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Development and demonstration of an innovative household dryer for the treatment of organic waste

DRYWASTE (LIFE 08 ENV/GR/000566)

Deliverable.10

Report on existing methods and techniques (best examples and good practices) on household organic waste management and treatment, including large scale drying systems (Revised)

March 2011

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INTRODUCTION

This report represents an extensive literature and World Wide Web review on the existing methods, of household waste management and treatment. Starting with a brief report on the existing European Union legislative framework, priorities and principles, of the EU environmental policy on the management and treatment of biodegradable waste, the most prominent success methods on advanced household organic waste treatment applied in EU countries are briefly reported, while existing household biodegradable solid waste management and treatment techniques (including large scale driers) applied at a national and European level are reported.

Biodegradable waste fraction can be treated as a separate fraction or as part of the mixed MSW stream. This type of waste can be source separated and treated with the already developed methods of Composting and Anaerobic Digestion or as part of the mixed waste stream by thermal treatment and landfill method. In household level Composting and Small Scale (AD) are mainly used for the treatment of biodegradable waste.

1. Bio-WASTE MANAGEMENT LEGISLATION FRAMEWORK

The first step on the management of biodegradable waste is the "GREEN PAPER" which sets the base up on which the "EU Legislation Framework" for this type of waste is built. This Section aims to provide a comprehensive description related to the priorities and principles of the existing European Union (EU) environmental policy on the management of Bio-waste. The relevant legislative framework is presented briefly below.

1.1 GREEN PAPER (Brussels, 3.12.2008 COM (2008) 811 final) {SEC (2008) 2936}

According to the "GREEN PAPER" on the management of Bio-waste in the European Union, Bio-waste is defined as biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises, and comparable waste from food processing plants. It does not include forestry or agricultural residues, manure, sewage sludge or other biodegradable waste such as natural textiles, paper or processed wood. It also excludes those by-products of food production that never become waste.

The total annual arising of bio-waste in the EU according to Eurostat data on municipal waste (2008), is estimated up to (76.5-102 Mt) food and garden waste included in mixed municipal solid waste and up to (37 Mt) from the food and drink industry. Bio-waste is a putrescible, generally wet waste. There are two major streams: green waste from parks, gardens etc. and kitchen waste. The former includes usually 50-60% water and more wood (lignocelluloses), the latter contains no wood but up to 80% water.

Nowadays, there are many different policies that apply to the management of Bio-waste, applied to many countries, though the aim of their effort is to reduce the quantity and give a final waste with a better quality, with less microorganisms and less toxicity to the environment. Bio-waste seems to be the type of waste to be used most in the future for the production of better quality compost and Green –energy.

1.1.2Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives

According to this revised directive, all types of waste should be treated in a way that reassures the environmental protection, while the human health must be protected in any means. This can be achieved only by preventing or at least by reducing the negative impacts that, waste management and generation creates and by reducing further and further the impacts of source use. This framework Directive sets a five step waste management hierarchy in the priority order shown below (**Figure 1.**):

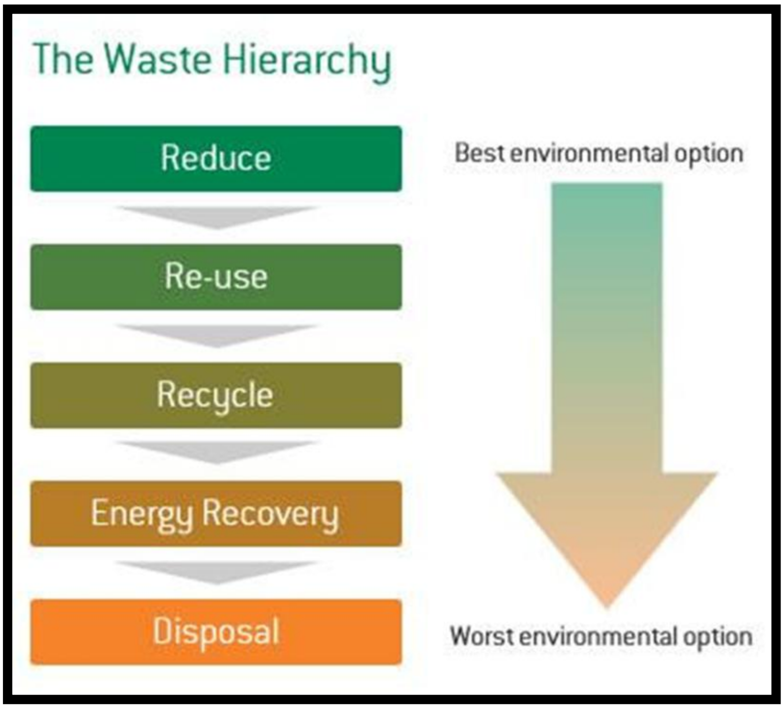

Figure 1.: The Waste Hierarchy (ACM Waste Management. 2010)

Highest priority is given to waste prevention followed by preparation for reuse, recycling, other energy recovery and disposal as the last and worst option. Policies may diverge from the hierarchy in the interests of minimizing overall environmental impact. This strategy sets out guidelines and describes measures aimed at reducing the pressure on the environment caused by waste production and management. The main thrust of the strategy is on amending i. the legislation to improve implementation, ii. Preventing the negative impact of waste and iii. Promoting effective recycling.

In particular, the Directive sets a 50% recycling target for at least paper, metal, plastic and glass from households - and possibly from other similar origins - to be met by 2020. This can work in favor of bio-waste recycling since bio-waste is the largest single fraction of household waste and Member States can include appropriate parts of it in the calculation of the 50% target. The target will be subject to review by 2014.

The Directive envisages the possibility of setting EU-wide "end-of-waste" criteria for compost. These can include quality and safety requirements so that composted bio-waste is no longer waste but a safe product, thus strengthening confidence and the market. Currently, national rules regarding compost quality and safety and even if compost is product or waste differ between Member States.

Facilities for the biological treatment of waste require a waste management permit. For recovery facilities Member States may derogate from the permit requirements provided they ensure environmentally sound waste management by laying down general rules for these facilities. Furthermore, it will allow the Commission to set minimum standards concerning health and environment for recovery activities not covered by the IPPC Directive.

1.1.3. Directive 1999/31/EC on the landfill of waste (Landfill Directive)

This Directive is a primary driver for the better treatment of bio-waste as it requires the diversion of biodegradable municipal waste from landfills to 75% in 2006, 50% in 2010 and 35% in 2016 of the amount of bio-waste generated in 1995. Countries with high reliance on land filling (over 80%, including most of the new EU12, **but also the UK and Greece**) have postponed the targets by a maximum of 4 years. While no requirements are set for the management of the diverted biodegradable waste the environmental costs need to be taken into account and the costs of land filling are increasing rapidly.

1.1.4 Directive 1996/61/EC on integrated pollution prevention and control (IPPC Directive)

This directive lays down the main principles for the permitting and control of installations based on best available techniques (BAT). It currently covers biological treatment of organic waste only if it constitutes pre-treatment before disposal. In the ongoing revision the Commission has proposed covering all biological treatment of organic waste above a capacity of 50 tons/day. This will increase the IPPC coverage of composting capacity from 81% to 89% and of anaerobic digestion from 89% to 99%.

1.1.5 Waste Incineration Directive 2000/76/EC

The incineration directive regulates the technical requirements for the operation of incineration plants, including emission limit values for selected potential contaminants (e.g. NOx, SOx, HCl, particulates, heavy metals and dioxins) in order to prevent, as far as practicable, negative impacts on human health and the environment. It is relevant for biowaste treatment as it covers incineration of most of bio-waste (including mixed waste containing biodegradable fractions).

1.1.6. Regulation laying down health rules concerning animal by-products not intended for human consumption 2002/1774/EC (The Animal By-products Regulation)

This Regulation lays down detailed rules for the protection of public and animal health that apply to the use of animal by-products in biogas and composting plants. Category (1) and Category (2) animal by-products are either excluded from such use or may only be used under strict conditions and following processing. Pending the adoption of harmonized requirements for the processing of Category (3) classified catering waste; Member States may adopt risk mitigating national rules for the processing of such material which must be at least equivalent to the standards set by the Regulation for the processing of Category (3) material of the same nature.

1.1.7 The Directive on the promotion of cogeneration (COM 2004/8/EC)

One of the best ways to use energy in an efficient way is by making use of cogeneration of electricity and heat (also known as combined heat and power or CHP), thus limiting waste heat. This is the objective of Directive 2004/8/EC., and it also applies to waste incineration. The heat developed in the incineration process can be used for district heating but also for industrial purposes, pre-treatment of fuel and for biogas production. In order to calculate if the cogeneration process is highly efficient under Directive 2004/8/EC, harmonized reference values have to be used as defined in Commission Decision 2007/74/EC. The list there includes reference values for electricity and heat from solid biodegradable (municipal) waste, liquid biodegradable waste and biogas, in order to promote the use of high efficiency cogeneration with such fuels. A qualification as high efficiency cogeneration may lead to guarantees of origin for CHP electricity and to (extra) state aid for operators of such units.

1.1.8 The proposed RES Directive, repealing Directives 2001/77/EC and 2003/30/EC

This proposal considers the use of biomass, i.e. the biodegradable fraction of products, wastes and residues from agriculture (including vegetal and animal substances), forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste, to count towards the renewable energy targets, but leaves it up to Member States to decide how certain renewable energy resources are to be supported.

In the Commission's estimation, around half of the EU's overall 20% renewable energy target will be met from bio-energy. Furthermore the RES Directive sets sustainability criteria for the use of biofuels and bioliquids, while encouraging the use of bio-wastes, e.g. cooking oil or bio-methane, for developing so-called second-generation biofuels. The RES Directive also foresees reporting on a need for sustainability criteria for all other uses of biomass for energy purposes.

1.1.9. Waste transport Directive EEC/259/93 and 94/721/EEC

The aim is to regulate imports and exports of waste inside and outside the EU. A reason for the transport directive is a conflict of principles. Based on the Extended Producer Liability and the Waste Hierarchy, the producer tries to recycle his waste in the cheapest way and tries to sell his recycled waste at the best price. However, this can form a conflict with the principle of Proximity and Self-sufficiency. The producer should recycle his waste as close as possible and sell it to the nearest producer. This is sound economic and environmental policy. However, this is in conflict with the principle of Proximity and Self-sufficiency. The transport directive divides the waste in three lists and sets priorities for each list:

• Green List: Free transport (just notification to government) e.g.: sorted MSW
• Orange List: Limited transport e.g.: unsorted MSW
• Red List: Transport restricted strongly: e.g.: hazardous waste
Products on the Green List can be traded freely. Products on the Orange and Red List are restricted and fall under the principles of Proximity and Self-sufficiency. Exports out of and imports into the EU are forbidden except for specific situations.

2. Household organic waste treatment methods

This Section aims to provide a comprehensive description related to the household organic waste management and treatment methods existing in the European Union, consisted as part of the (EU) environmental policy on the management of this type of waste. At this section, the relevant methods and practices are described in detail whereas the effectiveness and negative impacts of each method are also presented.

2.1. Composting

2.1.1. Introduction

Composting is a natural process which involves the aerobic biological decomposition of organic materials under controlled conditions. During composting organic matter from the biodegradable wastes is microbiologically degraded, resulting in a final product containing stabilized carbon, nitrogen and other nutrients in the organic fraction, the stability depending on the compost maturity (Golueke et al., 1955; Diaz et al., 1993).

Composting reduces both the volume and mass of the raw materials while transforming them into a stable organic final product which can be used as soil conditioner and improver. Composting can occur at a rapid rate when optimum conditions that encourage the growth of micro-organisms are established and maintained. As mentioned composting is a controlled aerobic biological decomposition of most organic solid matter and that differentiates the process from the natural occurring decomposition. Nevertheless, the biochemical process in composting and in the natural decomposition of the organic matter is the same.

Composting process is mainly carried out by 6 groups of microorganisms :(1) fungi, (2) actinomycetes, (3) bacteria, (4) worms, (5) protozoa, (6) larvae, etc. The bacteria include a wide spectrum of classes, families, genera, and species. For example, pseudomonades have been isolated and classified down to the genus level. Although actinomycetes are bacteria, they are named separately because of their particular role in the curing stage of the process (Golueke et al., 1955).

Two genera of actinomycetes have been isolated and identified; *Actinomyces and Streptomyces* (Golueke et al., 1955).The fungi rival the bacteria in terms of number and importance in the later stages of the process. The worms include nematodes and some earthworms (species of annelids).The larvae are of various types of flies.

Attempts for a hierarchy identification of microbes down to the species level on the basis of population and activity in the entire compost process had no success until now, because of the inevitable local differences in the gamut of environmental and operational situations. However, the following very broad generalizations have proven to be adequate for routine composting, particularly of MSW. In terms of number and activity, the predominant organisms are bacteria and fungi and, to a far lesser extent, protozoa. However, earthworms and various larvae may appear in the later stages of the composting process.

A fact which is referred as practical and important to the economy, is the presence of these organisms which is a characteristic of all wastes—particularly of yard waste and MSW. Hence, the use of inoculums (including enzymes, growth factors, etc.) not only would be unnecessary, it would also be an economic handicap.

2.1.2 Compost Phases

Composting characteristically is an ecological succession of microbial populations almost invariably present in wastes. The succession begins with the establishment of composting conditions. "Resident" (indigenous) microbes capable of utilizing nutrients in the raw waste immediately begin to proliferate. Owing to the activity of this group, conditions in the composting mass become favorable for other indigenous populations to proliferate. Plotting the effect of the succession of total bacterial content of the mass would result in a curve, the shape of which would roughly mirror those of the normal microbial growth curves and of the rise and fall of temperature during composting. Judging from the curve, composting proceeds in three stages, namely (1) an initial lag period ("lag phase"), and (2) a period of exponential growth and accompanying intensification of activity ("active phase") that (3) eventually tapers into one of final decline, which continues until ambient levels are reached ("curing phase" or "maturation phase"). In practice, this progression of phases is manifested by a rise and fall of temperature in the composting mass. A diagram of the temperature changes would give in a curve (figure.2), the shape of which would not be identical with that of the growth curve.

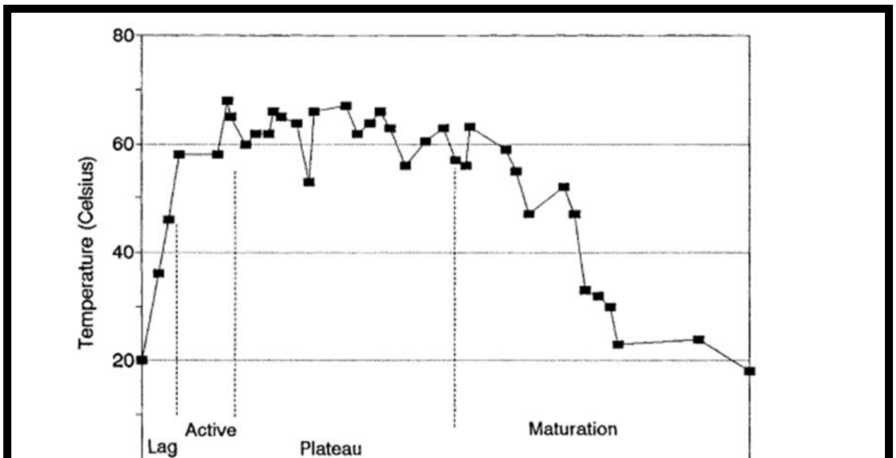

Figure 2.: Typical temperature curve observed during the various compost phases.
(Tchobanoglous and Kreith., 2002)

The whole process along with the characteristics of the final "humus" are all determined by the environmental factors of the process. More specifically, the operational parameters being followed, and the technology employed. Any change to all of these parameters, changes the quality of the final product and also influences the way and the time of the whole process, that is why all of these factors have to be as stable as possible. (Tchobanoglous and Kreith, 2002)

Lag Phase. The lag phase is the beginning of the whole compost process and begins as soon as composting conditions are established. It is a period where the microbes involving the process are adapted to the process environment. Microbes begin to proliferate, by using sugars, starches, simple celluloses, and amino acids present in the raw waste. Breakdown of waste to release nutrients begins. Because of the accelerating activity, temperature begins to rise in the mass. Pseudomonades have been identified as having the largest population among the process bacteria. Protozoa and fungi, if present, are not discernible. The lag period seems to last for a shorter period of time when highly putrescible materials or yard wastes are involved. It is somewhat longer with mixed MSW and woody yard waste, and is very protracted with dry leaves and resistant wastes such as dry hay, straw, rice hulls, and sawdust. (Tchobanoglous and Kreith, 2002)

Active Phase. The transition from lag phase to this phase is characterized by a large increase in microbial numbers (exponential) and a large raise of the microbial activity. This activity is characterized by a rise in the temperature in this phase of the composting mass. The rise continues until the concentration of easily decomposable waste remains great enough to support the microbial expansion and intense activity. Unless countermeasures are taken, the temperature may peak at 70°C or higher. The activity remains at peak level until the supply of readily available nutrients and easily decomposed materials begins to dwindle. In a plot of the temperature curve, this period of peak activity is indicated by a flattening of the curve (i.e., by a plateau).This “plateau” phase may be as brief as a few days or, if the concentration of resistant material is high, as long as a few weeks. The duration of the entire active stage (exponential plus plateau) varies with substrate and with environmental and operational conditions. Thus, it may last five or six days or two to five weeks. It should be pointed out that a sudden drop in temperature during the active stage is an indication of some malfunction that requires immediate attention (e.g., insufficiency of oxygen supply, excess moisture).Temperature drop due to turning is of brief duration. (Tchobanoglous and Kreith, 2002)

Maturation or Curing Phase. Eventually, the supply of easily decomposable material ends, and the maturation stage begins to dominate. In the maturation phase, the proportion of material that is resistant steadily rises and microbial proliferation correspondingly declines. Temperature begins an inexorable decline, which persists until ambient temperature is reached. The time involved in maturation is a function of substrate and environmental and operational conditions (i.e., as brief as a few weeks to as long as a year or two). (Tchobanoglous and Kreith, 2002)

2.1.3. Composting Technologies

Composting provides the humus and nutrients essential for a healthy soil. By returning compost to the soil, the soil is rebuilt and maintained for sustainable production. There are various methods and equipment available for the composting process depending on the kind of material and the time needed for composting process. The general experience in composting is that oxygen supply is maybe the most important factor, and this is the reason why the equipment tends to concentrate on the most efficient transfer of oxygen to all parts of the composting material because without it no compost process may occur. (Jorgensen et al., 1981,).

The most common composting technologies (figure 3.) are:

- windrow composting
- Aerated Static Pile Composting
- enclosed, or in-vessel composting

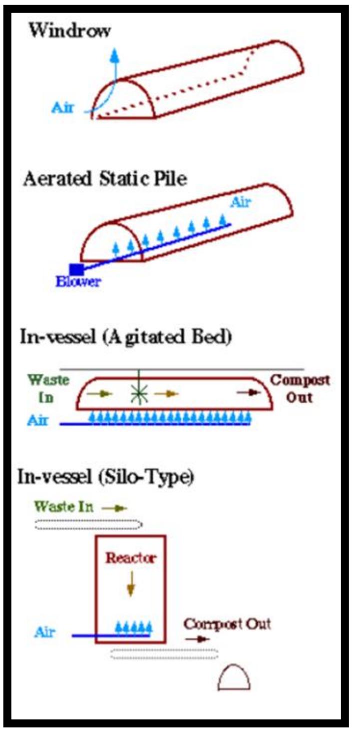

Figure 3.: Typical composting systems
(Dubois, González., 2004)

Windrow Composting

Windrow composting is the most common technology used. Windrows system according to most authors, seems to be very economical and easy to use technology. In the windrow process, the waste is placed in very long piles. The windrow process needs to be carried out very carefully giving the procedure details great attention so that the process is completed successfully. The windrows are usually 1–2,5 m high and 2–6 m wide (this is something that depends on the procedure used). The problems encountered to this procedure, mainly have to do with the form and shape of the windrow, something which affects several conditions of the process. For example, if the piles are too large, oxygen cannot reach the center. On the other hand, if the piles are too small they will not reach optimum temperatures. There is no ideal windrow size since this is something that has to do with weather conditions. The windrow process could be accelerated if the compost is turned periodically (usually over every four or five days). Mixing the pile periodically, help's the material to move from the inside out, thus allowing air diffusion throughout the pile speeding up the whole process.

Turning frequency is something that should be based mainly on temperature conditions, since temperature is among the most crucial factors in regard to the decomposition process. Temperatures below 38°C or above 60-64 ° C, are indicators that turning should be made in order to exceed proper circumstances for Composting process to take place. If the compost is somewhere between the limits (as they have been determined by a great number of experiments), turning could still be used in order to accelerate the decomposition procedure. The complete compost process may require two to six months depending on the method and the materials used for the process.

Picture 1.: *Overview of windrow composting operation*
(Dubois, González, 2004)

Picture2.: *View of machine used to aerate compost placed in windrows*
(Dubois, González, 2004)

Aerated Static Pile Composting

Aerated piles (Figure 4.) is the same process just like the windrow composting with the exception that air in forced to move through the static waste pile. When temperature reaches at elevated levels, a thermostatically controlled blower provides the oxygen required for the aerobic decomposition of the substrate while at the same time controlling the temperature.

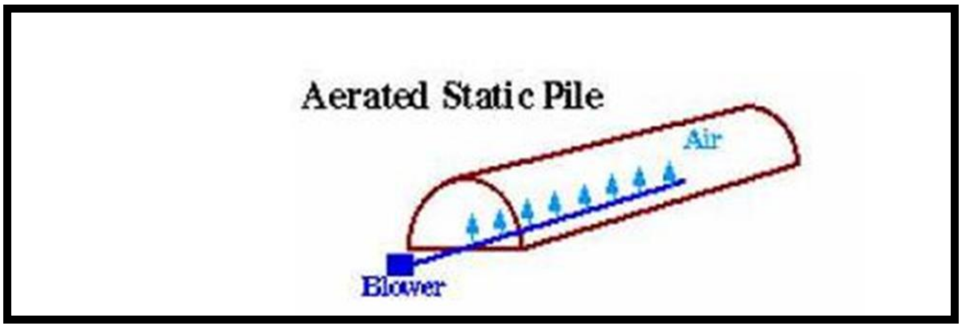

Figure 4.: Aerated piles diagram
(Dubois, González., 2004)

Because of the fact that there isn't any working mechanism for remixing during the composting process, aerated static piles are mostly used for sludge composting where the material is mixed with a dry porous substrate like woodchips and it forms a thin liquid film in which decomposition can occur.

