lohani, B.N. (1982). Urban Solid Waste Recovery and Recycling. *Environment and Development of the Third World (ENDA), Document No. 19*, 40-81.

Lohani, B.N. (1984). Recycling Potentials of Solid Waste in Asia through Organized Scavenging. *Conservation and Recycling, 7*, 181-190.

Lohani, B.N. et al. (1984). Recycling of Solid Wastes. *Environmental Sanitation Reviews No. 13-14*. Environmental Sanitation Information Centre, Asian Institute of Technology, Bangkok, Thailand.

Lund, H.F. (2001). *Recycling Handbook. McGraw Hill Inc.*, 2001. ISBN: 0-02-60329-4.

Muttamara, S., Visvanathan, C., & Sheng, Y.K. (1992). *Waste Recycling and Reuse in Bangkok, Thailand*. A Report Submitted to Agro-vision for Project on "The Promotion of Waste Recycling and Reuse in Developing Countries"

Muttamara, S., Visvanathan, C. & Alwis, K.U. (1994). Solid Waste Recycling and Reuse in Bangkok. *Waste Management and Research, 12,* 151-163

OECD (Organization for Economic Co-operation and Development) (1989). *Household Waste: Separation Collection and Recycling*. Retrieved: September 22, 2006: http://www.sustainable-development.gov.uk/sustainable/quality99/ch4a.pdf.

Pichonsajja, S. (2002). *The Role of The Formal and Informal Sectors in Solid Waste Management: A Case Study of Recycling Activities in Phitsanulok, Thailand*. Asian Institute of Technology (AIT), Thailand, Masters Thesis No. EV-02-26.

Pollock, C. (1987). Mining Urban Wastes: The Potential for Recycling. *Worldwatch Paper 76*.

Poerbo, H. (1996). Urban Solid Waste Management in Bandung: Towards an Integrated Resource Recovery Systems. *Environment and Urbanization, 12*, 60-69.

Soulalay, V. (2006). *Development of Environmental Sustainability Concepts for the Asian Institute of Technology (AIT) Campus*. Asian Institute of Technology (AIT), Thailand, Masters Thesis No. EV-06-39.

Sriboonjit, J. (2002). *Solid Waste Handling in Some Selected BMA Primary Schools*. Asian Institute of Technology (AIT), Thailand, Masters Thesis No. EV-02-2.

Sunavala, P.D. (1981). Recycling of Municipal Agricltural and Industrial Wastes to Generate Renewable Sources of Energy. *Journal of Scientific and Industrial Research, 40*, 547-560.

Suwarnarat, K. (1996). Solid Waste Management Perspective of Bangkok, A Crisis Situation. *Proceedings of the Joint Symposium for Solid Waste Treatment,* Bangkok.

Sykes, G.N. (1978). *Recycling: Two Alberta Case Studies*. A Master's Degree Project, University of Calgary, Alberta, United States of America, August 1978.

Tchobanoglous, G., Theisen, H., Vigil, S.A. (1993). *Integrated Solid Waste Management: Engineering Principles and Management Issues*. McGraw-Hill Inc., Singapore. ISBN: 0-07-112865-4.

The Department of Infrastructure, AIT (2006). *Annual Report*. Campus and Environment Committee, Asian Institute of Technology, Bangkok, Thailand.

The Society of the Plastics Industry (1994). *Plastics and the Environment: Progress and Commitment*. Publ No. AD113, 1275 K Street, N.W. Suite 400, Washington D.C.

Tsai, C. (1993). *Solid Waste Recycling and Re-use in Bangkok*. Asian Institute of Technology (AIT), Bangkok, Thailand, Masters Thesis No. EV-93-13.

Visvanathan, C., Tränkler, J., Joseph, K., Chiemchaisri, C., Basnayake, B.F.A. (2004). *Municipal Solid Waste Management in Asia*. Asian Regional Research Program on Environmental Technology, Asian Institute of Technology (AIT), Thailand.

Wentz, C.A. (1995). *Hazardous Waste Management*. McGraw-Hill, Second Addition, New York. ISBN: 0-07-113975-3.

Zurbrügg, C. (2002). *Urban Solid Waste Management in Low-Income Countries of Asia: How to Cope with the Garbage Crisis*. Scientific Committee of Problems of the Environment (SCOPE), Urban Solid Waste Management Review Session, Durban, South Africa, November 2002.

Appendix A

Experimental Procedures

Appendix A.1 Procedure for Sampling of Solid Wastes

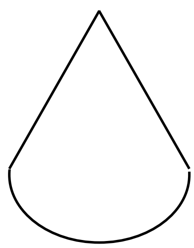
1. A crane is used to mix the incoming solid wastes inside the pit from each of the two trucks to obtain as much uniformity as possible.

2. About ¼ portion is grabbed by the crane and transferred to the side.

3. Transfer the sample to the working area.

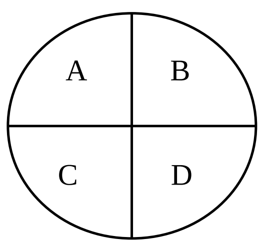
4. Mix the collected sample to the working area.

5. Pile it into a cone shape.



Side View

6. Cut it into four equal parts.



Top View

7. Take two diagonal sections (A and D) and mix together.

8. Repeat steps 5 and 7 to make a sample of about 50 kg.

9. Put the sample into two plastic bags.

10. Place into a truck and deliver it to the laboratory for analysis.

Appendix A.2 Procedure for Physical Classification of Solid Waste

1. Spread the waste sample out on a plastic sheet. Set small plastic pails and seats around the waste.

2. Classify the waste into the following categories and put each category into separate pails.

a. Paper
b. Vegetables (including meats, but excluding bones and shells)
c. Textiles
d. Wood and grass
e. Plastics
f. Leather and rubber
g. Ferrous metals
h. Non-ferrous metals
i. Glass
j. Stone and ceramics (including bones and shells)
k. Miscellaneous (over 5 mm)
l. Miscellaneous (under 5 mm).

For definition of the above categories, see Appendix A.3.

3. During classification, take notice of the following points. Separate the miscellaneous materials over 5 mm and under 5 mm by sieving. Then, using a pair of tongs, classify into the other categories as much as possible.

4. Weigh each category and record on the data sheet.

5. For each category, mix together very well and, if necessary, cut into small pieces.

6. Remove a portion of the sample for each category and discard.

7. Weigh the remaining portion of each category and record on a data sheet.

8. Place each category into the stainless steel trays and put them into an oven.

Appendix A.3 Definition of the Physical Components in Solid Waste

Component	Definition	Example
I. Combustibles		
1. Paper	Any material and paper	Paper bags, card board, tissue paper, etc.
2. Textile	Has its origin from yarn	Cotton, wool, nylon, etc.
3. Garbage	Waste from food stuff	Vegetable refuse, fruit skin, stem of green, corn, cob, etc.
4. Grass and wood	Any material and products made of wood, bamboo and straw	Furniture such as desk, chair, bed board, toy, coconut shell, etc.
5. Plastics	Any material and products made of plastic	Wrapping film, plastic bag, plastic bottle, plastic hose, plastic string, etc.
6. Leather and rubber	Any material and products made of rubber or leather	Ball, shoes, purse, rubber band, etc.
II. Non-combustibles		
1. Ferrous metals	Any material made of iron which can be attracted by magnets	Tin can, wire, fence, knife, bottle cover, etc.
2. Non-ferrous metals	Any material which cannot be attracted by magnets	Aluminium can, foil, ware, etc.
3. Glass	Any material and products made of glass	Bottles, glassware, light bulb, etc
4. Ceramics	Any non-combustibles other than metal and glass	Bricks, tiles and pottery
III. Miscellaneous	Any material, where in further classification of which is impossible and which do not belong to any component mentioned above, belong to this class. This class is divided into 2 parts: > 5 mm & < 5 mm.	Bones, pebbles, sand, earth, hair, etc.

Appendix A.4 Procedure for Bulk Density Measurement

1. Take the solid waste sample volume of around 500 l.

2. Load sample of waste into the container of known volume, preferably with the capacity of about 100 l, until lightly filled up to the container brim.

3. Lift the container up to about 30 cm off the floor and drop repeatedly four times.

4. Lightly fill the displaced portion of the container to the brim.

5. Record the combined weight of the container and the waste.

6. Subtract the weight of the container from the data shown in step 5.

7. Divide by the volume of the container (in this case, 60 l) to obtain the apparent density in kg/l.

8. Do this twice and record the average bulk density.

Appendix A.5 Methods for Chemical Analysis of Solid Wastes

Analytical Parameters	Pretreatment	Quantitative Analysis	Instrument
Carbon	Combustion (C → CO), adsorption 800^0C	Gravimetric analysis	Elemental analyzer
Hydrogen	Combustion (H → H_2O), adsorption 800^0C	Gravimetric analysis	Elemental analyzer
Nitrogen	Kjeldahl digestion (N → NH_3), then distillation	Volumetric analysis (neutralization)	Elemental analyzer
Sulphur	Combustion (S → SO_2 → SO_3), absorption	Volumetric analysis (neutralization)	Elemental analyzer
Chlorine	Combustion (Cl → Cl_2 → HCl), absorption	Volumetric analysis (Volhard method)	
Oxygen	(Ignition Loss) – {(Carbon) + (Hydrogen) + (Nitrogen) + (Sulphur) + (Chlorine)}		
pH	Dissolved in water (1:5)	Electrometry	pH meter with glass electrode
Calorific value			Bomb calorimeter
Moisture content		Gravimetric Analysis	

Appendix A.6 Procedure for Ash and Combustible contents

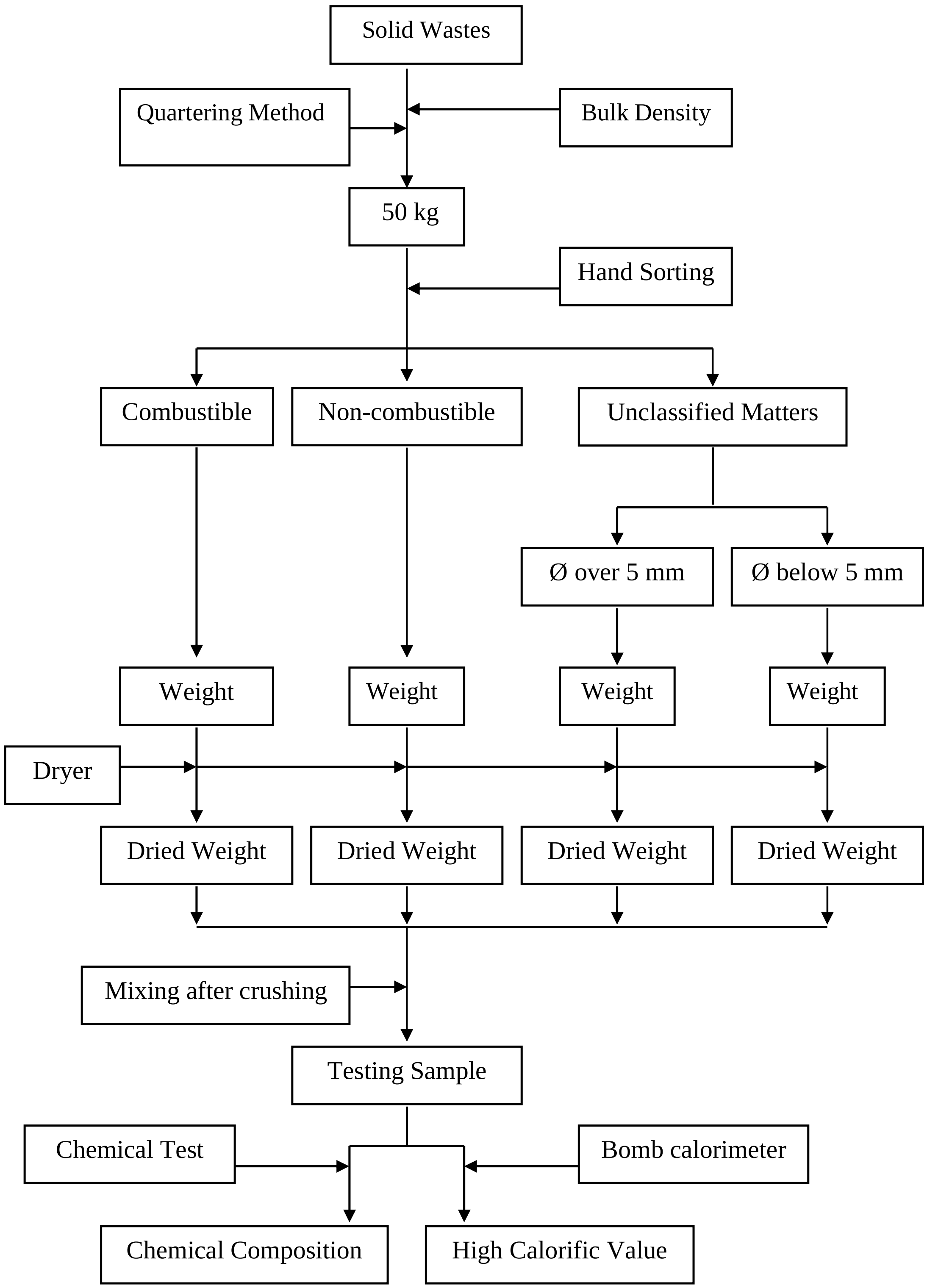
1. Dried sample after analyzing for moisture content is burnt by flaming in the flame hood to reduce the volume of the sample and then is transferred into a prepared porcelain dish.

2. Continue the burning of the sample in the porcelain dish by placing it in the muffle furnace at 550^0C for 2 hours with the door of the muffle furnace slightly open to allow air to enter for complete combustion.

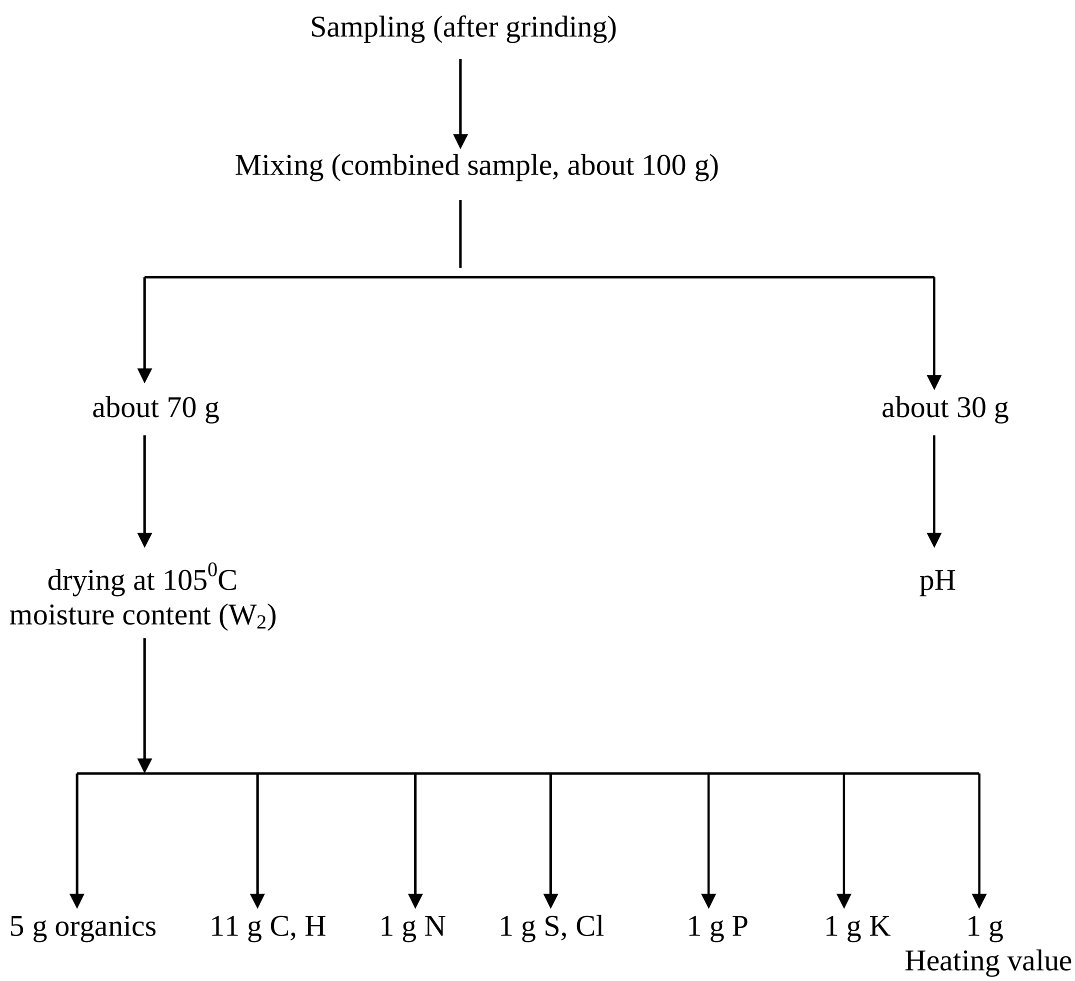
3. Cool the porcelain dish in a desiccator and weigh.

