



UNIVERSITY COLLEGE
OF BORÅS
SCHOOL OF ENGINEERING

Municipality Solid Waste Management

An evaluation on the Borås System

Kamran Rousta

Municipality Solid Waste Management, An evaluation on the Borås System

Kommunal avfallshantering, En utvärdering av avfallshanteringen i Borås

Kamran Roustia

Master thesis

Subject Category: Technology

Series and Number 3/2008

University College of Borås
School of Engineering
SE-501 90 BORÅS
Telephone +46 033 435 4640

Examiner: Dag Henriksson

Supervisor: Sobacken

Date: 2008-08-13

Keywords: Municipality, Waste, Management, Sustainability, Borås

Abstract

Municipality Solid Waste Management systems (MSWM) are large technical systems which involve many factors such as environments, technologies, people, businesses, politics, education, research, and also the sustainability aspects of the waste management systems. When these factors are amalgamated into a large system, MSWM turns to a very complicated phenomenon. These factors play different roles in MSWM, based on the type of the system. For instance, the type of MSWM utilized in Borås (A city in Sweden), requires people to contribute to the separation of waste materials at the source; i.e., where people live. This, in turn, leaves an important responsibility for people to take. The more responsible participation from the people, the better the system works. Although the system is equipped by the necessary technology to take of waste but its efficiency is properly relies on how people separate their wastes. However, people are not currently well educated to know what their genuine responsibilities are. As a result, it is argued that through public education, the main objectives of MSWM can be greatly enhanced in this city.

Contents

Preface.....	1
Acknowledgements	1
1. Introduction.....	2
1.1. Objectives	2
1.2. Method	2
2. An Overview on Municipality Solid Waste Management (MSWM).....	3
2.1. Definitions.....	3
2.1.1. Solid waste	3
2.1.2. Municipal solid waste	3
2.2. Solid waste management.....	3
2.2.1. Waste generation.....	4
2.2.2. Waste handling and separation, storage and processing at the source.....	5
2.2.3. Collection.....	5
2.2.4. Separation and processing and transformation of solid waste	5
2.2.5. Transfer and transport.....	6
2.2.6. Disposal.....	6
2.3. Hierarchy of Waste Management	6
2.3.1. Source reduction	7
2.3.2. Recycling	7
2.3.3. Waste transformation	7
2.3.4. Landfilling.....	7
2.4. Types and Properties of Municipal Solid Waste.....	7
2.4.1. Types & Sources.....	7
2.4.2. Properties	9
2.4.3. Hazardous Waste	9
3. Functions of Municipality Solid Waste Management.....	10
3.1. Waste generation.....	10
3.2. Waste handling, separation, storage, and processing at the source	10
3.3. Collection of solid waste.....	11
3.3.1. Collection of un-separated waste	11
3.3.2. Collection of separated waste at the source	12
3.3.3. Types of collection.....	12
3.4. Separation and processing and transformation of solid waste	13
3.4.1. Waste separation	14
3.4.1.1. Unit operation in the waste centers	14
3.4.1.2. MRFs development.....	16
3.4.2. Waste transformation	16
3.4.2.1. Chemical process	18
3.4.2.2. Biological transformation	19
3.5. Transfer and transport.....	23
3.6. Disposal.....	23
3.6.1. Overview of landfill design	24
3.6.1.1. Landfill design and layout	24
3.6.1.2. Landfill operation and management	24

3.6.1.3. Environmental monitoring	24
3.6.1.4. Safety	24
4. Overview on solid waste management in Borås	25
4.1. History.....	25
4.2. Waste Generation.....	25
4.3. Waste separation at source and collection	27
4.4. Material Recovery/Transfer Facilities (MR/TF) in Borås	29
4.4.1. Waste transfer and handling in Sobacken.....	30
4.4.2. Biological treatment in Sobacken.....	30
4.4.3. To prepare Refuse Derived Fuel; the RDF	33
4.4.4. Intermediate storage of hazardous waste and some industrial wastes	33
4.4.5. Landfill in Sobacken.....	34
4.5. Incineration plants in Borås	35
5. Important factors in MSWM.....	35
5.1. People and Inhabitants	36
5.2. Environment and sustainable development	36
5.3. Business	38
5.4. Other factors.....	38
6. Conclusion	39
6.1. Borås system evaluation	39
6.2. Future research.....	41
References.....	41
Appendix.....	42
<i>Appendix A: List of questions in the interview with Linda Ternström.....</i>	<i>42</i>
<i>Appendix B: List of questions in the interview with Hans Skoglund</i>	<i>43</i>
<i>Appendix B: List of questions in email communication with Anna-Karin Schön</i>	<i>44</i>

List of Figures

Figure 2-1: Solid waste management functions and the interrelations between them.....	4
Figure 2-2: Material flow and waste generation in society.....	5
Figure 2-3: Hierarchy of waste management.....	6
Figure 3-1: Schematic of a typical waste combustion plant	18
Figure 3-2: Schematic of typical process in composting	21
Figure 4-1: The amount of waste received by Sobacken in Borås	26
Figure 4-2: Black plastic, biodegradable	27
Figure 4-3: White plastic, combustible.....	32
Figure 4-5: A recycling center in Borås.....	28
Figure 4-6: View of Sobacken	29
Figure 4-7: Schematic of material flow between Sobacken and society	30
Figure 4-8: Optic sorting.....	30
Figure 4-9: Biogas production in Sobacken.....	31
Figure 4-10: Schematic of process of biogas production in Sobacken.....	31
Figure 4-11: Biogas plant in Sobacken.....	36
Figure 4-12: Composting in Sobacken	36
Figure 4-13: Preparing RDF in Sobacken.....	33
Figure 4-14: Intermediate storage in Sobacken	33
Figure 4-15: The amount of landfilling in Sobacken.....	34
Figure 4-16: The view of landfill area in Sobacken	35

List of Tables

Table 2-1 Source of solid wastes within a community.....	8
Table 3-1 Commonly used unit operations and facilities in MSW.....	15
Table 3-2 Transformation processes used for the management of solid waste	17
Table 3-3 Some advantages and disadvantages of Anaerobic process.....	20
Table 3-4 Reasonable and preferred condition for composting.....	21
Table 3-5 Different characters between composting and anaerobic digestion	23
Table 4-1 Amount of waste generation and their properties in 2006 in Borås	30

Preface

When I have followed my studies in the Master Program in Waste Management and Resource Recovery Technology at University College of Borås (UCB), I always ask myself, whether subjects are enough to become a waste manager. That is why I made a decision to review on a part of waste management, Municipality Solid Waste Management, and improve my knowledge about that by reviewing the available system in Borås.

Actually I have learned many things in this Master Program as well as writing this thesis. Now I look upon the waste from another angle. Wherever I see the wastes; I think how to take care about them both from an economical and an environmental point of view.

Now I can say, I know how to start planning for a municipality waste management. Which factors are very important and how it can be developed. This study made me confidence that there is a way to make money by attending to the environment as well as respecting to the society. I hope I continue using my knowledge accordingly.

However, I tried to write my thesis readable for non-specialist in order to get general information about this subject. Also this thesis can help the specialist to follow a real example of Municipality Solid Waste Management in Borås as well as my evaluation of this system.

Acknowledgements

Finally finishing my Master Program and my thesis, I owe many persons a great deal of gratitude for supporting my studies by showing both personal and professional interest.

I would like to sincerely thank my thesis advisor, Dr. Dag Henriksson whose directions and encouraging helps made my journey as smooth and constructive as possible.

I would also like to thank Anna-Karin Schön for her insightful assistance in responding to my questions.

I also had a very inspiring and helpful discussion with Hans Skoglund. Although I have visited Sobacken several times, but he showed me Sobacken from another angle that was very interesting for me. I appreciate him for the times he has spent talking to me as well as the helpful documents he gave to me about my thesis.

I also want to thank Linda Ternström who is responsible for Agenda 21 in Borås. I have gotten many ideas from her after I interviewed with her.

Also thank to all my teachers at the School of Engineering at UCB and all the other people not mentioned here but still not forgotten.

1. Introduction

Waste management could be a very intricate problem if there is a need for such a system to be implemented within a society. Training the people how to separate their wastes, choose the best technology for treatment the wastes, controlling the environmental impact of waste treatments method and many other economical and technical aspects make the MSWM as a complicated system. Some 20 years ago, landfilling was the only method for disposing the waste in many countries in Europe and Sweden as well. However, due to adverse environmental repercussions of landfilling, many environmental initiatives were introduced in order to stop the landfilling. These movements include constituting regulations for the application of restrictions to the landfilling and also the consideration of the waste as a source of energy cause to develop municipality solid waste management in the different angles such as social, environmental and economical aspects. That's why there are many factors such as, environment, society, technology, people, business, and sustainability aspects which should be noted for such systems. The important thing in waste management is how to organize all the factors to get the best results in each part.

Base on the goals of the society in its waste management system there are many methods to establish the system in each community. They can be base on the participating of the inhabitant, sorting at source, or can be base on technology.

As an example the Borås waste management system is a kind of the system which emphasizes on sorting at source. This system is growing up very fast during the last 20 years and now this city is one of the forerunner cities in Sweden in this field. This system manages the different factors which involves in the MSWM quite well. There are different methods such biological treatment, incinerators to get energy from waste as well as separation the different type of the waste in order to recycle the usable materials.

The topic of this thesis is urban solid waste management system. Chapter 2 and 3 review the functions of solid waste management and addresses the potential factors influencing the system. An evaluation of Borås solid waste management system is presented in Chapter 4. Finally, the evaluation of the important factors and advantages and disadvantages of incorporating such a system in a city are discussed in Chapter 5 and 6.

1.1. Objectives

The objectives of thesis are to:

1. Present a summary of the basics of urban solid waste management;
2. Present an overview of the characteristics of Boras' solid waste management;
3. Discuss factors involving urban solid waste management from the management point of view; and evaluate the Borås system from this angle

1.2. Method

Data and information were collected through literature review, secondary data, interview, field investigation and study visit, discussion, observation and case studies. Most materials in chapter two and three are coming from Tchobanoglous (1993) as well as the

materials from lectures during my studies. The information in chapter four and five is mostly from interviews, study visits, secondary data and field investigations.

2. An Overview on Municipality Solid Waste Management (MSWM)

This chapter has a general overview on municipality solid waste management by describing the elements and functions of the system in this process. Some definitions like waste hierarchy, functional unit of the MSWM are described very briefly. It is tried to give the vision to reader to find out what is MSWM and its functions and how they are working.

2.1. Definitions

2.1.1. Solid waste

Solid waste is the unwanted and useless parts of animal and human activities which are basically solid [1]. They can be arisen from agricultural, industrial and social activities. Solid waste is a consequence of life and it varies from one society to other. In early time human consumed the earth resource and he had not any problems about disposal of its waste. Traditional composting and producing the fertilizers were very typical solutions for most of the organic wastes during that time, the disposal of the solid waste can be traced from the time when human started to make community, society and urban life. Because of changing the consumption patterns, increasing the quantity of solid waste as well as the toxicity of them caused that it has been concerned more and more. The relation between collections, storage, and disposal of solid waste to the human health is so clear. Meanwhile ecological problems of the function of solid waste such as air pollution and soil contamination are so important. The leachate of the poor landfill which has contamination with the surface and the groundwater is an example of this ecological problem.

2.1.2. Municipal solid waste

The part of solid waste which is related to the municipality is called municipal solid waste. These kinds of waste encompass packaging, food waste, bottles including PET & glass, cans, papers and agricultural wastes are the wastes which are unwanted and useless for all inhabitants during their life.

In many technological societies, after the Industrial Revolution the problem of solid waste was appeared because of changing the consumption pattern of society.

The clear example of MSW is packaging which is usually used for many goods in our life. Usage of plastic and cardboard as the basic materials for packaging cause increasing the amount of waste in our life every day.

2.2. Solid waste management

Solid waste management can be defined by all the efforts which are related to the solid waste. These tasks are involved to storage, collection, transport, treatment, processing and ultimately disposal.

Social, economical, public health and technological aspects are the important concepts which should be considered in solid waste management. As we can see many circumstances can participate in this effort such as financial, legal, planning, engineering as well as sociology, public health, communication and so on. These make the solid waste management complexity. Solid waste management is divided in to 6 functions which are shown in Fig. 2-1 [1].