Paved surfaces for the pile construction areas that permit capture and control runoff and allow operation during wet weather are important for the whole process to be functionable. The most common aeration system involves the use of a grid of subsurface piping (Figure 2.7). Pipes that provide aeration, consists of flexible plastic drainage tubing assembled on the composting pad. Before constructing the static pile, a thin layer of woodchips is placed over the aeration pipes or grid so that the air distributed to the material is uniform. The static pile is then built up to 2.6–3.9 m using a front-end loader. A cover layer of screened or unscreened compost is placed over the sludge to be composted. Typically, oxygen is provided by pulling air through the pile with an exhaust fan. Air that has passed through the compost pile is vented to the atmosphere via a compost filter for odor control. (Nelson et al., 2009)

The temperatures in the inner portions of a pile are usually adequate to destroy a significant number of the pathogens and weed seeds present. The surface of piles, however, may not reach the desired temperatures for destruction of pathogens because piles are not turned as in the case of windrow composting technology

Aerated static pile composting systems (Figure.5) have been used successfully for MSW, yard trimmings, biosolids, and industrial composting. It requires less land than windrow composting. (EPA., 1995)

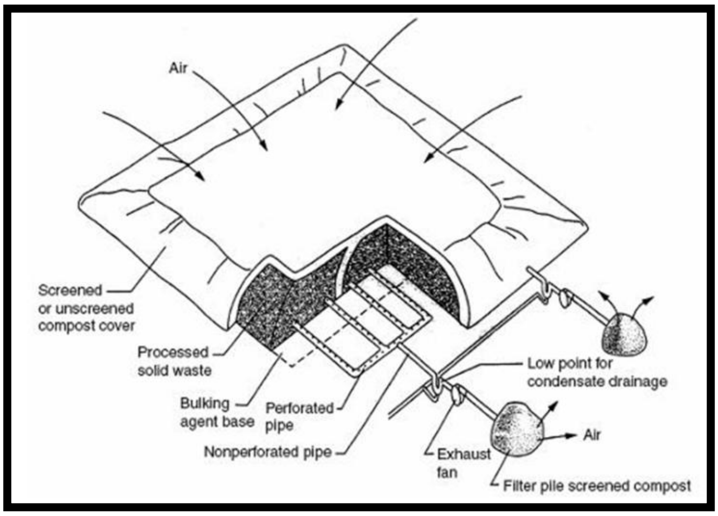

Figure 5.: Static aerated compost pile
(Tchobanoglous and Kreith., 2002)

In-Vessel Composting Systems

In vessel composting (Figure.6) systems are enclosed bioreactors which involve the controlled biodegradation of the organic matter. This means that temperature, oxygen and moisture levels are fully controlled at all times throughout the composting process while gases emitted during the bio-oxidation process are effectively treated (Bidlingmaier, 1996).. The systems require different condition to work with; some need minimal pre-processing, while others require extensive MSW pre-processing.

Although in-vessel technology is generally more costly than conventional composting systems its potential advantages include less labor, weatherproofing, reduced need of land, faster composting, effective process control thus providing a higher quality end product and more consistent, allowing its easier use and/or forwarding to the corresponding market (Misra et al., 2003)

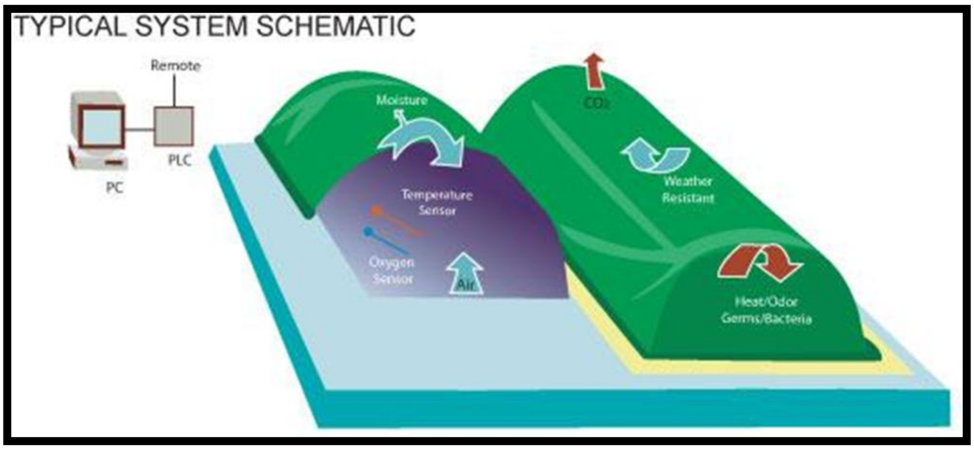

Figure 6.: Typical system schematic of in-vessel systems (Odour Stop.,2009)

In–vessel technology can be classified in vertical, horizontal and rotating drum reactors which can be single or multi-compartment units. Most in-vessel systems are continuous-feed systems, although some operate in a batch mode. Retention times depend on the feedstock material and range from one to four weeks. Nevertheless all in-vessel systems require further composting (curing) after the material has been discharged from the vessel.

Vertical in-vessel composting reactors

Vertical composting reactors are generally over 4 meters high, and can be installed in silos or other large structures. These systems rely on gravity to move material through the vessel. Organic material is typically fed into the reactor at the top through a distribution mechanism, and flows by gravity to an unloading mechanism at the bottom. Process control is usually a by pressure-induced aeration, where the airflow is opposite to the downward materials flow.

The height of these reactors makes process control difficult due to the high rates of airflow required per unit of distribution surface area. Neither temperature nor oxygen can be maintained at optimal levels throughout the reactors, leading to zones of non-optimal activity. These difficulties could be overcome by better air distribution and collection systems, such as changing the airflow direction from vertical to horizontal between alternating sets of inflow and exhaust pipes. (Richard., 1993)

A stable porous structure is important in vertical reactors which usually lack internal mixing. Tall vertical reactors have been successfully used in the sludge composting industry where uniform feedstocks and porous amendments can minimize these difficulties in process control, but are rarely used for heterogeneous materials like MSW. (Richard., 1993)

Horizontal in-vessel composting reactors

Horizontal reactors do not need the high temperature, oxygen, and moisture content that vertical reactors do by having a short airflow pathway throughout the whole process. They come in a wide range of configurations, including static and agitated, pressure and/or vacuum induced aeration. Agitated systems turn the material through the system continuously, while static systems require a loading and unloading mechanism. Materials handling equipment may also shred to a certain degree, exposing new surfaces for decomposition, but excessive shredding may also reduce porosity. Aeration systems are usually set in the floor of the reactor, and may use temperature and/or oxygen as control variables depending on the facility type. Systems with agitation and bed depths less than two to three meters appear effective in dealing with the heterogeneity of MSW. (Richard., 1993)

In-vessel Rotating drum reactors

Rotating drum reactors are sometimes called digesters and retain the material for only a few hours or days. While rotating drums can play an important role in MSW composting, they are normally followed by other biological processing, which may include in-vessel, static pile, and/or windrow systems.

The duration of the composting process varies with the technology employed, and the maturity and stability of the compost required. The assessment of compost maturity and stability is not easy, since there is not a single acceptable method that is commonly applied within the scientific committee. Therefore several methods have been established which are described in the next section. (Richard., 1993)

2.1.4. Compost stability/maturity determination

Compost stability is today recognized as maybe the most important characteristic. The main reason for that is because in specific situations, immature, poorly stabilized composts may be problematic. Continued active decomposition when these composts are added to soil or growth media may have negative impacts on plant growth due to reduced oxygen in the soil-root zone, reduced available nitrogen, or the presence of phototoxic compounds. Consequently, tests have been developed to evaluate the maturity of compost materials. It should be mentioned, however, that no clear agreement on the best approach exists. (Brinton., 2000)

1. **Carbon-based analysis** – compost maturity can be assessed by the carbon/nitrogen (C/N) ratio of the material, which falls from around 20 in raw organic waste to around 12 in a mature compost after some 12–14 weeks. This method suffers from a lack of sensitivity and the results vary depending on the C and N content of the starting material. Application to soils of immature composts with high residual microbial activity and high C/N ratios can result in uptake of the nitrogen from the soil by the compost, which will reduce, rather than enhance the soil fertility.

2. **Enzyme assays** – different enzymes change in concentration during the composting process. Further research is required to develop an accurate measure of stabilization using such assay techniques.

3. **Respiration measurements** – respiratory activity falls as composting proceeds. It has been proposed that compost may be considered stable when its oxygen uptake is less than 40 mg/kg dry matter per hour at 20°C.

4. **Phytotoxicity assays** – the presence of phytotoxins (organic materials toxic to some plants) can be assessed using cress seed emergence tests and assays for individual phytotoxins such as acetic, propionic, butyric and valeric acids and phenolic acids.

5. **Humification indicators** – measurement of humic substances, especially humic acid carbon to fulvic acid carbon ratio, may provide an effective measure of stabilization. Humic acid content increases as composting progresses.

6. **Molecular size determination** – molecular sizes rise as humic substances are formed. This test requires specialized equipment and expert operators. (Composting Council of Canada., 2010)

2.1.5. Composting process cost

Composting costs include costs that have to do with local criteria, facility operations and marketing of the finished product. The facility must be installed in a region according to each country's laws in a way that public health is not damaged at any means. There may be some more requirements something that depends on the whole compost facility design such as handling equipment such as shredders, screens, conveyers and turners. The cost of constructing and operating a windrow composting facility will vary from one location to another. The operating costs depend on the volume of material processed. The use of additional feed materials, such as paper and mixed municipal solid waste, which will require additional capital investment and materials processing labor. (Aarhus University., 2004)

The capital costs of windrow or aerated piles are considered to be lower in than in-vessel composting systems. However, the potential cost of the facilities could increase remarkably when cover and other mechanisms are required to control odors. In most of the cases though costs of windrow systems are the lowest compared to the other two techniques. Basically In-vessel system costs more than the other methods, mainly because it is more mechanized and more equipment maintenance is necessary, however the labor intensive trend's to be less. (EPA., 1994).

2.1.6.Environmental and health impacts

Composting is mainly used as high quality soil in agriculture. This practice prevents other chemical substances which have been used in the past and are dangerous, to be used as a fertilizer for soil improvement. The negative impacts of composting are dangerous gases emissions (Figure.7) such as: greenhouse gases (GHGs), volatile organic compounds (VOCs) and odors. In order for the composting process to be effective these gases have to be controlled. In soils and water systems the major concerns are due to deposition of salts and heavy metals.

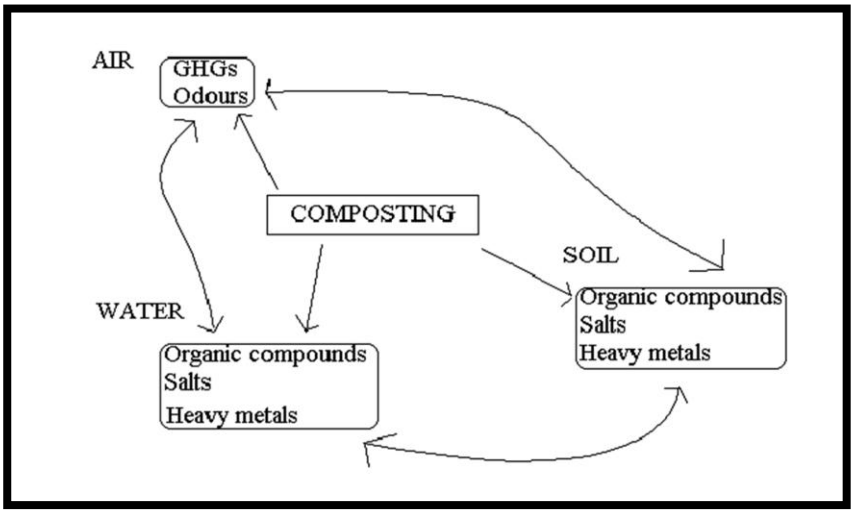

Figure 7.: Principal emissions from composting
(Dubois, González., 2004)

Compost air pollution

The basic air pollutants are VOCs, CO_2, CH_4, NH_3 and H_2S (Peigne & Girardin 2004). These pollutants have a very significant cost in human life quality and tent to destroy the atmosphere, causing severe environmental changes. The emissions of VOCs depend on the temperature, aeration and biological activity in the compost. The greenhouse gases CO_2 and CH_4 trap thermal energy that comes to the atmosphere, rising the global temperature of the Earth (Gardner et al. 1993,). Composting contribution to global warming due to GHGs emissions is relatively low in comparison to other treatment methods e.g. thermal treatment. In addition to the latter the carbon dioxide emitted to the atmosphere during the process is assumed to be short-cycle as only biogenic materials degrade. (Tsiliyannis., 1999).

Compost water pollution

The main pollutants of the water systems are caused by washout processes of soils treated with compost. Therefore, the contamination of water systems includes heavy metals, different organic compounds, e.g. phenols, PAHs, PCBs, etc., and salts, e.g. NO_3 NH_4 $^+$, etc. (He at al. 1992,; Peigne & Girardin 2004,).

Leachate production is also common. Leachate from water runoff and condensation at compost facilities occasionally contains levels of biological oxygen demand (BOD) and phenols that may exceed acceptable discharge limits, but pose few problems if absorbed into the ground or passed through a sand filter.(Balkwaste, 2010)

Compost soil pollution

Pollution of soils is mainly due to the addition of salts, heavy metals and different organic compounds. The soil changes and becomes toxic to the plants while heavy metals such as e.g. lead, zinc and copper, become part of the food chain and lead to toxic crops. If the bioavailability is high, these compounds can cause contamination in the whole food chain. Some of these substances are easier to mobilize by water or plants than others. This is a serious concern and sound practice requires controlling impacts through i) analysis of composts, ii) development and enforcement of land application standards and iii) research and development on pre-processing and process control mechanisms to limit or reduce contaminants. (United Nations Environment Programme. 2010)

2.2 Anaerobic Digestion (AD)

2.2.1.Introduction

Anaerobic digestion can be defined as the biological process during which the complex organic matter is decomposed by anaerobic microorganisms due to the absence of oxygen. Anaerobic microorganisms degrade the organic matter producing mainly CO_2,CH_4 water and stabilized organic matter (digestate). During the process CH_4 can be collected and used as an energy source. (Balkwaste, 2010)

Anaerobic digestion (AD) is typically employed in many wastewater treatment facilities for sludge degradation and stabilization, and it is the principal biological process occurring in landfills. Internationally, AD has been used for decades, primarily in rural areas, for the production of biogas for use as a cooking and lighting fuel. Nowadays, AD is used for the production of thermal energy that heats water (circulated with water pipes) to proper temperatures for the drying of organic material such as sludge and kitchen waste. Also many small scale (household) anaerobic digesters are operational in China and India for waste treatment and gas production. In the recent decades, Europe has developed large-scale centralized systems for municipal solid waste treatment with electricity generation as a co-product. (EPA., 2008)

2.2.2 The applications of the AD process in the Society

Anaerobic digestion of animal manure, manure is maybe the most common utilization of AD-technologies. There are several million low technology installations in Asia providing biogas for cooking and lighting and many more AD plants in Europe and North America. (EPA., 2008)

The AD process is applied to countries with large animal manure quantities per year and they have strict rules for the quality of the final stabilized product. There are two main concepts of manure based biogas production: the large scale, co-digestion plant and the small farm scale biogas plant. (Al Seadi., 2003)

Another AD application is the treatment of primary and secondary sludge resulted from the aerobic treatment of municipal wastewater which is common to many modern countries especially in the European Union. The system is widely utilized in thousands of installations in the industrialized world and connects with the municipal wastewater treatment systems. The anaerobic digestion process is used to stabilize and reduce the final amount of sludge. The digestate is used as a fertilizer on agricultural land, dried and incinerated or landfilled. Especially the biogas which is produced is mainly used as a wastewater treatment plant energy source (partly).Though in order for a wastewater treatment plant to be energy efficient more energy production is usually needed and if there is none energy from power plants is used.

Another important use of the AD process is in food industries and agro industries. A large number of AD plants are pre-treating organic loaded industrial waste waters from beverages, food, meat, pulp and paper, milk industries etc. before the final product is disposed. The biogas as in most of the AD processes is used to generate energy for the whole process. The environmental benefits and the high costs of alternative disposal will increase the application of this process in the future.

Finally, the treatment of source separated organic fraction of solid household waste is one of the areas with a large biomass potential all over the world nowadays. Many plants operate today with a total capacity of almost five million tones and more. The main effort of this application is the reduction of the organic waste flow to other treatment possibilities such as incineration or landfill which are considered as 2 of the treatment methods which have a great negative effect to the environment. Some AD treatment of organic household waste takes place at the manure based co-digestion plants. AD treatment of household waste though has negative impacts too that is why it needs to be improved and developed more in the future. (Christopoulos.,2005)

2.2.3. Digestion Process Description

The anaerobic digestion stabilization of the organic material is accomplished by a consortium of microorganisms working together. The four-steps of the digestion process are: hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Figure 8.):

1. Large protein macromolecules, fats and carbohydrate polymers (such as cellulose and starch) are broken down through hydrolysis to amino acids, long-chain fatty acids, and sugars.

2. In acidogenesis, the products from the previous process are been fermented to form three, four, and five-carbon volatile fatty acids, such as lactic, butyric, propionic, and valeric acid.

3. In acetogenesis, bacteria consume these fermentation products and generate acetic acid, carbon dioxide, and hydrogen. (NSWAI., 2010)

4. Finally, methanogenic organisms consume the acetate, hydrogen, and some of the carbon dioxide to produce methane. Three biochemical pathways are used by methanogens to produce methane gas. (EPA., 2008)

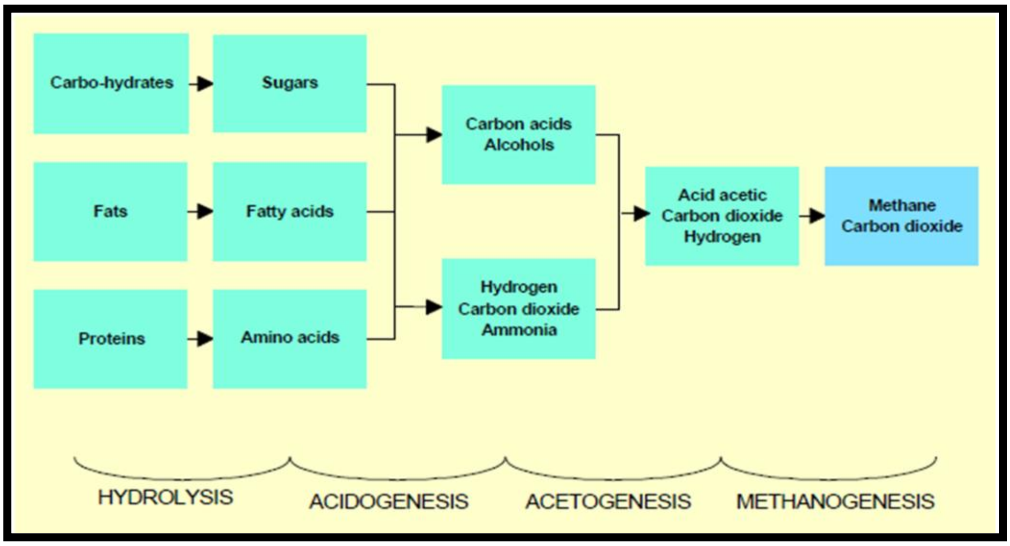

Figure 8.: Schematic diagram showing the main theoretical stages of the anaerobic digestion process. (University of Strathclyde., 2009).