4. Calculate the volatile solids content of the sample.

Appendix A.7 Guidance of Characteristics Analysis



Appendix A.8 Chart for Chemical Analysis



Appendix A.9 Calculation of Chemical Composition

W_1 : Moisture content (%)
W_2 : Moisture content of dried combustibles (%)
W_3 : Moisture content of non-combustibles (%)

U_1 : Non-combustibles (dry weight basis) (%)
U_2 : Non-combustibles (wet weight basis) (%)

c : Carbon content of measurement (%)
h : Hydrogen content of measurement (%)
n : Nitrogen content of measurement (%)
s : Sulphur content of measurement (%)
cl : Chlorine content of measurement (%)

H_1 : Heating value of measurement (%)

1. Total moisture content
$W = W_1 + W_2 \times (100 - U_1)/100 \times (100 - W_1)/100$ (%)

2. Total organic content
$B = B_1 \times (100 - W_2)/100 \times (100 - U_1)/100 \times (100 - W_1)/100$ (%)

3. Total ash content
$A = 100 - (W + B)$ (%) or
$A = U2 \times (100 - W_3)/100 + A_1 \times (100 - W_2)/100 \times (100 - U_1)/100 \times (100 - W_1)/100$ (%)

4. Element content
$C = c \times (100 - W_2)/100 \times (100 - U_1)/100 \times (100 - W_1)/100$ (%)
$H = h \times (100 - W_2)/100 \times (100 - U_1)/100 \times (100 - W_1)/100$ (%)
$N = n \times (100 - W_2)/100 \times (100 - U_1)/100 \times (100 - W_1)/100$ (%)
$S = s \times (100 - W_2)/100 \times (100 - U_1)/100 \times (100 - W_1)/100$ (%)
$Cl = cl \times (100 - W_2)/100 \times (100 - U_1)/100 \times (100 - W_1)/100$ (%)
$O = B - (C + H + N + S + Cl)$ (%)

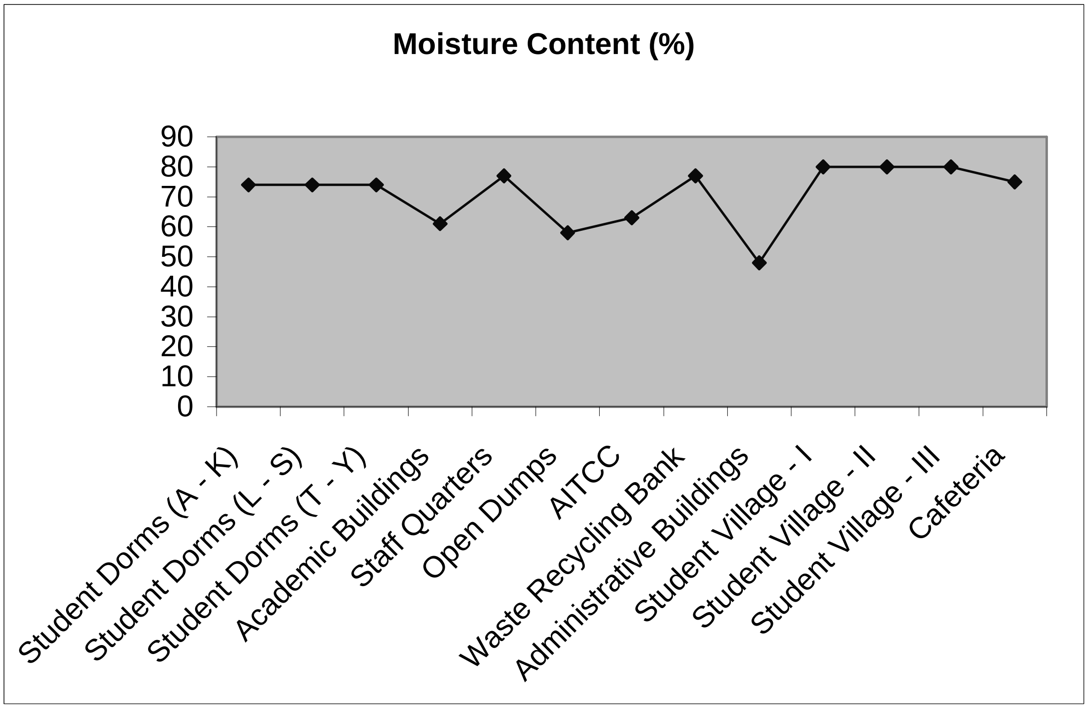
5. Heating Value
Higher Heating Value (Kcal/kg)
$H_0 = H_1 \times (100 - W_2)/100 \times (100 - U_1)/100 \times (100 - W_1)/100$ (%)

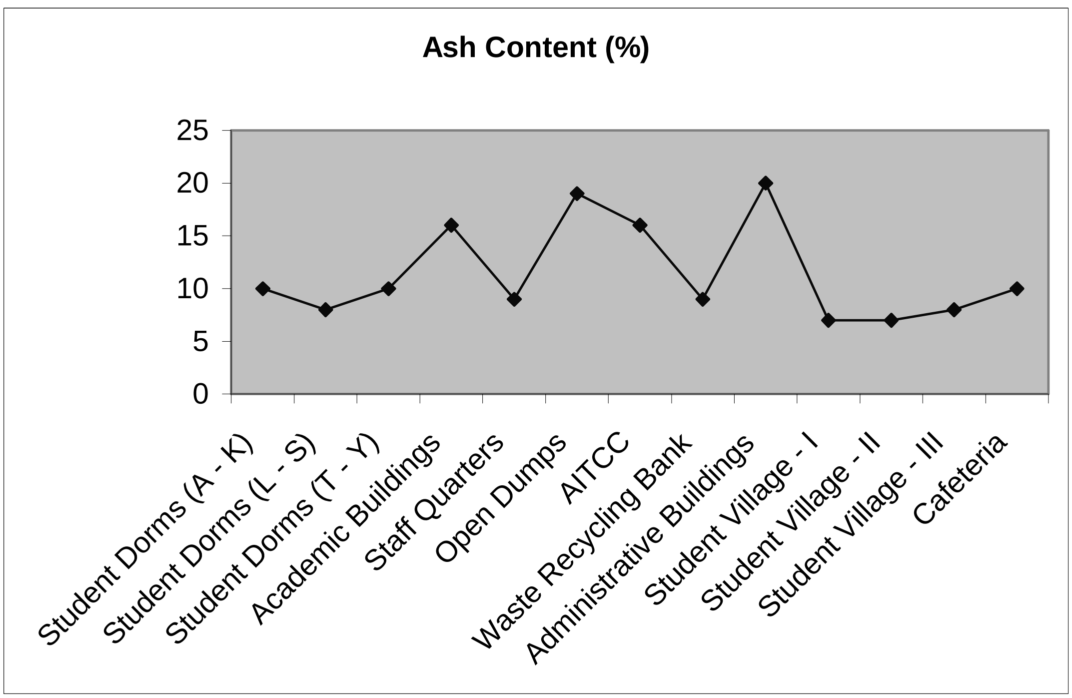
Lower Heating Value (Kcal/kg)
$H_u = H_0 - 6 \times (9 \times H + W)$

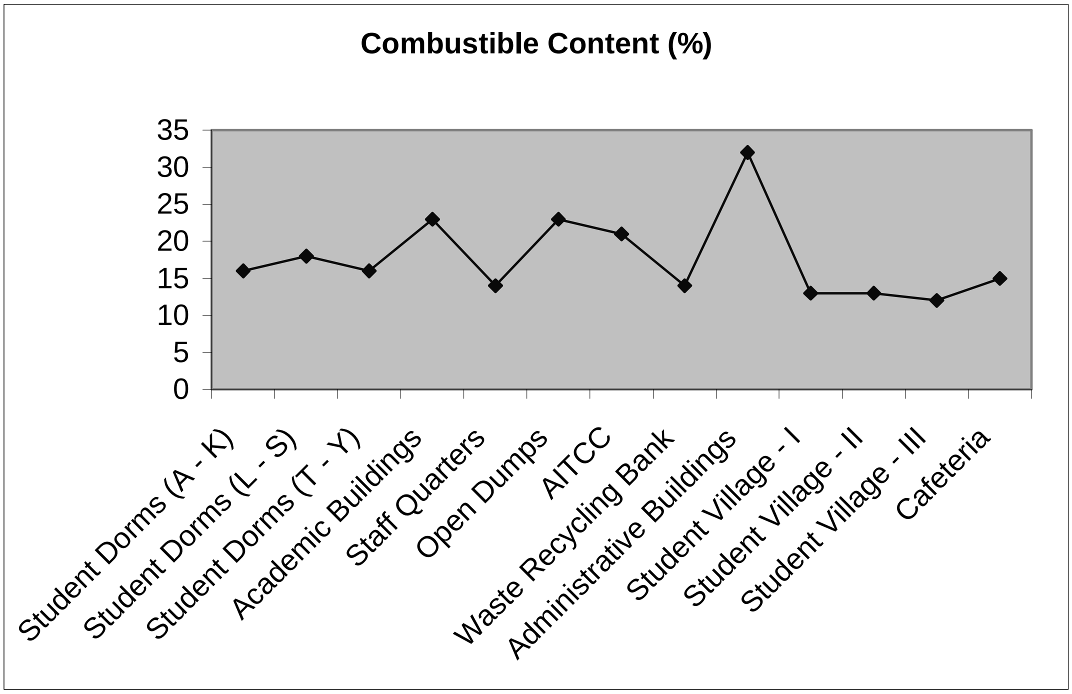
Appendix B

Physical and Chemical Characteristics of Solid Wastes

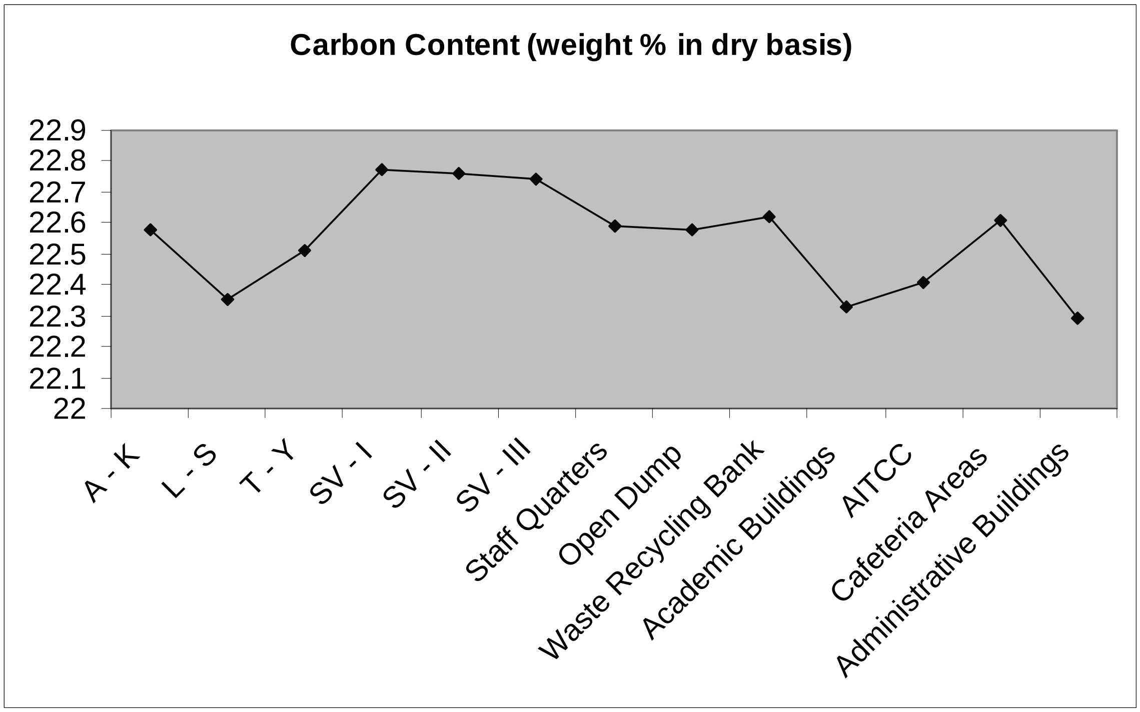
Appendix B.1 Analysis of Moisture Content, Ash Content and Combustible Content