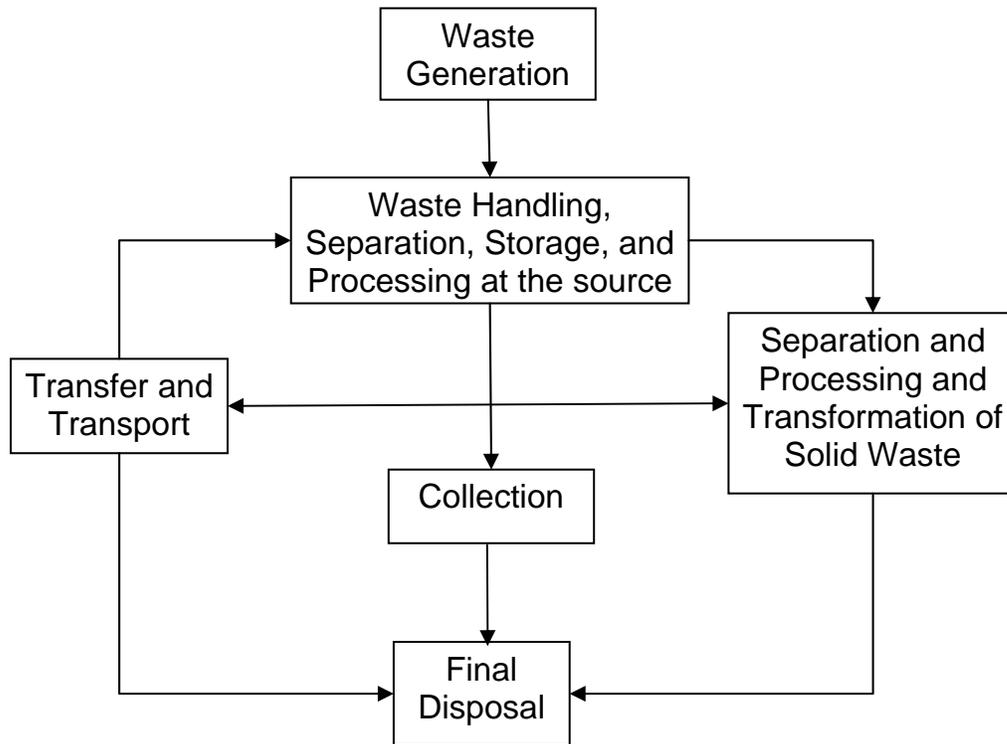


Figure 2-1: Solid waste management functions and the interrelations between them

Fig. 2-1 is demonstrated the simplified of the function of solid waste management.

The functions of solid waste management encompass (1) waste generation, (2) waste handling and separation, storage and processing at the source (3) collection, (4) separation and processing and transformation of solid waste, (5) transfer and transport, (6) disposal

2.2.1. Waste generation

All the activities which cause to throw away the useless and unwanted material during the process, manufacturing, distribution and consumption are defined as waste generation. Fig. 2-2 shows the types of the waste generation [1].

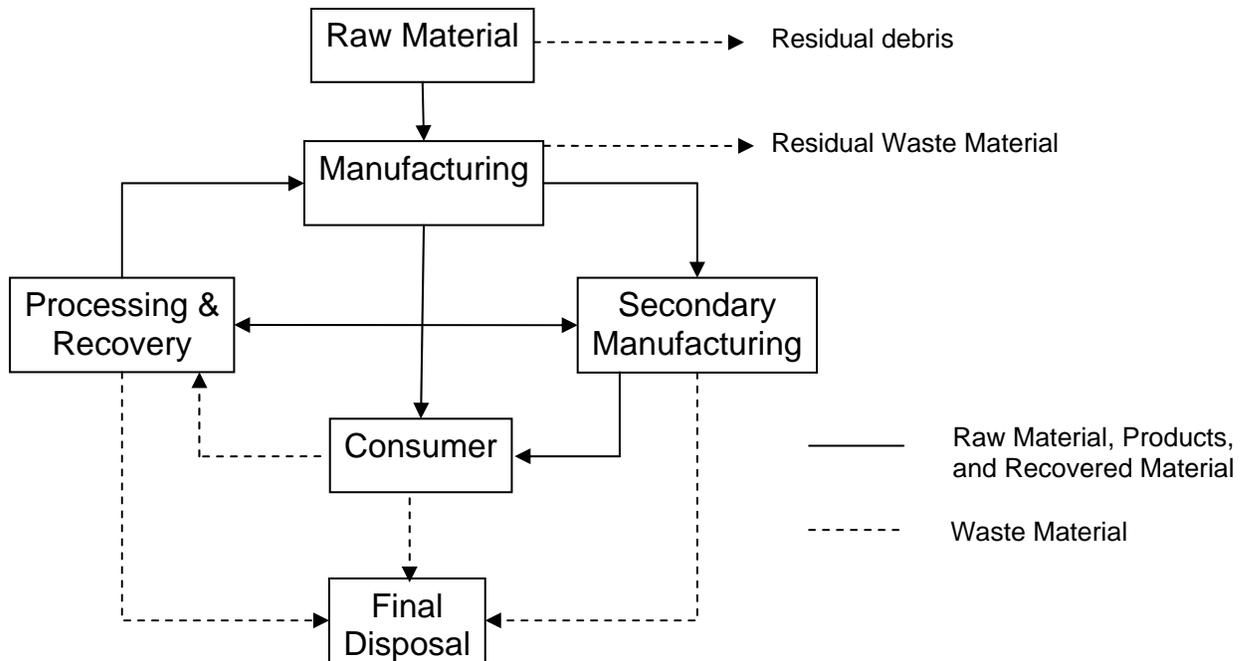


Figure 2-2: Material flow and waste generation in society

It is important to note that usually the control of waste generation is very hard. It needs many factors such as training, education, more legislation, social penalties and so on.

2.2.2. Waste handling and separation, storage and processing at the source

This second function itself is included handling and separation which are the activities involve to store the waste in the containers. Handling means the movement of loaded containers to the point of collection. The important function which can be traced is separation at source. It can not only prepare the material in the waste for recovery and recycling but also it can decrease the hazards of waste. Many developed cities start their MSWM from this point.

2.2.3. Collection

Collection is the task which encompasses the gathering of solid waste and separated the material and also transport of them to the location where the vehicles must be emptied. Always cost of this function is very high. The distance to waste transfer station as well as the amount of waste are the significant factors in this function.

2.2.4. Separation and processing and transformation of solid waste

Separation and processing are the activities which are related to recovery, recycling, and combustion of the waste separation manually or machinery shredding, and separation of ferrous by using magnets, volume reduction by compacting and combustion.

Transformation means to reduce the volume and the weight of waste before disposal by transforming them to the usable source by chemical or biological treatment. Producing biogas during anaerobic digestion is a clear example of this function.

2.2.5. Transfer and transport

Transfer of waste from the smaller trucks to the big one as well as transport the waste from the collection stations to the process station or disposal one is a description of this function.

2.2.6. Disposal

This is the final step in MSWM. Some materials transferred directly to the landfills but there are other wastes which are generated during other activities in waste management that also must be transferred to the landfills too. The important factors of landfilling are considering its environmental impacts and health problems. However landfilling is a task which should be responsible for the public health and the need of the future generation on the land.

Chapter 3 is discussing more about these functions and the important parameters in their process.

2.3. Hierarchy of Waste Management

The important factor in the waste management is to understand which implementing is more important than other, so the hierarchy in waste management is quite significant. Source reduction, recycling, waste transformation and finally disposal are the elements of this hierarchy [1] as Fig. 2-3.

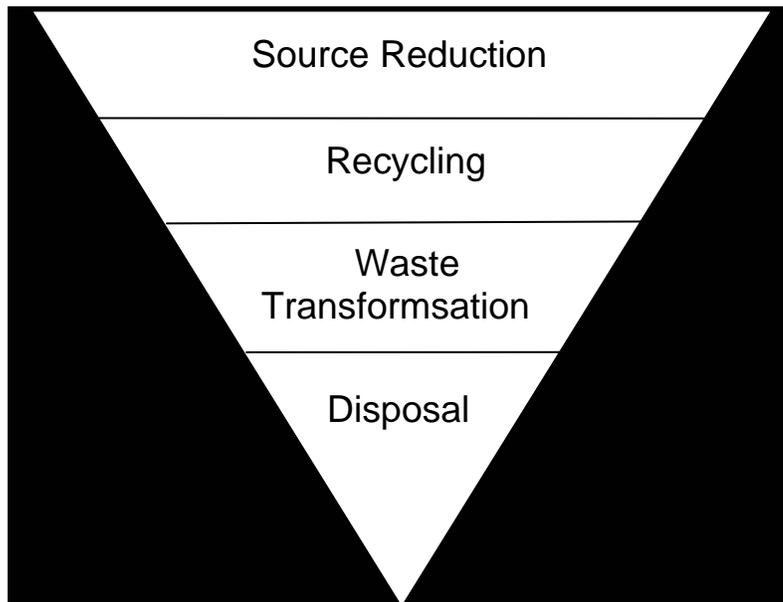


Figure 2-3: Hierarchy of waste management

Note: there are several definitions for the waste hierarchy in different ways. In this resource, Tchobanoglous (1993), as it is seen, it is subdivided to 4 steps which reusing of the material is considered a part of recycling. Sometimes in some other definition for waste hierarchy, the source reduction, reuse, recycling, energy recovery, and disposal are the ranking of waste hierarchy. But the important thing in the hierarchy is to identify the strategy for setting up a sustainable waste management in the society.

2.3.1. Source reduction

Top element of hierarchy is source reduction. The very simple meaning of this element is; it is too easy to avoid of waste generation as much as possible compare to treat the waste. This first involves not only reducing the quantity of waste but also decreasing its toxicity. Source reduction may occur during the manufacturing and processing by changing the design and packaging or may occur in the consumers' sides in the households by changing their consumption pattern.

2.3.2. Recycling

Recycling is the second highest ranking in the hierarchy. Nowadays it is mostly concerned because it is one of the ways of dematerialization and sustainability, where as it can reduce the consumption of resources as well as the toxicity in some cases. The term of recycling in the solid waste management concerns the activities which involve the separation and collection of the recyclable materials for reusing, remanufacturing and recycling.

2.3.3. Waste transformation

One step lower than recycling in the waste management ranking is, waste transformation. All the activities apply to recover the reusable and recyclable materials from the waste as well as converting the waste to the usable form such as composting or energy by the physical, chemical, biological treatments or combustion are called waste transformation.

2.3.4. Landfilling

Finally the last step of hierarchy is landfilling. Landfilling is disposal of solid wastes which is not be able to recycle or transform and also the residue which comes from the collection, separation and other activities during the waste management functions.

2.4. Types and Properties of Municipal Solid Waste

2.4.1. Types & Sources

The important thing for managing the MSW is to know the source, types, and composition of that in each local. The amount, rate of waste generation, the types and the compositions, changing the rate of generation, determining the hazardous components are quite important things which should be answered.

Generally there are 8 sources to generate the MSW. These sources are residential, commercial, institutional, construction and demolition, municipal service, treatment plant sites, industrial and agricultural.

Table 2-1 shows the summary of the types and resources of the MSW [1].

Table 2-1**Source 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, plastics, textile, leather, yard wastes, wood, glass, tin cans, aluminum, other metals, ashes, steel leaves, special wastes (including bulky items, consumer electronics, white goods, yard wastes collected separately batteries, oil, and tires), household hazardous wastes
Commercial	Stores, restaurant, markets, office buildings, hotels, motels, print shops, service stations, auto repair shops, etc.	Paper, cardboards, plastics, wood, food waste, glass, metals, special wastes (see above), hazardous wastes, etc.
Institutional	Schools, Hospitals, prisons, governmental centers	As above in commercial
Construction and demolition	New construction sites, road repair/renovation sites, razing of buildings, broken pavement	Wood, steel, concrete, dirt, etc.
Municipality services (excluding treatment facilities)	Street cleaning, landscaping, catch basin cleaning, parks and beaches, other recreational areas	Special wastes, rubbish, street sweepings, landscape and tree trimmings, catch basin debris, general wastes from parks, beaches, and recreational areas
Treatment plant sites; municipal incinerators	Water, waste water, and industrial treatment processes, etc.	Treatment plant wastes, principally composed or residual sludge
Municipal solid waste ^a	All of the above	All of the above

Industrial	Construction, fabrication, light and heavy manufacturing, refineries, chemical plants, power plants, demolition, etc.	Industrial process wastes, scrap material, etc. Non-industrial wastes including food wastes, rubbish, ashes, demolition and construction wastes, special wastes, hazardous wastes
Agricultural	Field and row crops, orchards, vineyards, dairies, feedlots, farms, etc.	Spoiled food wastes, agricultural wastes, rubbish, hazardous wastes

^a The term *municipal solid waste* (MSW) normally is assumed to include all of the wastes generated in a community with the exception of industrial process wastes and agricultural solid wastes.