Methanol is shown as the substrate for the methylotrophic pathway, although other methylated substrates can be converted. Sugars and sugar-containing polymers such as starch and cellulose yield one mole of acetate per mole of sugar degraded. Since acetotrophic methanogenesis is the primary pathway used, theoretical yield calculations are often made using this pathway alone. (EPA., 2008)

Acetogenesis produces a quantity of hydrogen. According to (EPA., 2008) for every four moles of hydrogen consumed by hydrogenotrophic methanogens a mole of carbon dioxide is converted to methane. Substrates other than sugar, such as fats and proteins, can yield larger amounts of hydrogen leading to higher typical methane content for these substrates. Furthermore, hydrogen and acetate can be biochemical substrates for a number of other products as well. Therefore, the overall biogas yield and methane content will differ because of the diversity of substrates, biological consortia and digester conditions. Typically, the methane content of biogas ranges from 40-70 percent (by volume). (EPA., 2008)

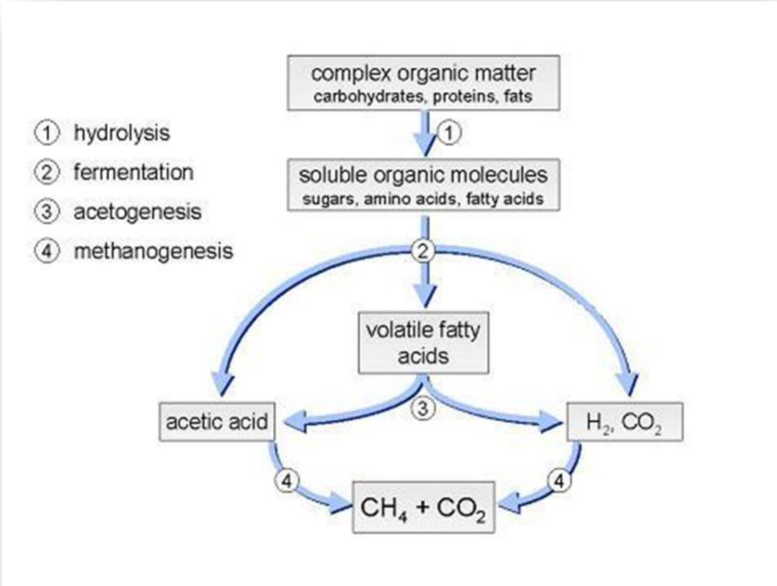

Figure 9.: Anaerobic digestion biochemical conversion pathways
(University of Iowa., 2009)

In order for Methanogenesis to occur, anaerobic conditions need to take place. The reactors used for the process has to be well sealed, something which will allow the biogas collection for converting it to energy and will eliminate methane emissions during the AD process. Except to methane and carbon dioxide production, other less harmful contaminants such as hydrogen sulfide and ammonia are produced, though they are produced in much smaller amounts (<1 percent by volume). The production of these trace gases in the biogas depends on the sulfur and nitrogen contents of the feedstock. However, these elements are also nutrients required by the bacteria, so they cannot be (EPA., 2008)

A very important parameter for the anaerobic digestion is the nutritional needs of the bacteria which need the proper food in order to degrade the waste substrates. These nutrients are carbon and nitrogen, but these two need to be provided in the proper amount (proper microbes diet). Otherwise, ammonia can build up to levels that can inhibit the microorganisms. The appropriate carbon/nitrogen (C/N) ratio depends on the digestibility of the carbon and nitrogen sources; therefore, the appropriate (C/N) ratio for organic MSW may be different from that for other feedstocks such as manure or wastewater sludge. (EPA., 2008)

If the proper conditions cannot be maintained, imbalances among the different types of microorganisms in the process will occur. One of the most common problems is the buildup of organic acids which kills the methanogenic organisms and gives even more acidity to the process environment. Produced acid can be controlled in a natural way by using inherent chemical buffers and by the methanogens themselves as they consume acids to produce methane. These controls cannot confront the difficulties if too much feed is added and organic acids are produced faster than they are consumed, if inhibitory compounds accumulate, or if the feed stream lacks natural pH buffers such as carbonate and ammonium. (EPA.,2008)

Solids concentration higher than about 40% TS can also result in process inhibition, likely due to the reduced contact area available to the AD microorganisms. The content of TS in the MSW typically ranges from (30-60) %, this is the reason why water needs to be added each time this problem occurs. Process water can be used, but this may also result in the buildup of inhibitory compounds. Thus, low-solids digesters require the addition of fresh water. In higher temperatures which occur to smaller reactors a given waste stream is needed to be processed. However, the micro-organisms themselves are adapted to relatively narrow temperature ranges. Mesophilic and thermophilic microbes are adapted to roughly 30-40°C and 50-60°C respectively. (EPA., 2008)

2.2.5. AD stages

Generally the overall AD process (Figure 10.) can be divided into four stages: Pretreatment, waste digestion, gas recovery and residue treatment. Most digestion systems require pretreatment of waste to obtain homogeneous feedstock. The preprocessing involves separation of non-digestible materials and shredding. The waste received by AD digester is usually source separated or mechanically sorted. The separation ensures removal of undesirable or recyclable materials such as glass, metals, stones etc. In source separation, recyclables are removed from the organic wastes at the source. If source separation cannot be achieved, mechanical separation could occur even though the final product hasn't got the same quality because it is not as clean as in source seperation.The waste is shredded before it is fed into the digester. Inside the digester, the feed is diluted to achieve desired solids content and remains in the digester for a designated retention time. (Verma.,2002)

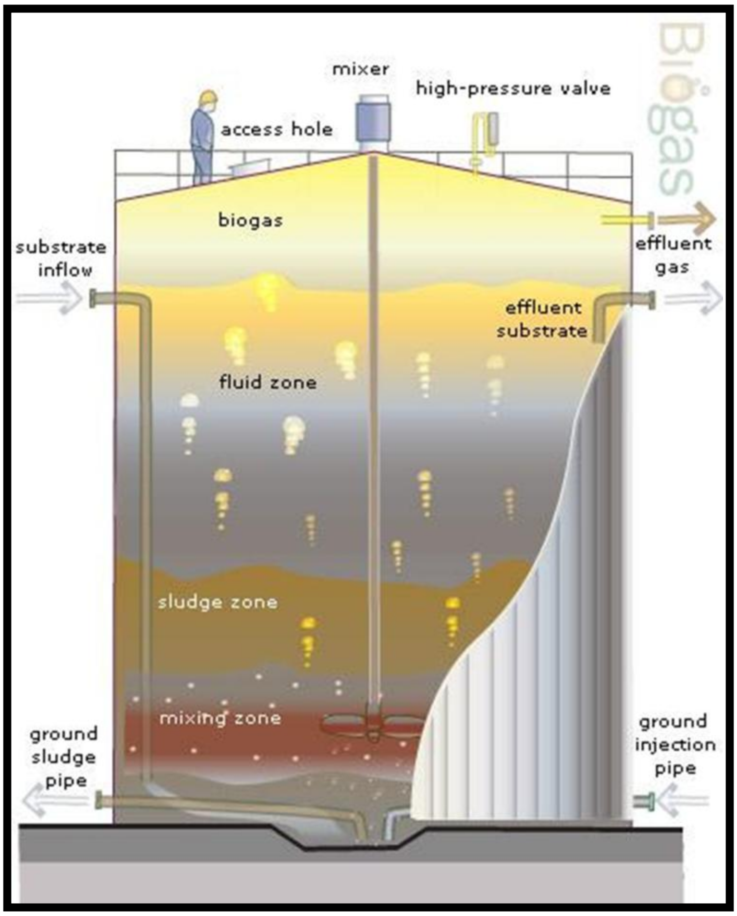

Figure 10.: AD basic process description
(Southern Energy Network., 2009)

For the dilution, a wide range of different kind of water sources may be used such as clean water, sewage sludge, or re-circulated liquid from the digester effluent. In order for the temperature in the digesting vessel to be maintained inside the vessel, a heat exchanger is usually required. The final product (biogas) obtained this way is scrubbed to obtain pipeline quality gas. In case of residue treatment, the effluent from the digester is dewatered, and the liquid recycled for use in the dilution of incoming feed. The biosolids finally are been composted. (EPA., 2008)

Digesters range in complexity from simple, empty cylindrical cans with no moving parts to fully automated and integrated industrial facilities. The simplest are easy to design and maintain, but require consistent monitoring and are less efficient. The most complex, on the other hand, are designed to detect subtle changes in conditions, such as may occur with small changes in feedstock feed rate, concentration, and quality. (Buekens.,2005)

Considerations such as the design and feedstock, give different technical choices, such as batch or continuous flow, vertical or horizontal orientation, and capacity, total solids content, number of stages, mixing and pre-treatment. Digester processes are constructed for meeting specific conditions, design, locations, types of waste, and the desired degree of autonomy and complexity. Vertical tanks are gravity driven, the material flowing generally downward, though the path can vary, depending on interior boundaries in the chamber. In other cases, material is pumped into the bottom of the tank and removed from the top, causing general upward flow accompanied by a lesser, downward, gravity driven flow. Horizontal tanks require greater space and are closer to plug flow than to perfect mixing. (Buekens.,2005)

2.2.6. Categories of Engineered AD Systems

(Vandevivere et al.,2002) categorizes the (MSW AD) systems into 3 main categories :

- One-stage Continuous Systems
  - Low-solids or 'Wet'
  - High-solids or 'Dry'
- Two-stage Continuous Systems
  - Dry-Wet
  - Wet-Wet
- Batch Systems
  - One Stage
  - Two Stage

(EPA., 2008)

Single-stage digesters: are considered to be simple in design, build, and operation and are generally less expensive. The organic loading rate (OLR) of single-stage digesters is limited by the ability of methanogenic organisms to tolerate the sudden decline in pH that results from rapid acid production during hydrolysis.

Two-stage digesters separate the initial hydrolysis and acid-producing fermentation from methanogenesis, which allows for higher loading rates but requires additional reactors and handling systems.

Another important design parameter is the total solids (TS) concentration in the reactor, expressed as a fraction of the wet mass of the prepared feedstock. The remainder of the wet mass is water by definition. The classification scheme for solids content is usually described as being either highsolids or low-solids.

High-solids systems are also called dry systems and low-solids systems may be referred to as wet systems. A prepared feedstock stream with less than 15% TS is considered wet and feedstocks with TS greater than 15-20 percent are considered dry (although there is no established standard for the cutoff point). Feedstock is typically diluted with process water to achieve the desirable solids content during the preparation stages.

Before AD became an accepted technology for treating MSW, single-stage wet digesters were used for treating agricultural and municipal wastewater. However, MSW slurry behaves differently than wastewater sludge. Because of the heterogeneous nature of MSW, the slurry tends to separate and form a scum layer which prevents the bacteria from degrading these organics.

The scum layer tends to evade the pump outlets and can clog pumps and pipes when it is removed from the reactors. To prevent this, pretreatment to remove inert solids and homogenize the waste is required. Solids can also short circuit to the effluent pipe before they have broken down completely, therefore design modifications were made to allow longer contact time between bacteria and dense, recalcitrant material.

Furthermore, MSW tends to contain a higher percentage of toxic and inhibitory compounds than wastewater. In diluted slurry, these compounds diffuse quickly and evenly throughout the reactor. In high enough concentrations, this can shock the microorganisms, whereas in a dry system the lower diffusion rate protects the microbes.

Because of these constraints, dry systems have become prevalent in Europe, making up 60 percent of the single-stage digester capacity installed to date. Dry digesters treat waste streams with (20-40) % total solids without adding dilution water. However, these systems may retain some process water or add some water either as liquid or in the form of steam used to heat the incoming feedstock. Furthermore, as organic matter breaks down, the internal MC of the digester will increase. Nonetheless, heavy duty pumps, conveyors, and augers are required for handling the waste, which adds to the systems' capital costs. Some of this additional cost is offset by the reduction in pretreatment equipment required. Most dry digesters operate as plug flow digesters, but due to the viscosity of the feed, the incoming waste does not mix with the contents of the digester. This prevents inoculation of the incoming waste which can lead to local overloading. Therefore, most of the digester designs include an inoculation loop in which the incoming OFMSW is mixed with some of the exiting dig estate paste prior to loading.

Multi-stage systems: are designed to take advantage of the fact that different portions of the overall biochemical process have different optimal conditions. By optimizing each stage separately, the overall rate can be increased. Typically, two-stage processes (Figure 11.) attempt to optimize the hydrolysis and fermentative acidification reactions in the first stage where the rate is limited by hydrolysis of complex carbohydrates. The second stage is optimized for methanogenesis where the rate in this stage is limited by microbial growth kinetics. Since methanogenic archaea prefer pH in the range of 7–8.5 while acidogenic bacteria prefer lower pH, the organic acids are diluted into the second stage at a controlled rate. Often a closed recirculation loop is provided to allow greater contact time for the unhydrolyzed organic matter.

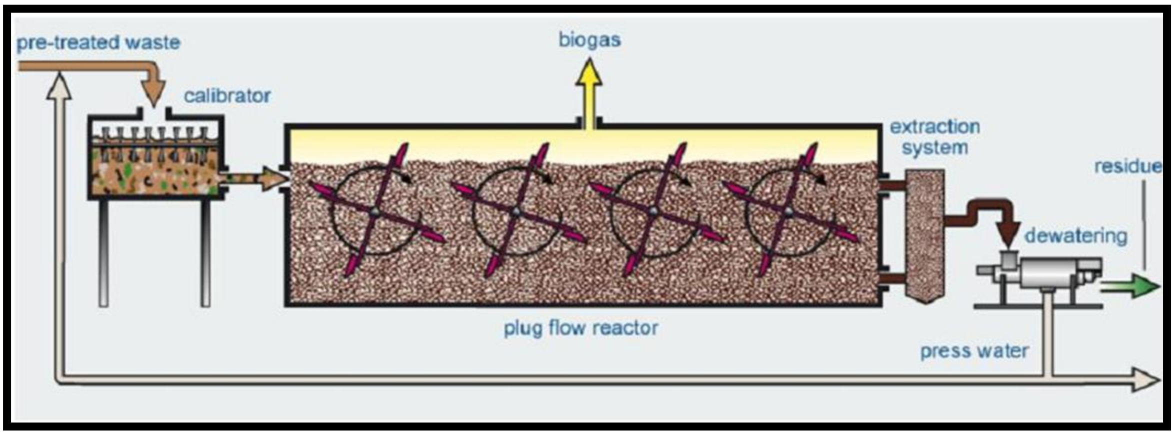

Figure 11.: Two stage process
(EPA., 2008)

Some multi-stage systems apply a microaerophilic process in an attempt to increase the oxidation of lignin and make more cellulose available for hydrolysis. Although adding oxygen to an anaerobic environment seems counterintuitive, sludge granules can shield the obligate anaerobes from oxygen poisoning and the practice has been shown to increase biogas yield in some situations. In two-stage systems, because methanogens are more sensitive to oxygen exposure than fermentative bacteria, the air may preferentially inhibit methanogens, which could help maintain a low pH in the hydrolysis stage. However, if the oxygen is not completely consumed and the biogas contains a mixture of oxygen and hydrogen and/or methane, hazardous conditions could be created.

Process flexibility is one of the advantages of multi-stage systems. However, this flexibility also increases cost and complexity by requiring additional reactors, material handling and process control systems. On the opposite end of the spectrum, batch or sequential batch systems aim to reduce complexity and material handling requirements. As opposed to continuous wet and dry systems, the feedstock does not need to be carefully metered into a batch reactor, thereby eliminating the need for complex material handling equipment. The primary disadvantage of batch digesters is uneven gas production and lack of stability in the microbial population. To surmount these issues, batch systems can also be combined with multi-stage configurations.

Batch Reactors: are loaded with feedstock, subjected to reaction, and then are discharged and loaded with a new batch. Substrate is sealed in the digester for the complete retention time. When unmixed, the content of the digester stratifies into layers of gas, scum, supernatant, an active layer, and stabilized solids at the bottom. Retention times range from 30-60 days, with typically an organic loading rate between 0.5 and 1.6 kg TVS/m^3 reactor volume/day. There are three types of batch systems (Figure 12.):

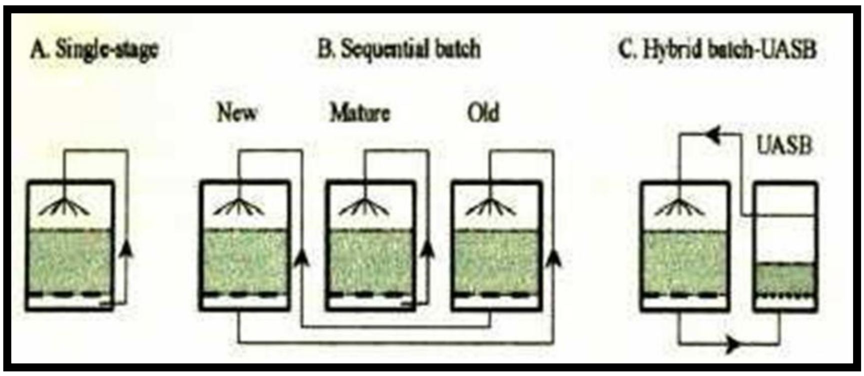

Figure 12.: The (3) types of batch reactors systems
(EPA., 2008)

- Single stage batch
- Sequential batch system
- Up flow Anaerobic Sludge Blanket reactor

The single-stage batch system involves re-circulating the leachate to the top of the same reactor. An example of such a system is the Biocel process in Lelystad, The Netherlands also has started to operate these systems in the 90's and treats 35,000 tons/y of source-sorted biowaste. The system which operates at mesophilic temperatures, consists of fourteen concrete reactors each of them has 480 m^3 capacity. The waste fed to these unstirred reactors is pre-mixed with inoculums. The leachates are collected in special chambers at the bottom of the reactors and recirculate on top of it. The waste which is kept inside the reactor needs approximately 40 days, until the whole process stops occurring. The Biocel plant produces on the average 70kg biogas/ton of source-sorted biowaste which is 40 % less than from a single stage low-solids digester treating similar wastes. (Verma.,2002)

The sequential batch process comprises two or more reactors. The leachate from the first reactor, containing a high level of organic acids, is re-circulated to the second reactor where methanogenesis occurs. The leachate of the methanogenic reactor, containing little or no acid, is combined with pH buffering agents and re-circulated to the first reactor. This guarantees inoculation between the two reactors. (Monnet.,2003)

The third type of batch process is the hybrid batch-UASB process, which is very similar to the multi-stage process with two reactors. The first reactor is simple batch reactor but the second methanogenic reactor is an up flow anaerobic sludge blanket (UASB) reactor. (Monnet.,2003)

2.2.7. Environmental Aspects of Anaerobic Digestion

Anaerobic digestion of organic waste and manure provides direct and indirect positive environmental benefits (Figure 13.):

- Increased recycling and resources saving
- Sanitation of wastes and manure and breaking the chain of pathogen transmission energy savings through production of a renewable energy source - the biogas utilization of digestate as fertilizer and the fiber fraction as soil improver leads to energy savings from the production of mineral fertilizers and to saving rare sources of organic matter (e.g. peat).
- Less greenhouse gas emission by displacement of fossil fuels by the CO_2 neutral biogas
- Less air pollution by emissions of methane and ammonia and less leakage of nutrient salts to ground and surface water.

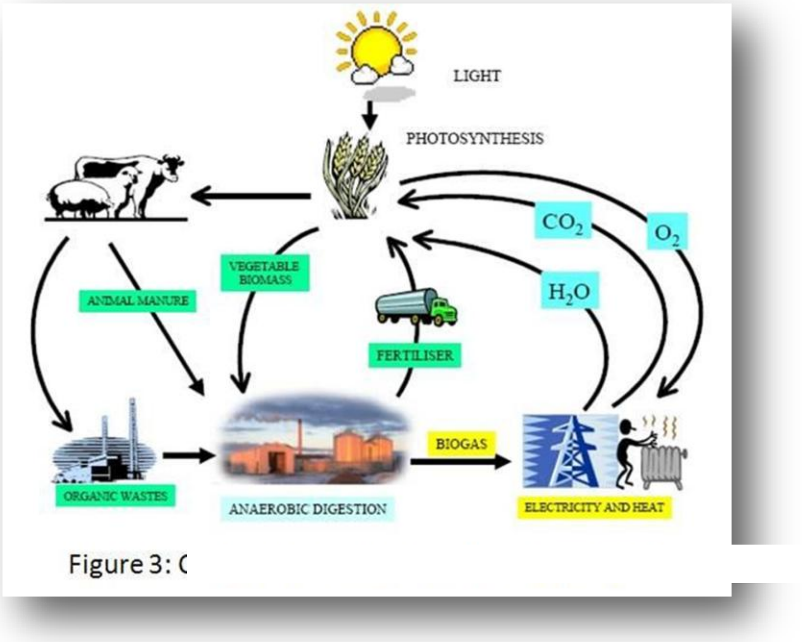

Figure 13.: AD life cycle
(University of Iowa.,2009)

Anaerobic digestion has a limited impact on the environment, which is related to the biogas production itself:

- ✓ Risk of odors, solved by burning odorous components in the exhaustion air or other odor treatment techniques

- ✓ Risk of explosion, solved by utilization of explosion-proof equipment.

2.2.8. The main aspects of Quality Management of AD Residues

<u>Chemical Pollution</u>

The chemical aspects of quality management of digestate are related to the presence of:

- Heavy metals and other inorganic contaminants
- Persistent organic contaminants
- Macro elements (NPK)

Heavy metals in digestate usually come from anthropogenic sources. Domestic wastewater effluent contains metals from metabolic wastes, corrosion of water pipes, and consumer products. Industrial effluents and waste sludge may substantially contribute to metal loading. Agricultural wastes can contain persistent organic contaminants such as (Pops) pesticide residues, antibiotics and other medicaments. Industrial organic waste, sewage sludge and household waste can contain aromatic, aliphatic and halogenated hydrocarbons, organ-chlorine pesticides, PCBs, PAHs etc. (Al Seadi.,2003)

Biological Pollution

According to where they come from, a fact which differs from one region to another and from time to time, organic wastes can contain various hazardous matters, which can result in new routes of pathogen and disease transmission to the whole feeding chain. Therefore, proper quality control of these types of biomass must be done in relation with the biological treatment. The main problems usually are related to:

- Pathogens
- Seeds and Propagules
- Transmissible Spongiform Encephalopathy (TSE

(Al Seadi.,2003)

Physical Pollution

The digestate should be clean, in different circumstances, it could cause an even more pollution, aesthetic damage to the environment, increase the AD plants cost operation and affect operational stability of the plant, wear and damage the plant components etc. The most frequent physical impurities are:

- Plastic and rubber
- Metal
- Glass and ceramic
- Sand and Stones
- Cellulosic materials (wood, paper etc)
- Other

(Al Seadi.,2003)

Technological Issues

When designing a digester system, planners must consider the specific needs of the site and available waste stream as well as the existing infrastructure. A summary of advantages and disadvantages of the different AD systems is provided in Table 1.

	Criteria	Advantages	Disadvantages
Single-stage, Wet Systems	Technical	Derived from well developed waste-water treatment technology Simplified material handling and mixing	Short-circuiting Sink and float phases Abrasion with sand Complicated pre-treatment
	Biological	Dilution of inhibitors with fresh water	Sensitive to shock as inhibitors spread immediately in reactor VS lost with removal of inert fraction in pre-treatment
	Economic and Environmental	Less expensive material handling equipment	High consumption of water and heat Larger tanks required
Single- stage, Dry Systems	Technical	No moving parts inside reactor Robust (inert material and plastics need not be removed) No short-circuiting	Not appropriate for wet (TS <5%) waste streams
	Biological	Less VS loss in pre-treatment Larger OLR (high biomass) Limited dispersion of transient peak concentrations of inhibitors	Low dilution of inhibitors with fresh water Less contact between microorganisms and substrate (without inoculation loop)
	Economic and Environmental	Cheaper pre-treatment and smaller reactors Very small water usage Smaller heat requirement	Robust and expensive waste handling equipment required
Two -stage Systems	Technical	Operational flexibility	Complex design and material handling
	Biological	Higher loading rate Can tolerate fluctuations in loading rate and feed composition	Can be difficult to achieve true separation of hydrolysis from methanogenesis
	Economic and Environmental	Higher throughput, smaller footprint	Larger capital investment
Batch Systems	Technical	Simplified material handling Reduced pre-sorting and treatment	Compaction prevents percolation and leachate recycling
	Biological	Separation of hydrolysis and methanogenesis Higher rate and extent of digestion than landfill bioreactors	Variable gas production in single-reactor systems
	Economic and Environmental	Low cost Appropriate for landfills	Less complete degradation of organics (leach bed systems)

(Table 1.): Summary of digester technology advantages and disadvantages

(EPA., 2008)

3. Large scale biodegradable waste treatment methods

3.1 Thermal treatment

Introduction

The biodegradable fraction of household waste besides the already recorded treatment methods of (composting and AD) can be treated as part of the mixed waste fraction in large scale facilities. These methods are also recorded for completeness of the report.

Thermal treatment is a term that describes all of those waste treatment technologies, used for the combustion or heating of all kind of waste. There are many different technologies which differ by the:

- The specific waste catered for.
- Amount of oxygen and
- Process temperature

Thermal methods for waste management aim at the reduction of the waste volume, the conversion of waste into harmless materials and the utilization of the energy that is hidden within waste as heat, steam, electrical energy or combustible material. They include all processes converting the waste content into gas, liquid and solid products with simultaneous or consequent release of thermal energy. (Moustakas.,2010)

The important technologies are:

- **Incineration**
- **Gasification**
- **Pyrolysis**
- **Plasma technology**

All of the above mentioned technologies produce large quantities of heat which can be recovered as process heat, steam or hot water for district heating or for the production of electricity. Although incineration is by far the most widely applied, the three most widely spread types of thermal waste treatment are:

- Pyrolysis: thermal degradation of organic material in the absence of oxygen
- Gasification: partial oxidation
- Incineration: full oxidative combustion.