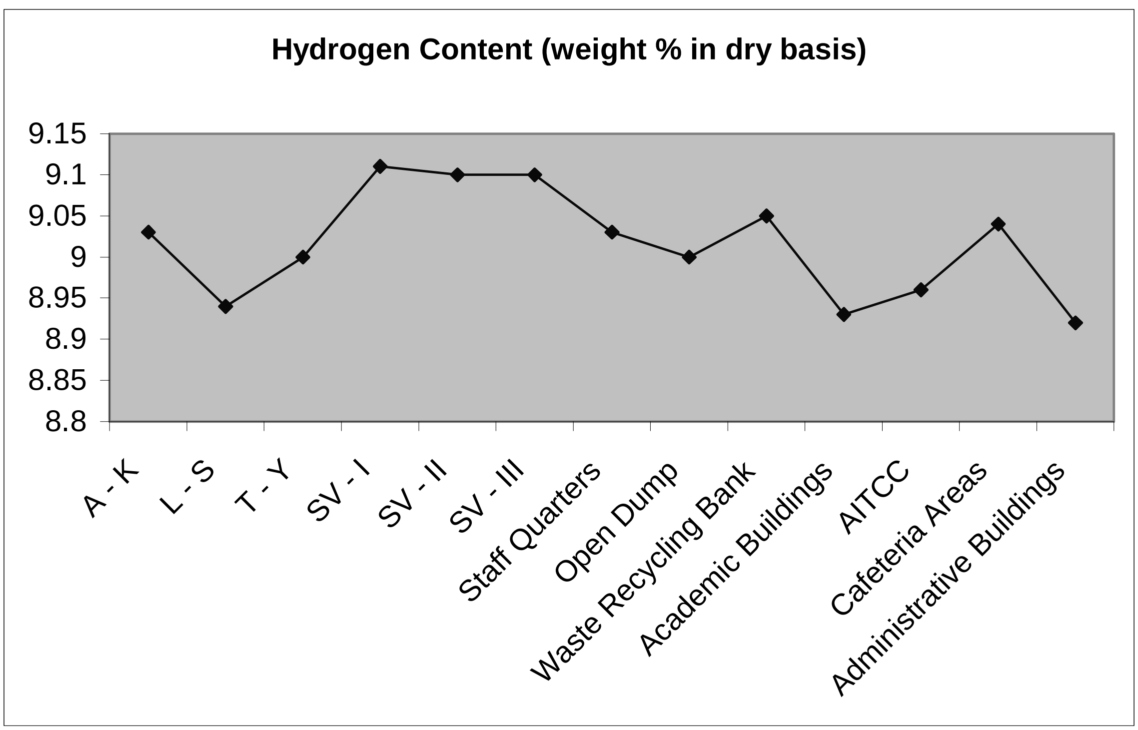


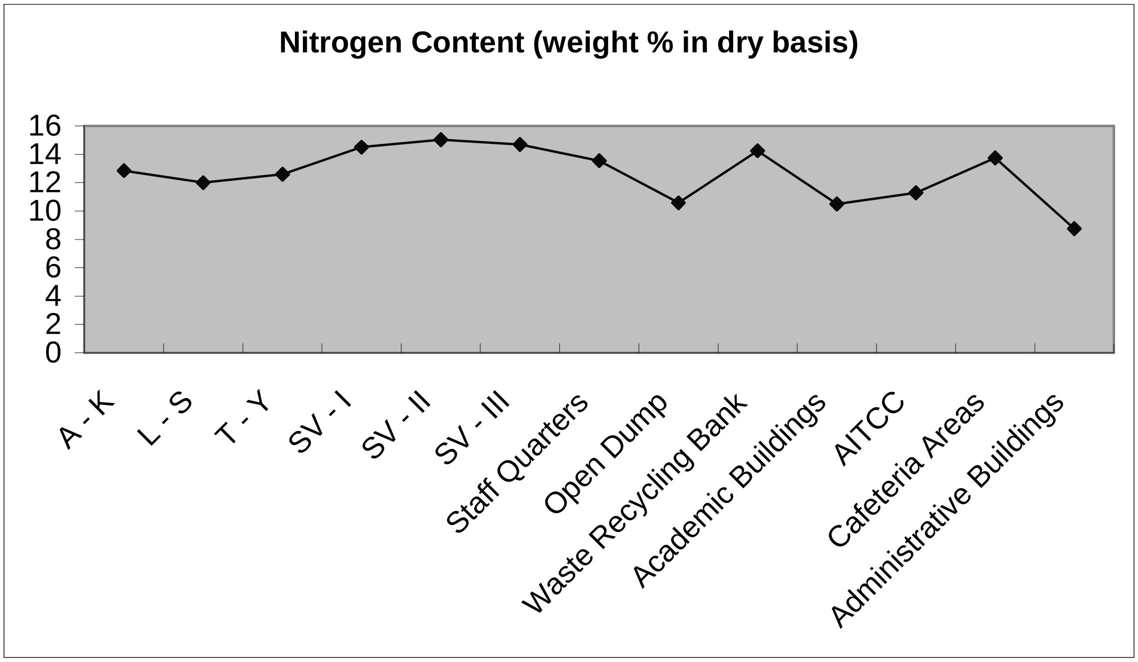


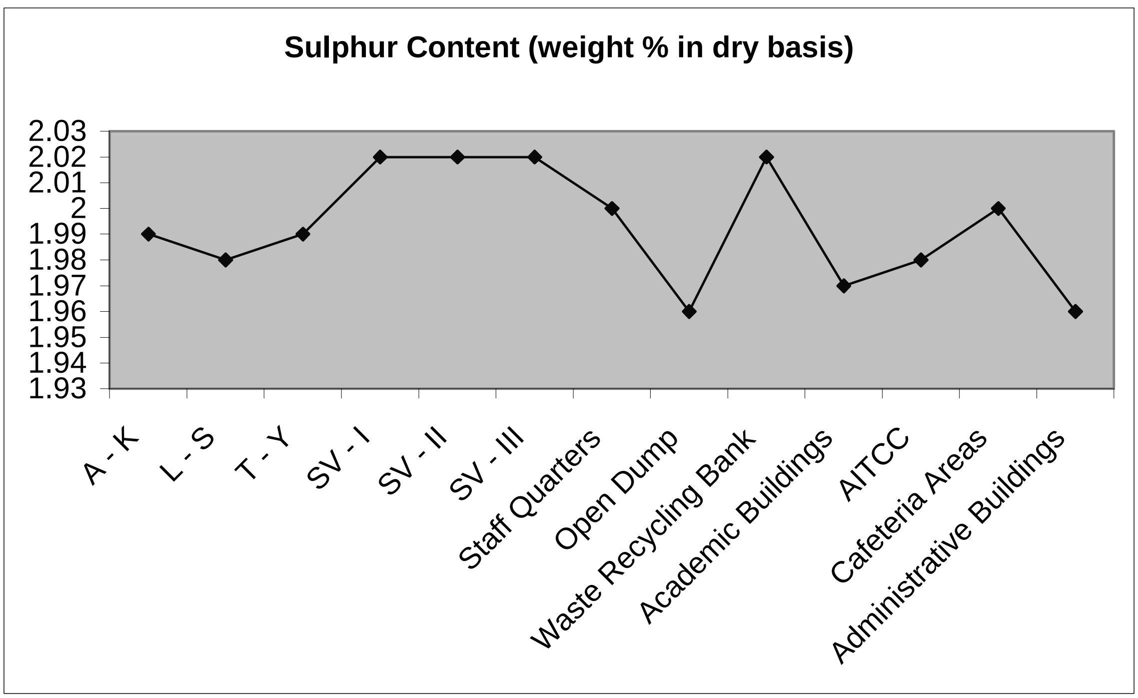

Combustible Content (%)
35
30
25
20
15
10
5
0
Student Dorms (A - K)
Student Dorms (L - S)
Student Dorms (T - Y)
Academic Buildings
Staff Quarters
Open Dumps
AITCC
Waste Recycling Bank
Administrative Buildings
Student Village - I
Student Village - II
Student Village - III
Cafeteria

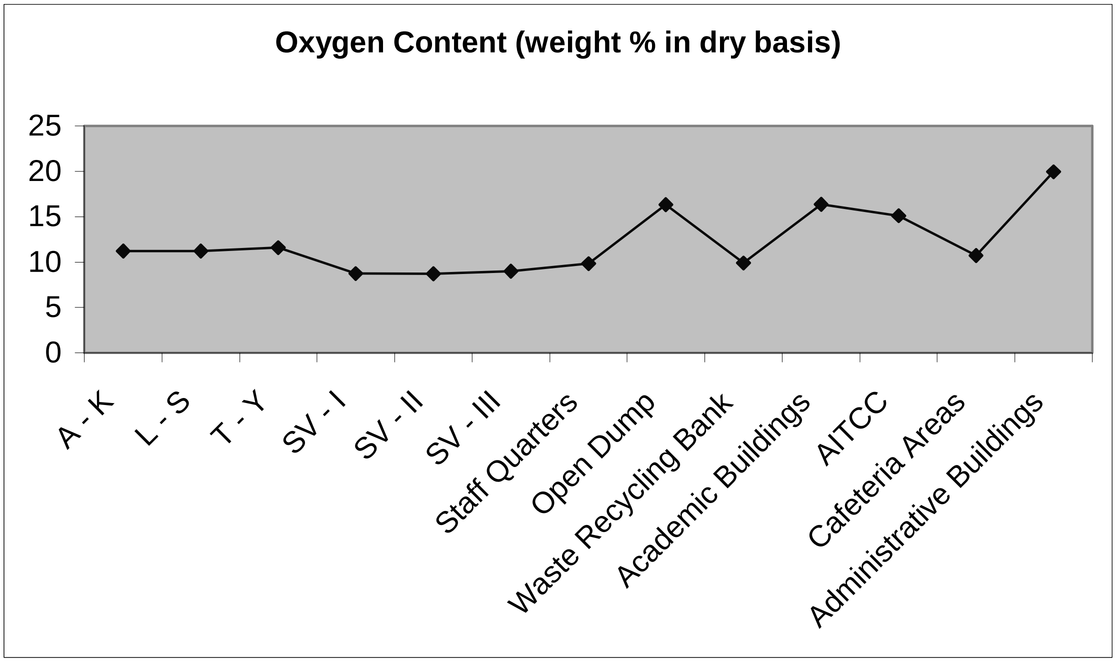
Appendix B.2 Chemical Element Composition of Solid Waste

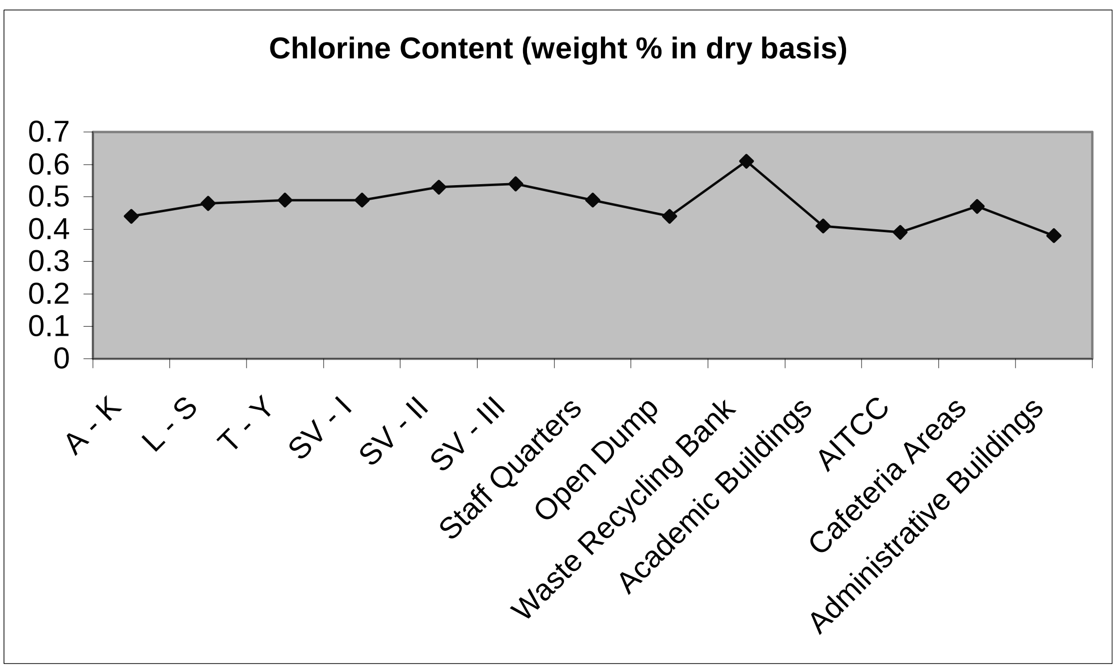




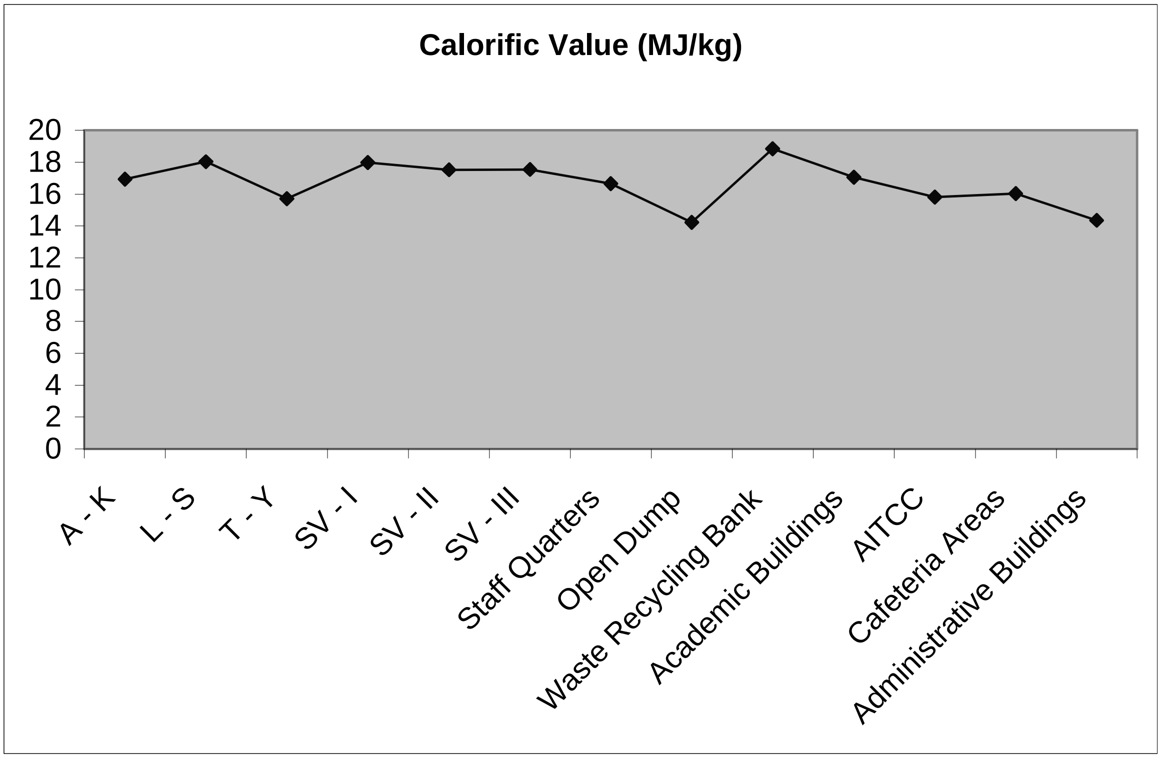

Nitrogen Content (weight % in dry basis)
16
14
12
10
8
6
4
2
0
A - K
L - S
T - Y
SV - I
SV - II
SV - III
Staff Quarters
Open Dump
Waste Recycling Bank
Academic Buildings
AITCC
Cafeteria Areas
Administrative Buildings


Sulphur Content (weight % in dry basis)
2.03
2.02
2.01
2
1.99
1.98
1.97
1.96
1.95
1.94
1.93
A - K
L - S
T - Y
SV - I
SV - II
SV - III
Staff Quarters
Open Dump
Waste Recycling Bank
Academic Buildings
AITCC
Cafeteria Areas
Administrative Buildings


Oxygen Content (weight % in dry basis)
25
20
15
10
5
0
A - K
L - S
T - Y
SV - I
SV - II
SV - III
Staff Quarters
Open Dump
Waste Recycling Bank
Academic Buildings
AITCC
Cafeteria Areas
Administrative Buildings


Chlorine Content (weight % in dry basis)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
A - K
L - S
T - Y
SV - I
SV - II
SV - III
Staff Quarters
Open Dump
Waste Recycling Bank
Academic Buildings
AITCC
Cafeteria Areas
Administrative Buildings

Appendix B.3 Calorific Value of Solid Wastes



Appendix C

Details of Recyclable Material Categories and Prices

Table C1: Detail of Recyclable Materials Categories and Prices at Recycling Firms

Categories	Average Price (baht)	Unit	Remarks
Paper and Cardboard			
Newspaper	3.03	kg	
Cut paper	1.85	kg	
Mixed paper	1.3	kg	
Black and white paper	3.08	kg	
Notebook paper	2.72	kg	
Computer paper	5.00	kg	
Pound paper	6.00	kg	
Cement bag	1.10	kg	
Cardboard	2.60	kg	
Whisky box	1.50	kg	
Glass			
Whisky bottle (round-shape)	1.28	bottle	
Whisky bottle (flat-shape)	0.49	bottle	
New beer bottle	0.52	bottle	12 bottles/5.5 kg
Old beer bottle	0.47	bottle	
Soy sauce bottle	0.29	bottle	
Soft Drink Bottle	1.50	bottle	
Lipowitan-D Bottle	1.13	bottle	
Red Bull bottle	0.75	bottle	
Klauster beer bottle	0.38	bottle	
Old beer bottle	0.57	bottle	
Fish sauce bottle	0.78	bottle	
Sponsor bottle	0.84	bottle	8 bottles/kg
Big pesticide bottle	1.23	bottle	
Small pesticide bottle	1.00	bottle	Some shops do not buy
White glass	0.95	kg	
Red and brown glass	0.73	kg	
Ferrous Metal			
Thick steel	2.3	kg	
Thin steel	1.13	kg	
Cut steel	1.68	kg	
Nail	1.78	kg	
Plow steel	1.78	kg	
Lathe steel	0.6	kg	
Stripe steel (>5 kg)	3.5	kg	
Engine steel	2.83	kg	
Non-ferrous Metal			
Soft drink aluminium can	33.00	kg	
New rim aluminium	46.00	kg	
Thick aluminium	39.00	kg	
Cleaned thin aluminium	42.00	kg	
Stripe aluminium	49.00	kg	
Aluminium work	21.00	kg	
Electronic pan aluminium	21.00	kg	
Mixed aluminium	12.00	kg	