2.4.2. Properties

For better handling in waste management, identifying the properties of the wastes is essential. A physical, chemical and biological property of the wastes helps to choose the better treatment for them. Physical properties of wastes such as specific weight, particle size and size distribution, compact waste porosity, moisture contents are the properties which determine how to collect, store, separate, transport and transfer the waste. Likewise determining the chemical substance in the waste will be useful for the chemical treatments such as combustion. For example by determining the chemical properties of the waste, the amount of released energy from the burning of the waste can be estimated. The usual chemical compositions of the waste are carbon, hydrogen, oxygen, nitrogen, sulfur, ash and trace elements. The other properties of the waste are biological properties. In biological treatment the organic parts of MSW are using as a feedstock due to produce biogas or composting in the specific process. So determining the nutrients and the other elements which are contributed in the process is very important. Odor production and biodegradability are the factors that are identified by the biological properties of waste.

2.4.3. Hazardous Waste

Hazardous waste is the part of waste which is dangerous for the health and the environment [1]. Identifying and treatment of the hazardous waste are very important tasks in MSWM because they are persisted and have long term effect. The existence of the hazardous component in each process of waste management such as burning, composting, and landfilling; the impacts of them are very dangerous for both; environment and health. There are several ways to classify and identify the hazardous wastes in the groups of ignitable, corrosive, reactive, poison, flammable, and toxic which are not being discussed in this thesis. Because of these dangerous factors the collecting, transportation and landfilling of the hazardous waste occur completely separated from other waste streams.

In commercial and residential sources, hazardous wastes are found in households and cleaning products, personal care products, automotive products such as waste oil, paint and related products such as oil-base paints and solvents, and pesticides [1]. Usually in the developed societies the inhabitants take care about the collection of these wastes and there are especial places in drop-off centers for collecting of hazardous wastes.

3. Functions of Municipality Solid Waste Management

As it was mentioned in chapter 2 the function of the solid waste management is too complicated. In this chapter each function is explained very briefly in order to have a vision of processes in MSWM.

3.1. Waste generation

In order to design the waste management system, one of the important factors is waste generation. Determining the total amount of MSW helps to design the collection routs, material recovery and disposal facilities. There are several methods to measure and estimate the waste quantities. Load count analysis, weight-volume analysis and material analysis are the typical methods which are applied in this field. Measuring the volume of the corresponding waste in the specific time is the method which is used in the count analysis and volume-weight method. More data analyzing is needed for the material balance. The amount of waste goes to recovery and recycling, the ash and flue gas in combustors are the samples data. In this method first a boundary should be drawn, after that all the in flow and out flow should be considered, then the amount of waste can be measured [1].

Generally, by using the available data and making a statistical analysis of the waste in a city, the total amount of waste is determined. This amount of waste, as it was mentioned before, can come from many sources such as residential, commercial, institutional, construction and demolition, municipal service, treatment plant sites, industrial and agricultural.

There are several factors which can be affected on waste generation. Source reduction is one of the important ones. All the activities which can occur through the design, manufacturing, packaging, distributing and consumption in order to reduce the amount of the waste generation are called source reduction; for example using the minimum material in packaging, designing the products with the longer term life. The other factor is recycling which occurs during the waste management process. Beside these technical factors there are other factors which are related to the public attitude and the local legislation.

3.2. Waste handling, separation, storage, and processing at the source

The critical step in solid waste management is the handling and separation of the waste before collecting. All the activities which correspond to the solid waste before being placed in to the containers which are used to carry it to the material recovery facilities or recycling centers are called waste handling. These activities promote the flow of the waste stream in the waste management system. Before transportation, the separation of the papers, cardboards, aluminum cans, plastics and so on is very important in reducing

the cost of facilities and equipments in recycling centers. For this purpose there are several methods for separating the waste in different sources. In residential sources, based on the type of the buildings, local population and the collection method, the waste handling is varied. In the low dense areas usually each inhabitant collects his wastes at home and puts in the containers near that local, but in high apartments, using the chute opening which can collect the waste of one apartment or more, is typical. This system can be with or without vacuum. On the other hand for the commercial and industrial sources according to the wastes' types and their volume, usually some containers are used near the waste generation place. They are transferred to the big containers which are used for transferring the waste to the disposal sites. However, it is important to note that choosing the type and volume of the container is quite important for the waste handling. In this part the source of waste generation, the amount of waste generation, the period of waste transporting and the odor problems should be considered. In some cases there are some solutions to use the recovery facilities at the source; for examples there some composting methods for the residential sources which can produce compost from the compostable part of their part. Getting the energy by burning the waste in the combustors at the source is also used. In the commercial and industrial sources due to reduce the volume of the wastes and the cost of transport, using the shredders and compactors are the other samples of the tasks which can be occurred before collection [1].

3.3. Collection of solid waste

The function of the collection of the solid waste management is one of the most complex and difficult tasks in MSWM. It includes both gathering the MSW from sources and transporting them to the place where the containers should be emptied. When the sorting system at the source is not available, the waste collection is more complicated. Solid wastes are generated by each residential, commercial, industrial and other source, and then they should be collected from those places and be transferred to the waste refinery centers. That's why this function has the highest cost in the waste management system. The collection operation depends highly on the waste handling at the source. Separated waste, un-separated waste, distance between collection area and disposal centers and routs are the important factors to design the collection system.

3.3.1. Collection of un-separated waste

For avoiding the low rate waste generation residential sources, there are four common types of the waste collection [1]:

1. Curb, in this method the homeowners must be responsible for putting the full containers on the collection day in the place where the vehicles could pick them up. Then they should return it when it is emptied.
2. Alley, which is used for the storage of the part of the city in the specific containers.
3. Set out-set back, the homeowners have no responsibility to carry the full and empty containers, just they should set out the full one to be ready for the crews to transfer the wastes to the vehicles and it is up to them to set the empty container back to that place again.

4. Set out, is the same as the set out-set back system but the homeowners should be responsible for the empty containers.

There are several methods to empty the loaded containers to the vehicles:

Direct lifting of loaded containers to the vehicles manually, mechanically and sometimes using of small lift due to empty the loaded containers to the big vehicles to transfer the wastes to the waste centers are the methods usually used in this function.

In the other side in the high-rise apartments, the collection system depends on the size and types of the containers are used, the loaded containers usually are emptied mechanically in the big vehicles.

In the commercial and industrial facilities they usually use the containers which are able to set on the vehicles; when the containers are full, especial vehicles can set them by themselves and carry them to the waste centers. At the same time they put the empty one instead of the full one due to be used for the next waste handling process.

3.3.2. Collection of separated waste at the source

For the residential curbside collection, the system depends highly on the design of sorting and separating the waste in the community; for example in some communities just there are two containers for separating the recyclable materials such as papers and the other heavy materials. In the other communities several containers are used for separating many recyclable materials. Typically for each container one vehicle is responsible for emptying and carrying it to the recycling centers. In the commercial and industrial facilities, there are separated containers for recyclable materials. They often make a contract with someone who is responsible for collecting the specific recyclable materials [1].

3.3.3. Types of collection

There are several containers which are used for the waste collection. The Vehicles which are used in collecting system of MSWM are typically in two systems; hauled container system and stationary container system [1].

1. Hauled container system

Hauled container system is quite suitable for the places with the high amount of waste. This system can minimize the number of the collection rate which results in the reduction of the collection system's cost. Likewise the availability of the different size and shapes of these containers make them usable for collecting different wastes. Hoist truck, tilt-frame containers and trash-tailors system are the main types of this system.

The hoist-truck systems are suitable for the small operation collection and collecting the wastes just from the few pick up points. Sometimes it is used to collect the compaction scraps such as metal and the construction wastes.

For the large containers which can transfer the huge amount of the wastes, tilt-frame container system is used. Some of them - for better efficiency - are

mobilized by compactors due to reducing the volume of the waste in order to carry more wastes; it is why handling by this system is very economic.

Trash-tailor system is very similar to tilt-frame system, but it is typically used for collecting the heavy rubbish such as sand, metal scraps and the construction and demolition wastes.

In all these handling systems, the driver usually works alone. Some times for more safety - especially when the hazardous wastes are carried - one person may help the driver so the maximum workers in this system are two.

2. Stationary containers system

This system is used for all types of MSW. It can be applied with the containers which are able to load manually or mechanically. In some cases, after collecting the waste of each area in order to reduce the cost of transferring the waste from sources to the waste centers, they use the big containers to carry the wastes of two or more areas to the waste centers by one big container. As the time of the loaded container is high, manual loading is more effective than mechanical one. Typically one driver and one collector are the total crews in this system for the curbside and alley collection method, but sometimes according to the area size one or two collectors will help the driver.

It is important to note that for designing the collection system in MSW, the analysis of the collection system and the route design are the essential factors. The cost increases by increasing the time and the distance in the collection route. The discussion about the route design is a logistic knowledge and it is outside of this project.

3.4. Separation and processing and transformation of solid waste

The fourth function of the MSWM is the separation and processing and transformation of the solid waste.

This occurs in material recovery facilities (MRF) or in material recovery/transfer facilities (MR/TF) and that includes the drop-off or buy-back centers for separating the wastes, material separation facilities, biological treatment facilities and facilities to convert the waste to fuel.

The aim of this part of MSWM is to separate the recyclable and reusable material as much as possible on the base of the waste hierarchy. This opportunity can occur in 5 steps [1]:

1. Using material directly from the separated waste such as wood pallets, lumbers, gal drums and ...
2. Using the waste as a raw material for remanufacturing and reprocessing such as paper, cardboard, glass, cans and ...
3. Using the waste as feed stock for biological transformation such as compostable material, food wastes, garden wastes and ...

4. Using the waste as the fuel sources, such as converting the waste to biogas, bioethanol and prepared the combustible parts as fuel to get the heat energy from them.
5. Putting the remaining in the landfills; that should be avoided as much as possible.

3.4.1. Waste separation

As it was mentioned before, the best way of separating the waste is to separate them at source. There are two common ways for this purpose; Drop-off and Buy-back centers. Drop-off centers are the place where the facilities for the waste separation are available. The residents carry their wastes to these centers and put their separated wastes in to the specific containers. In the Drop-off centers, there are several required containers for each recyclable, reusable and the other types of wastes. When the area is very populated and the materials are densely, usually some problems are inevitable in these centers so Drop-off centers are typically located near the shopping centers or the residential area in order to reduce the transport and increase the capacity of the centers and especially to encourage the participation the residents. The buy-back centers are the same as the Drop-off centers, but the residents should pay based on the amount of the wastes they transfer there. This method can control the generation of the waste at the sources to some extent.

In addition there are some optional methods to separate the wastes as well:

1. Waste separation at source which is accomplishes manually by each inhabitant.
2. Waste separation at MRF and MR/TF

MRF, material recovery facilities, and MR/TF, material recovery/transform facilities are used for the further process on the separated wastes which are coming from the Drop-off and Buy-back centers.

The recyclable and reusable materials will be separated in this part if the wastes are carried commingled to the centers. Improving the quality of recovered materials occur in these facilities too.

However it is important to note that the design of the facilities and the process in the MRFs as well as waste separation at source depends on the established goals the waste diversion. These goals can identify how to separate the wastes at source, which wastes should be separated and how to design the process to convert the waste for the further process.

3.4.1.1. Unit operation in the waste centers

In each MRF, there are several unit operations to separate and process the wastes. They have been designed to (1) modify the physical properties of the waste materials, (2) to remove easily the specific components from the waste streams, (3) to process the separated materials for the other usage.

Although the discussion about all these unit operations is out of this project, to give a general view of them and their applications in the waste refinery centers, they are summarized in the Table 3-1 [1].

Table 3-1**Commonly used unit operations and facilities for the separation and processing of separated and commingled MSW**

Item	Function/material processed	Preprocessing
Shredding		
Hammer mills	Size reduction/all types of wastes	Removal of large bulky items, removal of contaminants
Flail mills	Size reduction, also used as bag breakers/all types of wastes	Removal of large bulky items, removal of contaminants
Shear Shredder	Size reduction/all types of glass	Removal of large bulky items, removal of contaminants
Glass crushers	Size reduction, also used as bag breakers/all types of wastes	Removal of all non-glass material
Wood grinders	Size reduction/yard trimming/all types of wood wastes	Removal of large bulky items, removal of contaminants
Screening		
	Separation of over- and under-sized material; trammel also used as bag breaker/all types of wastes	Removal of large bulky items, removal of contaminants
Cyclone separator	Separation of light combustible materials from air stream/prepared waste	Material is removed from air stream containing light combustible materials
Density separation (air classification)	Separation of light combustible materials from air stream	Removal of large bulky items, large pieces of cardboard, shredding of waste
Magnetic separation	Separation of ferrous metal from commingled wastes	Removal of large bulky items, large pieces of cardboard, shredding of waste
Densification		
Balers	Compaction into bales/paper, cardboard, plastics, textiles, aluminum	Balers are used to bale separate component
Can crushers	Compaction of flattening/aluminum and tin cans	Removal of large bulky items

Wet separation	Separation of glass and aluminum	Removal of large bulky items
Weighing facilities		
Platform scales	Operational records	
Small scales	Operational records	

3.4.1.2. *MRFs development*

As it was discussed before, the MRFs are the places where the processing takes place. The facilities, unit operation and equipment which are designed for MRFs, depends on the established goals for the waste diversion. The function of MRFs directly depends on (1) how it can play the role to serve the waste management system, (2) the types of the recovered materials, (3) how the waste and recovered materials should be delivered and (4) how to store the recovered materials [1].