3.2. Incineration

The incineration (combustion) of carbon-based materials in an oxygen-rich environment (greater than stoichiometric), typically at temperatures higher than 8500, produces a waste gas composed primarily of carbon dioxide (CO_2) and water (H_2O). Other air emissions are nitrogen oxides, sulphur dioxide, etc. The inorganic content of the waste is converted to ash. This is the most common and well-proven thermal process using a wide variety of fuels. During the full combustion there is oxygen in excess and, consequently, the stoichiometric coefficient of oxygen in the combustion reaction is higher than the value "1". In theory, if the coefficient is equal to "1", no carbon monoxide (CO) is produced and the average gas temperature is 1,200°C. The reactions that are then taking place are:

$C + O_2 \rightarrow CO_2 + 393.77J$ (1)

$C_xH_y + (x + y/4)\ O_2 \rightarrow xCO_2 + y/2\ H_2O$ (2)

In the case of lack of oxygen, the reactions are characterized as incomplete combustion ones, where the produced CO_2 reacts with C that has not been consumed yet and is converted to CO at higher temperatures.

$C + CO_2 + 172.58J \rightarrow 2CO$ (3)

The object of this thermal treatment method is the reduction of the volume of the treated waste with simultaneous utilization of the contained energy. The recovered energy could be used for:

- heating
- Steam production
- Electric energy production

The typical amount of net energy that can be produced per ton of domestic waste is about 0.7 MWh of electricity and 2 MWh of district heating. Thus, incinerating about 600 tonnes of waste per day, about 17 MW of electrical power and 1,200 MWh district heating could be produced each day. (Moustakas.,2010)

The method could be applied for the treatment of mixed solid waste as well as for the treatment of pre-selected waste. It can reduce the volume of the municipal solid waste by 90% and its weight by 75%. The incineration technology is viable for the thermal treatment of high quantities of solid waste (more than 100,000 tonnes per year) (Moustakas., 2010). A number of preconditions have to be satisfied so that the complete combustion of the treated solid waste takes place:

- adequate fuel material and oxidation means at the combustion heart
- achievable ignition temperature
- suitable mixture proportion
- continuous removal of the gases that are produced during combustion
- continuous removal of the combustion residues
- maintenance of suitable temperature within the furnace
- turbulent flow of gases
- adequate residence time of waste at the combustion area (Gidarakos, 2006).

3.2.1. Key features of a waste incinerator

A waste incinerator is not an isolated furnace, but a complete industrial installation containing most or all of the following features:

- Waste storage and handling
- Waste feeding
- Combustion in the furnace
- Heat recovery followed by steam and electricity production
- Air pollution control (flue gas treatment)
- Residue (ash and wastewater) handling

The combustion is not a one stage process. Before the waste ends up burning, drying which is one of the most important parameter takes place, heating up and release of volatile substances from the combustible material, Ignition and oxidation of volatile substances and finally combustion of solid carbon in the presence of oxygen finishes the process. (Bontoux.,1999)

3.2.2.. Mass-burn incineration

During combustion (Figure.14), the waste is burnt in the presence of a good supply of air, so that organic carbon is essentially completely oxidized to CO_2.In order for this process to be effective, the waste to be burnt is mixed well at the drying stage in order to dry properly. Along with water vapor and trace products of combustion, $CO_2$is discharged to the atmosphere. Energy is recovered in the form of steam, which is used to drive energy production turbines for electricity generation which is usually used for the incineration plant energy consumption. Some incinerators may also provide steam or hot water for process or community heating schemes as well as electricity in combined heat and power (CHP) applications. There are two main approaches to waste combustion – mass-burn incineration and process and burn incineration, in which a refuse derived fuel (RDF) is first prepared.

Mass-burn incineration (Figure 2.18) is currently the most widely deployed thermal treatment option, with almost 90% of incinerated waste being processed through such facilities. As the name implies, waste is combusted with little or no sorting or other pre-treatment. Waste arriving at a mass burn incinerator is tipped into a loading pit and from there after the drying process takes place usually at 75-80^{o}C (something that differs between different facilities), it is transferred by crane and grab system into the combustion chamber loading chute. The waste is then conveyed through the combustion chamber, usually on a moving grate system (of which there are many designs) or through the slow rotation of the combustion chamber itself (rotary kilns).

Whatever system is used, its purpose is to ensure thorough mixing, effective drying and even combustion of the waste, so that complete burn-out has occurred by the time the ash residue is discharged into a water-filled quenching tank at the end of the combustion chamber. Air is introduced from below and above the grate at flow rates adjusted to suit the rate of combustion.

The hot combustion gases pass through heat exchange sections of the combustion chamber, where steam is generated for energy recovery. The cooling combustion gases then pass through various stages of emission control. These include dry or wet scrubbers for removing acid gases (SO, HCl), injection of reducing agents such as ammonia or urea for controlling NOx emissions, activated carbon injection for dioxin control, and finally particulate removal by filtration or electrostatic precipitators, before the cleaned gases are discharged to the atmosphere.

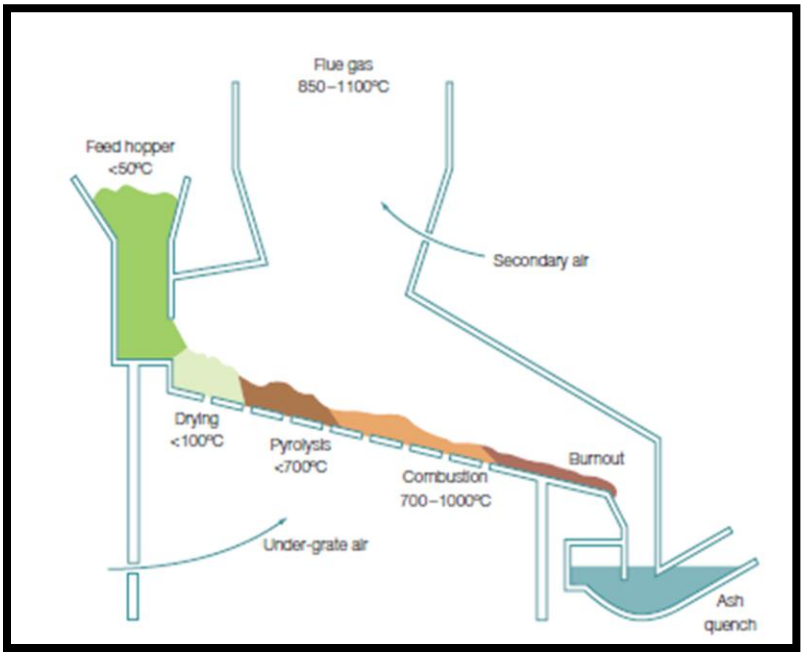

Figure 14.: Combustion processes for mass burn incineration. (Thermal methods of municipal waste treatment., 2009)

Mass burn incinerators are specifically designed to cope with all components in the MSW stream, which generally has a relatively low average gross calorific value (GCV), in the range 911 GJ/tone – about one third that of coal or plastics. However, individual types of waste vary markedly in their calorific values, from zero for wet putrescible wastes to over 30 GJ/ton for some plastics. Loading an even mixture of wastes into the combustion chamber is therefore very important to ensure that the overall heat input stays in 9-11 GJ/ton range for which the plant is designed to operate. Wastes are therefore mixed in the loading pit to even out obvious differences in composition before loading the combustion chamber.

Excess amounts of high CV waste like plastics can lead to high temperature corrosion of heat exchange surfaces due to the high concentrations of chloride found in MSW. The need to avoid high temperature corrosion by limiting combustion chamber temperatures is one of the main reasons why the thermal efficiency of waste incinerators is low, compared with coal-burning steam cycle power stations. On the other hand, if the GCV of incoming waste falls much below about 7 GJ/tone, then the waste may not burn properly (or even at all) under the conditions inside the combustion chamber, and efficiency of energy recovery would markedly decrease. A pilot fuel would therefore be required to sustain efficient combustion and to ensure that statutory temperature conditions are achieved to prevent the formation of harmful products of incomplete combustion. Such conditions may occur when high quantities of wet garden waste come through the waste stream, especially in spring and autumn.

Several material streams emerge from mass-burn incineration. The greatest of these is the ash residue discharged from the combustion chamber, which may represent between 20 – 30% of the mass of waste consumed. The ash may be processed by stabilizing and grading to form a useful secondary construction material that can be used for low-grade applications such as road or car-park base layers. Re-use of incinerator ash varies from country to country. Most of the existing incinerators in the UK and all plants in the Netherlands have an ash processing facility. Ash which cannot be re-used is landfilled. Metals can also be recovered from the bottom ash and sold to preprocessors. In plants with an ash-processing facility, nearly all of the ferrous metal can be recovered; otherwise up to 90% can be recovered. Non-ferrous metal can also be recovered in plants with ash processing.

Emissions standards for incinerators have recently been tightened through new emission limits imposed under the new incineration directive and extensive treatment of the flue gases is necessary to meet the new limits. Residue is produced from the air pollution control system, representing about 2-4% by weight of the incoming waste.

This material consists of salts and surplus alkali from acid gas neutralization; although some plants using wet scrubber systems currently discharge the scrubber residues to water as a salts solution. In addition, fly ash containing dioxin and heavy metals is produced. This material requires disposal at hazardous waste landfills, usually after some form of stabilization or immobilization in an inert medium such as cement has taken place. In Germany, salt caverns are used for storage of such hazardous materials.

To be cost-effective, mass burn incinerators require a guaranteed supply of waste within known limits of composition, available throughout the life of the plant. Because of the large scale of operation, such facilities may effectively 'lock-in' supplies of waste that could otherwise go for recycling. In addition, the requirement for bulk waste to be provided within a relatively narrow range of calorific value means that removal of particular waste streams for recycling could cause the remaining waste to fall outside the acceptable range.

For example, removal of paper and / or plastics for recycling would increase the relative proportion of putrescible waste in the residue and lower its calorific value. On the other hand, removal of putrescible wastes as well, for composting, would help to keep the calorific value of the residue in the acceptable range, but reduce the overall quantity of waste available for processing. Reduction in either the calorific value or quantity of waste consumed would reduce the amount of energy recovered, the sale of which provides one of the main income streams (along with the disposal fee) of the incinerator. Reductions in the sales value of energy would then feed through into higher disposal charges for the waste.

3.2.3. Types of incinerators

There are various types of incinerators (Figure.15): Moving grate, fixed grate, rotary-kiln, fluidized bed, etc (Fig.).

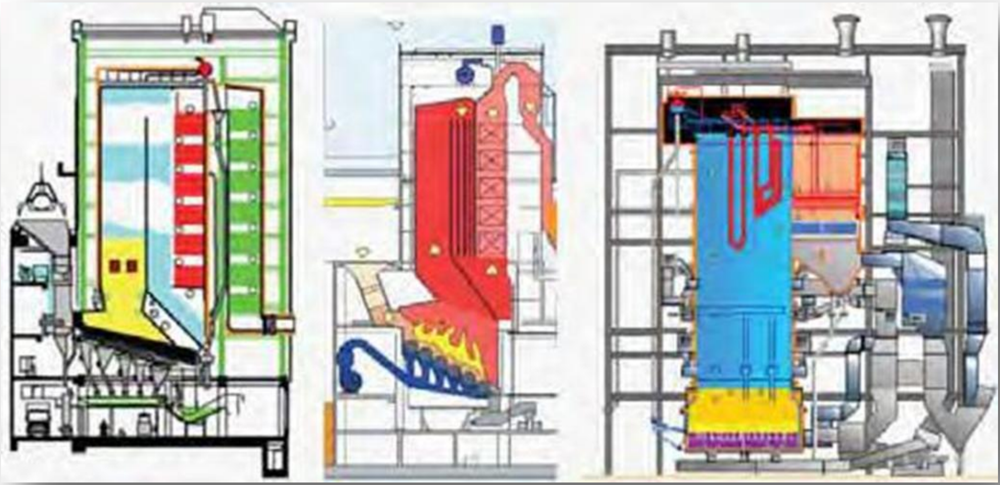

Figure 15. : Three types of incinerators: (a) fixed grate (left), (b) rotary kiln (middle), (c) fluidized bed (right)
(Solid Waste Management through the Application of Thermal Methods.,2010)

<u>Grate furnaces</u>

Grate furnace incinerators (Figure 16.) are by far the most common technology for the incineration of MSW. They perform the so-called mass burn which requires minimal pre-processing (such as sizing, shredding, etc.) and occurs in facilities of varying size (from 50 to more than 2000 tons of waste per day) usually fed continuously. The waste streams they receive are not always very consistent.

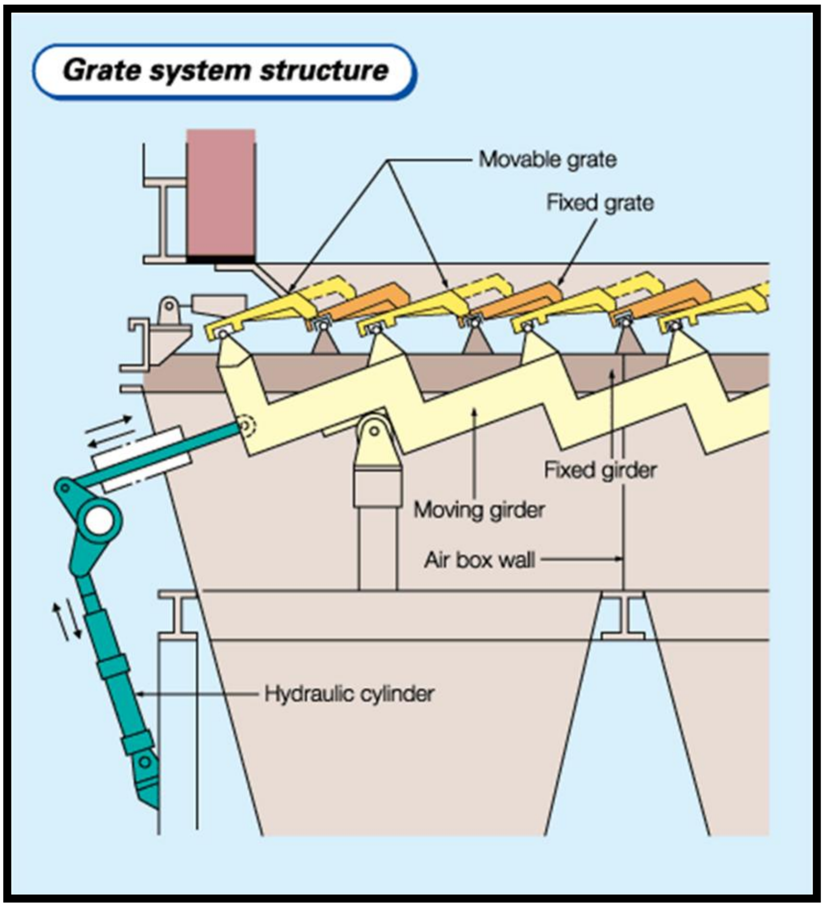

Figure 16.: Grate system structure

(Thermal methods of municipal waste treatment. .,2009)

As indicated by their name, grate furnace incinerators consist of a furnace in which the waste burns over a grate. The operation temperature of the furnace is between 750°C to 1000°C. Air for combustion is circulated evenly with the use fans or blowers under and over the grates. The grates have many different shapes and vary between them (either fixed or moving). The moving grates are designed to increase mixing and air flow in the mass of burning waste in order to achieve a more complete combustion. These variations produce significantly different types of gaseous emissions from the incinerators and the burning process products have varying quantity and quality. The large excess (in the order of 100%) of air needed for the satisfactory combustion of wastes in these furnaces has two main disadvantages: energy loss in the stack through the gases and need for a large boiler volume to handle the extra volume of gases. (Bontoux.,1999)

Rotary kiln furnaces

Rotary kiln waste incinerators (Figure 17.) are not so popular for the mass incineration of waste in Europe but are commonly used for the incineration of hazardous wastes. A rotary kiln rotates the waste in a cylindrical furnace in order to optimize mixing and provide a uniform burn. (Bontoux.,1999)

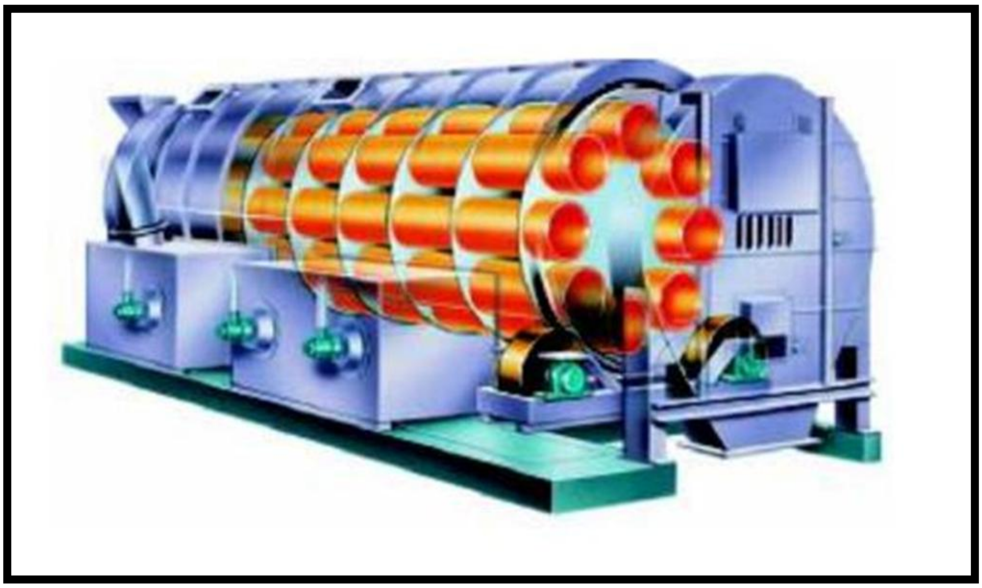

Figure 17.: Rotary kiln waste incinerator

(Thermal methods of municipal waste treatment,. 2009)

It usually operates in a gas temperature range of 800°C to 1000°C, possibly with a post-combustion chamber reaching temperatures of 850°C to 1200°C, and resists well to high temperatures. Gases, liquids, pastes, solids and even some items that are somewhat bulky can be handled in large quantities by rotary kilns. Even though they are mostly used in a continuous mode, they can also be operated in batch mode. Small ones can even be mobile and allow on-site treatments. (Bontoux.,1999)

Fluidized bed furnaces

This technology consists in a bed of sand kept in a fluid motion by hot air flowing upwards through it. This air is also used as primary combustion air. Fluidized beds for waste incineration typically operate in a maximum temperature range of 750°C to 1000°C, more typically from 750°C to 850°C and they have high combustion efficiency. (Bontoux.,1999)

Two main types of fluidized beds are used in Europe for the combustion of waste. In 'bubbling' beds, air velocity is maintained close to the maximum above which bed material is carried away. In 'circulating' beds, air velocity is high enough to entrain part of the bed material which is then captured and returned to the bed. This second design allows more fuel to be burned in the bed because more heat can be carried out of the bed by the recirculated material. In terms of efficiency of energy recovery, fluidized bed combustors have an advantage over grate furnaces because they can operate with only 30-40% excess air. (Bontoux.,1999)

Fluidized beds (Figure 18.) can handle liquids, solids, pastes and gases as long as they can be injected through nozzles and they neither melt nor slag. This bars the incineration of bulky items but has the advantage of maintaining a more uniform temperature in the furnace. This is why they are mostly used for refuse derived fuel (RDF) after significant pre-treatment. RDF is a material proceeding from waste specially prepared so that it can be used as a fuel.

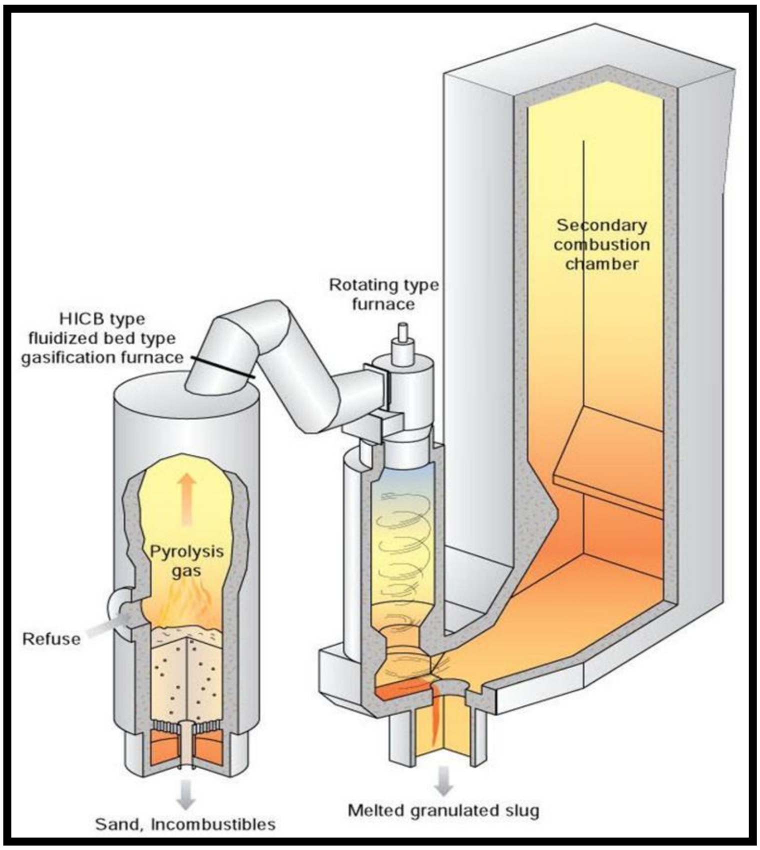

Figure 18.: HICB type fluidized bed type gasification furnace sketch drawing

(Thermal methods of municipal waste treatment., 2009)

It has been processed and brought to known specifications for combustion (e.g. calorific value, ash content, particle size) even though it does not fulfill the stringent criteria of fuels and remains legally a waste. RDF is mostly pre-treated municipal solid waste. In rare cases, fluidized beds are also used for the incineration of municipal solid waste. (Bontoux.,1999)

Other incinerators

Waste incineration can be used for specific kind of waste such as organics using smaller facilities which produce the same result (energy production). These kind of incinerators exist in the industrial sector and apply for the treatment of food waste, plastics, etc. As a result, they usually benefit from optimized operating conditions and treat much smaller tonnages of waste that the mass burn facilities.