Bottle cap aluminium	18.00	kg	
Medicine can aluminium	19.00	kg	
Car wheel aluminium	38.00	kg	
Burnt aluminium	5.50	kg	
Mosquito net aluminium	5.00	kg	
Non-ferrous Metal (cont'd)			
Aluminium pot	31.00	kg	
Thick burnt copper stripe	48.00	kg	
Thin burnt copper stripe	46.00	kg	
Well-separated copper stripe	55.00	kg	
Thick brass	39.00	kg	
Thin brass	30.00	kg	
Brass lathe	28.00	kg	
Soft lead	13.00	kg	
Stainless steel	17.00	kg	
Plastic			
Mixed plastic	4.00	kg	
PET drinking water bottle	8.00	kg	
PET cooking oil bottle	3.50	kg	
Drinking water bottle	7.00	kg	
PVC boots	7.50	kg	
Fish sauce plastic cap	3.50	kg	
Normal saline bottle (cap cut)	8.50	kg	
Black cable sheet	4.00	kg	
Coloured cable sheet	2.00	kg	
Fertilizer bag	0.70	bag	
Others			
Kapok mattress	4.00	kg	
Coconut meat	3.70	kg	
Coconut shell	0.50	kg	
Crushed coconut meat	1.70	kg	
Candle	9.00	kg	
Cut candle	4.00	kg	
Car batteries (black)	5.90	box	
Car batteries (white)	6.90	box	

Appendix D

Tha Kong Data and Table of Calculations

Table D1: Recycling Costs Incurred by the Collection Crews at Wongpanit

Category	Weight (kg/day)	Cost of Recycling (baht/kg)	Total Cost (baht)
Aluminium	468	37.00	17,316.00
Batteries	54	6.50	351.00
Used candles	94	6.50	611.00
Cardboard	4,290	3.35	14,371.50
Coconut meat	6	3.95	23.70
Copper	40	49.00	1,960.00
Glass	18,956	1.00	18,956.00
Lead	11	13.00	143.00
Paper	17,406	3.35	58,310.00
Plastic	7,060	3.50	24,710.00
PVC boots	196	7.50	1,470.00
Steel	2,918	3.25	9,483.50
Total (per day)	**51,449**		**147,706.00**
Total (per year)	**18,778,885**		**53,912,690.00**

(1) Total Recycling Cost Incurred by the Collection Crews at Wongpanit = 53,912,690.00 baht

Table D2: Recycling Costs Incurred by Tricyclists, Pick-up Traders and Street Scavengers from Roadsides

Category	Weight (kg/day)	Cost of Recycling (baht/kg)	Total Cost (baht)
Paper	353	3.35	1,182.55
Cardboard	254	3.35	850.90
Plastic	152	3.50	532.00
Glass	758	1.00	758.00
Ferrous metals	334	3.25	1,085.50
Non-ferrous metals	87	30.50	2,653.00
Aluminium cans	20	37.00	740.00
Total (per day)	**1,958**		**7,802.00**
Total (per year)	**714,670**		**2,847,730.00**

(2) Total Recycling Costs Incurred by Tricyclists, Pick-up Traders and Street Scavegers from Roadsides = 2,847,730.00 baht

Table D3: Recycling Costs Incurred by Tricyclists and Pick-up Traders from Households

Category	Weight (kg/day)	Cost of Recycling (baht/kg)	Total Cost (baht)
Paper	95	3.35	318.25
Cardboard	41	3.35	137.35
Plastic	38	3.50	133.00
Glass	156	1.00	156.00
Ferrous metals	102	3.25	331.50
Non-ferrous metals	27	30.50	823.00
Aluminium cans	16	37.00	592.00
Total (per day)	**475**		**2,492.00**
Total (per year)	**173,375**		**909,580.00**

(3) Total Recycling Cost Incurred by Tricyclists and Pick-up Traders from Households = 909,580.00 baht

Table D4: Recycling Costs Incurred by SLF Scavengers at the Tha Kong Municipality Landfill

Category	Weight (kg/day)	Cost of Recycling (baht/kg)	Total Cost (baht)
Plastic bags			
White plastic bags	63	2.00	126.00
Black plastic bags	61	1.00	61.00
Glass			
Pesticides bottles	10	1.60	16.00
Red glass	305	0.30	91.50
White glass	311	0.50	155.50
M-100 bottles	156	0.90	140.40
Fish sauce bottles	14	1.10	15.40
Flat liquor bottles	5	2.50	12.50
Sponsor bottles	17	2.50	42.50
Plastic			
Mixed plastic	179	4.80	859.20
PET bottles	13	30.00	390.00
Drinking water bottles	22	8.00	176.00
PVC shoes	1	5.00	5.00
Paper and Cardboard			
Pound paper	12	3.00	36.00
Mixed paper	158	1.00	158.00
Cardboard	16	1.00	16.00
Ferrous and Non-ferrous Metals			
Aluminum cans	11	34.00	374.00

Table Contd.			
Steel	52	3.45	179.00
Copper	5	49.00	245.00
Total (per day)	**1,411**		**3,122.00**
Total (per year)	**515,015**		**1,139,457.00**

(4) Total Recycling Cost Incurred by SLF Scavengers from the Tha Kong Municipality Landfill = 1,139,457.00 baht

Calculations:

(a) Overall Recycling Cost = (1) + (2) + (3) + (4) = 58,809,457.00 baht

(b) Benefit/Cost Ratio of the Tha Kong Municipality = $\frac{\text{Value of Recyclables}}{\text{Overall Recycling Cost}}$

From Table 4.12, the value of recyclables in the market is 60.66 million baht

Therefore, the Benefit/Cost Ratio = $\frac{\text{60.66 million baht}}{\text{58.81 million baht}}$ = 1.03

(c) Similarly, from Table 4.2, the value of recyclables is 15,100 baht

Since, the overall recycling costs in the Tha Kong Municipality is 58.81 million baht for an population of 78,600, it can be calculated for a population of 3,800 as 2.84 million baht.

Hence, the Benefit/Cost Ratio for AIT = $\frac{\text{15,100 baht}}{\text{2.84 million baht}}$ = 0.005

Application of 3R Principles to Solid Waste Management on the Asian Institute of Technology (AIT) Campus

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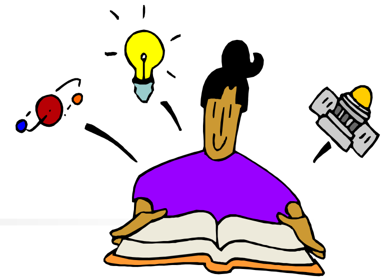
Environmental Engineering & Management
School of Environment, Resources & Development,
Asian Institute of Technology, Bangkok
May 2007

Introduction & Background

- Average population of AIT: 3,800
- Need for proper disposal of thousands of tons of solid waste/year
- Aggravation of solid waste management problems at AIT
- Odour problems caused by solid wastes: increase in population of disease vectors
- Site selection of waste recycling facilities also a major problem

Thesis Objectives

- To conduct a solid waste study in AIT using a mass balance diagram
- To study the physical and chemical properties of solid waste collected from the various locations in the AIT campus
- To perform a technical feasibility study on the solid waste management of the AIT campus
- To study the options for solid waste reduction, reuse and recycling in the AIT campus



Scope of Work

- Analysis of physical and chemical components of solid wastes in AIT
- Evaluation of wastes for recycling and reuse processes
- Market potential of secondary materials from the collection crew to traders
- Mass balance of solid wastes is determined from the solid waste audit
- Improvement of existing solid waste management practices
- To analyze and identify specific aspects of recycling activities by the formal & informal sectors

Literature Survey

Solid Waste Management Systems

The 6 functional elements are:

- Waste Generation
- Storage
- Collection
- Transfer & Transport
- Reduce, Reuse, Recycling & Recovery
- Disposal

The 3R Concept

- Reuse
- Recycle
- Reduce

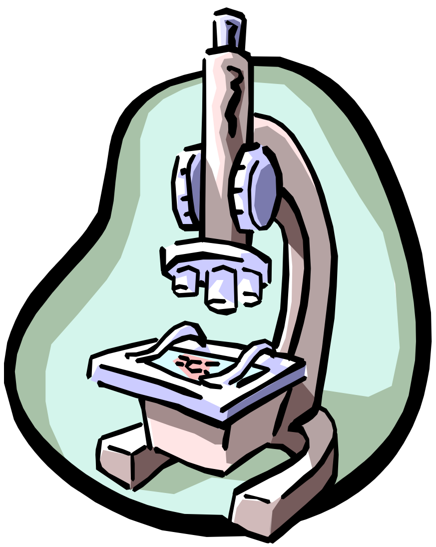
- The importance & benefits of the 3R concept is that it is the most effective of solid waste management methods!!

Technical Feasibility Studies

Benefit-Cost Analysis (BCA) :

- What is Benefit-Cost Analysis?
- Significance in Solid Waste Management
- Significance of Benefit-Cost Ratio in Recycling Industries
- Importance to National Economy
- Application to SWOT Analysis

Research Methodology



Analytical Strategy

Primary Data:

- Samples are taken from various locations in AIT
- Physical and chemical paramaters of the solid wastes are analyzed
- Sampling is done over a period of 30 days for reliability of data
- Sampling is done at a frequency of 1 time/day from each location
- Analysis is done according to the American Public Works Association Manual on Municipal Refuse Disposal

Analytical Strategy

Schedule for sampling of solid wastes at AIT

Location	No. of samples	Frequency	Total
Student Dorms (A-K)	10	1 time/day	10
Student Dorms (L-S)	10	1 time/day	10
Student Dorms (T-Y)	10	1 time/day	10
Staff Quarters	10	1 time/day	10
AIT Conference Centre	10	1 time/day	10
Student Village I	10	1 time/day	10
Student Village II	10	1 time/day	10
Student Village III	10	1 time/day	10
Cafeteria Area/Mini-marts	10	1 time/day	10
Academic Buildings	10	1 time/day	10
Administrative Buildings	10	1 time/day	10
Waste Recycling Bank	10	1 time/day	10
Open Dumps	10	1 time/day	10

Secondary Data

Data from Internet:

- Solid Wastes that can be recycled
- Cost of selling by scavengers
- The quantity of solid waste sent to the recycling stations

Tha Kong Municipality Data:

- Recycling costs at transfer station and waste recycling facilities
- Total weight of solid wastes at transfer stations
- Segregation efficiency of AIT
- Transportation costs

Secondary Data Collection

Data Analysis Phase:

- Calculate representative weight of solid waste from samples & find the composition
- Calculate the total weight of the solid wastes produced
- Calculate the total weight of recyclable & non-recyclable wastes
- Calculate the saving costs made at the Tha Kong Municipality & transfer stations

Solid waste parameters to be analyzed

Physical Parameters:

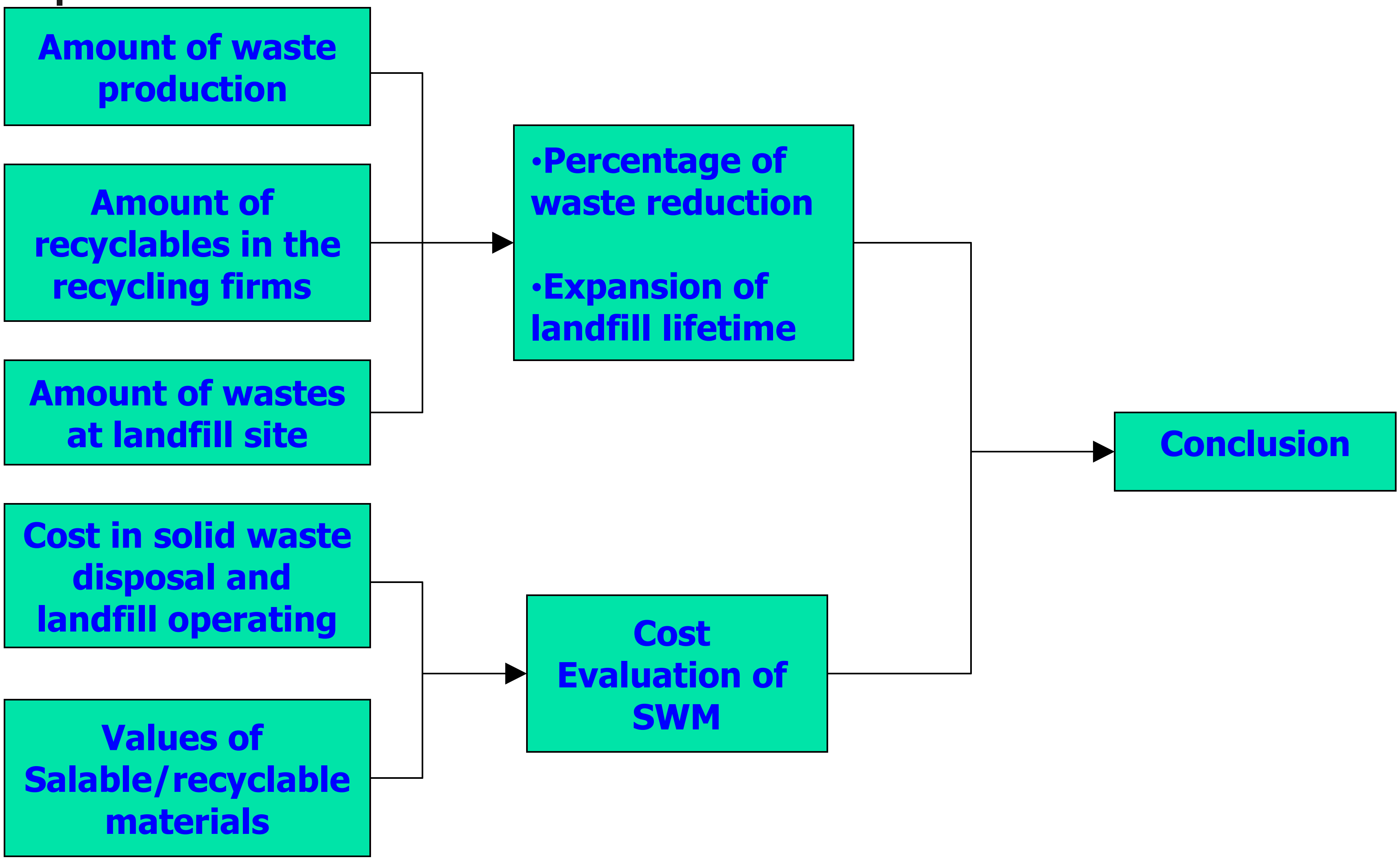
Parameter	Analytical Method
Solid Waste Compositions	Quartering, Hand Sorting & Weighting Method
Bulk Density	Quartering & Weighting Method
Total Solid	(100-Moisture Content)%
Volatile Solid	Ignition at 550^0C
Ash Content	(total solid-volatile solid)%