By this definition, it is quite clear that the design of the MRFs for separated and commingled wastes is very different. For a better design, some engineering considerations are so important. After determining the function of the MRF, identifying the materials which should be separated at that time and in the future is the next step; for example separating the papers, aluminum cans, metals, tires, plastics and other recyclable materials should be defined by their specifications. Developing the process by flow diagram is the third step. This flow diagram shows the flow of the materials when they receive to the centers until they leave. Determining the process rating load helps select the capacity of the facilities in order physical, chemical and biological transformation of the wastes. These facilities should be adapted to the MRFs goals in the waste refinery. Environmental controls and aesthetic considerations are a part of the MRFs design. Surface water, ground water, climate change, public health, odor problems and emission controls are the samples of this step. At the end it should be considered whether these facilities can be adapted in the future by changing the waste generation rate, types and other circumstances or not.

3.4.2. **Waste transformation**

The term of waste transformation means to reduce the volume and the weight of the waste requiring disposal to recover them by conversion products or energy. These functions take place by biological and chemical treatments. The Table 3-2 shows the typical processes in waste transformation [1].

Table 3-2**Transformation processes used for the management of solid waste**

Transformation processes	Transformation means or methods	Transformation or principal conversion product(s)
Physical		
Component separation	Manual and/or Mechanical separation	Individual component found in commingled municipal waste
Volume reduction	Application of energy in the form of a force or pressure	The original waste reduced in volume
Size reduction	Application of energy in the form of shredding, grinding, or milling	The original waste components altered in form and reduced in size
Chemical		
Combustion	Thermal oxidation	Carbon dioxide (CO ₂), sulfur dioxide (SO ₂), other oxidation products, ash
Pyrolysis	Destructive distillation	A gas stream containing a variety of gases, tar and/or oil, and a char
Gasification	Starved air combustion	A low-Btu gas, a char containing carbon and the inert originally in the fuel, and pyrolytic oil
Biological		
Aerobic composting	Aerobic biological conversion	Compost (humus-like material used as a soil conditioner)
Anaerobic digestion (low-or high-solids)	Anaerobic biological conversion	Methane (CH ₄), carbon dioxide (CO ₂), trace gases, digested humus or sludge
Anaerobic composting ^a	Anaerobic biological conversion	Methane (CH ₄), carbon dioxide (CO ₂), digested waste

^a Anaerobic composting occurs in landfills.

3.4.2.1. Chemical process

The common chemical process for the wastes is combustion which can reduce the volume of the waste by 95%. The heat production of this process is also used as a source of energy. The simple and common process of combustion is shown in the Fig. 3-1.

The process can be divided to 4 main parts.

(1) waste handling includes waste storage pits, crane and charging chute (2) combustion part includes furnace, combustion chambers, grates, quench tanks and ash collection system, (3) energy production facilities include boilers and steam turbine, generator, (sometimes just use the steam as a produced heat), (4) environmental control facilities include ammonia injection, dry scrubbers, lime, baghouse, draft fan and stack [1].

In Fig. 3-1 the 4 mentioned part with their typical equipment for each part by surrounded blue, red, orange and green lines respectively for parts 1 to 4.

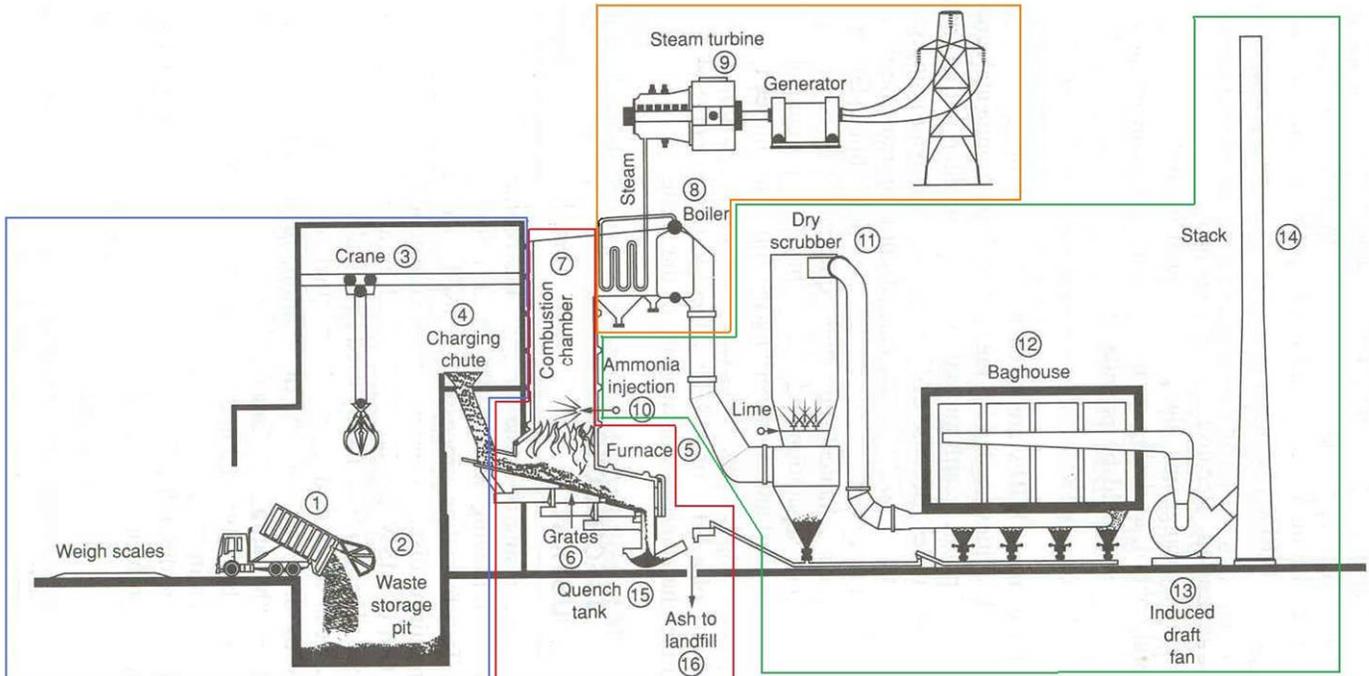


Figure 3-1: Schematic of a typical waste combustion plant

It is not supposed to discuss further about the steps of the combustion process in this project.

The important thing for the combustion of waste is separating the combustible wastes from others. Whatever this happens better, the energy produced in combustors has a better quality. Generally two methods are used in the combustors: (1) mass fired combustors which can burn any types of the waste so the produced heat is extremely variable and it depends on the composition of the burnt wastes. (2) RDF (refused-derived fuel) fired combustors are the combustible parts of the waste stream which are separated and treated for burning [1]. The efficiency and controlling the process in these kinds of

combustors is much easier than the mass-fired combustors. It is important to note that the implement of the combustion facilities has several issues that are mentioned as following [1]:

1. Place choosing: there are several parameters such as aesthetic and environmental aspects, transport between MRFs and combustors, resident health, safety which should be considered in the choosing of the sitting place for the combustion facilities.
2. Air emissions, the emission controls in the combustors are the other issues in combustors. In order to reduce the amount of pollution in the flue, the gas needs the complicated and costly facilities which are the critical part of the combustors.
3. Liquid emission, the waste water comes from removed facilities, scrubbers and pumps, and the cleaning facilities equipment is another issue for the combustors which should be concerned carefully.
4. Disposal of residue
5. Disposal of bottom ash, fly ash and scrubbers' products needs special process or sometimes special landfill.
6. Economic, typically the cost of combustion plant is very high and for better choice with the other treatment method life cycle cost analysis is purposed.

3.4.2.2. Biological transformation

Biological treatment of the solid waste is one of the contemporary solutions in MSWM. In the simple word, biological process is converting the organic components of the waste by some microorganism or bacteria in the specific situation with or without air to the usable form. This conversion not only helps recovery of the wastes but also, it is useful to reduce the environmental impacts of them. The results of converting the organic part of the wastes by biological process could be biogas, bioethanol, valuable biochemical products and in some cases indirectly electricity. Besides them, reducing the environmental impacts of the pollution by biological treatment (bioremediation) is the other application in this field. In summary, biological treatment takes place in two categories (1) aerobic and (2) anaerobic. These processes are explained briefly as follow:

1- Anaerobic Digestion (AD)

Breaking down the organic waste by bacteria in an oxygen-free environment is the definition of the anaerobic digestion [1]. The production can be methane rich biogas.

In fact AD is a biological process that occurs naturally in the environment with little or no oxygen. For a long time AD has been used by the farming community to process cattle slurry into a soil enhancer. However, with better capturing of by-products, the process is now being promoted by some sections of the waste industry as a suitable technology for treating biodegradable municipal waste.

The by-products in this process are (1) Biogas, which is made up about 60% methane (CH₄) and 40% carbon dioxide (CO₂). This can be burnt to generate heat and/or electricity, (2) Bio liquid or liquor digestate, which can be used, if of suitable quality, to

improve soils as a conditioner or fertiliser (3) Fibre digestate, which can also be used, if of suitable quality, as a compost to apply to soil.

Application of AD is treating all types of biodegradable waste, including food waste, in order to convert them to something usable in by-products. It occurs by breaking down the organic materials within an in-vessel or controlled environment. This is usually an airtight container, known as a digester. The process occurs in two stages. At the first stage which is done in the digester; two phases take place (1) Acidification phase (acetogenesis) in which microorganisms release some enzymes that convert the organic compounds into fatty acids, hydrogen and acetic acid and (2) Methanogenesis in which Methane and carbon dioxide are produced from the organic acids. At the second stage, the task is to treat the by products. Biogas is scrubbed so it is fit to be used in the generation of electricity or as a fuel. Liquid and solid digestates are used as soil enhancers or disposed, according to their quality. It is important to note that the suitability of the digestates depends on the number of factors such as its level of contamination and how biodegradable is. The operation conditions in the process are the circumstances which are quite significant. In order to have a maximum rate in digestion, typically pH level should be kept between 5.5-8.5 and the temperature between 30-60°C.

However, there are many discussions about the design of the anaerobic process in one or two steps reactors, dry or wet and many other factors which are out the scope of this thesis. Also this process has several advantages and disadvantages which are summarized in Table 3-3 [1].

Table 3-3

Some advantages and disadvantages of Anaerobic process

Advantage	<p>Process the range of different kind of solid wastes</p> <p>Produce the useful by products</p> <p>Have net air and solid emissions compare to incineration, landfill</p> <p>Because of requirement the small area to establish the plant it is possible to set up it near the town which causes to reduce haulage distances and associated traffic pollutants</p>
Disadvantage	<p>Need the significant control in operation to get the results in digestion process</p> <p>Need a lot of water in the process and consequently to produce a large amount of waste water which should be treated</p> <p>Negative local environmental impacts such as odor</p>

Meanwhile, based on the types of the waste which are supposed to be treated by this process, economical aspects should also be considered. But generally, in the most developed countries, this process is used because of its lower emissions and the usage of some of the by products like methane as a source of energy. The most important factor is producing the energy from wastes; it is one the goals of the most countries in order to catch the sustainable development.

2- Aerobic process:

A typical process at the presence of the air is composting. *Composting* is the aerobic decomposition of the organic materials by micro-organisms under controlled conditions. During composting micro-organisms consume oxygen while feeding on the organic matter. Figure 3-2 shows the composting process briefly.

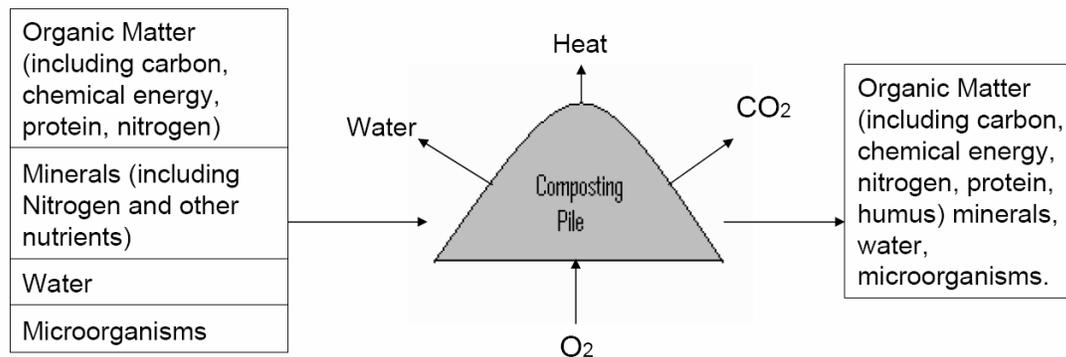


Figure 3-2: Schematic of typical process in composting

Operational conditions are quite important for composting. These conditions depends on C:N (carbon/nitrogen) ratio, moisture, oxygen, particle size, pH and temperature. Table 3-4 is defined the best condition for the composting.