A popular design is the "starved air" or "two-stage" incinerator where wastes are burned and partially paralyzed at the front end of a hearth with the resulting char being fully burned out at the back end. These kind of facilities are mainly used for hospital waste. (Bontoux.,1999)

Another kind of incinerator that looks like the rotary kiln and is often water cooled, is popular for burning hazardous wastes because they can burn sludge and liquids as well as solids. Catalytic combustors are special furnaces that rely on a catalyst to burn wastes with low organic concentration. (Bontoux.,1999)

3.2.4. Environmental Aspects of Incineration

Dioxins and furans

Maybe the most important problem concerning the incineration process is the dioxins and furans emitted (by waste incinerators and other combustion installations. This is because these chemicals have been proven to cause cancer to many mammals when they are absorbed in large quantities by the organisms. (Bontoux.,1999)

20 years ago when technology was not in the standards it is today, in the EU the main sources of dioxins and furans have been mainly steel furnaces and waste

incinerators. Nowadays the main sources of these emissions are still the waste incinerators with the difference that those emissions have been decreased in volume substantially. National differences between countries still remain mainly due to the existence of older installations. (Bontoux.,1999)

There are 3 types of dioxins and furans emitted in the atmosphere and they come from different sources. First, they can be present in the waste which escaped destruction due to insufficient incineration temperatures (<800°C) something that nowadays is extremely rare due to modern technology, Secondly, D/F may be formed at temperatures of 500 to 700°C in the gas phase if organic molecules and chlorine donors (such as NaCl, PVC, and HCl) are present in waste and Thirdly, they can be formed by a variety of solid phase mechanisms at less than 500°C on particles flowing through the incinerator (e.g. soot). Certain metals can catalyze the formation of D/F at these low temperatures (e.g. in particular Cu at 400°C). For example, fly ash in its cooling phase can provide an ideal ground for the formation of D/F. (Bontoux.,1999)

D/F monitoring is still today a very difficult process due to lack of standard and continuous methods. The only control of these emissions concentrations can be provided by controlling the combustion process in every stage in a way that can give less D/F in the atmosphere.

Heavy metals and salts

Heavy metals cannot be destroyed, even by combustion but they end up in the residues. Their volatility and leach ability are influenced by the conditions of incineration and some tend to escape through the smokestack. In order to avoid adverse effects on human health and the environment, two options are available.

The first and preferable option, is to remove them as far as possible from the waste before incineration. Because the scope for this first option is limited, the second option is therefore to decrease their bioavailability. When waste is thermally treated, the only possibility is to transform the metals into a solid, non leachable form. This means that (a) atmospheric emissions must be decreased as much as possible by capture from the flue gas and (b) that the metals in the solid phase (ashes, slag, etc.) are in a stable chemical state (which they should normally be). While it would be interesting to recover the metals in a metallic form for recycling, recent technological developments in this direction still fall short of a widespread solution to this problem. (Bontoux.,1999)

Heavy metals can be grouped into various classes, each with its specific issues. Metals such as cadmium (Cd), chromium (Cr), mercury (Hg) or lead (Pb) can be highly toxic. However, while Cd and Cr recovery can be interesting in metallurgy, uses for Hg and Pb are decreasing fast. For Hg, uses in thermometers and batteries are disappearing and will hopefully result in lower concentrations in waste in the long-term. For Pb, uses in pipes and gasoline are ending while use in accumulators is likely to decrease dramatically in the next few years thanks to emerging battery technologies.

Copper (Cu) and nickel (Ni) tend to be less toxic than Cd, Hg or Pb, but they are potent catalysts and contribute to a complex organic chemistry in the flue gases of combustion plants. In particular, they can contribute to the post-formation of dioxins in the flue gases. In terms of recovery, Cu is undesirable in steel making but, along with Ni, it is potentially worth being recovered for use in the non-ferrous metals industry.

Iron (Fe) and aluminum (Al) are less toxic and can also act as catalysts. However, they are essential elements for cement making and get captured in the clinker, contributing as raw material. In general, studies have shown that leaching of metals from cement mortar is very limited and does not appear to be a cause of concern during service life, but some controversy goes on.

This list is far from being exhaustive but illustrates the diversity of issues raised by the various metals present in wastes (and other materials such as coal, minerals, etc) and the possibilities to match specific wastes with certain combustion facilities for an optimum result (e.g. high Ni waste to blast furnaces, high Fe and Al to cement kilns,...). Metals are present in relatively high concentrations in ashes and slags, but this is insufficient to make them attractive for metal recovery because they are often in undesirable chemical forms and because they are mixed. (Bontoux.,1999)

CO_2 emissions and global warming

The incineration of waste generates CO_2. This gas is one of the most important greenhouse gases but the contribution of incineration to this phenomenon is something to be discussed in the future. One thing is for sure that these emissions should be controlled in the future in order not to cause the phenomena which only untreated waste can cause such as global warming

NOx, SOx, other emissions and emission control

It has been observed during all these years this technology operates in the field of waste treatment, that combustion conditions influence the type of emissions produced during this process. For example, high temperature combustion (>1400°C) increases the emission of thermal NOx from atmospheric nitrogen (Bontoux.,1999). The presence of chlorine or sulphur in the waste will cause the emission of HCl and SOx, but in cement plants equipped with a cyclone pre-heater kiln, they will be to a large extent neutralized by the basic raw materials. NOx, SOx and HCl contribute to the acidification of rain. (Bontoux.,1999)

In view of the environmental and health concerns raised by all the emissions from combustion installations, European and national environmental regulations have set emission limit standards. The immediate response of the operators of combustion installations was to apply end-of-pipe flue gas treatment systems to reduce specific emissions: dust, SO_2, etc. The array of technologies implemented is large: post-combustion chambers, dry and wet scrubbers, electrostatic precipitators, cyclones, activated carbon filters, bag filters, etc. These processes use energy to transfer the airborne pollution to a solid phase. The wet scrubbers transfer the contaminants to a water phase that needs further treatment. All flue gas treatments impact negatively on the energy balance of the systems that burn waste. (Bontoux.,1999)

3.2.5. Pyrolysis

Pyrolysis is a process which transforms waste into a medium calorific gas, liquid and a char fraction in the absence of oxygen, through the combination of thermo-cracking and condensation reactions. Typically, a pyrolysis process will produce char, oil, steam and syngas. A look at the SilvaGas process for RDF shows that it is really a pyrolysis process. The chemical equation for the Silva Gas (Battelle) process is:

$C_{20}H_{32}O_{10} + 11.6H_2O\ (l) + 5.7H_20\ (g) \rightarrow 7.7C + 1.5CO_2 + 5.7CO + 7.3H_2 + 12.3CH_4 + 18.6H_20 + 1349.3\ kJ$ (1)

There are more water molecules on the right hand side of the equation than on the left hand side. Hence, the steam input was not essential to the mass and energy balance and can be subtracted from both sides. The result defines the pyrolysis reaction as

$C_{20}H_{32}O_{10} \rightarrow 7.7C + 1.5CO_2 + 5.7CO + 7.3H_2 + 12.3CH_4 + 1.3H_2O + 1.4C_2H_4 + 1349.3kJ$ (2)

Pyrolytic processes are always endothermic (they absorb thermal energy). They are typically performed in packed beds, fluidized beds or rotary kilns. Where a fluidized bed is used, a fluidizing gas is necessary. Many experimental studies use nitrogen, but this would not be economic for a commercial plant. Practical choices for a commercial plant would either be steam or exhaust gases from the syngas combustor (which may be a gas turbine). Exhaust gases primarily contain steam and carbon dioxide, but also some oxygen. The use of exhaust gases would alter the process from being a pure pyrolytic process to a partial air gasification process. Examples of potential commercial processes of pyrolysis for MSW include Nexus and Thide Environmement technologies.

The Nexus process pyrolyses unsorted MSW waste in containers at 500°C. This should be equivalent to pyrolysis on a packed bed. Heating can take many hours. The gaseous output is 64%, including steam and oil vapor. The remainder is classified as solids. The solids contain carbon char, metals, glass and ash. The gaseous output is burnt in a boiler without treatment or cooling. Exhaust gases from the boiler are filtered and scrubbed to remove acid gases. Because of the high oil content, it is probably not practical to cool and clean the syngas for use in a gas turbine. In the Thide Environmement process, pyrolysis also occurs at 500°C. Pyrolysis takes place in an externally heated rotating drum. Heat and mass balance data for this process have not been published. Pyrolysis processes are already in commercial use by the metals industry for treating contaminated non-ferrous scrap. An example of this is the Alcan process for delacquering aluminum cans. Two options exist therefore for recovering contaminated metals – separate then pyrolyse, or pyrolyse then separate. The first is probably cheaper but the second may recover more metal.

Pyrolysis has been extensively researched with respect to the conversion of polymers back to petrochemical feedstocks. Polyethylene (PE) and polypropylene (PP) decompose rapidly at temperatures between 400 and 600°C to give a complex mixture of olefins and alkanes. At 400°C, the yield is mainly waxes. The gaseous fraction increases with temperature. Polystyrene (PS) initially decomposes at 290°C to yieldstyrene, diphenylbutene and triphenylbutene. After prolonged heating, or at higher temperatures, these components primarily form toluene, ethyl benzene, cumene and triphenylbenzene. PVC begins to degrade rapidly above 250°C, yielding hydrogen chloride gas. In addition to hydrogen chloride, small quantities of benzene and other hydrocarbons are released. At higher temperatures, the dehydrochlorinated polyene undergoes further cracking to yield a mixture of aliphatic and aromatic compounds and a carbonaceous char. PET degrades at about 300°C to yield a mixture of terephthalic acid monomer and vinyl ester oligomers. Longer reaction times and higher temperatures produce volatiles, including formic acid, acetaldehyde, carbon oxides, ethylene and water.

The pyrolysis of plastics with a high PVC content requires special techniques. One approach is to add lime. The lime reacts with the PVC to form calcium chloride. In fluidized bed, the calcium chloride forms undesirable agglomerates. Hydrogen chloride is released from PVC at temperatures well below pyrolysis temperatures where the bulk of the hydrocarbon gases are formed. It is therefore possible to cleave most of the chlorine from PVC at a temperature just above 300°C and collect it separately. As not all the chlorine will be removed in this way, further treatment is needed.

Ammonia can be added as an alternative to lime and this forms ammonium chloride. Ammonium chloride is less of a problem in a fluidized bed. Pyrolysis of mixed plastics produces oils that typically contain between 50 and 500 ppm organic-bound chlorine. Fortunately no chlorinated dibenzodioxins can be detected in the organochlorides.8 If the feed stock initially contains dioxins then fluidized bed pyrolysis at 700°C will reduce levels by about 75%. For the produced oils to be acceptable for use by a petrochemical plant, the levels of organ chlorides would need to be less than 10 ppm. This can be achieved by introducing sodium vapor to the syngas at 500°C.

3.2.6. Gasification

Gasification involves heating carbon rich waste in an atmosphere with slightly reduced oxygen concentration. The majority of carbon is converted to a gaseous form leaving an inert residue from break down of organic molecules.

Gasification is a thermo chemical process involving several steps. First, carbonaceous material is dried to evaporate moisture. Depending on the process, pyrolysis then takes place in a controlled, low air environment in a primary chamber, at around 45°C, converting the feedstock into gas, vaporized liquids and a solid char residue. Finally gasification occurs, in a secondary chamber at between 700-1000°C (dependent on gasification reactor type). Here the pyrolysis gases and liquids and solid char undergo partial oxidation into a gaseous fuel, comprising a variety of gases (dependent on reactor configuration and oxidant used). These gases include carbon monoxide, carbon dioxide, hydrogen, water, and methane (and much smaller concentrations of larger hydrocarbon molecules, such as ethane/ethane). Oils, ash tars and small char particles are also formed in the reaction, acting as contaminants. The heat source for the gasification process can be heated coke. Superheated steam can also be injected at this point to facilitate the conversion into gaseous fuel.

Process description varies for different specific technologies and is generally patented. The conversion process can utilize air, oxygen, steam or a combination of these gases. Gasification using air the most widely used technique produces a fuel gas suitable for boiler/engine use, but it is difficult to transport in pipelines. Nitrogen is evolved since air is used in the oxidation process.

Gasification (Figure.19) using oxygen (which is more expensive due to cost/hazard of oxygen generation) produces a medium heating value (MHV) gas which can either be used as a synthesis gas (e.g. for conversion to methanol) or for limited pipeline distribution. Steam (or pyrolytic) gasification produces a MHV gas.

A variety of gasification reactors (running at either atmospheric pressure or pressurized) have been developed, including fluidized (Figure 2.21) and fixed bed. There are numerous advantages/disadvantages to each configuration. Incomplete oxidation due to reactor design and feedstock anomalies can contaminate the product gas, and where air is used, this will result in higher than expected NOx emissions. Circulating fluidized bed gasifies are seen as more versatile since char can be recycled.

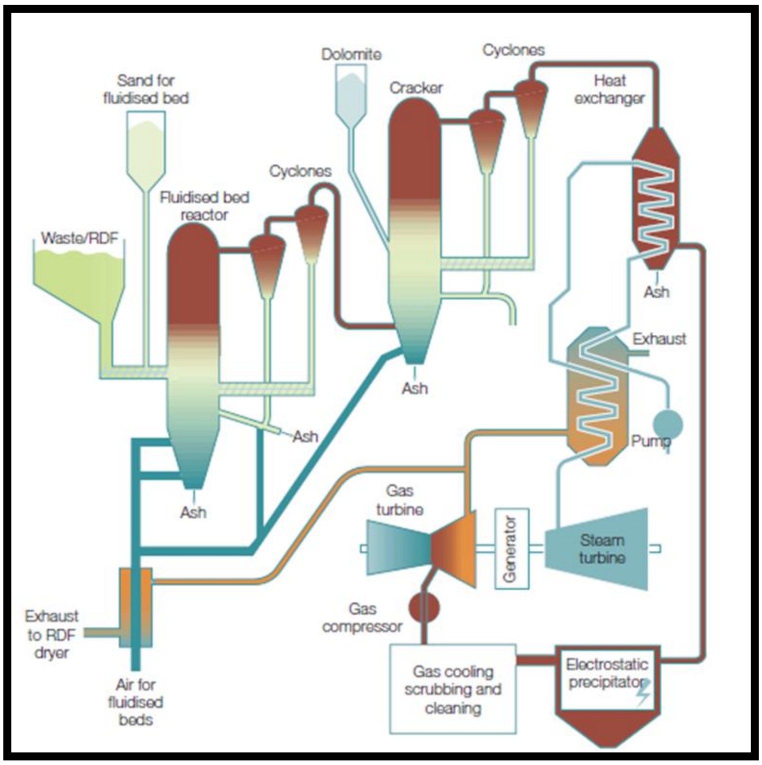

Figure 19.: TPS circulating fluidized bed gasification plant and gas cleaning plant

(Thermal methods of municipal waste treatment.,2009)

The fuel gas can be used in thermal combustion engines to produce energy; in a steam turbine or a boiler; or as a raw material resource to produce methanol, hydrogen or methyl acid. Syngas includes carbon dioxide, methane, carbon monoxide, hydrogen, nitrogen and ammonia. Small quantities of hydrochloric acid, hydrofluoric acid, hydrobaric acid, sulphur dioxide and nitrogen oxides and particulates are produced along with trace metals or heavy metals, notably cadmium and mercury.

Gasification is widely considered as an energy efficient technique for reducing the volume of solid waste and for recovering energy. Useable energy of some 500 to 600 kWh per ton of waste is generated by gasification.

Gasification technologies have been operated for over a century for coal producing town gas and have long been promoted as being a viable, cleaner alternative to incineration for residual municipal wastes. It is more widely used and more developed than pyrolysis for several reasons. First, a highly efficient process produces a single gaseous product. Second, gasification does not have the heat transfer problems associated with pyrolysis. However, plants are known to have closed down due to waste variability and material handling problems. Newer processes have been developed in order to overcome these problems through extensive pre-processing of the feedstock waste.

3.2.7. Plasma Technology

Plasma is a mixture of electrons, ions and neutral particles (atoms and molecules). This high temperature, ionized, conductive gas can be created by the interaction of a gas with an electric or magnetic field. Plasmas are a source of reactive species, and the high temperatures promote rapid chemical reactions.

Plasma processes utilize high temperatures, resulting from the conversion of electrical energy to heat, to produce plasma. They involve passing a large electric current though an inert gas stream under these conditions, hazardous contaminants, such as PCBs, dioxins, furans, pesticides, etc., are broken into their atomic constituents, by injection into the plasma. The process is used to treat organics, metals, PCBs (including small-scale equipment) and HCB. In many cases pre-treatment of wastes may be required.

An off-gas treatment system depending on the type of wastes treated is required, and the residue is a vitrified solid or ash. The destruction efficiencies for this technology are quite high,>99.99 %. Plasma is an established commercial technology, however the process can be very complex, expensive and operator intensive. Different kinds of plasma technologies are:

- Argon plasma arc
- Inductively coupled radio frequency plasma (ICRF)

- AC plasma
- CO2 plasma arc
- Microwave plasma
- Nitrogen plasma arc (Thermal methods of municipal waste treatment.,2009)

A typical plasma gasification plant is presented in (Figure 20.)

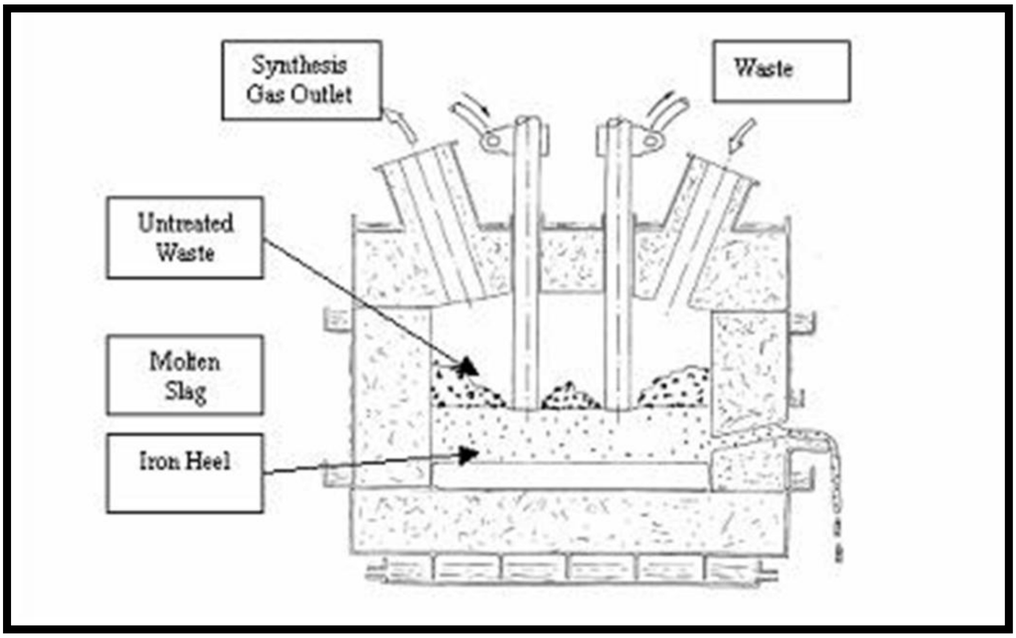

Figure 20.: A typical plasma gasification plant

In the process shown in the above Figure, waste is fed into a plasma arc furnace from the top and falls onto a layer of molten slag. A layer of untreated waste is maintained on top of the molten slag, where the gasification reactions occur. Air is introduced at that level. This layer of untreated waste, called a “cold top”, also acts as a filter to heavy metals and reduces entrainment of waste from the furnace. Product gases exit through a pipe located in the upper section of the furnace. Gasification reactions are complex reactions, consisting of a combination of gas-solid and gas phase reactions, as demonstrated in Tables 2 and 3. (Moustakas et. al.,2003)

Reaction	Heat of Reaction	Reaction Name
$C + O_2 \rightarrow CO_2$	+ 393,790 kJ/kmol	Combustion
$C + 2\ H_2 \rightarrow CH$	+ 74,900 kJ/kmol	Hydrogasification
$C + H_2O \rightarrow CO + H_2$	- 177,440 kJ/kmol	Steam-carbon
$C + CO_2 \rightarrow 2CO$	- 172,580 kJ/kmol	Boudouard

(Table 2.): Solid Gas Reactions

The treated waste should have a maximum particle size of 2.5 cm and a maximum moisture content of fifty per cent. In case, the particle size is larger, a machine for cumbering the treated waste is first used. If the moisture content is higher than fifty per cent, the waste to be treated is dried in order to reduce the moisture content.

Reaction	Heat of Reaction	Reaction Name
$CO + H_2O \rightarrow H_2 + CO_2$	+ 2,853 kJ/kmol	Water-gas shift
$CO + 3\ H_2 \rightarrow CH_4 + H_2O$	+ 250,340 kJ/kmol	Methanation

(Table 3.): Gas Phase Reactions

Waste is fed to the electric arc furnace from a feed hopper, through a rotary air lock. The temperature inside the furnace is about 1700°C. In the furnace, the inorganic portion of the waste melts and is tapped periodically in a slag mold, to produce solid slag blocks, or in water, to produce slag granules. The organic portion of waste is converted to synthesis gas (comprising mainly of carbon monoxide and hydrogen), by the addition of metered amounts of air and steam. This synthesis gas is then fed to the secondary combustion chamber (SCC), where it is combusted with air to form carbon dioxide and water. The temperature in the SCC is maintained at 1100°C using burners (usually propane burners). The combustion gases leaving the SCC are cooled down rapidly in the quench vessel by atomized water in order to avoid the synthesis of dioxins. The combustion gases are passed through a packed bed scrubber where the acid components of gas (such as HCl and SO_2) are neutralized by a caustic soda solution. Part of the water being re-circulated in the scrubber is sent to drain after filtration through a bag filter. The gases through the whole system are pulled through an induced draft blower, which maintains all equipment under a negative pressure. (Moustakas et. al.,2003)

Once gasification is completed, the inorganic portion of waste melts by contact with a pool of molten slag. The layer of molten slag is maintained in the liquid state by a current flowing through two graphite electrodes. Electrodes are positioned slightly above the surface of the bath, creating two electric arcs. The current also flows through the molten bath. Thus, both resistive and arc mode heating are used. Below the surface of the slag, a layer of molten iron (or iron heel) is maintained, improving the flow of the current through the slag. (Table 4.) shows the typical application range of the main different thermal technologies. (Moustakas et. al.,2003)

Technology	Typical application range (tones/day)
Moving grate	120-720
Fluidised bed	36-200
Rotary kiln	10-350
Modular (starved air)	1-75
Pyrolysis	10-100
Gasification	250-500

(Table 4.): Typical throughput ranges of thermal technologies

3.3. Landfilling

3.3.1. Introduction

Historically landfilling has been the major practice for municipal solid waste disposal. Nowadays municipalities are forced to find new methods for waste disposal due to critical environmental problems from old landfills and a lack of land availability caused by a fast growing population and a higher rate of waste production. Landfilling solid waste is a permanent disposal process by which we spread, compact, and cover (seal) waste with either ash from the Waste-to Energy facility or soil. It is still the most common form of disposal in the vast majority of cases and the main waste treatment method for countries such as Greece.