Solid Waste Parameters to be analyzed

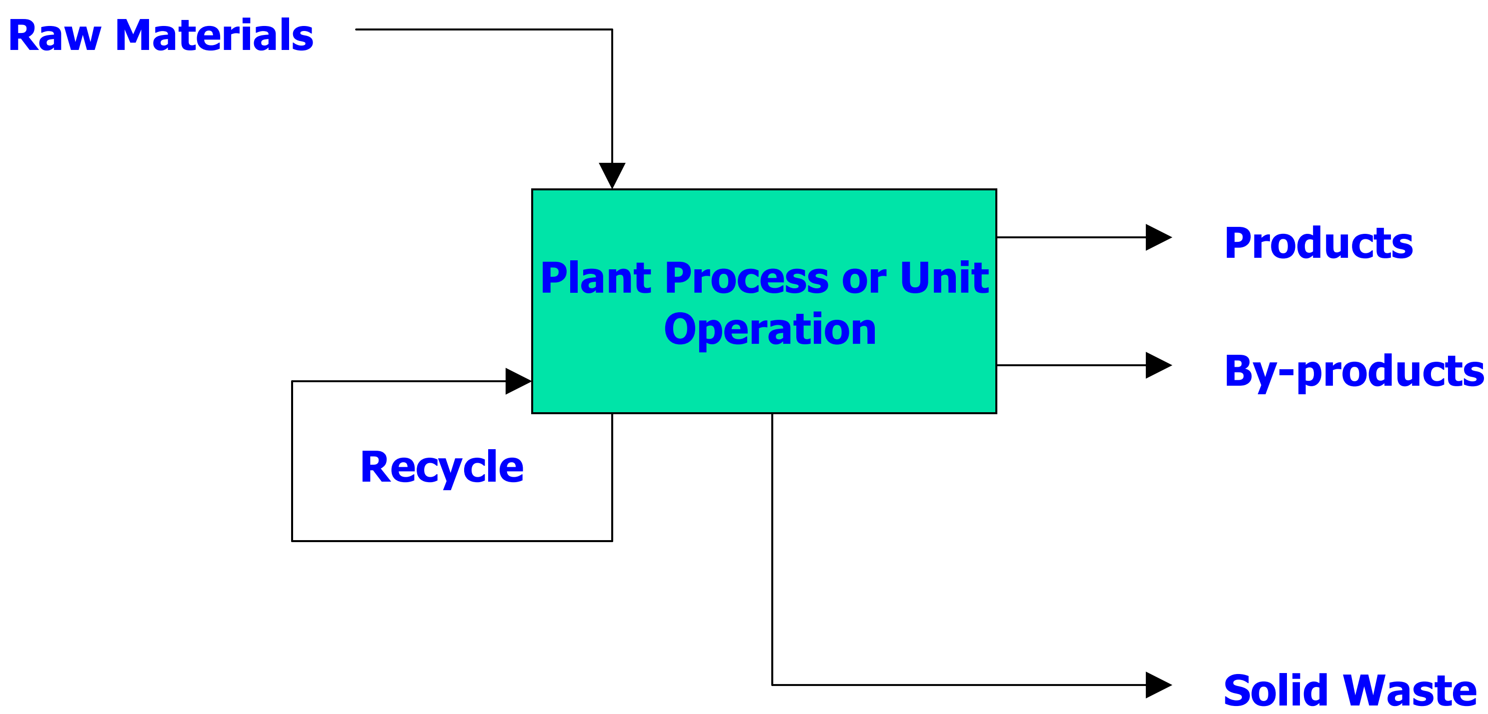
Chemical Parameters:

Parameter to be analyzed	Method of Analysis
Carbon (C)	Gravimetric
Hydrogen (H)	Gravimetric
Nitrogen (N)	Volumetric (Neutralization)
Chlorine (Cl)	Volumetric (Volhard Method)
Sulphur (S)	Volumetric (Neutralization)
Oxygen (O)	Ignition Loss – (C + H + N + S+ Cl)
Moisture Content	Gravimetric Analysis
Calorific Value	Calorimetric

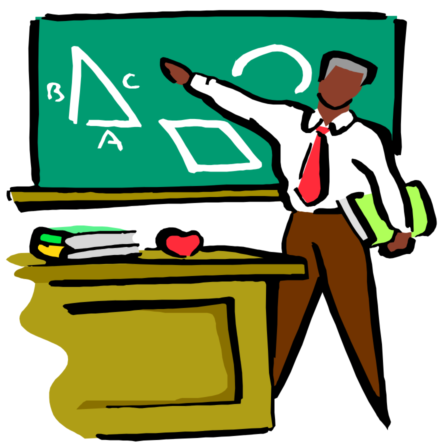
Methodology of BCA



Components of a mass balance of a typical recycling facility

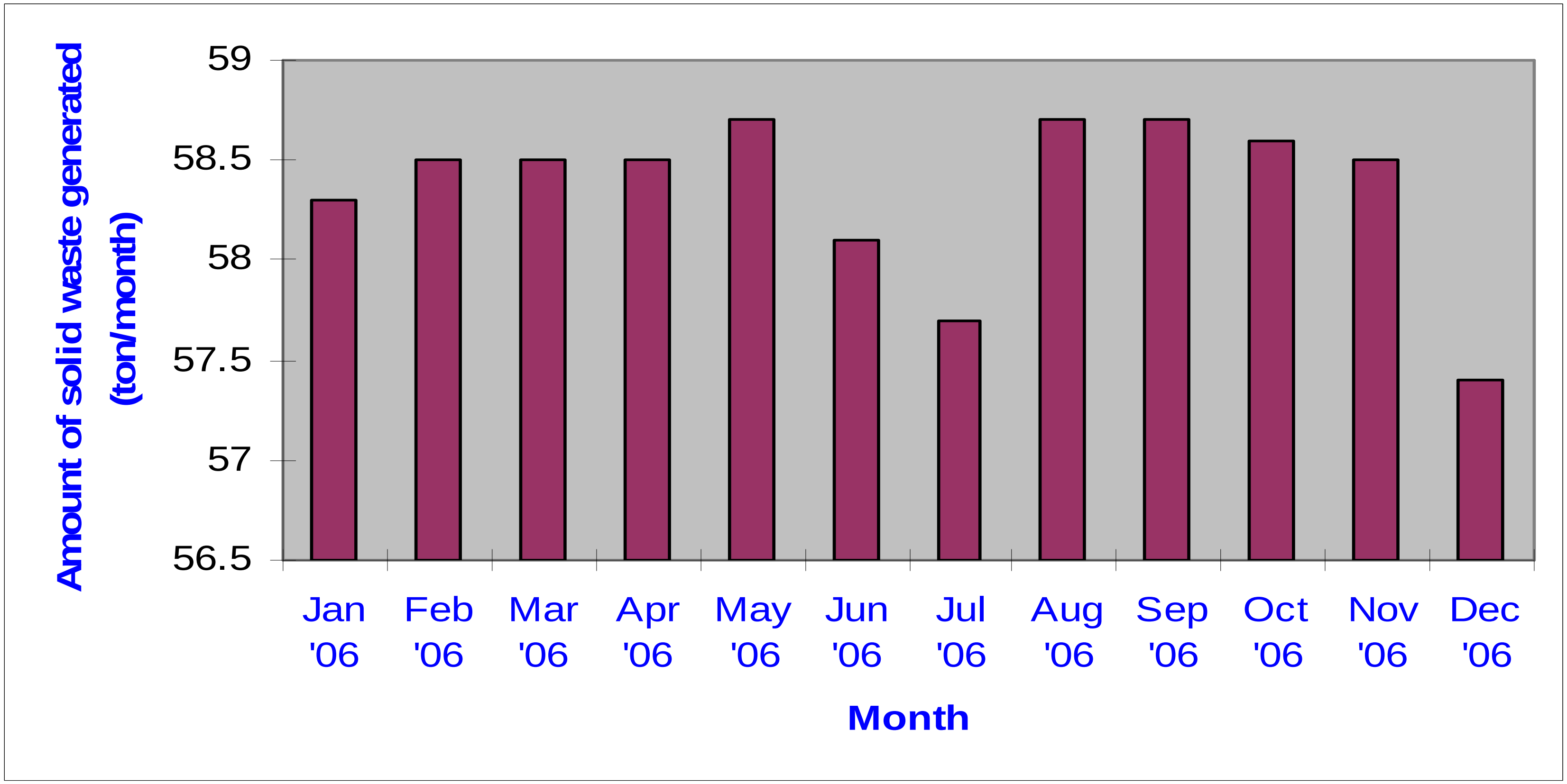


Results & Discussions



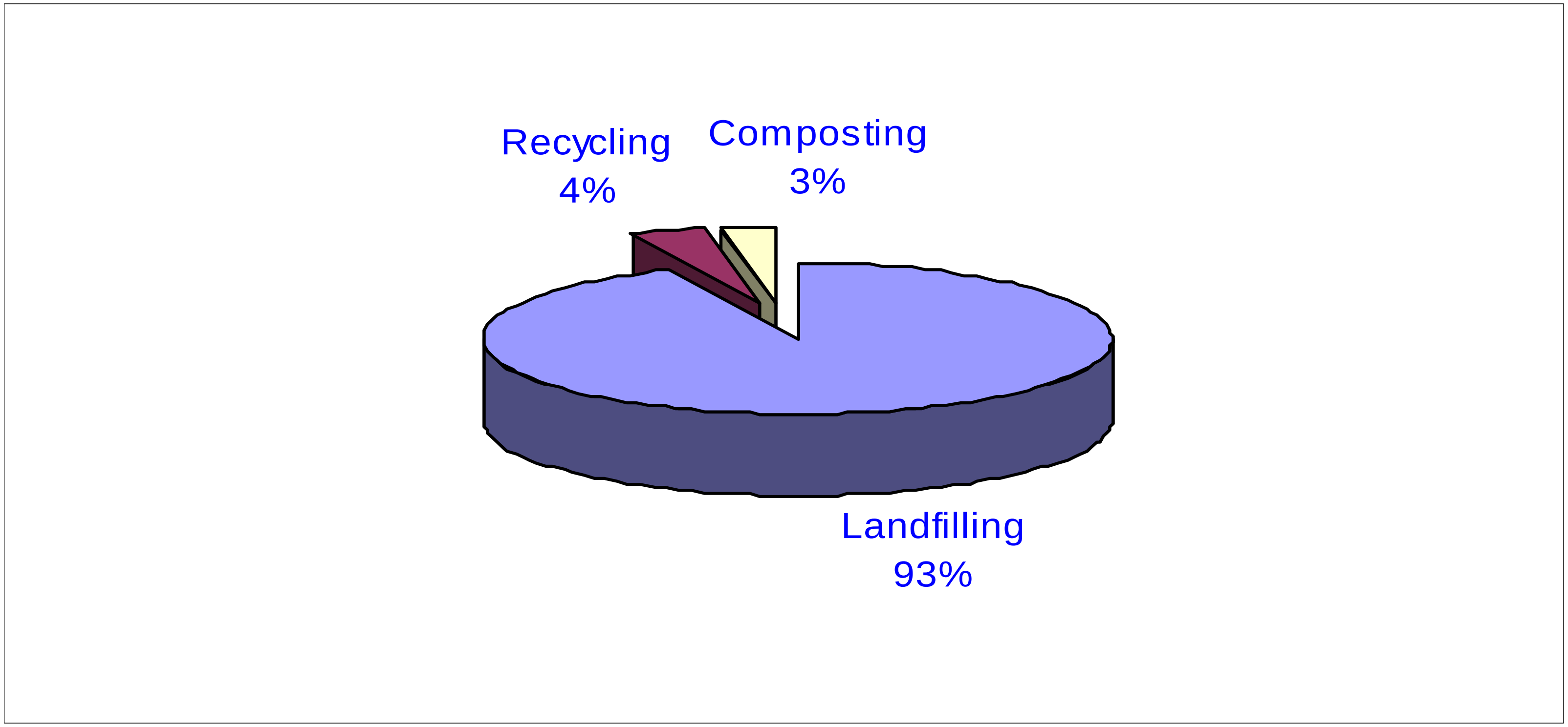
Solid Waste Audit Study

Monthly variations in the solid waste generation in AIT (Dept. of Infrastructure, AIT, 2006)