Table 3-4

Reasonable and preferred condition for composting

Condition	Reasonable range	Preferred range
C:N ratio	20:1 – 40:1	25:1 – 30:1
Moisture content	40 – 65%	50 – 60%
Oxygen concentration	Greater than 5%	Much greater
Particle size (in inches)	1/8 – 1/2	Varies
pH	5,5 – 9,0	6,5 – 8,0
Temperature (°C)	45 – 65	55 – 60

In fact Composting begins when the appropriate materials are piled together. Aeration is continually required to recharge the oxygen supply. It is provided either by the passive air exchange (natural convection and diffusion) or by the forced aeration (blowers/fans). Mechanical agitation of the composting materials, or turning, supplies a limited amount of oxygen; but this is quickly consumed and must be replenished by the passive or forced air movement.

There are four general groups of composting methods (1) Passive composting, (2) Windrows, (3) Aerated Piles, (4) In –Vessel Composting [1].

Passive composting involves simply stacking the materials in piles to be decomposed during a long period of time with little agitation and management. Piles of this nature require a proper management. It includes making sure that the mixture is porous enough to allow the air to penetrate. The pile is remixed periodically to rebuild its porosity. The pile must also be small enough to let the passive air move (less than 6 feet high and 12 feet wide) .It is a common method in composting but it is slow and it has a great potential for making odour problems.

In the windrows method the mixture of raw materials is placed in long narrow piles (windrow). They are usually agitated or turned on a regular basis and the rate of air exchange depends on the porosity of the windrow.

The air is supplied in the aerated piles system by blower. In fact, this method relies on a variety of forced aerations and mechanical turning techniques to speed up the composting process.

In-Vessel composting refers to a group of methods which confine the materials within a building, container, or vessel. It can be silos, rotated drum and so on.

There is much technical information about how to design and choose the methods of composting, recipes for composting which are out of the scope of this report.

There are several benefits by composting. It produces a useful end product with positive environmental characteristics. In some applications, the compost is an excellent soil conditioner with some fertilizer values. It also reduces the amount of the waste transported to the landfill as well as the harmful effects of landfilling of organic wastes such as leachate and landfill gas production and it is the least expensive of all the other disposal alternatives.

A simple comparison between aerobic and anaerobic process is shown in the Table 3-5. This table demonstrates the difference between the critical characters in aerobic and anaerobic process.

Table 3-5**Different characters between composting and anaerobic digestion**

Characteristic	Composting	Anaerobic digestion
Energy use	Net consumer	Net producer
End products	Humus, water, carbon dioxide	Sludge, methane, carbon dioxide
Volume reduction	Up to 50%	Up to 50%
Produced time	20 – 30 days	20 – 40 days
Primary goal	Compost production	Energy production
Secondary goal	Volume reduction	Volume reduction, waste stabilization

3.5. Transfer and transport

Transfer and transport in MSWM mean all the activities related to the transfer the wastes from one location to another. In many cases the wastes are not brought directly from the sources to the MRFs so some transfer and transport facilities such as loaders, truck, small collection vehicles, and conveyors are used. One of the reasons to use these facilities is the high distance between sources and the MRFs. The other reason is using these facilities in the MRFs to get better flow of the waste material. In summary, the factors which tend to use these facilities in MSWM are (1) to avoid the illegal dumping due to large haul distance (2) usually the disposal sites are far from the collection routs, (3) to use the capacity of the collection vehicles, (4) existence of low density of residential area service, (5) using the hauled container system, (6) to use of hydraulic and pneumatic collection system [1].

3.6. Disposal

The last function of the MSW is landfilling. In a simple word, landfilling means, disposal of the waste on the earth. The wastes which can not be recycled, reused, recovered to the material and energy by chemical and biological transformation should be put in the landfills. There is also a tax on landfilling in many developed and developing countries so disposal of the waste is one of the important parts from the environmental and economical point of view.

In the following it will be discussed about the overview of landfills design but it is not going through the details.

3.6.1. Overview of landfill design

Since the environmental impacts of landfills are very important, design, planning and operation of them are so complicated. The involved factors are mainly about how to protect the environment from the impacts of the landfills. These factors are summarized as follow [1]:

3.6.1.1. Landfill design and layout

The amount and types of the wastes which are supposed to be put in the landfills will determine the methods and type of the landfilling. Type of landfilling depends on the types of the waste, landfill operation and local situation. For example landfills for the hazardous waste, landfills for minimizing production of biogas and landfills for the wetland are subsequently the samples of the role of these factors in designing the landfills. The place for the landfills, distance between sources to the landfills, land area, soil and climate condition, surface and ground water situation and local restriction are the other parameters involved in designing the landfills.

3.6.1.2. Landfill operation and management

As the types of the collected wastes in the landfills are different, different reactions may happen. The results of these biological, chemical reactions make some problems such as emissions, leachate, odour and other harmful environmental impacts. One of the biggest issues in landfill operation is how to care and control these impacts. For example capturing the landfill gas and treating it to produce methane to be used as a source of energy is one of these tasks. The other example is, collecting the leachate and treating that in order to reduce the harmful component before releasing in to environment. Controlling the surface water is another task which should be done in the landfill operation. That is usually done by using the cover in each layer of the landfills.

In the other side, operation of the landfills needs some equipment to transport and transfer, excavate, compact and sometimes to mix the wastes in the landfills. For this reason some equipment such as high track compactor, rubber tired, front end loader and others are used in the landfill operation.

3.6.1.3. Environmental monitoring

Monitoring and controlling all the impacts of the landfills are very essential in order to reduce the impacts. Controlling the ground water, gas production, air in the landfill, and leachate are the tasks which should be considered in the land fill operation. The other controls are the closure and post closure of the landfills. Sometimes landfills should be controlled for about 30 to 50 years after filling up. Controlling the pests, vectors, birds, blowing materials are the other monitoring which should be measured in this part.

3.6.1.4. Safety

In the landfills operation the parameter of safety includes public health, safety of the workers, site safety and security are very important. Because of the large area, working

the big trucks and equipment as well as the impacts of the landfill, usually there are some regulations for the sites and workers who are working at the site.

4. Overview on solid waste management in Borås

4.1. History

The city of Borås is located in the southern part of Sweden near Gothenburg with the area about 1000 km². It has about 50000 households and 100000 inhabitants. About 20 years ago, the study about a new waste management method in Borås was started. Between 1988 and 1991 the first task for the source separation for the 3000 households occurred. The very first plan of the waste refinery center started to work in 1991 which has developed by full scale sorting with optical sorting system at that time. The new and modern landfill was opened in 1992 and in 1995 the first biological treatment system started to work in the field of anaerobic digestion and composting. Caring for the hazardous wastes and the storage of them took place in 1998 and in 2002 biogas production from biological treatment were used for the vehicles in the system. After this year the second program for the developing the waste management system was started. In 2003 the first public biogas station was opened and in Aug 2004 the first buses in Borås started running by biogas. The new incineration plant for the waste burning was opened in 2004 and 2005 [20]. There are several developing tasks in this field such as new fermentation plant which will be started to work in the near future.

4.2. Waste Generation

The people in Borås generate more than 250000 tones of wastes per year [23]. The amount of waste which is just received by the waste refinery centre in Borås, Sobacken, between 2004 and 2006 is shown in the Fig. 4-1 [20]. There are some other wastes that are not transferred to Sobacken so there is no exact statistics from them.

The household part is collected by the white and black plastic bags (which are collected from the households) and the industrial part is collected from the waste collection centers, commercial source and the others are brought to Sobacken. The source and compositions of these wastes in this city are more and less the same as resources which were discussed earlier in chapter 2.4.1. The generation of wastes in Borås usually changes seasonally.

It is important to note that the industrial wastes are collected by other companies such as STENA, LBC that are in charge of it.

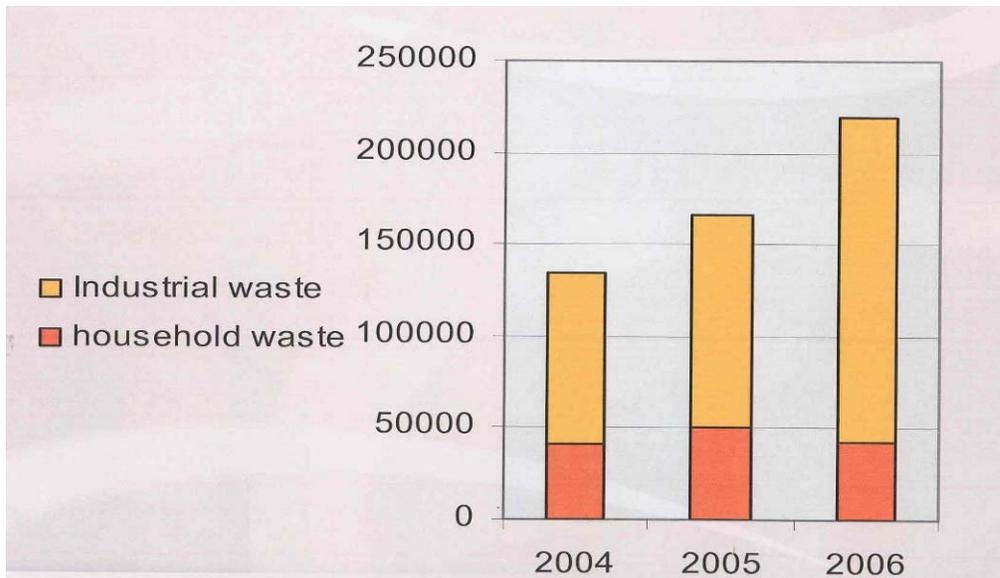


Figure 4-1: The amount of waste received by Sobacken in Borås

As the figure demonstrates, during these three years the total amount of waste generation is increasing about 20% and 33% respectively in 2005 and 2006.

According to the data from Sobacken, Table 4-1 demonstrates the amount and property of the generated wastes in 2006 in Borås [23].

Table 4-1

Amount of waste generation and their properties in 2006 in Borås

Waste properties	Amount (tonnes)	Treatment
Combustible	95420	Energy recovery
Organic and compostable	27377	Aerobic and anaerobic digestion
No organic and combustible	7347	Landfilling
Contaminated soil	71250	Treated and landfilling
Recyclable	16183	Recycling
Hazardous	2435	Volume reduction, waste stabilization
Total	220012	

4.3. Waste separation at source and collection

The people in Borås play a very effective role in the waste management. All the solid waste should be sorted at source by them. There are two plastic bags for the separation of compostable and combustible wastes, respectively black and white. All the food wastes go to the black one and the light plastics, the small papers, different wastes which are not sorted in the sorting place should be put in the white plastics.



Figure 4-2: Black plastic, biodegradable



Figure 4-3: White plastic, combustible

For the low- and high-rised apartments, there are some containers for putting these plastic bags in them. The size and number of these containers depend on the population density of that area. In some parts of Borås there is chute system for waste collection in the high-rised apartment as well. For transfer the waste from these places to Sobacken (waste refinery centre in Borås), usually is used truck containers. The frequency of collection for these types of building varies from every 7 to 14 days [22].

In the other side for the houses, each villa should rent one or two containers for collecting its wastes. They put these containers near their house and put the white and black plastic bags in them. It is similar to the set off-set back collection system. It is usually used a truck with mechanical system for emptying the container by itself in order to collect the wastes from them. It is handled every two weeks for collecting the wastes from villas [22].



Figure 4-4: The sample waste collection truck

Totally, there are 32 trucks that are working for collecting the wastes of the households. About 11 of them are involving in the collection of the black and white plastics. The usual types of the trucks are shown in Fig. 4-4. About 9 of them are using biogas as fuel and there are some other trucks which are bigger than this type. Also there are 5 double containers which can carry a large amount of waste in the larger

distance. For transporting the hazardous waste there is one special truck which is specially designed for transferring the hazardous wastes [22].

There are almost 80 sorting places in Borås [19]. In these stations which are almost located near each avenue, the other types of waste such as, glass, hard plastics, metals, papers, cardboard, papers from packaging should be sorted in each special container. In some of these stations, there is also a special container for home batteries. After filling up, these containers are transferred to the recycling facilities in order to use these kinds of waste as a source in their production. Each container is cared by one recycling company to transfer it. Usually the trucks with the mechanical mechanism can empty the containers. The frequency of collection varies for each type of wastes as well as the population density. For example for the papers it occurs once per week or two weeks [22].