Landfill sites have to be well designed to prevent surface water and groundwater pollution, to minimize all impacts from operations and to facilitate site closure, and post-closure care. Landfill system design report must contain: the suggested site boundaries, buffer area, waste fill area and contours, surface water control works, on site roads and structures, final cover design, design of liner and leachate collection system and landfill gas control works, monitoring facilities for groundwater, leachate and surface water, site closure and post-closure care facilities (Botlin., 1995). When designing landfill site the following characteristics must be considered: the geology, hydrogeology, topography, drainage, and permafrost of the site and transport facilities. (Ontario's Ministry of the Environment.,2010)

3.3.2. Configurations of sanitary landfilling

Sanitary landfill is an engineered facility that needs detailed planning, careful design and efficient operation as to minimize potential environmental problems. There are three configurations of sanitary land filling, depending on the landfill site topography: the area, the ramp and the trench method.

In the **area method,** waste is spread on the ground and then compacted to 2 meters. Waste can be stacked into different layers with this method. To cover compacted waste soil or synthetic material is used. It is usually put after each operation day or more often. The **ramp method** is a kind of the area method. It is mainly used for sloping land. Wastes are spread and compacted on a slope. The **trench method** is the preferred method for disposing waste by land filling. It is the most economical and manageable plan. It's used for flat or gently sloping land. In the trench design trenches are dug twice as wide as the tractors. The waste is then placed in and then soil is added to cover it. When selecting the waste to put in the trench it is important to separate wet wastes from dry waste (Council of European Professional Information Societies – CEPIS., 2009).

3.3.3. Mechanical Biological treatment

Prior to landfilling sometimes Mechanical Biological Treatment (MBT) is undertaken. Such pre-treatment can lead to the material to be landfilled being relatively friendlier to the environment. There are four stages of this process: waste input and control, mechanical conditioning, biological treatment and emplacement of treated waste at a landfill. The mechanical stage is to sort out the non-biodegradables and any recyclables. Next, the residual waste is prepared for biological treatment by comminution, mixing and, if necessary, moistening. The biological stage effects extensive biological stabilization of the waste. The waste is exposed to atmospheric oxygen to induce aerobic decomposition, or by breaking it down in the absence of atmospheric oxygen in anaerobic fermentation process. The last step is deposition of the treated material.

There are several advantages of MBT: reduction of the waste volume, lengthening the useful life of the landfill, while reducing the rate of gas formation, hence reducing the danger of landfill fires and reducing the leachate load (The Deutsche Gesellscheft fur Technische Zusammenarbeit – GTZ.,2009).

3.3.4. Landfill system

Nowadays solid waste landfills are of a 'dry tomb' design. The waste is isolated from water that can generate leachate from solid waste, which may cause groundwater pollution. The main concept of dry tomb is to isolate waste from the environment in a compacted soil and plastic sheeting tomb. Plastic sheeting is a thin layer of HDPE (high –density polyethylene). It is combined with a compacted soil-clay layer to form composite liner. A typical double composite liner landfill containment system is shown in (Figure 21.). (Fred Lee., 2010)

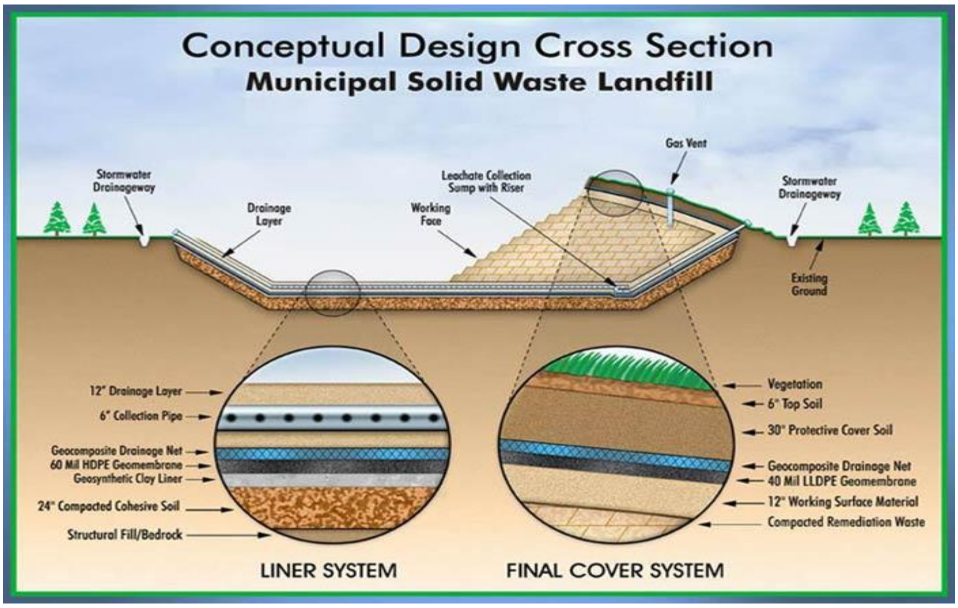

Figure 21.: Conceptual design cross section
(Epperson Waste Disposal., 2009)

3.3.5. Leachate collection and removal system

Leachate is a noxious, mineralized liquid capable of transporting bacterial pollutants produced when water moves through the refuse (Botlin., 1995). Leachate generated in the solid waste passes through a filter layer which underlines the waste. It is supposed to keep the solid waste from infiltrating to leachate collection system. This system usually consists of gravel. It allows leachate to flow across the top of the liner to the top of the HDPE liner. Then it flows across to the top of the liner to a collection pipe and is transported to a container, where the leachate can be pumped from the landfill. Lower composite liner represents a leak detection system for the upper liner. It is located between the two composite clay liners. It is suggested that geosynthetic liners should be used as an add-on to the regular clay liner. Geosynthetic liners are thin layers of bentonite clay which is encased in a woven material. Together with clay liners they minimize leachate formation through infiltration or ground water intrusion (Fred Lee., 2010).

3.3.6. Landfill cover

The landfill cover is designed with a sloping surface as to enhance surface runoff. Runoff is then collected by drainage channels constructed at the surrounding edge of the landfill. Materials (geomembranes) usually used for waste cover are: low-permeability plastic sheeting layer, HDPE, very flexible polyethylene (VFPE), or polyvinyl chloride (PVC) (Zanzinger, 1999, pp. 2-3). Above the layer there is a drainage layer. Above there is topsoil that serves as vegetation layer. It is designed to promote the growth of vegetation that will reduce the erosion of the landfill cover. Landfill covers should be monitored as to detect when moisture leachate through the cover occurs. Usually it is a visual inspection of the vegetative soil layer. All the cracks and depressions that are observed are then filled with soil (Fred Lee., 2004).

3.3.7. Landfill gas

The anaerobic decomposition of organic materials in a municipal solid waste landfill will generate a combination of gases, mainly methane and carbon dioxide. The migration of landfill gas underground can pose safety risk for landfill construction. In smaller landfills the gas venting layer provides the effective collection and dispersion of landfill gas. The gas is passively released through vents installed in a landfills cover system. The gas venting layer in larger landfills is eliminated and the gas is actively collected via horizontal trenches and collection wells then burned in flares or utilized in projects that make use of the energy value of the methane component of the landfill gas. Landfill gas collection system should be installed. It should be designed to have at least 95% probability of collection all landfill gas generated at the landfill (Fred Lee., 2010).

3.3.8. Bioreactor landfill

A bioreactor landfill is a sanitary landfill that uses microbiological processes to transform and stabilize the decomposable organic waste within 5 to 10 years of implementation, compared to 30 to 100 years for dry Subtitle D landfills (those that accept MSW and so-called nonhazardous industrial waste). To promote waste stabilization, moisture (usually leachate) is added. Stabilization means that waste does not produce landfill gas any more through the biochemical reactions of bacteria utilizing some of the organic components in wastes as a source of energy (Fred Lee., 2010).

There are three different types of bioreactor landfill configurations: **aerobic** leachate is re-circulated into the landfill and air is injected, **anaerobic**-leachate is also re-circulated into the landfill but biodegradation occurs in the absence of oxygen, **hybrid** - aerobic-anaerobic treatment to degrade organics in the upper part of the landfill and collect gas from lower part (EPA., 2004).

3.3.9. Environmental and health impacts

The major concern regarding land filling sites is the release of gases and leachates. The pollution of the aerial systems occurs through release of gas. The contamination of terrestrial and aquatic systems comes through leachates and landfill gases (El-Fadel et al., 1997, Tsiliyannis., 1999).

The quantity of gases released from landfills has decreased due to the installation of covers. These covers not only stop the gases from spreading into the atmosphere, but can also recover and use them in energy recovery systems, e.g. methane that can be burned and produce energy. The properties of the leachates vary greatly depending upon the different abiotic factors like temperature, moisture, aeration conditions and diversity of waste, etc. We will go through the main pollutants generated in leachates.

The impermeable layer of a landfill has a lifetime of 30 - 40 years. Even if state of the art technology is used the lifetime of a landfill cover is limited. The majority of the toxic emissions will be released during the lifetime of the covers. However, the toxic substances stored will not disappear and the toxic emissions won't stop completely. (Ludwig et al., 2003,).

Air pollution

Landfill gases cause global warming and unpleasant odors (El-Fadel et al., 1997; Tsiliyannis., 1999). The air contamination decreases significantly with the new technologies imposed by the new EU legislation, e.g. covers and recovery of gases. Still the functioning of these techniques is not completely successful and problems regarding the maintenance and proper working of the covers are of major interest nowadays.

Soil pollution

Pollution of soils is due to leachates and gases. Leachates are composed by a high variety of substances depending on the kind of waste land filled, the climatic characteristics (e.g. at some temperatures some processes are favored instead of others) and the aeration systems. All these factors determine the properties of the resulting leachate. The common compounds present in leachates are different organic compounds, heavy metals, salts and gases. Landfill gases can escape through weakness or breaks in the insulation walls of landfills. Then, they move through the different layers of the soil until they find their way to the surface. Depending on the properties of the soil, this can be quite far from the landfill site. During their travel, they contaminate the soil (and also the water currents – see water pollution section) with the particulate materials suspended on them. Once they get to the surface they can cause fires and explosions (El-Fadel et al., 1997; Tsiliyannis., 1999).

Water Pollution

Landfills can cause pollution from discharges, insufficient bottom sealing and washout processes. The main pollutants of the aquatic systems are organic materials, different kinds of hormones and landfill gases that have a high solubility in the water currents. If the landfill has an insufficient bottom sealing, as it happened with the old ones, there is groundwater pollution (Schwarzbauer et al., 2002).

4. Materials Sorting Processes

4.1 Introduction

Materials Sorting Processes are used to provide a waste stream which could be further used for the production of energy or composting, and a waste stream which cannot be processed further, a fact which troubles modern societies and brings them to the question of how to handle the leftovers.

Solid waste is the unwanted or useless solid materials generated from combined residential, industrial and commercial activities in a given area. It may be categorized according to its origin (domestic, industrial, commercial, construction or institutional); according to its contents (organic material, glass, metal, plastic paper etc); or according to hazard potential (toxic, non-toxin, flammable, radioactive, infectious etc). (Caribbean Youth Environment Network.,2010)

The main waste fraction that needs to be separated from the mixed solid waste stream is the organic (Biowaste, Kitchenwaste, Paper, etc). The modern methods used for this separation are source separation and mechanical biological treatment of mixed Municipal Solid Waste. The first method gives a material clean from waste substances unwanted in the future treatment processes (Composting, Anaerobic Digestion) for the production of compost and biogas, which is better (in quality) than the MBT process.

4.2. Waste composition

There are different types of materials collected from households. The most prominent materials are the following :(Wastesum.,2010)

Paper

Paper and paperboard are found in a wide variety of products in two categories of MSW—nondurable goods and containers and packaging. In the nondurables category, newspapers comprise a large portion of total MSW generation. Other important contributions in this category come from office papers, and commercial printing including advertising inserts in newspapers, reports, brochures, and the like. Waste paper can be classified as bulk or high grade. The highest grade includes manila folders, hard manila cards, and similar computer-related paper products. High-grade waste paper is used as a pulp substitute. Bulk grades consist of newspapers, corrugated cardboard, and mixed paper waste (unsorted office or commercial paper waste). Bulk grades are used to make paperboards, construction paper, and other products. The Institute of Scrap Recycling Industries has established standards and practices that apply to paper stock for repulping in the United States and Canada (ISRI., 2002). Over the past decade, legislative programs have been developed in several countries that require a certain percentage of recycled fiber content in newspaper, office paper, and other products. Such initiatives increase the demand and the quantity of paper available for recycling. (Pfeffer, 1992).

Glass

Glass in MSW is found primarily in glass containers, although a portion is found in durable goods. The glass containers are used for beer and soft drinks, wine and liquor, food products, toiletries, and a variety of other products.

Picture 3.: Glass waste

Aluminum

Aluminum waste consists of industrial scrap, which is a by-product of aluminum manufacturing processes ("new scrap"), and old scrap consisting of postconsumer items such as used aluminum beverage cans, window frames, building siding, and foil. Nearly 80% of the aluminum in MSW consists of used beverage containers.

There are numerous successful community recycling programs for mixed aluminum scrap and aluminum cans. These programs are generally self-sufficient and, in some municipal programs, provide an income to subsidize other recycling activities (Pfeffer., 1992).

Used aluminum cans are collected in curbside pickup programs, at buy-back locations, at recycling centers, and by scrap metal dealers. A number of states have established mandatory deposits for beverage containers and have installed redemption centers at supermarkets. Cans brought to collection centers are processed in a number of ways. (Wastesum.,2010)

Ferrous Materials

Ferrous metals are those containing iron and are used in the manufacture of consumer goods. Consumer ferrous waste includes appliances, automobiles, food, and nonfood containers. Among all the materials recycled worldwide, iron and steel represent the greatest tonnages. Iron has been manufactured for thousands of years and scrap was recycled even in the earliest times of production. (ISRI., 1993).

Plastics

Plastics (Fiqure.32) possess many properties that make them desirable, if not indispensable, for the modern consumer. These synthetic polymers are shatter-resistant, waterproof, lightweight, durable, and strong. As a result, plastics have replaced glass and a number of other materials in packaging, construction, and other uses.

Picture 4.: *Plastic waste*

The largest source of plastics in MSW is containers and packaging. Containers for soft drinks, milk, water, food, and other products are among the largest portion of plastics in containers and packaging. The remainder of plastic packaging is found in bags, sacks, wraps, closures, and other miscellaneous packaging products.

Yard Waste

The USEPA (1999) defines yard waste as grass, leaves, and tree and brush trimmings from residential, institutional, and commercial sources. There are limited data on the composition of yard wastes; however, it is estimated that the average composition is about 50% grass, 25% leaves, and 25% brush on a weight basis. These numbers will vary as a function of climate, region of the country, and season of the year.

Food Waste

Food wastes include uneaten food and food preparation waste from residences, commercial establishments (restaurants, etc.), institutional sources (school cafeterias, hospital cafeterias), and industrial sources (factory lunchrooms).

Picture 5.: *Food waste*

Textiles

The primary sources of textiles in MSW are clothing and household items such as sheets and towels. However, textiles are also found in such items as tires, furniture, and footwear.

Wood

The wood is found in durable goods such as furniture and cabinets for electronic goods, and in the containers and packaging category in shipping pallets and boxes.

4.3. Recycling

There are different kind of materials that could be recycled in also many different ways according to the type and pollution ability of them. These include many different types of paper such as (newspaper, cardboard, mixed paper, etc.), glass (e.g. amber, green, and/or flint), cans (e.g.aluminum, ferrous, bimetal), and plastics (e.g.PET, HDPE, PS, PVC, PP, LDPE, etc.), as well as ,many other items made of various materials biodegradable and not.

There are two types of systems used for the separate collection of the recyclable materials including biowaste. The first one needs the participation of the public body only throughout the separation process at source (household separation). The second one needs the public participation not only at source separation but also at transportation to the proper facilities for further treatment. These sites may be bottle and paper banks situated at the local supermarket, civic amenity sites for the disposal of many types of material or the local scrap merchant. In other words there are the 'bring' and the 'collect' systems. However, the participation of the public to such schemes can be low, something that depends on many factors such as (the Country, the education level, economy factors etc).

The 'collect' systems involve house-to-house curbside collection of designated recyclable materials, source separated by the householder and placed in separate containers. There are a number of varieties of the 'collect' system. For example, the recyclable materials are all placed in one container; therefore the mixture has to be sorted, either by processing equipment or by hand at the central materials recycling facility. Alternatively, the materials may be sorted at the curbside by the collector.

More sophisticated systems involve the separation of the recyclable materials into several containers or sections of a container by the householder for separate collection. The latter two systems require a more elaborate collection vehicle to collect the separated waste streams. The advantages of the 'collect' system include convenience for the householder and higher recovery rates of recyclable materials. However, the associated costs of "collects" systems is significantly higher than 'bring' recycling systems since separate collections or purpose-built vehicles, with separate enclosures, are required while additional costs are needed for the sorting and transport of the recyclable materials to the reprocessing facility.(Wastesum.,2010)

There are many different kinds of recycling programs which can be either voluntary or mandatory. Among the various alternative recycling program alternatives the following are the most commonly applied:

1. Return of bottle bill containers or use of reverse vending machines
2. Drop boxes, drop-off centers, or buyback centers for recyclables
3. Curbside (kerbside) collection of homeowner-separated materials
4. Materials recovery facilities (MRFs) for the separation of commingled recyclables (collected at curbside, collected in drop boxes, or collected in special blue bags) using various levels of mechanization for waste processing
5. Mechanically assisted hand separation of recyclables from raw waste (front-end processing or mixed-waste processing)
6. Fully automated separation of recyclables from raw

When considering all of the different types of materials that can be included in a recycling program, the various methods for segregation, and the various means and methods of collection, as well as the various types of processing and separation systems that are available, the combinations and permutations seem endless. Specific expertise is required to evaluate the optimum method for a given community, based upon its population, geographic location, and proximity to markets.

There are three main methods that can be used to recover recyclable materials from MSW:

1. Collection of source-separated recyclable materials by either the generator or the collector, with and without subsequent processing

2. Commingled recyclables collection with processing at centralized materials recovery facilities (MRFs)

3. Mixed MSW collection with processing for recovery of the recyclable materials from the waste stream

4.3.1. Source Separation

Source separation is defined as the removal of potentially recyclable materials from the waste stream, conducted by the individual consumer and commercial establishment. MSW Source separation constitutes an alternative and complementary stage of an effective solid waste management program. The parameters that influence the implementation and the successfulness of such a scheme are the following (HSWMA., 2008):

- the type and the quantity of the recycling materials to be separated
- the quality of the recovered materials –
- the existence of suitable markets
- the easiness of its operation and the cost of alternative solid waste management techniques established in the region under investigation
- level of public awareness and willingness to participate

The collection of the segregated MSW can take place by elaborating various methods including door to door collection, collection in appropriate bins, and collection in centers. The separated materials can be collected individually in single-compartment trucks, or they can be collected at the same time in a specially designed multi-compartment recycling vehicle. The segregated components are then transported to a consolidation site for further processing and subsequent shipment to markets.

Several schemes and pilot tests have demonstrated that householders are able to accurately sort their solid waste into different categories if appropriate and clear guidance is given. For example, a study carried out in Leeds, UK, showed that householders could sort their waste into six different categories with a 96.5% success rate (Forrest et al., 1990). A US study showed similar results (Beyea et al., 1992). Clear instructions to the householder are essential for the successfulness of a source separation scheme.

4.3.2. Commingled Recycling

Here the generator only needs to separate recyclable materials from non-recyclables. Newspapers are appropriate to be kept separate from the rest of the commingled recyclables so that contamination can be prevented.

The sorting of recyclables may be done at the source (i.e. within the household or office) for selective collection by the municipality or to be dropped off by the waste producer at recycling centers. (Tchobanoglous and Kreith., 2002)

4.3.3. Collection of Mixed MSW

In the third approach to recycling, there is no segregation of recyclables from other waste materials. Mixed wastes (including recyclables) are set out at curbside as would be done for landfilling or incineration. One collection vehicle is required for collection of the mixed waste—normally, the familiar packer truck. The mixed waste is then transported to a central processing facility, which employs a high degree of mechanization, including separation equipment such as shredders, trommels, magnets, and air classifiers to recover the recyclables. Mixed-waste processing of recyclables is also known as *front-end processing* or *refuse-derived fuel* (RDF) processing of MSW. (Tchobanoglous and Kreith, 2002)

4.4. Waste collection

Collection of commingled (unseparated) and separated (recyclables) solid waste is a critical part of any solid waste management program. Collection starts with the containers holding materials that a generator has designated as no longer useful (solid waste and recyclables) and ends with the transportation of solid wastes or recyclables to a location for processing (e.g., a materials recovery facility), transfer, or disposal. Solid waste collection involves both the provision of a service and the selection of appropriate technologies. The service aspect is set through an agreement between waste generators and the waste collector or collection agency, and the waste collection contractor or agency selects the technology to be used for collection.

When considering collection technology, the basic components are surface streets and roadways, over-the-road trucks, and sturdy containers (Picture 6.) for storage. There have not been dramatic changes to these components since motor-driven vehicles replaced horse-drawn carts (Merrill., 1998). Technology changes will make the truck and labor more efficient, but the basic collection truck will be used for many more years. (Tchobanoglous and Kreith., 2002)

Picture 6.: *Typical examples of containers and enclosures used for solid waste storage*
(Tchobanoglous and Kreith., 2002)

4.4.1.Types of Collection Systems

Solid waste collection systems may be classified from several points of view, such as the mode of operation, the equipment used, and the types of waste collected. Based on the mode of operation, collection systems are classified into two categories:

- Hauled- container system (HCS).
- Stationary container system (SCS).