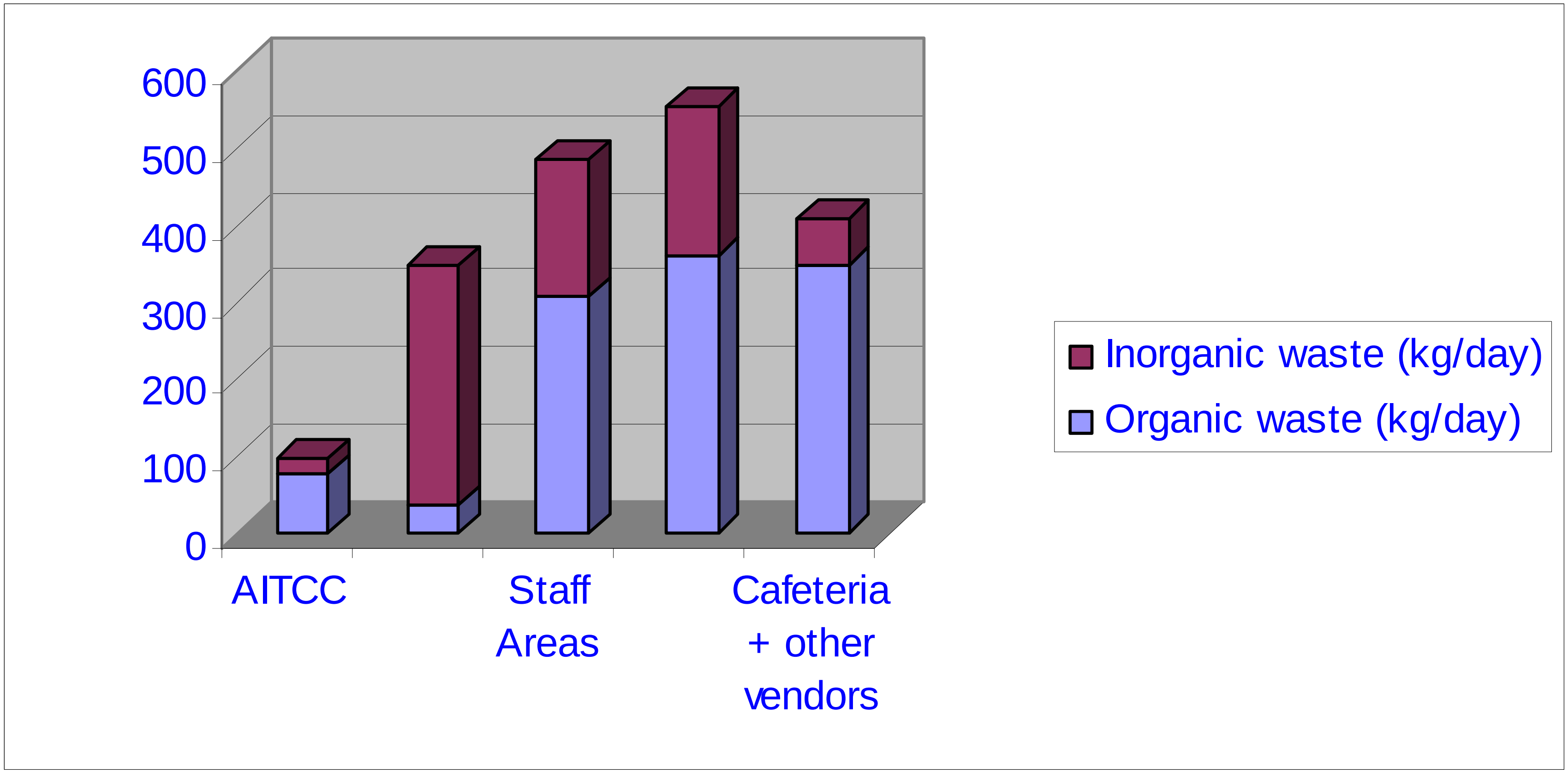
Solid Waste Audit Study

Percentage Composition of Treatment Methods of Solid Waste in AIT



Solid Waste Audit Study

Composition of Solid Wastes at AIT



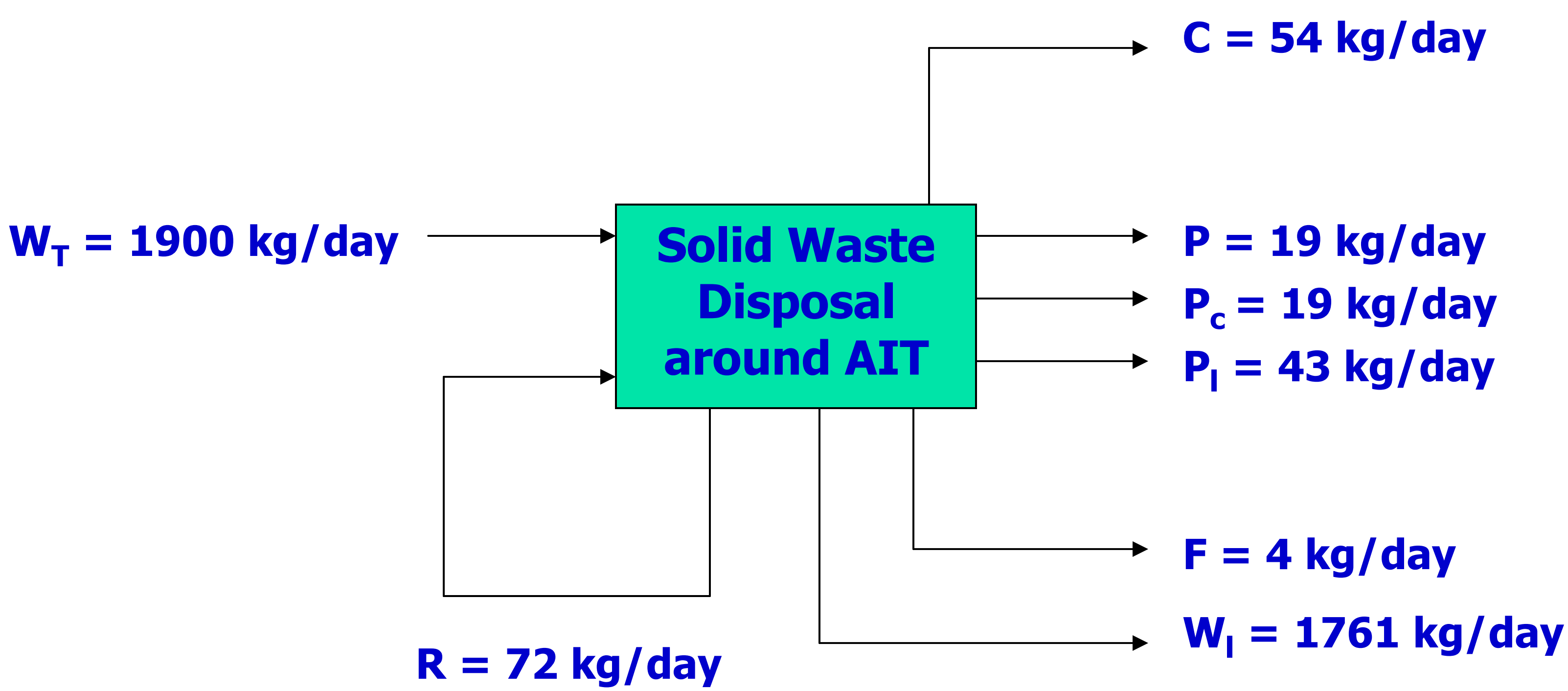
Solid Waste Audit Study

Amount of Recyclable Wastes

No.	Items	Amount of Recyclable Wastes	
		(kg/month)	(Sales/month in Baht)
1	Newspapers	95	380
2	Cardboard	300	1,200
3	Plastics	235	3,400
4	Black/White Paper	1,260	8,800
5	Mixed Paper Pieces	400	800
6	Cans	10	420
7	Steel	27	80
8	Glass	13	20
	Total	**2,340**	**15,100**

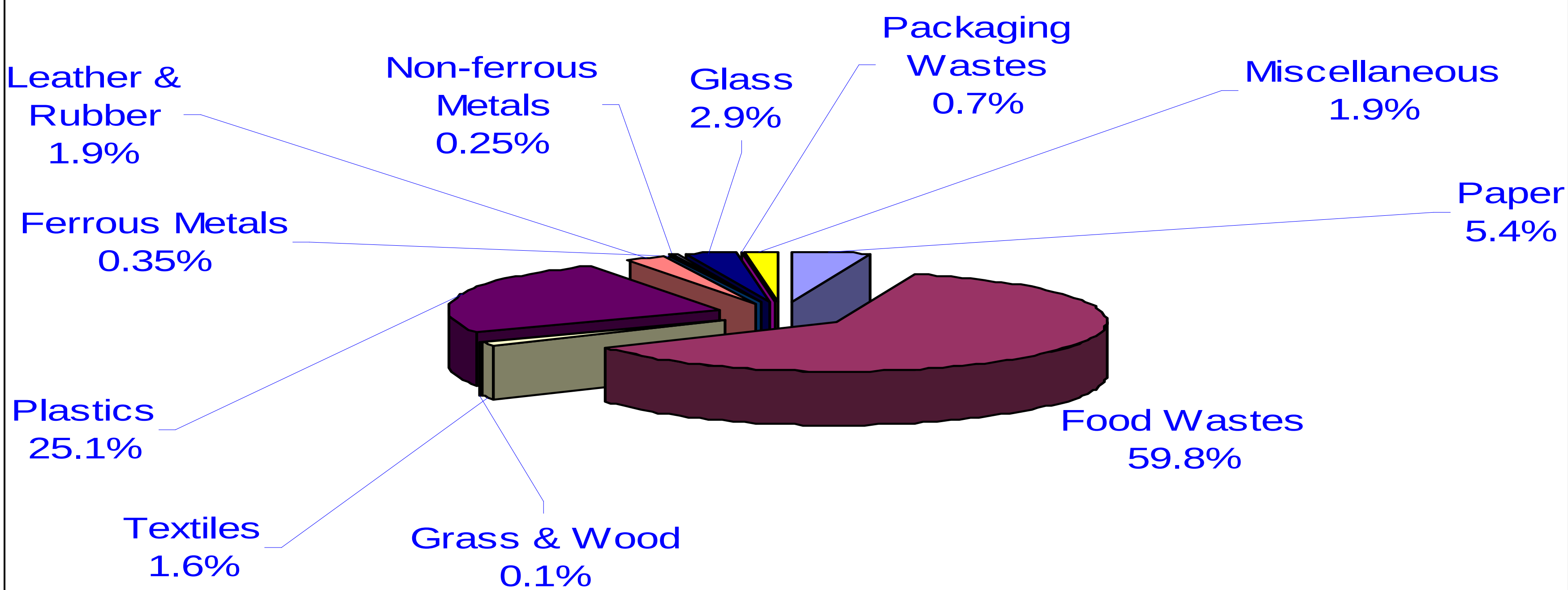
Solid Waste Audit Study

Result of the mass Balance of solid waste generation composition and disposal component of AIT