For the other types of waste which are usually heavy and big as well as the hazardous wastes, there are 5 recycling centres in Borås community. These kinds of waste should be transferred by inhabitants to these centres and be sorted in each special containers which are available for wood, combustible wastes, metals, cardboards, papers, compostable wastes, garden wastes, hard plastics, metal for packaging and glass. On the other side the other wastes, such as WEEE (waste from electric and electronic equipments) such as refrigerators, computers, monitors and etc are sorted separately [19]. The hazardous wastes such as lamps, batteries, sprays, paints and solvent should be sorted in the special places in these centres by the help of their staff. Each container is equipped with a mechanical compactor in order to reduce the volume of the waste in the containers. Since the containers in these centres are big and heavy, usually the big trucks are used to transfer them. At the same time the trucks bring the empty one and put it instead of the full one.



Figure 4-5: A recycling center in Borås

4.4. Material Recovery/Transfer Facilities (MR/TF) in Borås

In 1992 the waste treatment centre, Sobacken, was established in Borås. It is located approximately in 8 km south-west of downtown Borås [20]. All the activities related to sort, separation, composting, biogas production and landfilling take place in Sobacken to treat the wastes which come mostly from households and some from industry. There are several reasons to choose the place of Sobacken. In summary, geological reasons such as the level of ground water, collecting the surface water, preventing the soil contamination, as well as decreasing the distance between this centre and the city are some of them [7].



Figure 4-6: View of Sobacken

The capacity of Sobacken is to treat about 300000 tones of waste per year. The Sobacken activities are summarized as follows [7], [20]:

1. Optical sorting the wastes from households to separate the combustible part from the part which is treated by biological process
2. Producing the biogas and compost from the biological part of households wastes and the wastes from the industry or the animal wastes
3. Sorting the wastes from other sources in order to prepare for recycling centre
4. Landfilling the waste from the treatment activity in the plant, as well as the other wastes such as ash from incineration plant, asbestos and some fraction of construction and demolition wastes.
5. To prepare the fuel for the incineration plant from the combustible parts of the wastes

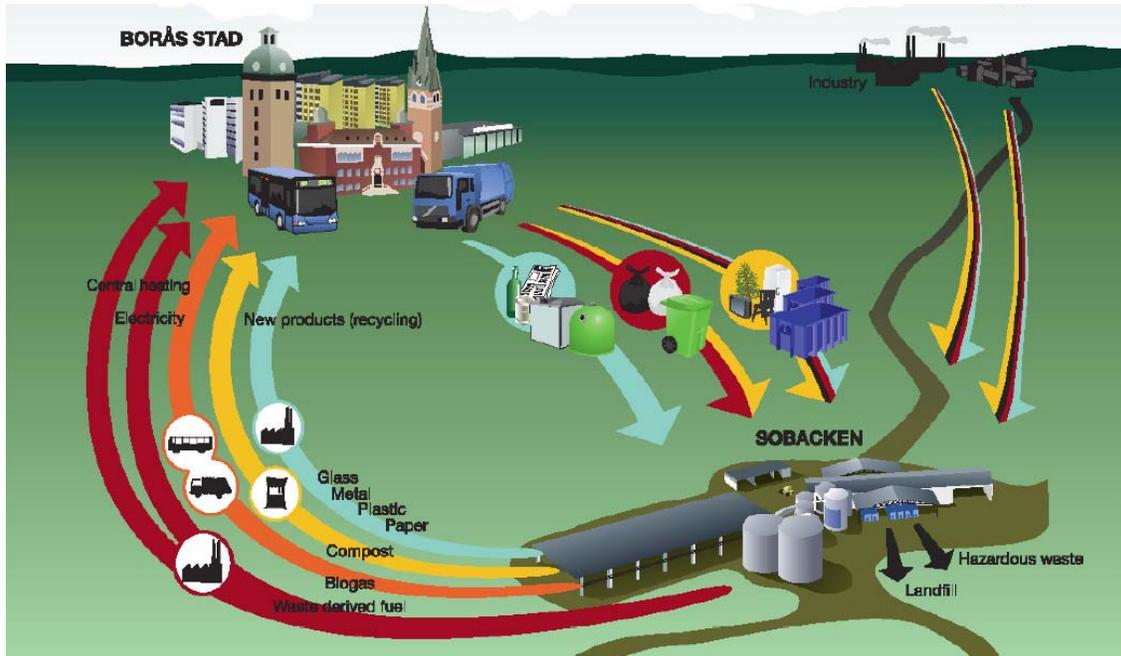


Figure 4-7: Schematic of material flow between Sobacken and society

4.4.1. Waste transfer and handling in Sobacken.

In Sobacken, there are many facilities for handling and transferring the wastes. All the wastes which come from households in the black and white plastic bags go directly to the optic sorting machine in order to separate the white and black plastic bags. In this machine the different types of conveyor are used for handling the waste.

Besides the optical sorting, there are many types of equipments such as loaders; small trucks are used for handling the wastes in the site.



Figure 4-8: Optic sorting

4.4.2. Biological treatment in Sobacken

One of the main tasks for treating the waste in Sobacken is biological treatment. In Sobacken two methods -anaerobic and aerobic digestions- are applied to produce biogas and compost. The amount of biogas production is shown in Fig. 4-9 [20].

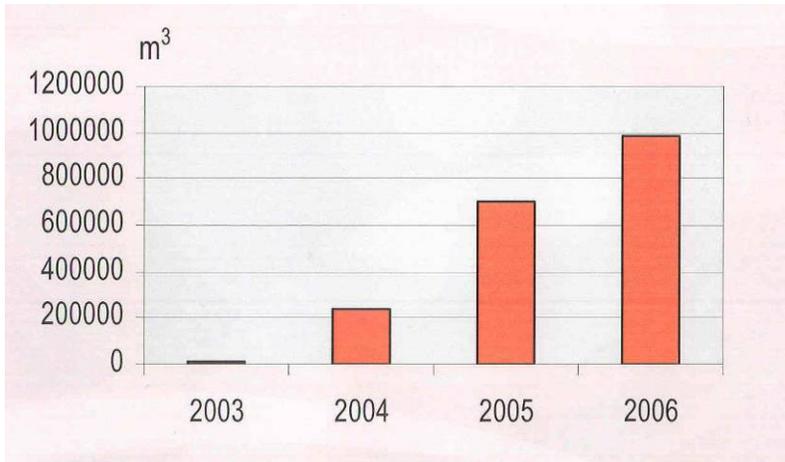


Figure 4-9: Biogas production in Sobacken

Fig.4-10 shows the material flow of biogas production in Sobacken. Sobacken receives biomass in two lines. First line is coming from black plastic bags which are separated in optical separation process in a solid form plus fluid organic waste, and the second line receives from industries such as waste from grocery stores, slaughterhouses and food production as well as animal wastes which are both solid and liquid [20].

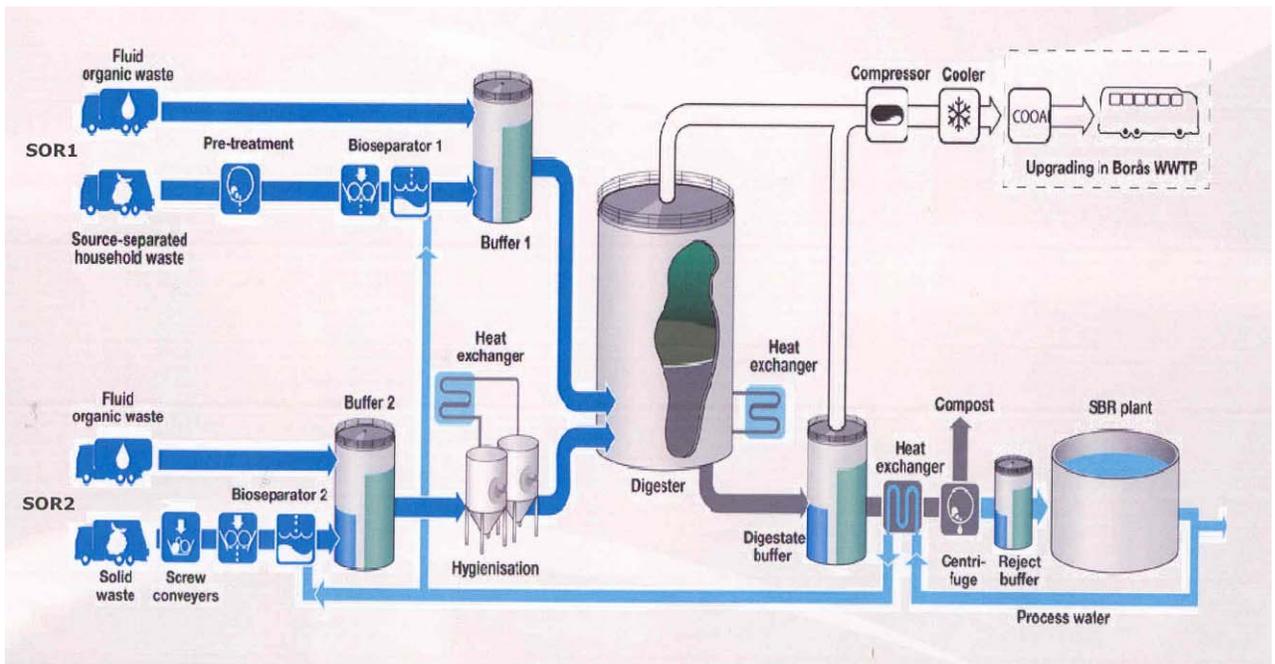


Figure 4-10: Schematic of process of biogas production in Sobacken

The black plastic bags from the first line after optic sorting, is handled to the bag opener machine. After opening the black bags the drum sieve machine separates the black plastics from the waste stream and the wastes are transferred to the magnet separation for getting the available metals from the stream. There is a shredder machine which reduces the size of the wastes to the desired size and then in a bio separator, biomass is made into

fluid. After that they transfer to the buffer tank 1 to be treated at 55 °C for 6 hours. If there are some liquid wastes in the first line they will be pumped directly to the buffer tank 1 as well. In the other side, in the second line which comes from the industry in the solid form, after shredding, in bio separator the biomass is blended and the packaging material are separated from the waste stream. Then they are transferred to the buffer tank 2 for sanitation at 70 °C for 1 hour. The liquid waste which comes from the industry is transferred directly to the buffer tank 2. To avoid bad odour from the process, all ventilation air from the building passes a bio filter before being released to the atmosphere [7].

After sanitation, the waste stream is transferred to the digestion tank with 3200 m³ volume. The reactor chamber has the capacity about 100-200 m³/day bio waste to convert to biogas. The total solid (TS) in the stream is about 20%. The process is continuous, one-stage and thermophilic. During an anaerobic digestion, in 18 days, and specific conditions of temperature (about 55 °C), pH and moisture, the biogas is produced [7].



Figure 4-11: Biogas plant in Sobacken

The biogas production from this process includes 55%-80% Methane. For this reason it should be purified to 97% in order to be used as a fuel for the vehicles [7]. It is transferred to the purification plant, at the waste water treatment plant, by pipe. After purification, the biogas is transported through a pipe line to the filling stations. It is mixed with the biogas production from the sludge digester and is transferred to the two filling stations which one is for busses and private cars and the other is for the waste collection trucks [22].



Figure 4-12: Composting in Sobacken

The sludge from digestion tanks goes to the middle tank to be added by polymers in order to make the better condition for the composting process. After dewatering, solid part is transferred to the composting process under the roof and the other in a SBR (Sequencing-Batch-Reactor) is denitrified. The solid digested after mixing in an open windrowing under the roof by the special machine, is transferred to the pipes for starting the under control aerobic process. Blowing the air to these pipes not only avoids the anaerobic process and controlling the temperature but also removes the bad smell from the process. During this process the fertilizer or compost materials are produced after 10 weeks and after packaging they are transferred to the storage to sell. Beside this type of composting, there is other specific composting site in Sobacken for composting the masses, generally soils which are contaminated with oil that comes from some industries near Borås [7].

4.4.3. To prepare Refuse Derived Fuel; the RDF

In order to deliver the high quality of fuel for the incineration plant in Borås in order to burn the waste, Sobacken prepares the combustible parts of the waste in its site. By separating the metals from the stream and crushing the combustible parts the RDF is produced in order to reduce their size less than 100 mm [7]. Part of this waste stream comes from the white plastics which are separated during the optic sorting. But the other part comes from commingled wastes from industry or sorted wastes from recycling centers. The unsorted wastes first should be sorted in the site and after separating away the recycling part, the combustible part is transferred to the shredder the same as the white plastic bags. After crushing, the solid fuel is transferred to the incineration plant in Borås daily in order to be burnt and produce the energy from them. For waste handling in this part a wheel loader is usually used.