It is the collection systems in which the containers used for the storage wastes are hauled to the processing, transfer or disposal site, emptied and returned to the original point or to some other location.

<u>Hauled container systems (HCS):</u>

There are two types of hauled container system: 1) tilt -frame container, 2) trash-trailer. Tilt-frame hauled container system has become widespread because of large volume that can be hauled but trash trailer is better for the collection of especially heavy rubbish. The application of both tilt -frame container and trash-trailer are similar, where, the collector is responsible for driving the vehicles, loading full containers, and unloading empty containers, and emptying the contents of the container at the disposal site. (Osp., 2010)

<u>Stationary container systems (SCS):</u>

It is the collection systems in which the containers used for the storage of wastes remain at the point of waste generation except when moved for collection. There are two types of stationary container systems: 1) self-loading collection vehicles equipped with compactors. 2) Manually loaded vehicles. Trips to the disposal site, transfer station or processing station are made after the content of the collection vehicle is full. (Osp., 2010)

4.5. Mechanical and Manual Operation

There are two types of sorting processes which are used today in waste recovery facilities. The Manual sorting, which produce higher quality product from the mixed waste stream, but is not so efficient because of the very slow processing rates. Manual sorting also yields more rejected materials and misses a considerable portion, for example HDPE and PET plastics waste stream due to the inability to target certain container shapes. If a plastic substance cannot be distinguished with the naked eye, it cannot be efficiently manually sorted and will therefore not be separated. Furthermore, it is extremely difficult for a sorter to distinguish between PVC and PET plastics, but these resins can be separated more quickly and accurately with the use of automated systems. (Dubanowitz., 2000) The same happens to kitchen waste which cannot be separated from the mixed waste stream as easy as in source separation.

When there are bulky items such as (appliances, furniture, etc.) and specified contaminants (e.g., hazardous waste) must be separated prior to mechanical separation process in order for the further treatment of these materials to be efficient. Manual separation is also applicable to the removal of contaminants from source-separated materials. (Contaminants refers to components other than the materials specified for separate collection.). (Tchobanoglous and Kreith., 2002)

manual separation (Picture 7.) of materials usually includes a sorting belt or maybe a table, which contains the mixed waste stream. Workers are stationed at the right and at the left of the belt for the materials separation. Hoppers or other receptacles for receiving removed items are positioned within easy reach of the sorters.

Picture 7.: *Manual Waste Sorting*
(Portal of Prague., 2010)

Automated sorting has lower labour costs when compared to manual sorting. Automation also assures the health of the employees that work to such kind of facilities. Furthermore, the processing machines can be adjusted by adding new sensors so that they can process different kind of materials, and can consequently take more from the waste stream as new markets develop. (Dubanowitz., 2000)

However nowadays it is not yet feasible to have automated waste separation facilities because the presence of man still remains the most important factor for the effective separation of the waste materials. Many mistakes can occur during the automated separation process while these machines often need external help for the separation of different kind of materials. (Dubanowitz., 2000)

4.6 Material recovery process

Mechanical separation is a process which is comprised by many parts such as size reduction, screening, air classification, magnetic separation, and non-ferrous (e.g., aluminium) separation. The most important parts of a MBT facility are shown at the table below (Table 5.).(Tchobanoglous and Kreith, 2002)

➢ Size Reduction	➢ Glass Separation
➢ Air Classification	➢ Non-Ferrous separation
➢ Screening	➢ Densification
➢ Magnetic Separation	➢ Conveyors

(Table 5.): *Mechanical unit processes used in waste processing facilities*

(Tchobanoglous and Kreith, 2002)

As soon as the waste stream arrives in the facilities, it is dropped on to the tipping floor. The unloading of the materials from the collection vehicles onto the tipping floor must be efficient to protect the materials to be seperated.The tipping floor must be constructed from proper materials. The Tipping floors use frontend loaders to move the mixed waste onto conveyors that rise up to the separation systems. This approach characterizes the tipping floor as one of the most inefficient components of the material recovery facility since dropping and moving the materials on the floor requires additional equipment and causes large amounts of glass breakage and facility contamination. Because of glass breakage on the tipping floor, many facilities can only recover mixed glass. (Dubanowitz., 2000)

The solution to such problems is to deposit materials directly onto a sunken belt conveyor. The continuous movement of the discharged material by the conveyors eliminates the need for the vehicles to pull forward when unloading, lowering the facility's area requirements. In addition, frontend loaders will not be needed to constantly manipulate and route the materials on the floor, which will reduce both congestion and the contamination from broken glass. (Dubanowitz., 2000)

4.6.1.Materials Size Reduction

Size and volume reduction, is of great importance for various methods of treatment and disposal of MSW as well as for cost-effective transportation of recovered materials. Specifically the food waste need to be reduced in volume in order to avoid further contamination of the environment and high transportation cost. There is a wide range of size reduction methods available and many types of size reduction equipment. Such equipment is employed to reduce the particle size or increase the density of material in order to meet market specifications or to reduce the cost of storage and transportation. Either incoming MSW or separated and outgoing components can undergo size reduction. Among the most common equipment used for size and volume reduction of MSW are the Densifiers, Compactors, Baler, Shredders, Hammermills (Vertical or Horizontal Shaft), Rotary Shear, Hammer Wear ,Dewatering Methods, etc.

4.6.2.Dewatering methods

Belt filter press

Belt filter press systems usually include a gravity drainage feeding section, and a mechanically applied pressure belt arrangement. In gravity drainage, through simple screens, a large portion of free water is removed. Pressure is then applied at an increasing rate on the waste contained between supporting porous belts (Demetrakakes., 1996). The dewatered waste cake is removed from the belt with scrapers. In certain arrangements, a small vacuum must be applied (4-6 kPa) to facilitate the removal of water accumulating at the surface of the belts (Snyman *et al*., 2000). A prefl occulation step is often considered to suit particular waste applications that are too liquid and to maximize dewatering efficiency right from the start of the process during gravity drainage. In roller press dewatering, the waste material is pressed between rotating roller drums, where the single belt material only serves for conveying. The bottom rollers are perforated to allow for drainage of the pressed liquid.

The basic system is composed of a top roller that presses down on to two bottom rollers and the drums rotate to facilitate the passage of the material on a conveyor belt (Orsat *et al*., 1999). This system is well adapted to combining with electroosmotic dewatering. larger groove angles can help to further reduce the moisture content during roller pressing of sugar cane bagasse.

Screw press dewatering

In a screw press, the material is introduced in a perforated chamber where an endless screw forces the material along the length of the chamber towards the discharge. The pressure force of the screw drives the water out through the perforations of the holding chamber. For this type of dewatering process, the waste feed must have a certain particle size large enough not to clog the perforations of the holding system and to flow through without excessive resistance.

Rotary and centrifugal presses
A centrifugal dewatering system consists of a basket or a solid bowl and a conveyor, both of which can rotate at high speed. As the bowl rotates, the heavier solids gravitate to the bowl wall where they accumulate. The separation of solids from the liquid depends on the G-force, time and permeability of the waste mass (Leung., 1998).

Membrane filter press
A membrane filter press comprises a stack of filter plates held tightly closed by pressure. The filter plates have a filtration drainage surface that supports a filter media, in most cases a polypropylene filter cloth held in place by a more rigid polypropylene structure. The mixed solid-liquid waste is pumped into the chambers under pressure. The filtered liquid passes through the filter cloth, against the drainage surface of the plates, and is directed towards discharge collectors. The pressure gradient between the cake and the filter material provides the driving force for the flow. Solids are retained on the filter cloth forming a filter cake. The filter plates are separated and the filter cake is discharged. At this stage a vacuum step may be introduced to further reduce the moisture content. In a study by (El-Shafey *et al*. 2004), brewer's spent grain was dewatered to a low moisture level of 20-30% when combining membrane filter pressing (500 kPa) with vacuum drying.

Electroosmotic dewatering
Electroosmosis is caused by the electrical double layer that exists at the interface of suspended particles subjected to an applied voltage across a solid-liquid mixture. In waste slurries, the solid particles possess a slight electric charge known as the zeta potential. Hence, when exposed to an electric field, the charged particles and the liquid fraction are entrained to move in opposite directions: one towards the anode, the other towards the cathode (Orsat *et al*., 1996). On the one hand, electrophoresis is the movement of charged particles

within solution under the influence of an electrical field, and on the other hand with electroosmosis, the electric field causes the movement of the electrically neutral solution (Weber and Stahl., 2002). The position of the electrodes is selected in order to promote the gravity flow of water (Chen and Mujumdar., 2002).

4.6.3.Drying Technology

Drying sludge is a common method for its volume reduction used worldwide today. This method can be used for drying of organics too although it is known today for its “achievements” at sludge treatment. The main goals of thermal drying of sludge are:

- to eliminate water from sludge and diminish volume of sludge (approx. 4-5 times) inmorder to make the transportation cost lower and the sludge storage easier;
- to increase sludge calorific value, so that sludge could be easily incinerated without any additional fuel;
- to make sludge hygienic (without pathogenic organisms);
- to stabilize sludge (what is achieved by drying sludge to the sludge dry mass above 90% of DS);
- to improve sludge structure before spreading by the agricultural equipment;
- to make sludge a fertilizer or a soil conditioner of high market value. (A.Flaga, 2003)

The above mentioned positives of sludge drying should be mentioned that they are exactly the same for organics too.

The system used most in different facilities, is the drum drying (Figure.22). Here is a brief schematic diagram of the Andritz drum drying system to explain this method.

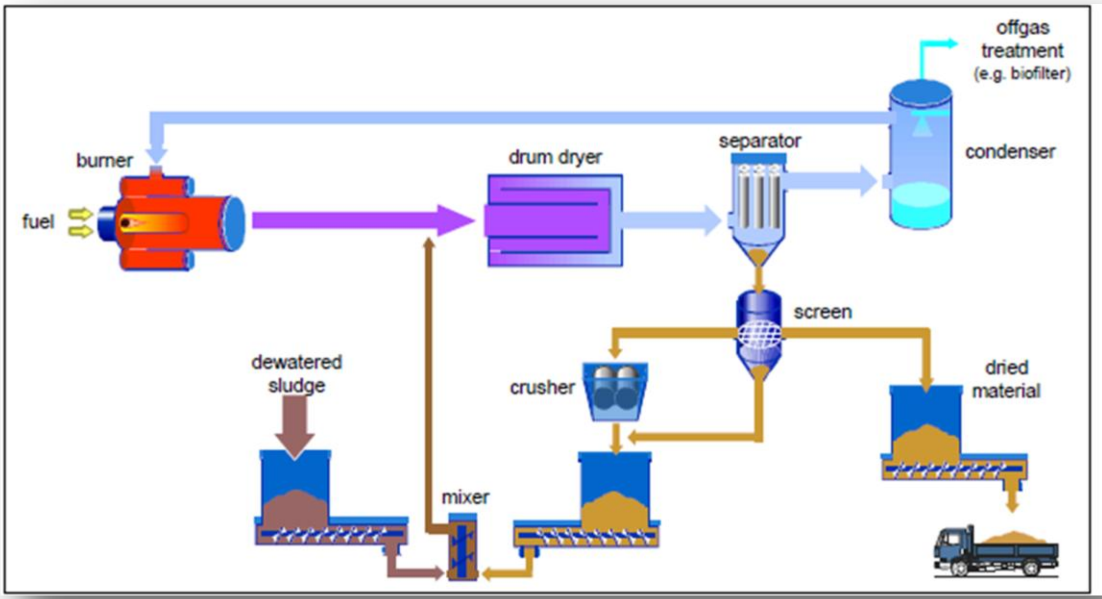

Figure 22.: Andritz drum drying system
(Krebs et.al.,2007)

A dosing device feeds dewatered sludge to a mixer, where it is mixed into sludge that has already been dried. This produces material which is no longer sticky and also creates a moist granule mixture.

This mixture is brought to the drum inlet and dried to 95% d.s. by hot air in the triple pass rotating drum. Since this material is retained in the drum for 20 minutes and reaches a temperature of 80 to 85°C, the granulate produced meets all the hygienic requirements. The finer product (<0.8 mm) from the drum is returned to the mixer for use as backfeed material.

The final product is suitable for long-term storage without the risk of unpleasant odors developing and can be put to a multitude of uses.

Drying is also used in food industry in large scale of course for organics volume reduction. (Krebs et.al.,2007)

4.6.4.Air Classification process

Air classification is a method of separating mixed waste into streams by way of differences in their respective aerodynamic characteristics. The aerodynamic characteristic of a particular material is primarily a function of the size, geometry, and density of the particles. (Tchobanoglous and Kreith, 2002) The process consists of the interaction of a moving stream of air, shredded waste material, and the gravitational force within a confined volume. In the interaction, the drag force and the gravitational force are exerted in different directions upon the particles. The result is that waste particles that have a large drag to- weight ratio are suspended in the air stream, whereas components that have a small ratio tend to settle out of the air stream. The suspended fraction conventionally is referred to as the “air-classified light fraction” and the settled fraction is termed “air classified heavy fraction”. The confined volume in which the separation takes place is called an “air classifier”. (Tchobanoglous and Kreith, 2002)

In air classification of shredded mixed MSW, the paper and plastic materials tend to be concentrated in the light fraction, and metals and glass are the principal components of the heavy fraction.

Since the density of a material (e.g., paper) is not the only characteristic of a particle that affects the air classification process, fine glass particles, by virtue of their high drag-to-weight ratio, may appear in the light fraction. On the other hand, flat, unshredded milk cartons or wet cardboard may appear in the heavy fraction. Moisture affects the separation of the various components, as a result of its influence on the density of a material. The influence can be particularly pronounced in the case of paper where its density can approach that of typically denser components, such as food waste that normally would report to the heavy fraction. Air classifiers may be one of a number of designs. All three require dust collection, blower, separator, and control facilities. (Wastesum.,2010)

The velocity of the air stream required to lift a particle in a vertical column (e.g., a vertical air classifier) must exceed a minimum value, termed the floating (or terminal) velocity. The floating velocity is a function of a number of parameters. The influence of the parameters on the floating velocity is illustrated in (Table 6.) for a variety of waste components. (Tchobanoglous and Kreith, 2002)

Waste Component	*Moisture Content (%)*	*Density (kg/m3)*	*Particle Geometry*	*Typical Floating Velocity (m/sec)*
Paper				
Newsprint	10	560	Flake	0.9
	40	840	Flake	1.1
Ledger	10	758	Flake	1.1
	40	1,138	Flake	1.3
Corrugated	10	192	Flake	3.5
	40	320	Flake	4.4
Linerboard	10	650	Flake	1.8
	40	974	Flake	2.2
PE coated	10	746	Flake	3.0
	30	1,066	Flake	3.5
Plastic				
PE film	3	912	Flake	4.4
PE rigid	3	912	Irregular	8.7 to 15.3
Wood				
Lumber	12	480	Splinter	2.2 to 8.5
	30	603	Splinter	2.5 to 9.9
Plywood	12	552	Flake	5.9
Textile	5	242	Flake	2.3
Rubber	3	1,773	Irregular	18.0
	3	1,773	Flake	8.4 to 12.0
Aluminium				
Sheet	0	2,688	Flake	2.4 to 4.6
	0	2,688	Irregular	9.8 to 44.2
Can	0	58	Cylinder	6.6
Ferrous				
Sheet	0	7,840	Flake	4.0 to 5.9
	0	7,840	Irregular	16.6 to 75.0
Can	0	144	Cylinder	9.9
Glass	0	2,400	Irregular	2.9 to 22.5

(Table 6.): *Typical floating velocities for various components of shredded mixed waste (Tchobanoglous and Kreith., 2002)*

Air classification serves respectively to:

1. Remove light organic matter entrained with the ferrous metal; and
2. Separate light aluminum from heavier aluminum castings, copper, bronze etc.

4.6.5. Magnetic Separation (Ferrous Materials)

The contents of waste material which can be magnetized are normally separated using overhead magnetic separators (Figure.23). Besides tin plate many combined materials with a large variety of particle shape are contained in the household waste material. This leads to a strongly polluted scrap product. Good possibilities exist to clean this material using magnetic separators with changing pole configuration or with rotating vertex. Although, due to cost reasons these technologies are used only rarely.

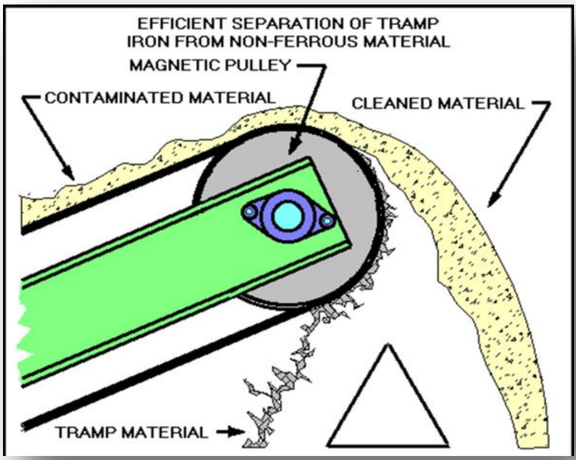

Figure.23.: Magnetic Separation

If the fine fraction of the waste material is to be biologically treated a widely separation of ferrous metals and combined materials is necessary. Due to the difficult material conditions a recovery of 95% is not possible in many cases. Furthermore, a lot of combined materials based on metals can be found such as batteries which cannot be separated using conventional magnetic fields. (Wastesum.,2010)

4.6.6. Eddy-current separation (Non Ferrous Materials)

The most important non-ferrous metal contained in household waste material is aluminum which can be found in the form of cans, different packaging or e.g. as bottle caps. The eddy current unit (Picture 8.) operation separates aluminum products from other nonmetals. An aluminum separator employs either a permanent magnetic or electromagnetic field to generate an electrical current (eddy), which causes aluminum cans (nonferrous) to be ejected and separated from other materials. Eddy current separation is based on the use of a magnetic rotor with alternating polarity, spinning rapidly inside a nonmetallic drum driven by a conveyor belt.

Picture 8.: *Eddy Current Separator*

4.6.7. Optical Sorting

Optical sorting is relatively new method that is applied for MSW sorting. During this process a light source, typically infrared (IR) or near-infrared (NIR), illuminates materials (mixed MSW) moving on a conveyor belt. Multiple sensors analyze the spectral signal of the reflected light, which is unique for different materials. The spectral (or multispectral or hyperspectral) signal is converted to a visual image using colors or patterns and the object's visual image is used to identify the physical location and makeup of the object. Typically, hundreds of separate jets of air from a nozzle then push different items into separate bins as shown in Figure 24.

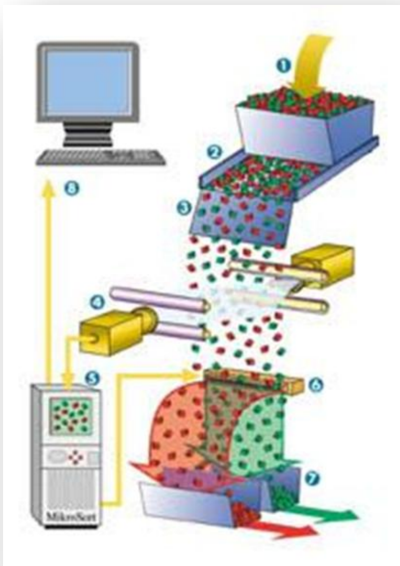

Figure 24.: Optical sorting

4.7. Mechanical Biological Treatment technology

4.7.1. Materials recovery facility

An MRF is a facility that separates the mixed waste fraction into waste streams ready to be recycled with one of the methods used for recycling such as (Composting, Anaerobic Digestion, etc). There are two types of these facilities 1) The clean MRF and 2) The dirty MRF.

Clean MRF

There are many types of clean MRFS (Figure 25.) but the basic principle is that the recyclable (mixed) materials (e.g. paper, glass, etc) are separated into waste streams, shredded and packaged into boxes, ready for the final process which shall be recycling. (Wastesum.,2010)

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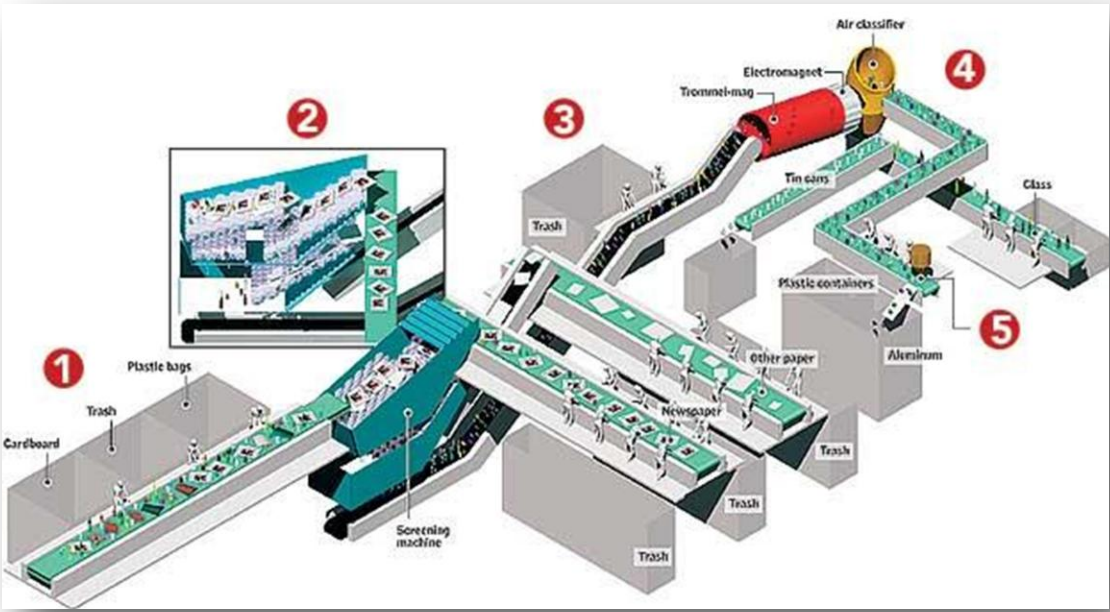


Figure 25.: Diagram of MRF process
(Wastesum.,2010)

The whole main process conducted in these types of facilities is separated in the following steps:

1: As incoming mixed recyclable materials is transferred along a conveyer belt, workers pull out manually, large items such as cardboard and plastic bags and deposit them into bins. At this stage, also, unusable materials are thrown away.