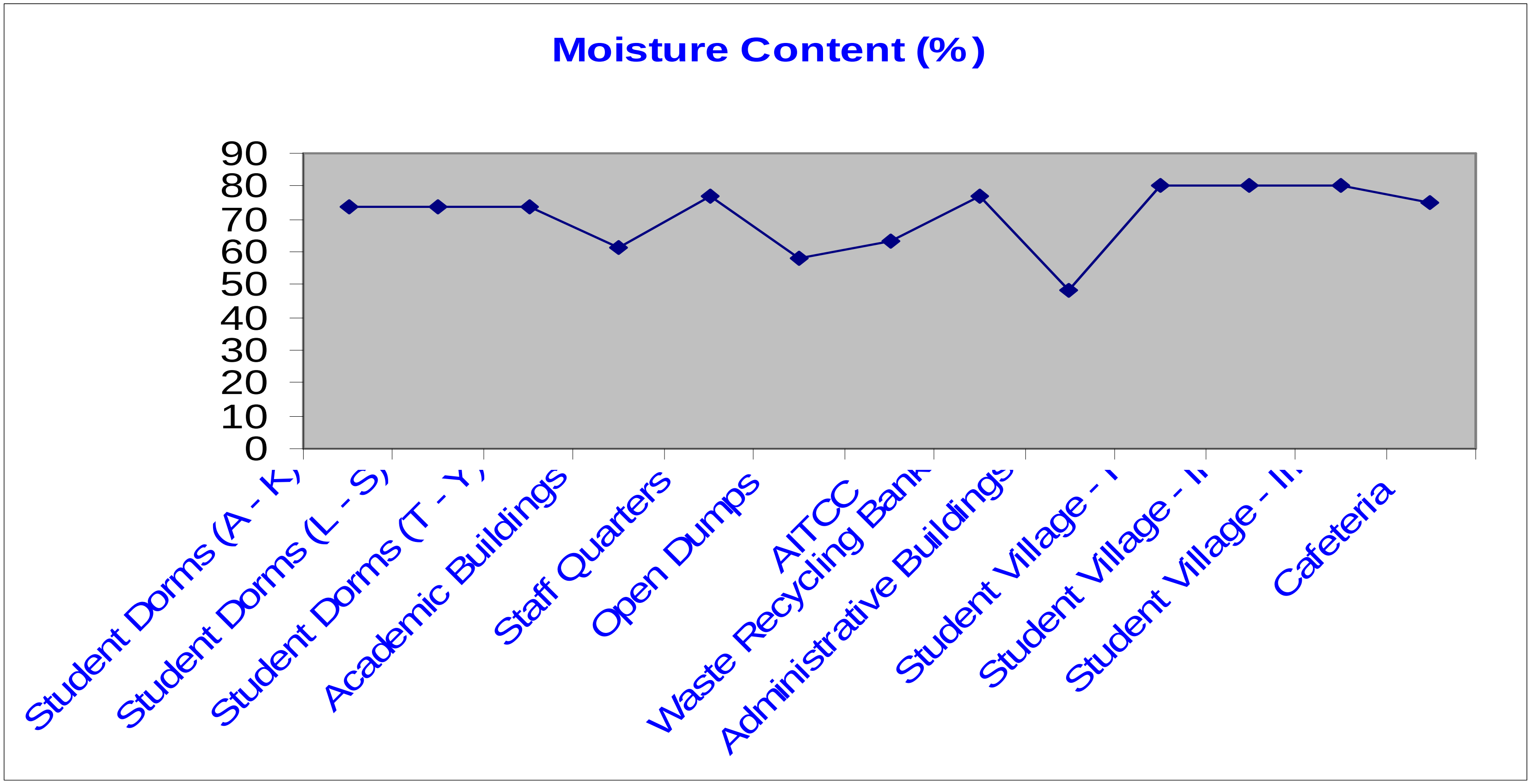
Results of Physical & Chemical Analysis

Physical Composition of Solid Wastes in AIT



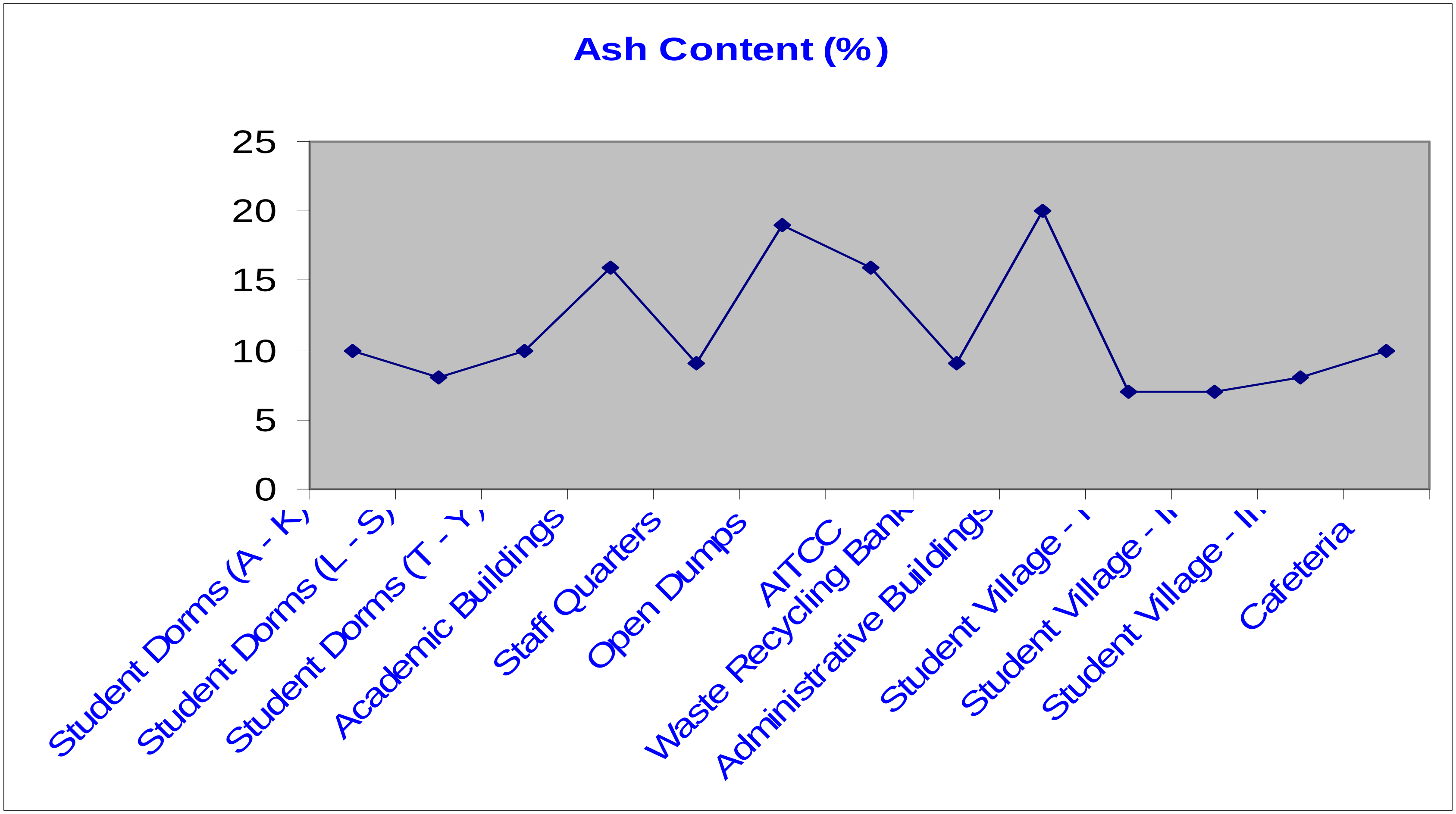
Physical Analysis of Solid Wastes

Analysis of Moisture Content



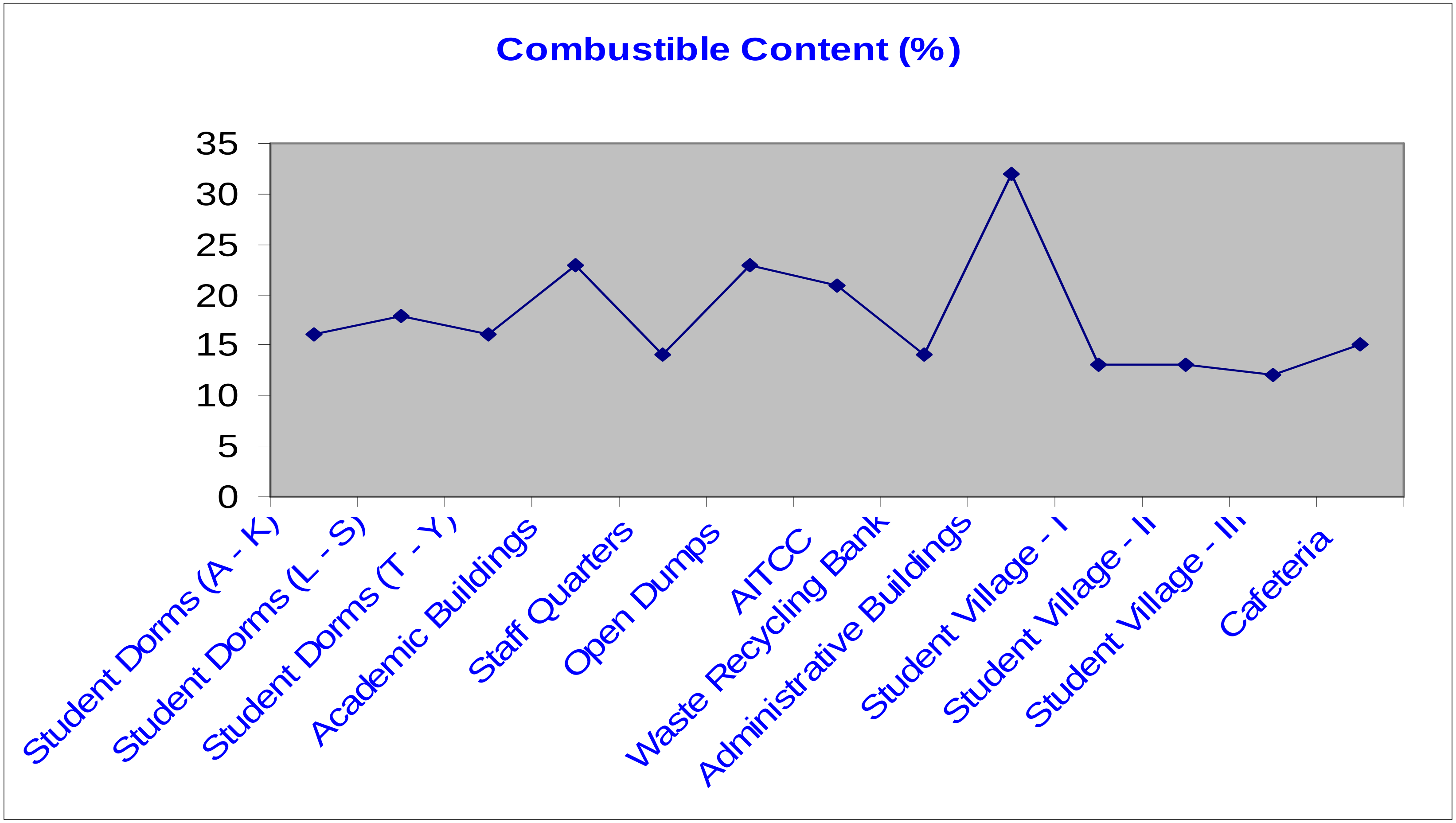
Physical Analysis of Solid Wastes

Analysis of Ash Content



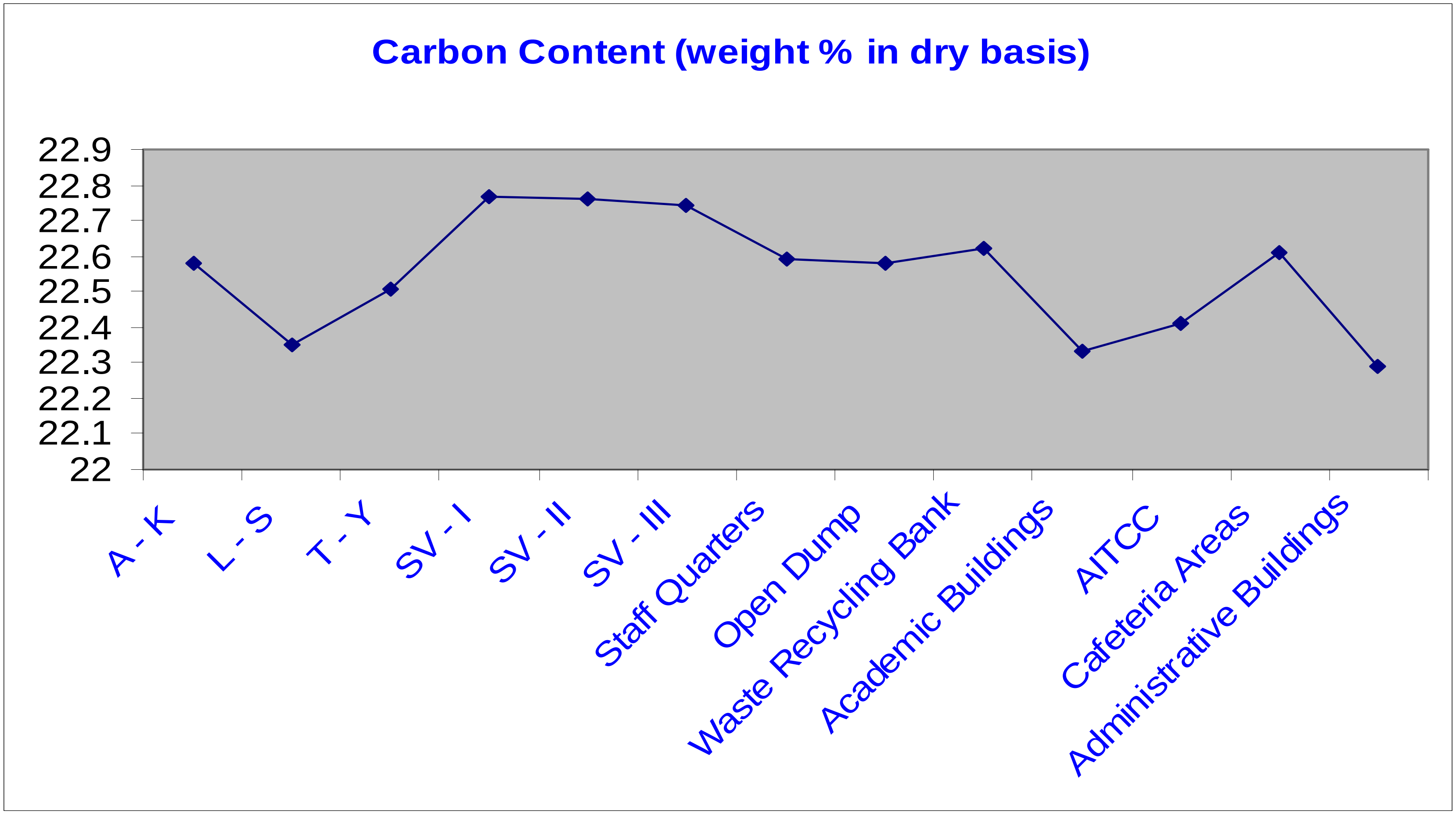
Physical Analysis of Solid Wastes

Analysis of Combustible Content



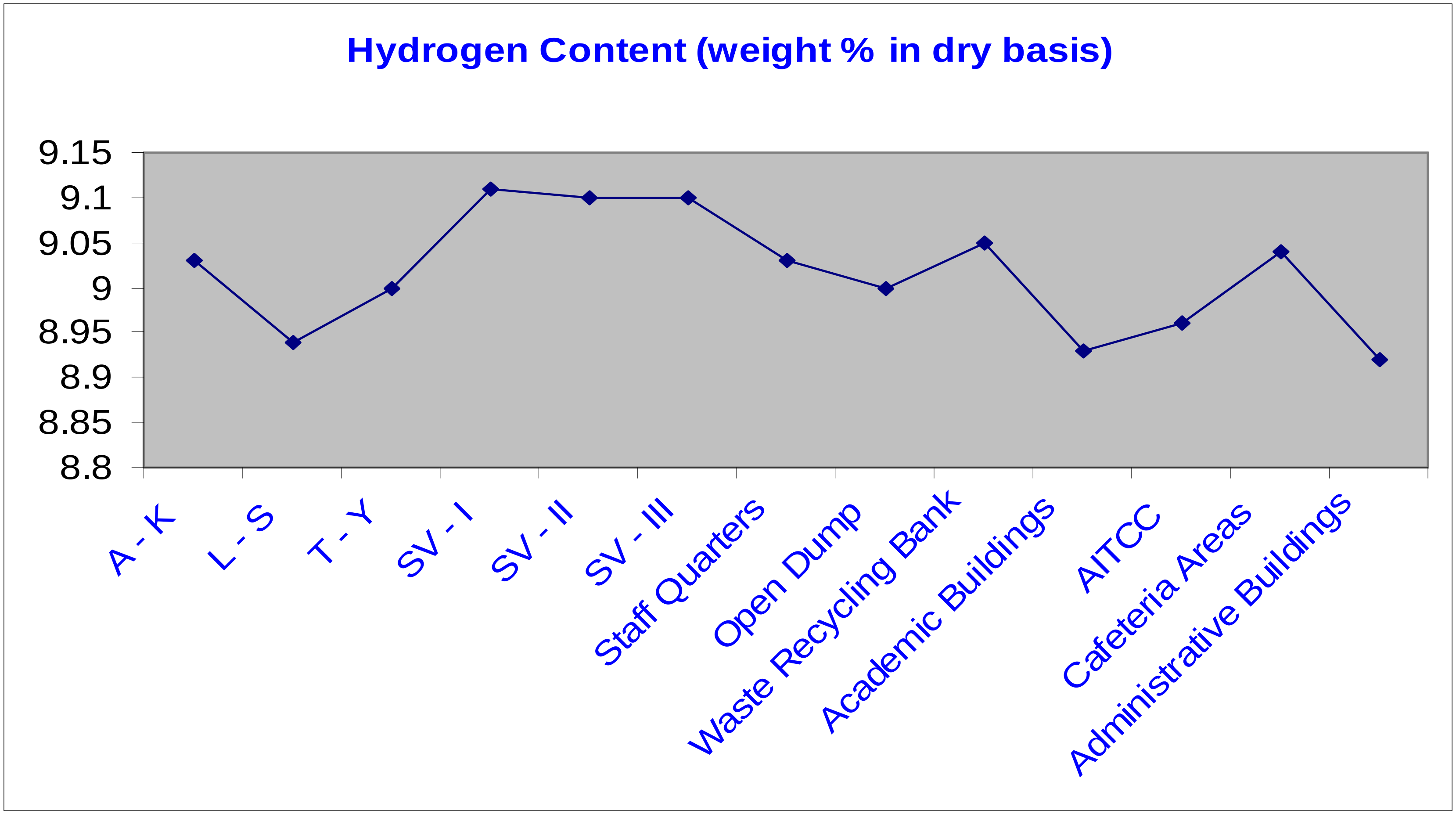
Chemical Analysis of Solid Wastes

Elemental Analysis of Carbon



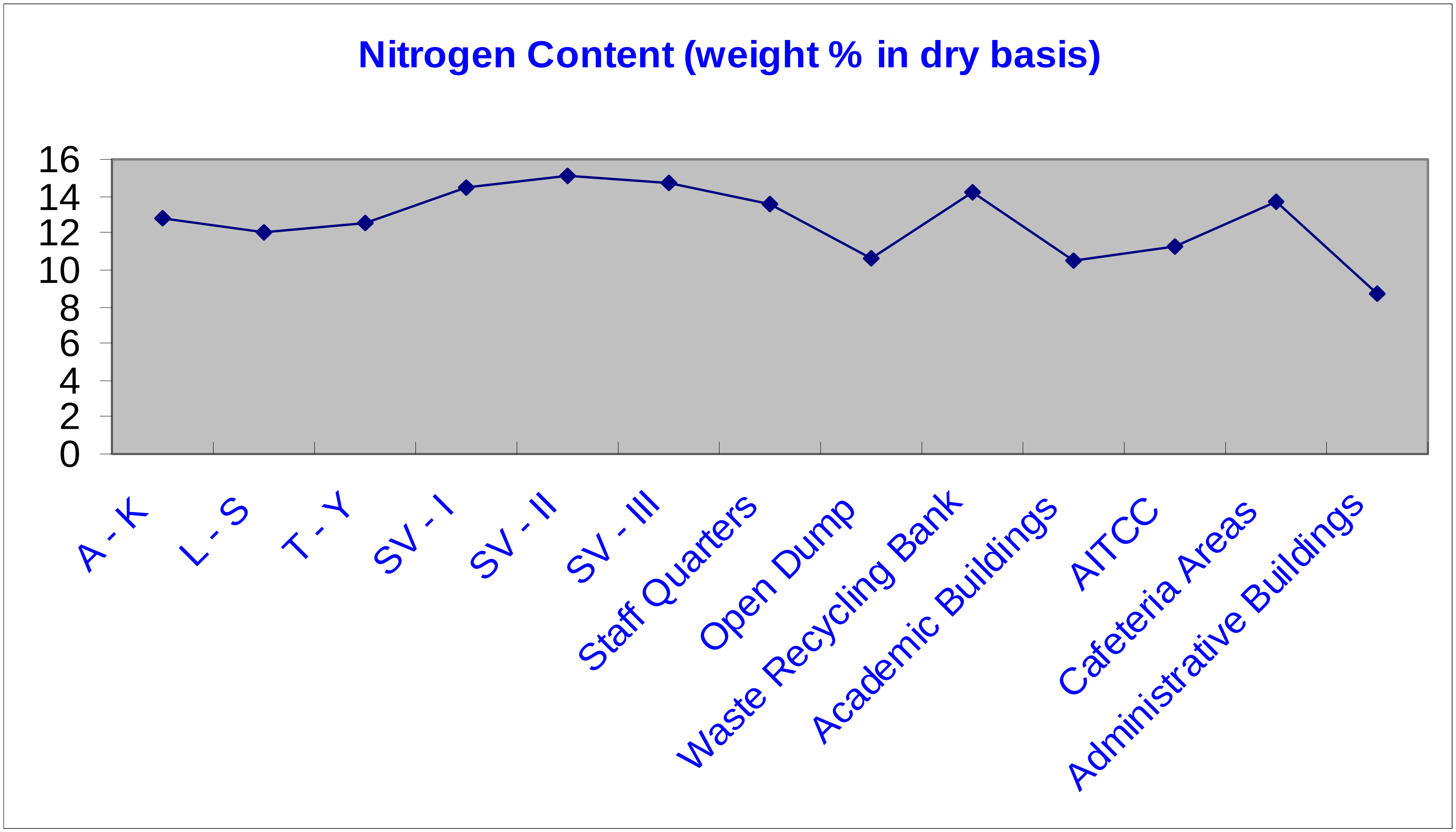
Chemical Analysis of Solid Wastes

Elemental Analysis of Hydrogen



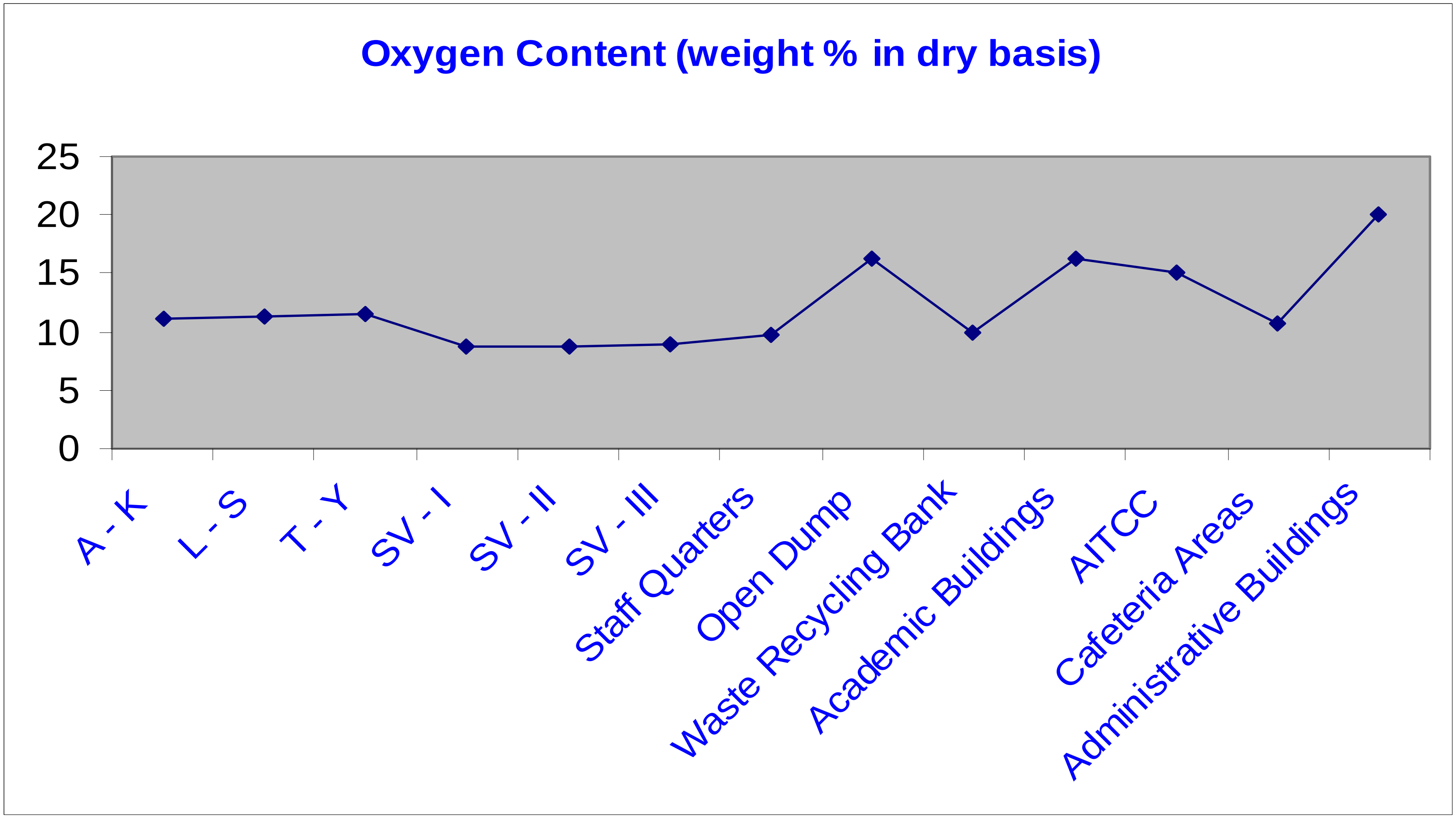
Chemical Analysis of Solid Wastes

Elemental Analysis of Nitrogen



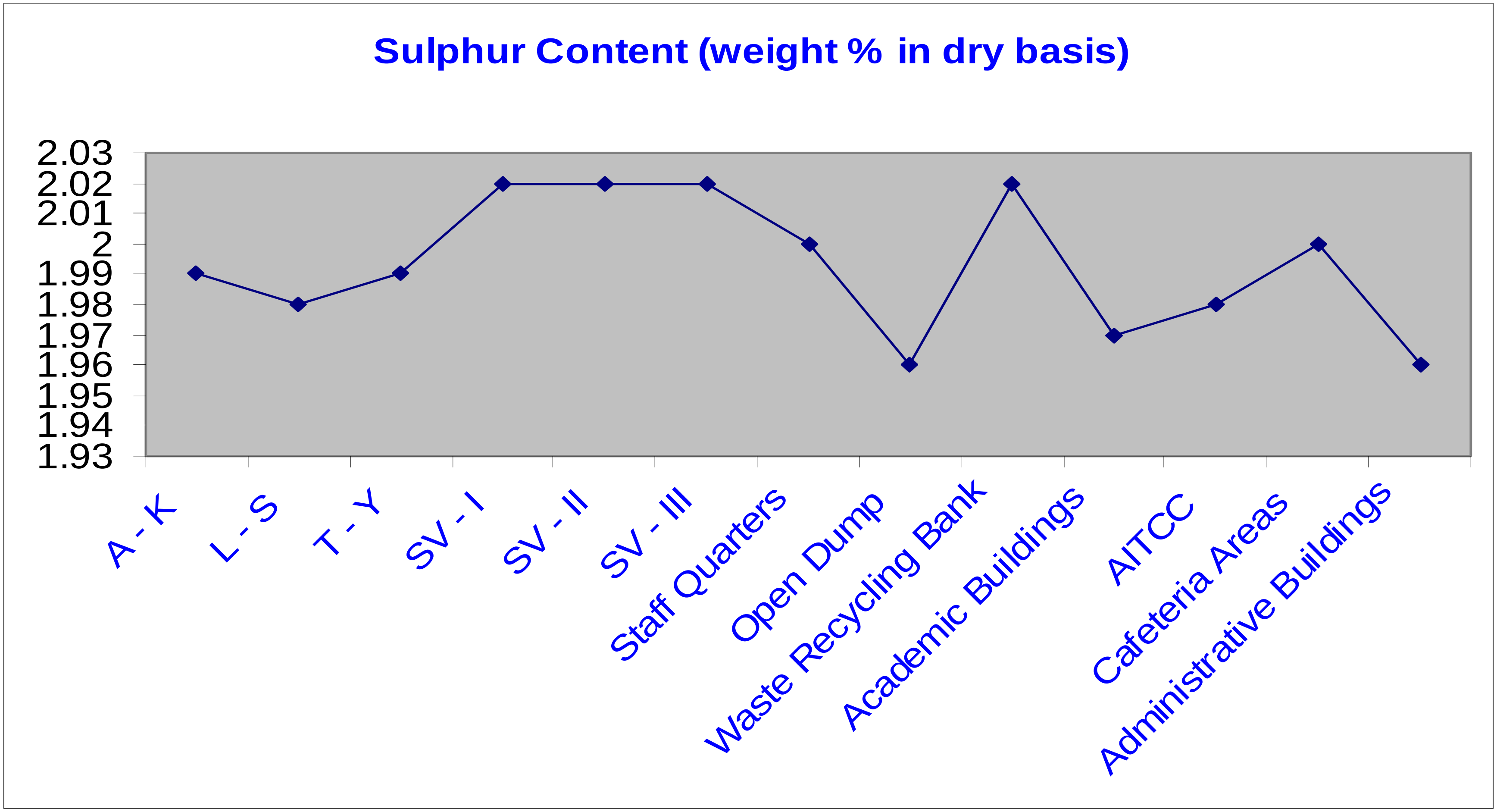
Chemical Analysis of Solid Wastes

Elemental Analysis of Oxygen



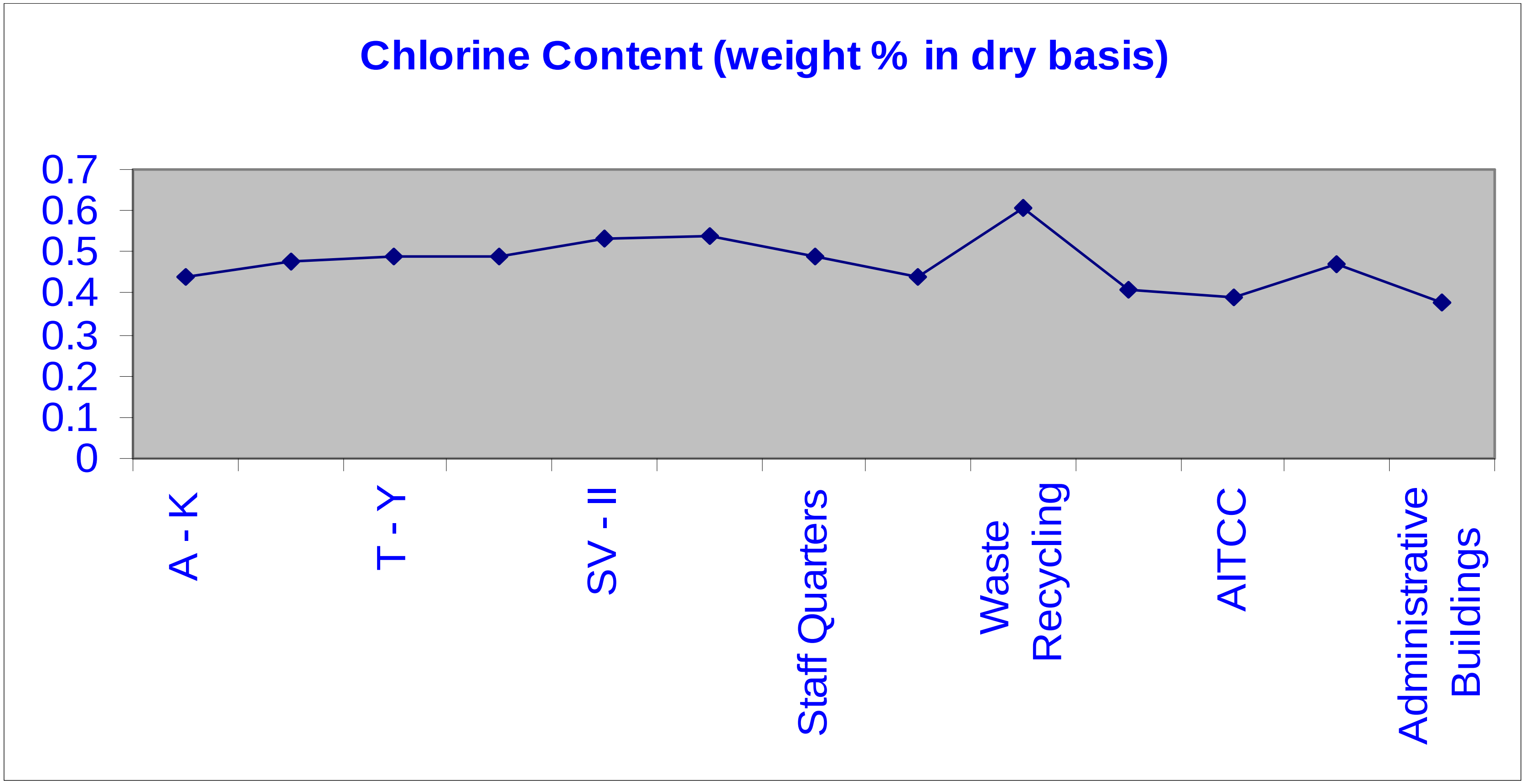
Chemical Analysis of Solid Wastes

Elemental Analysis of Sulphur



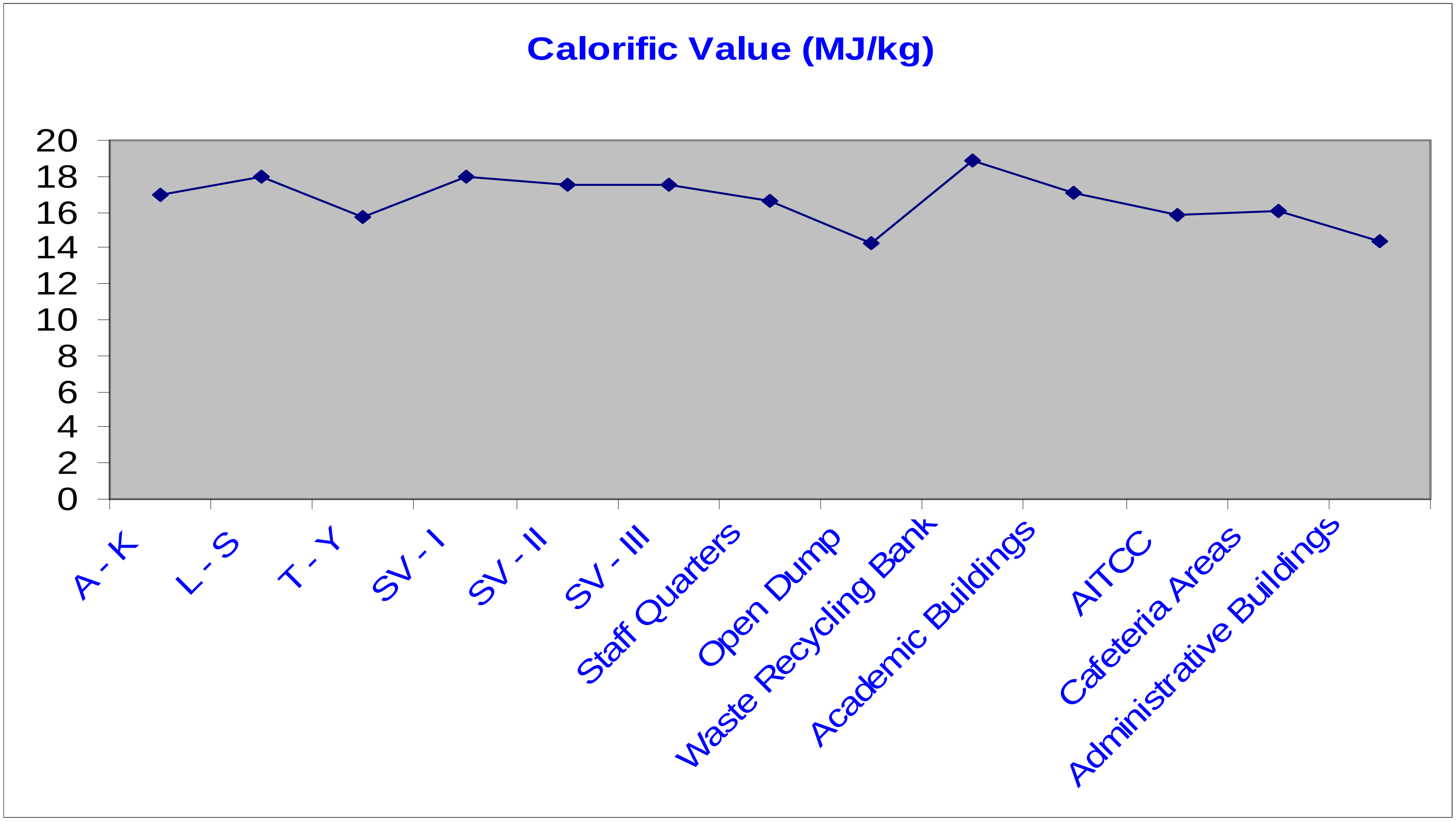
Chemical Analysis of Solid Wastes

Elemental Analysis of Chlorine



Chemical Analysis of Solid Wastes

Calorific Value of Solid Waste



Potential for Application of 3R Principles

Opportunities in Application of 3R Principles:

- Use of cardboard paper cups instead of plastic cups
- Avoid throwing food and organic wastes into plastic bags
- Use less paper and utilize paper to maximum
- Plastic cups and bags should be reused until rendered useless