Figure 4-13: Preparing RDF in Sobacken

4.4.4. Intermediate storage of hazardous waste and some industrial wastes

Sobacken is also working as an intermediate collection and sorting centre. Some other streams of waste such as industrials come also to Sobacken for sorting and intermediate storage [7].



Figure 4-14: Intermediate storage in Sobacken

All the hazardous wastes which are collected in the recycling centers are transferred to Sobacken. Sobacken is playing as an intermediate storage of hazardous waste. These wastes such as aerosols, electronics, chemicals, paints, batteries, and light bulbs are stored in Sobacken and then the companies which carry each of them will take them from Sobacken.

4.4.5. Landfill in Sobacken

From 1990 to 2006 the amount of landfilling has decreased dramatically in Borås from 100000 to less than 10000 tones per year. This occurred because of the modern integrated solid waste management in this city as well as the legislation and tax on landfilled waste (440 SEK per ton). The Fig. 4-15 shows the amount of landfilling in Borås between 1990 and 2006 [20].

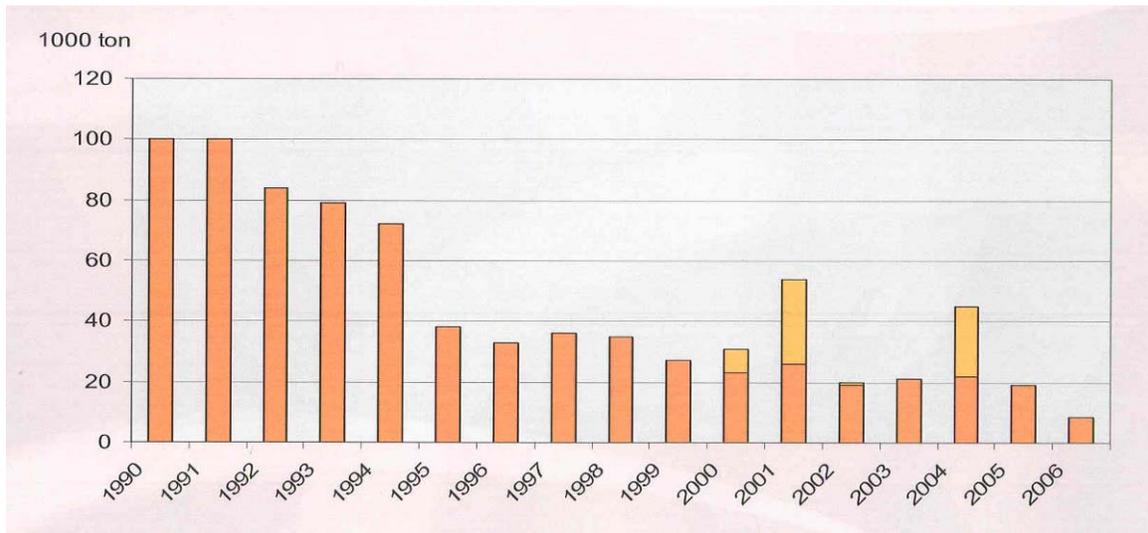


Figure 4-15: The amount of landfilling in Sobacken

Currently the landfill is nearly 10 ha. Total amount of 470000 tonne waste has been placed in the landfill since 1992 [23]. Since 2003 it's not allowed to put any combustible waste in the landfill and since 2005 organic waste is forbidden as well. The landfill is probably filled up in 2-3 years from now. Main fractions that are going to the landfill are contaminated soil, construction and demolition wastes, the activity from waste treatments facilities, and ash from incineration and so on. One important part of the landfilling in Sobacken is controlling the leachate from landfills. The leachate water from the landfill area is collected in a pond with the capacity about 30000 m³. Then these leachate waters are pumped to the sewage plant for treatment. This reduces the environmental impacts of the leachate water as much as possible [7]. Landfill gas is also collected and burned.



Figure 4-16: The view of landfill area in Sobacken

4.5. Incineration plants in Borås

According to Olofsson, M; Waste Refinery in the Municipality of Borås, the combustion plant for burning the waste and recovering the energy from them in Borås has been located close to the city centre and it was established in the spring 2005. This plant is working based on CHP plant (combine heat and power) with the capacity of 40 MW_{th} and 5 MW_{el}. There are two fluidizes-bed boilers which each of them is able to burn the 7 tones of waste per hour which contains 30% households and 70% industrial wastes. The boilers are equipped by the facilities in order to reduce the environmental impacts of waste combustion as much as possible. The dry flue gas cleaner system plus ammonia-based and de-NO_x system for the furnaces are working in order to reduce these impacts. The specification of the production steam is 49 bar and 405°C which it is supposed to increase in near future to 500°C [6]. The heat production is going to the district heating system in Borås for the households and the electricity production is going to electricity network distribution.

5. Important factors in MSWM

In the last two chapters, we could find a clear feature of municipality waste management, its functions, and also a review on the system that is being applied in Borås. If we go further through the waste management we can understand that, it is completely a large technical system. As an example, looking through the Borås system, demonstrates that many factors are involved in the system. In my opinion, people, politics, community and regulations, business, environment and sustainable development, and research and technology are the factors which make the waste management an extremely complicated system in this city. I am going to discuss briefly about some of these factors and their roles in the available system in Borås.

5.1. People and Inhabitants

As mentioned before there are about 100000 inhabitants in Borås. The Borås method, separation at source is completely based on the participation of the inhabitants. The people in Borås are playing an essential role in the WM system. Wherever the people have properly participated, the system is working more efficiently. I would summarize the tasks of the inhabitants as follows:

1. They buy the goods and generate the wastes; at the same time this waste is the source of a business for the waste facilities in the community
2. They should separate all the parts at home and then put combustible parts in the white plastic bags, compostable parts in the black plastic bags. They should also separate the cardboards, hard plastics, aluminium cans, PETs, glass, batteries, metals, hard packaging, hazardous wastes, as well as garden wastes and bring them to the recycling centres.
3. They are playing the role as direct or indirect customers to purchase the energy production from the waste such as district heating or even biogas as well as composts.

The above demonstrate that, people not only should do their jobs properly as much as possible in this system, but also they are also the real customers.

5.2. Environment and sustainable development

Borås city is one of the forerunner cities in Sweden which applies the waste management system to reach the sustainable and environmental goals. Some sustainable goals that are defined in the Agenda 21 of this city could be reached earlier than the set [21]. The role of the WM system in the city in reducing the environmental impacts is completely demonstrated. The following tasks are expressing the role of the WM system concerning environment as well as sustainability:

1. Reducing the volume of landfilling which could reduce the greenhouse gas impact as well as the leachate and their impact
2. Separating the recyclable material at source which helps the dematerialization; a main part of the sustainable development
3. Converting the combustible part to the energy as a renewable energy in order to decrease the use of fossil fuels, also helps the sustainable development
4. Converting the compostable part to biogas as a renewable energy
5. Separating the hazardous waste and decreasing their impact on the environment

As it was mentioned in section 3.6, putting the commingled wastes in landfill have a very dangerous environmental impact. The aim of the waste hierarchy is, to avoid the landfilling. But there are some questions; is always landfilling a bad example compared to the other applications in the waste hierarchy? Is it true that recycling is better than incineration? To answer to these types of question, we need to analyse each method of the waste management for each waste from environmental impact as well as energy consumption aspects. The life cycle assessment (LCA) is applied for doing these

analyses. According to Baumann (2004), LCA means that "a product is followed from its "cradle" where raw material are extracted from natural resources through production and use to its "grave", disposal". Also LCA is a method which is applied for analysing and evaluation the environmental impacts, material consumption and energy consumption for different parts of material flow.

There are some LCAs in order to compare the methods of waste management for the different wastes [12]. The results of the LCAs in comparison with the methods in waste management strategy are very dependent on the type of waste. For the recyclable materials such as, glass, metals, aluminium cans, PETs, cardboards, paper it has been concluded in some studies, that although the recycling in itself is consuming much more energy it is still preferable compared to incineration and land filling methods. The same comparison between landfilling and biological process shows that biological treatment is the best method for compostable material.

For example Anna Björklund from KT H, is in her paper comparing recycling with other methods such as incineration and land filling, from global warming impacts as well as energy consumption aspects. The result of her research demonstrates that recycling of the recyclable material is always preferable in global warming as well as energy consumption aspects compared to incineration and land filling.

Meanwhile, all application in the waste hierarchy is a task to reducing the environmental impacts, if they will be done properly. For different wastes we need to have different methods in order to get the best results to reduce the environmental impacts. This diversity of methods in waste management strategy in Borås besides the other factors has made a low pollution community of this city [21]. Reducing the land filling from 1994 to 2006 to 10%, producing the energy from combustible wastes by controlling and monitoring the environmental impacts of incineration, increasing the capacity of the biological treatment to produce biogas and compost, all have made Borås having the standard environmental measures from pollution aspects [21]. Now the community expresses that the waste management system could obviously help to reduce the environmental impacts in this city [21].

Sustainability is a very complicated topic. According to Kenneth Geiser (2001), sustainability means that "the amount of activity should meet the needs of the present while reserving the resources necessary to support continuation of the activity in the future".

In many developed countries and societies there are many programs about sustainability and sustainable development. But the main part in the sustainability which can refer to waste management is to reduce the use of materials (dematerialization) as well as reducing the environmental impacts of disposal of waste. Based on Kenneth Geiser (2001) dematerialization means "increasing the intensity of service derived from each material of use". This could involve recycling and reusing materials, designing products that use fewer materials". When we look at the hierarchy of waste, it is obvious that whenever we go to the top we are closer to the sustainable goals.

This also happened in Borås. The Borås strategy in waste management really helps the society to get their sustainable goals in Agenda 21 [21]. Sorting the waste at source and sorting the recyclable wastes are the main tasks daily occurring in this field.

5.3. Business

The term of business in MSWM should be seen from separation to land filling. Some function, such as collection system and land filling have more costs and less income. But some other functions such as incineration and biogas production can be quite profitable if all the circumstances are working well. Summing up the system is profitable.

About 30 years ago, WM was just collecting the waste and putting it into land fills. The inhabitants would pay the community for this service. Nowadays they are still paying and at the same time the community has income from the waste facilities which use waste as a resource to produce energy and useful products.

In Borås the collection function is a very high cost function [23]. But the energy production in the CHP plant, and biogas production as well as reduction of the amount of land fillings have made a lot of benefit for this community. There is no exact data available to show how much profit or income has been gained just by waste process in Borås, because the company, “Borås Energi & Miljö”, involved in this job, is also doing other business. According to the website of this company in 2006, its total income was about 510 million SEK. Meanwhile during the recent years, the investment of the developing and research in this field as well as the setting up of new incineration plants, biological treatment and district heating production, demonstrate that the system can be profitable.

In my opinion, the important part of this business is the resource of the process, which is waste. In this business they don't pay any purchase fee for buying the raw material. Meanwhile there are some regulations that some process such as incineration should be paid for burning each tones of wastes. In the end of the process there are also some valuable products like electricity, heat, biogas and fertilizers. I think the business situation for the WM system is a win-win situation both from economical and environmental point of view.

5.4. Other factors

As mentioned before the MSWM is a large technical system and there are also some other factors involved. Technology is an inseparable part of this system. By review of the function of the MSW in chapter 2, we would see that the role of technology in all the functions is absolutely obvious. Today, in MSWM from collection to disposal, the numbers of solutions which are provided by technology are too many. Depending on the goals of the waste management system there are many technical solutions that can be chosen. For instance in Borås, for developing the technology in the field of treatment of the waste, the community have a close co-operation with the university of this city as well as other companies and research centres. Waste Refinery Centre is now carrying out 12 projects in waste management in Borås and Gothenburg. It is important to note that developing of technology needs a close relation between research centres, companies which in Borås this is done quite well.

The other important parameter is the role of the politicians in defining the goals of the community when it comes to the environment and sustainable goals. As it was discussed before MSWM had an efficient role in reducing the environmental impacts and some parts of the sustainability. System aware politicians want to invest more in this field and

this in its turn develops the system within the society too fast. One of the reasons of developing the system in Borås is exactly this one. The global and local regulations could help to develop the system through for example, avoiding the land filling of compostable waste and tax on land filling.

In my opinion the waste management system in a community is, to walk on a narrow bridge. Environment, business, sustainable development, technology and most important of all the inhabitants are the factors which all should be considered in this way. If one of them is attended more; it causes the system not to reach its goals.

6. Conclusion

In this chapter I am going to evaluate the waste management system from the management system point of view in Borås.