- Plastic bags should be used to a minimum extent
- Avoid food wastage as far as possible
- Avoid use of plastic spoons, plates in cafeteria areas as far as possible

Sustainable Development

How can we make this more Sustainable???

Future Park: Leading By Example

Waste Segregation Systems

Results of BCA

Important Aspects:

- Tha Kong Municipality showed benefits in recycling activities
- AIT showed no benefits in recycling activities
- High amount of food wastes resulted in large solid waste disposal costs at AIT
- Lack of awareness at AIT in disposal of plastic wastes
- Provision of Awareness and Participation Programmes most necessary for AIT

Conclusions and Recommendations

Conclusions

- AIT Solid Waste : 93% Disposed; 4% Recycled; 3% Composted
- AIT Solid Waste : 60% Organic; 40% Inorganic
- Solid waste can be used as RDF
- Solid waste cannot be used as fertilizers
- AIT does not earn any income from recycling activities
- Tha Kong benefits from recycling activities
- Organic degradation is high due to high moisture content
- Solid waste not safe to be disposed in landfill
- Plastic waste is as high as 25.1%
- Packaging waste is about 0.7%
- An awareness programme is highly essential at AIT

Recommendations

- 3R options to be considered at AIT
- Site Selection of Recycling Facilities
- Awareness and Participation Programmes necessary
- Formalization of Solid Waste Management Systems

Thank You for Your Kind Attention!!