6.1. Borås system evaluation

By looking at chapter 3, it is so clear that the city of Borås could develop its system in MSWM very fast during the following 20 years. The amount of land filling has been reduced dramatically, the new biological plant has been established and also there is a modern incineration plant to produce heat and electricity from the waste. Although the environmental regulation is the driver of the growing system, the role of research, education, technology and the willingness of the community, when it comes to investments, are absolutely obvious. On the other side the Borås system is completely based on the participation of the inhabitants. People play an essential role in this system when separating the wastes at source. As discussed before, in the Borås system, separation is a very effective function, done by the inhabitants. It is true that people are generating the wastes and they should take care about the environment locally and globally but instead, they are really participating in the system. That means if they do not do their job properly the system can not work properly in its process and might not be profitable. In my opinion in a waste management system, like Borås, communication with people is a big part of the system. This communication should be done:

1. To inform people how to minimize the waste generation, which is very important in providing the first step of the waste hierarchy and the sustainable goals
2. To inform people how and why they should separate the waste

In Borås, unfortunately there are no instructions in how people can reduce the waste generation [23]. During the later years the amount of generated waste is not decreasing but instead increasing. That is why they are missing the first step of the hierarchy little by little. This makes the society go far from the sustainability and in the future it causes a lot of problems for the system. Now, the intention might be to work all the facilities with the maximum capacity and for that they need the waste as a source for the process. But this is very dangerous for the society from the sustainability point of view. I have tried to find the answer to why they are not working on how they can reduce the amount of waste. The answer could be that it is very hard to convince people about their consumption pattern. In my opinion it can be possible with an interdisciplinary research in sociology, psychology, and waste management to make a program to introduce the ways to people and show how they can consume but still generate less waste. As a result, I would say,

the waste management in Borås takes care of the second step of the hierarchy up to the last step but now they are completely missing the first step, which is waste minimization.

On the other hand, there are lots of activities to inform people about how to separate the waste. Some of them are not enough, some of them are not complete and some of them are not done seriously. For example for informing the households about how to separate the wastes, the company responsible, “Borås Energi & Miljö” has printed some brochures and distributed to the households. It has also a website with some information. I was informed that, during these 20 years they have performed just two or three types of this information which seems not being enough. Unfortunately, these brochures specially the last one are more commercial instead of training ones. In my opinion the things they should attend about these brochures are:

1. Less text, more pictures and symbols, easy to follow by readers, the aim of brochures should not be commercial, but training
2. In different languages, because there are a lot of immigrants living in Borås
3. Distributing every six months or at least yearly to remind people about their job

Meanwhile in Sweden, according to myself, the schools should have a special program for the students to teach them how they should care about the environment and how to separate the wastes. But in practice, based on a project at the Institution of Pedagogy at University College of Borås, this program is not being properly carried out at the schools. It can be very important for a society like Borås to attend to this more and more.

Also immigrants have a very short introduction, during the time they are studying the Swedish language, SFI. According to themselves it is not enough [21]. The role of information to the immigrants has been demonstrated in a report in 2001 “Plockanalys av hushållsavfall I Borås Kommun” by Bo Segerberg, a “Miljökonsult” an Environmental Consultant. The statistics in this report show that the avenues where the majority of the inhabitants are immigrants, the results of the sorting are very bad. Meanwhile it demonstrates other places are not successful properly in sorting. This situation still exists in Borås [22].

The waste management system in Borås needs to communicate to people much more. For example it would be good if the system could be evaluated by a questionnaire to ask people about the strengths and weakness of the system. Surely there are lots of ideas from the inhabitants that can help the system to develop. In this system, whenever people are doing the job properly, the system will be working better. Just a simple failure in sorting, especially in white plastics, makes irreparable damages to the facilities. Last year for example burnable material in the white plastics, caused explosion in the shredding facilities at Sobacken. Its repair took several months. These are the risks of this system and the best way for avoiding them is to train, inform, and educate the inhabitants as much as possible.

It is important to note that this system -separation at source- is not the only system for MSW but it is one of the easiest and cheapest ways. There is an alternative for Borås to use the automatic waste separation facilities which is working base on different aspects. Some of them are working base on infrared spectroscopy [24]. Different wavelengths show the different range of properties that can help the machine to separate the different

kind of rubbish such as cardboard, different kind of plastics, glass, metals [9]. But the maintenance and investment of such system are really high compare to the available system in Borås. Better MSWM needs better sorting. For better sorting using automation waste management separation or using inhabitant as a participator in the system for separating the waste are the ways which Borås uses the easier one, second one. Meanwhile when the people are participating in the system the knowledge of the society is improved about environmental aspects. This cause that the society can reach the sustainable goals faster. But it needs to inform and educate the people more about the system to get the better results.

6.2. Future research

Separation at source is one of the low cost methods in MSWM, because people are doing a lot to separate all the wastes and prepare them for recycling, and other processes. In my opinion in a system like that of Borås, whenever people are working well in separation, the system needs less maintenance as well as simple preparation facilities for the process. As a result, the system will be more profitable. One of the interesting subjects, which can be developed in Borås, is, how people can participate more in the system and what will be the effect of this. In other words it is to have the quantitative perspective of the influence of people in the waste management system. Meanwhile, going further in the first step of the hierarchy, researching in the consumption pattern can be other subjects that Borås need to attend to.

References

1. Tchobanoglous, G. (1993). *Integrated Solid Waste Management: engineering principles and management issues*. New York : McGraw, cop. 1993
2. Geiser, K. (2001). *Materials matter: toward a sustainable materials policy / Ken Geiser*. Cambridge, Mass. : MIT Press, cop. 2001
3. Baumann, H. (2004). *The hitchhiker's guide to LCA : an orientation in life cycle assessment methodology and application / Henrikke Baumann & Anne-Marie Tillman*. Lund : Studentlitteratur, 2004
4. Leander, J.; Rytterstedt, M.; Säfvestad, H. (2007). *Insamling och förbehandling av hushållsavfall i Borås kommun: Konsekvensbeskrivning av tre alternativ*
5. Johansson, A.; Olofsson, M.; Wikström, E.-L.; Ekvall, A.; Gustavsson, L.; Tullin, C.; Jarlsvik, T.; Assarsson, A.; Andersson, B.-Å.; Peters, G.; (2006). *Waste Refinery in the Municipality of Borås*
6. Johansson, A.; Olofsson, M.; Wikström, E.-L.; Ekvall, A.; Gustavsson, L.; Tullin, C.; Jarlsvik, T.; Assarsson, A.; Andersson, B.-Å.; Peters, G.; (2006). *The Performance of a 20 MWth Energy-from-Waste Boiler*
7. Golder Associates AB, (2003). *Teknisk beskrivning Sobacken Avfallsanläggning*.
8. Miljookonsult B Goldstein, (December 2006). *Miljövinster med att minska totala avfallsmängder*
9. http://www.sintef.no/content/page1____1239.aspx

10. Eriksson, O.; Carlsson Reich, M.; Frostell, B.; Björklund, A.; Assefa, G.; Sundqvist, J.-O.; Granath, J.; Baky, A.; Thyselius, L.; *Municipal solid waste management from a systems perspective*. Journal of Cleaner Production 13 (2005) 241–252.
11. Holiwast (2006). *Report on waste treatment option*. Holistic Assessment of Waste Management Technology (2006).
12. Anna Björklund, Göran Finnveden, *Recycling revisited-Life cycle comparison of global warming impact and total energy use of waste management strategy*. Resource Conservation and Recycling 44 (2005) 309-317
13. Edward Cohen-Rosenthal, *Making sense out of industrial ecology: a framework for analysis and action*. Journal of Cleaner Production 12 (2004) 1111-1123
14. Swedish environmental protection agency (1999), *Waste Management, The Swedish Experience*
15. Naturvårdsverket (1998), *Styrning och källsortering av avfall I Borås*
16. Naturvårdsverket (2007), *Delmålsrapport om avfall*
17. Bo Segerberg (2001), *Plockanalys av hushållsavfall I Borås Kommun*, Miljökonsult
18. Miljömål för Borås (October 2006), < <http://www.boras.se>>
19. Borås Energi och Miljö, < <http://www.borasenergimiljo.se>>
20. Hans Skoglund (2007), *Sobacken presentation*, Borås Energi och Miljö
21. Interview with Linda Ternström, responsible for Agenda 21 in Borås, phone: +46-33-35 82 76
22. Interview with Hans Skoglund, Avdelningschef Insamling/Transport, Borås Energi och Miljö, phone: +46-33-35 74 91,
23. Email communication with Anna-Karin Schön, Miljöchef, Borås Energi och Miljö, phone: +46-33-35 74 45
24. <http://www.sustainabilitymatters.net.au/news/7675-Jet-sensors-help-sort-waste>

Appendix

Appendix A: List of questions in the interview with Linda Ternström

1. What is your idea about the sustainable development and how has it done in Borås?
2. What is the relation between Agenda 21 and sustainable development goals?
3. Is there any feedback about how the available system in Borås is working?
4. How did you see the influence of the waste and waste management in the Agenda 21?

5. How much could the waste management system in Borås help to reach the sustainable goals in this city?
6. How does the performance of the Agenda 21 authorize in Borås?
7. How do the inhabitants, students, migrants inform about the environmental issues?
8. What is your idea about the relation between developing technology and increasing the amount of waste?
9. How can we encourage the inhabitants to minimize the waste generation?
10. What is your idea about relation between technology and knowledge of people in the environmental issues?

Appendix B: List of questions in the interview with Hans Skoglund

1. How many years the waste collection system in Borås is working? Explain a little about its history)
2. Which part of waste management in Borås is managing by collection system? (What are the defined tasks and duties for collection system?)
3. Where are wastes collected from? (Households, villas, apartments...)
4. Which parts of Borås and its surroundings are wastes collected of? Which area?
5. How many households, centers, industries ... are their wastes collected by this system?
6. How was it designed and formed? (very brief)
7. How does it developed? (very brief)
8. Which types of trucks and machinery and how many of them are used in this system? (if photos are available, it would be very useful)
9. Are the trucks equipped with compactor? Are there any compactors in waste collection system before transferring to the Sobacken?
10. Which types of wastes are transferred directly to Sobacken? Where are the other parts transferred?
11. What happens to the wastes which collect from drop-off centers? (For examples papers, metals...)
12. Who is responsible for collecting the aluminum cans and PET which are sorted in the shopping centers?
13. Which trucks are used for hazardous waste? After collection where are they transferred?
14. What is LBC Company doing? How is its cooperation with your system?
15. What is the total amount of wastes which are collected per year?

16. Do you have any statistics to show how many tones of each type of waste per year are collected? Is there any other statistics in this field?
17. What is the total traveled distance for waste collection in Borås?
18. What is the portion of tasks for collection from households (black and white plastics) compare to the other types of waste?
19. Is there any measure which shows the average weight of black and white plastics?
20. What is the total cost of waste collection in Borås per year? What is it percentage compare to the other functions? Is there any statistics which shows how much of these cost are related to equipment (service, maintenance, developing) and how much for labors?
21. How do you think the people can influence in system with their cooperation?
22. Have you had any questionnaire to ask about idea and satisfaction of the inhabitants?
23. Have you had any training program or education for the people in Borås in which how they should collect their waste?
24. Have you done any research program to optimize or develop the available system?

Appendix B: List of questions in email communication with Anna-Karin Schön

1. What is the total waste generation in Borås? (Per day, Month or any data is available)
2. What are their rates? (per day, month, or any data is available)
3. What quantities of MSW are received by Sobacken?
4. How do the properties vary? (Daily, weekly, seasonally...)
5. What are their compositions? (Paper, glass, plastics...)
6. What are their sources? (Residential, commercial, industrial, institutional, construction and demolition, agricultural, municipal waste and waste water treatment)
7. What is the contribution of above sources to generate the total waste in Borås?
8. How much of them going to recycling and reusing?
9. How much is used for burning?
10. How much are treating by biological treatment?
11. How much are put in landfill?
12. What is the amount of hazardous waste and their composition?
13. Which methods are used for measuring the amount of waste?
14. What is the frequency of collection from curbsides for household?

15. What is the frequency of collection from drop-off centre?
16. What is the frequency of collection from the separation centers?
17. How do the collection frequencies vary?
18. How many separation centers are available in Borås?
19. Which types of vehicles are used for collection?
20. Is it true if we say collection system is the most expensive function in waste management? How is it for Borås?
21. How much waste does Sobacken received from industry and how much from households?
22. Does the Sobacken receive the wastes just from Borås? What about Mark and Bollebygd?
23. Do you have a special landfill (or treatment) for hazardous waste in Sobacken? If yes what is its specification and if no what happens to these kinds of wastes?
24. Do you have any data for the available landfills in Sobacken? such as type, capacity, operations, environmental monitoring,
25. What is the source of contaminated soil which is treated in Sobacken? Is it from demolition and construction or others? Which treatment is occurred to it?
26. Is waste management in Borås profitable or not? If yes how much has the company profit from the waste or how many percent?
27. Are there any special programs such as training, advertising, brochures, for the inhabitants during the last year to learn them about waste generation or how they can minimize their waste generation?