2: The recyclables are led to a double-deck screening machine which separates newspapers, mixed paper and containers into separate streams. Material bounces over rows of square wheels spinning 1,000 times per minute. Blasts of air dislodge cans and bottles from newspapers. Gaps between rollers allow smaller items to fall onto conveyer belts.

3: Workers again remove any trash and discard it, manually.

4: Next is the trommel-mag, a large, rotating tube with small holes in the sides and an electromagnet at one end. Small items such as bottle caps fall through holes. Then, the electromagnet separates tin cans. The remaining recyclable materials pass through the air classifier, where a powerful fan blows lightweight aluminum and plastic onto one conveyer, and heavier glass material onto another. Workers sort glass and plastics.

5: An electromagnetic device diverts aluminum cans into a storage bin. (Wastesum.,2010)

Dirty MRF

A dirty MRF accepts the mixed waste stream (not recycled) and separates the materials which have the potential to be recycled into different waste streams and then they are packaged exactly like in the (clean MRF). The facility is a combination of manual and automatic processes which gives only a small percent of non recyclable materials that need to be landfilled. (Wastesum.,2010)

4.7.2. Mechanical biological treatment

An MBT process is the combination of a materials recovery facility and a form of biological treatment such as composting or anaerobic digestion. These plants can process household, industrial and commercial mixed waste.

This kind of waste treatment, involves conveyors, industrial magnets, eddy current separators, trommels, shredders and other systems, or hand sorting. In some cases, the MRF is integrated into a wet MRF in order for the recyclable materials are washed to be sent for recycling.MBT can alternatively process the waste to produce a high calorific fuel byproduct called refuse derived fuel (RDF). RDF can be used in cement kilns or power plants and is generally made up from plastics and paper. (Wastesum.,2010)

Biological processing compartment

The second stage of the MBT process is the Biological Compartment which can include:

- Composting compartment
- Anaerobic digestion compartment
- Biodrying compartment

The first two processes are described at the beginning of this report. In the last process (Biodrying) the waste material undergoes a period of rapid heating through the action of aerobic microbes. During this partial composting stage the heat generated by the microbes result in rapid drying of the waste. These systems are often configured to produce a refuse-derived fuel where a dry, light material is advantageous for later transport combustion. (Wastesum.,2010)

In some of the systems, both Anaerobic digestion and Composting compartments exist and the combination of both gives the best results as for the treatment process.

Products of the MBT facility:

The products of the Mechanical Biological Treatment technology are:

- Recyclable materials such as metals, paper, plastics, glass etc.
- Unusable materials (inert materials) prepared for their safe final disposal to sanitary landfill
- Biogas (in the case of the anaerobic digestion)
- Organic stabilized end product
- High calorific fraction (refuse derived fuel – RDF)

4.7.3. Environmental Impacts from MBT Plants

Carbon Dioxide and Methane

The CO_2 emissions from these types of plants come from biogenic materials. The quantity of this greenhouse gas depends on the stages of the whole process. Another parameter is how pure the final product has become after the mechanical sorting process. Finally several factors that have to do with the waste treatment process affect CO_2 concentration in the environment.

Ammonia NH_3

Ammonia is produced in many stages of these waste treatment plants. The concentration is analogical to the waste type and the contamination of it from many different chemical substances (materials that could not be separated during the process).

An additional problem is represented by the partial oxidation of NH_3 to N_2O, which is linked to the damaging of filters. This is also a potent greenhouse gas, so the minimization of this secondary emission is also of relevance. Another secondary emission is that of nitrosamines, the formation of which has been observed in biofilters. (Greenpeace, 2003)

Organic Materials (TOC)

A summary of the concentrations of some pollutants was given by (Fricke et al., 1997) These data were obtained and combined with data from 5 other cases. For all the investigated elements/compounds, the highest discharges were established within the first 14 days (the maximum values of the individual substances are in brackets):

- *Aldehyde:* maximum value > *100 mg/m3* (Acetone: 140 mg/m^3; 2-butanone: 55 mg/m^3)
- *Terpenes:* maximum values > *50 mg/m^3* (Limonene: 56 mg/m^3; π-Pinene: 14 mg/m3; ß-Pinene: 6.4 mg/m3)
- *Aromatics:* maximum values > *30 mg/m^3* (m-, p-xylene: 38 mg/m^3; ethyl benzene: 13 mg/m^3; toluene: 11.5 mg/m^3; o-xylene: 10 mg/m^3; styrene: 5.9 mg/m^3; benzene: 0.3 mg/m^3
- *Acetates:* maximum values > *30 mg/m^3* (ethyl acetate: 32 mg/m^3)
- *Alkanes:* maximum values: > 10 *mg/m^3* (nonane: 12 mg/m^3; decane: 43 mg/m3)
- *CFCs:* maximum values: > *1 mg/m3* (R11: 3.1 mg/m3; R12: 1.7 mg/m3)
- *Alphatic chlorinated hydrocarbons:* maximum values: > *1 mg/m3* (tetrachlorethene: 2.7 mg/m3; trichlorethene: 1.38 mg/m3), evidence of di- and trichloromethane, 1,1,1-trichloroethane, 1,1-dichlorethene. (Greenpeace, 2003)

The above figures represent maximum values in the *crude gas*. There still appear to be gaps in knowledge concerning the emissions of Total Organic Carbon and the emissions values for individual materials.

Methane (CH4)

It is not yet certain whether the non methane content (NMVOC) will need to be recorded within a VOC limit. In the event of such regulations, compliance could be achieved relatively easily using optimized washer/biofilter systems. A calculation of the methane (which from the human toxicological point of view is irrelevant as a trace element), would also lie within the logic of TA Luft (effect orientation). Methane is a potent greenhouse gas. Life cycle assessment calculations show that the methane concentrations of from 1,000 to >50,000 mg/m3, which are possible with open-air composting, or housed-in systems which are insufficiently supplied with oxygen (or with waterlogging in the biofilters), would have a formative influence on the results and exclude the equivalence of the measures.

CFCs

Indicator substances here are, as expected, the frequently used old CFCs, R11 and R12. Life cycle assessment calculations have indicated that emissions on this scale have a noticeable influence on the total result for the greenhouse effect and potential ozone depletion effect categories. Within the framework of equivalence considerations and sustainability aims, a reduction of these emissions should therefore be called for. On the part of the biological waste air purification processes, an effective reduction of emissions is not adopted. Care therefore needs to be taken with MBT to ensure that waste containing CFCs is as far as possible excluded or filtered out early, but at all events that it does not enter the biological stages. (Greenpeace., 2003)

4.8.Household treatment of Biodegradable waste separated at source

Another existing method of handling a specific fraction of waste (garden waste, kitchen waste and specific type of paper) generated at households is composting at source (Picture 9.). There are many types of composters today. The only thing someone must do is separate the specific waste stream at source and put it inside the composter (which is usually installed in a yard) for the compost process to take place. Kitchen composters can be installed too for the treatment of kitchen waste.

Picture 9.: *Household composter*

The process usually takes from 6-12 months. This depends on temperature, the materials to be composted, etc. The final product (compost) can be used as a fertilizer for agricultural purposes.

Finally mainly in Asia a household treatment method has been used for quite sometime. It is the household (AD) treatment method. This method is mainly used in agricultural territories. The producer can produce biogas for electricity and fertilizer (as a by-product of the anaerobic digestion process). The method though hasn't been widely used because of the complexity of the AD process and the lack of AD household systems without problem generation, such as insufficient biogas production, odours, etc.

5. Existing practices on the management and treatment of biodegradable waste

5.1. Introduction

A World Wide Web research was conducted in order for the most prominent methods of treating and managing biodegradable waste at source to be identified. The research showed that for the household treatment of biodegradable waste mainly two methods are used worldwide today. These are (Home composting and Home anaerobic digestion). The Composting method is widely used today in most of the developed countries in the world in addition to the household anaerobic digestion which is not used as much as composting. Household anaerobic digesters though are a coming force in the field of household waste treatment techniques but research has to be done first in order for this technology to become efficient and available for a wider use by the public.

In the waste management sector, most of the source separating schemes for biodegradable waste applied mainly in the EU refer to source separation with the use of (bags, bins etc.) and further treatment at household level (such as composting) or at large scale waste treatment facilities. There are countries such as Sweden that use different source separation techniques such as 'vacuum systems' for the transportation of waste to the treatment facilities.

The large scale driers for the drying of waste are mainly used today in sludge processing (sludge drying) and for drying (pellets,grass,woodchips,etc). The drying systems are also used in incinerators as part of their processes in order to prepare the final input waste for incineration. The reason for this is that the incoming waste has to be dried out first to become flammable (in order for the excess moisture of the waste material to be removed).

In this section, some of the most successful management-treatment schemes and practices which are currently operating at a national level and among countries of the European Union (EU) are presented. These schemes are drawn from several EU Member States, and consist of different technologies, including mechanical treatment, composting, anaerobic digestion and thermal treatment techniques. Starting with a brief analysis on the existing EU municipal waste situation, we focus on centralized and decentralized, large and small scale facilities and management schemes that treat Biodegradable waste. The case studies considered are from the countries of, Italy, Germany, Netherlands, UK, Greece and Sweden. Also 4 of the most successful international waste management facilities studies are been identified.

5.2. Waste streams considered in this section

Municipal waste means waste from households and other waste which, because of its nature or composition, is similar to waste from households (cf. the Landfill Directive) (Eionet.,2010). Some of this waste is biodegradable, e.g. paper and cardboard, food waste and garden waste.

Biodegradable waste means any waste that is capable of undergoing anaerobic or aerobic decomposition, such as food and garden waste, and paper and paperboard (cf. the Landfill Directive). In this report, only the biodegradable waste included in municipal waste is addressed. (EEA Report No7., 2009)

Biowaste means biodegradable garden and park waste; food and kitchen waste from households, restaurants, caterers and retail premises and comparable waste from food processing plants (cf. the Waste Framework Directive (2008/98/EC)). (EEA Report No7., 2009)

5.3. Waste management in the EU-27

According to Eurostat (Figure 26.), In the **EU27**, 522 kg of municipal waste was generated per person in 2007, from which 42% was landfilled, 20% incinerated, 22% recycled and 17% composted. On average (unweighted), the European citizen generated 10 % more waste in 2007 than in 1995. The waste volume grew even faster (11.5 %) in the EU-15 Member States. (EEA Report., 2009)

The amount of municipal waste generated varies significantly across Member States. More than 750 kg per person was generated in 2007 in Denmark, Ireland and Cyprus. Luxembourg, Malta and the Netherlands had values between 600 and 750 kg per person and Austria, Spain, the United Kingdom, Germany, Italy, France, Estonia, Sweden and Finland between 500 and 600 kg. The next group of Member States included Belgium, Portugal, Bulgaria, Hungary, Greece, Slovenia and Lithuania with values between 400 and 500 kg of municipal waste per person. The lowest values of below 400 kg per person were found in Romania, Latvia, Poland, Slovakia and the Czech Republic.(Eurostat.,2009)

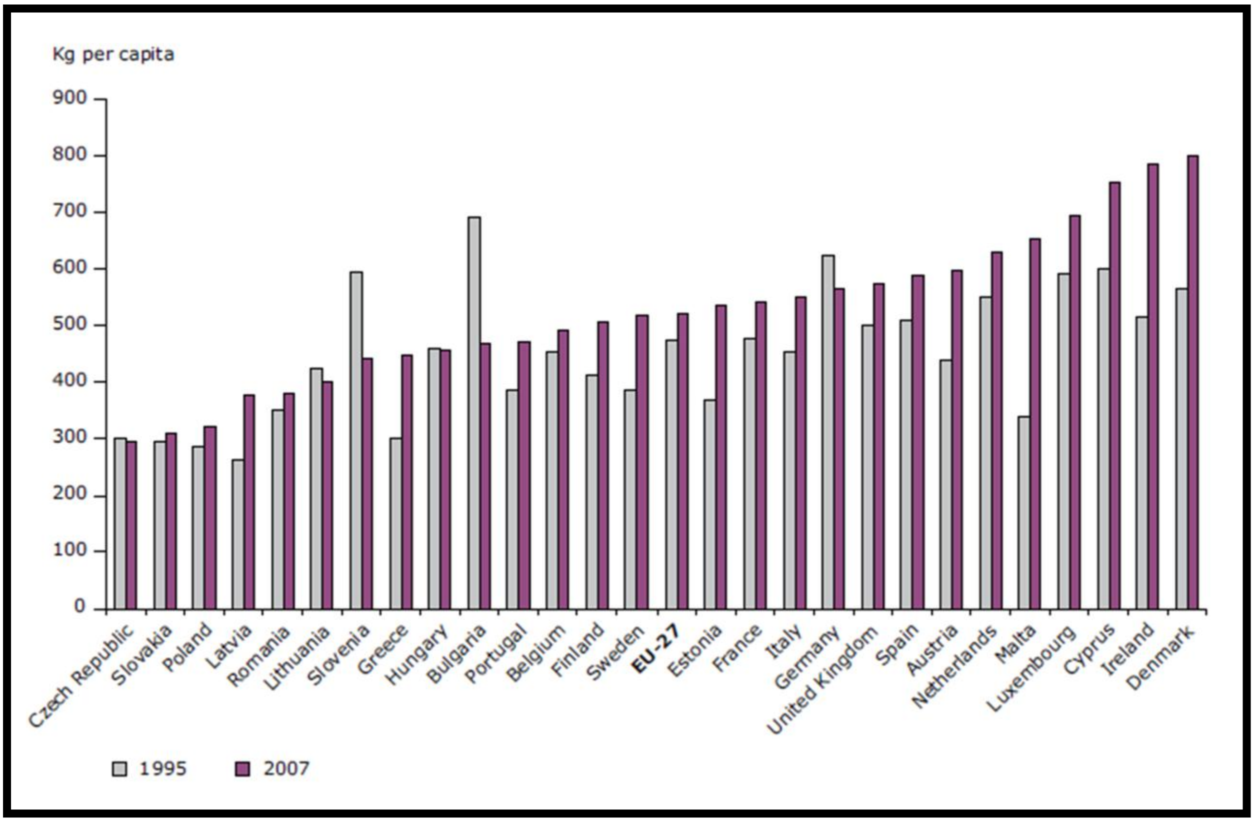


Figure 26.: Generation of municipal waste in the EU-27, 1995 and 2007
(EEA Report No 7.,2009)

A study published by the UK Waste and Resources Action Programme (WRAP) shows that almost one third of the food bought in Britain each year, or 6.7 million tones, is just thrown away. From this quantity, , 4.1 million tones can be avoided, i.e. it is food that is no longer wanted or it has been allowed to go past its best. It corresponds to 70 kilograms waste per person. In this study it is also found that approximately 1 million tones of the waste, or 15 kilograms per person, comprise products unopened or whole when thrown away. (WRAP., 2010)

The treatment methods differ substantially between Member States. In 2007, the Member States with the highest share of municipal waste landfilled (Figure 27.) were **Bulgaria** (100% of waste treated), **Romania** (99%), **Lithuania** (96%), **Malta** (93%) and **Poland** (90%). (EEA Report No 7., 2009)

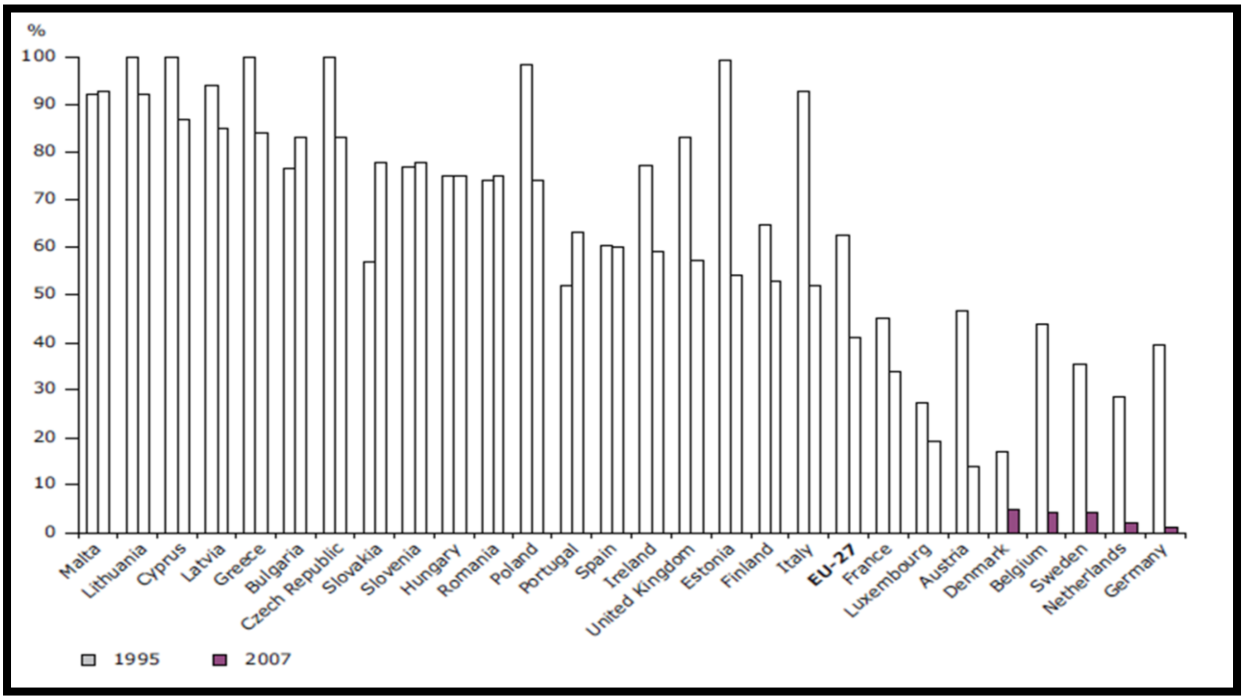


Figure 27.: Percentage of municipal waste that is landfilled in the EU-27, 1995 and 2007
(EEA Report No 7/.,2009)

The highest shares of incinerated municipal (Figure 28.) waste were observed in **Denmark** (53%), **Luxembourg** and **Sweden** (both 47%), the **Netherlands** (38%), **France** (36%), **Germany** (35%) and **Belgium** (34%). Eleven Member States had no incineration at all. (EEA Report No 7/.,2009)

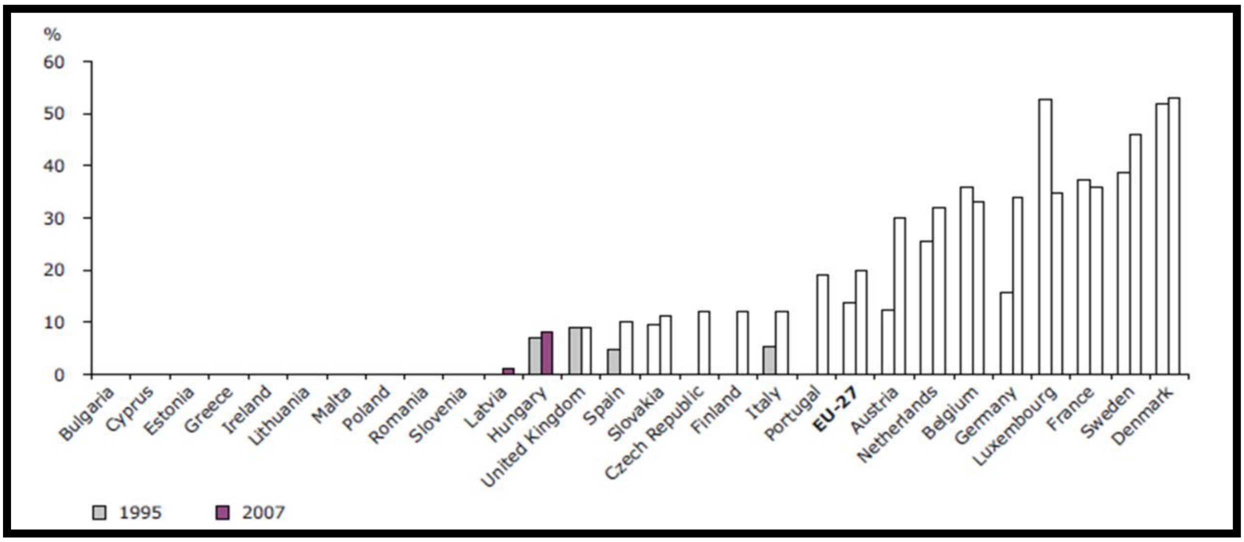


Figure 28.: Percentage of municipal waste that is incinerated in the EU-27, 1995 and 2007 (EEA Report No 7/.,2009)

The Member States with the highest recycling rates for municipal waste were **Germany** (46%), **Belgium** (39%), **Sweden** (37%), **Estonia** and **Ireland** (both 34%). (EEA Report No 7/2009)

Composting of municipal waste was most common in **Austria** (38%), **Italy** (33%), **Luxembourg** and the **Netherlands** (both 28%), and not done at all in **Bulgaria**, **Cyprus** and **Romania**. Composting and recycling accounted for over 50% of municipal waste treated in **Germany** (64%), **Belgium** (62%), the **Netherlands** (60%) and **Austria** (59%).(EEA Report No 7/.,2009)

6.Italy

The Italian strategy

Italy uses two methods for MSW treatment: Landfilling and separate collection of waste. This strategy has made Italy's regions to define instruments with which the mixed waste stream will be diverted from Landfilling which is considered to be the worst scenario for waste management nowadays. Separate collection, especially of biodegradable fractions of municipal waste but also of packaging waste, plays the most important role. Though there are differences in waste management strategies between different regions in Italy. For example the northern regions focus more on composting and incineration while the southern regions use more mechanical biological treatment (MBT process). A national target is set for every region (which has to be achieved) and refers to the quantity of waste that has been diverted from landfilling. These targets have been defined in kilograms per inhabitant in order to improve monitoring at the local level. Italy has reached a target of (50% diversion from landfilling in 2006) something that keeps evolving. There is, however, a considerable difference between the performance of the northern regions and the southern and central regions a fact that has to do with the plan that each region follows, Socioeconomic parameters, etc. (EEA Report No 7/.,2009)

6.1. Waste management situation

Italy has traditionally landfilled most of its waste, although schemes for recovering materials such as wood and paper have been rooted in society, Italy still landfilled 82 % of its BMW in 1995. Although Italy could have got a derogation period from the Landfill Directive's targets on landfilling BMW it decided not to do so. BMW generation increased by 20 % until 2005, which makes it more difficult to meet the Landfill Directive targets, as they are based on the reference year 1995. The increase may partly result from economic growth and improved waste statistics. (EEA Report No 7/.,2009)

Italy has steadily increased its separate collection of biodegradable waste fractions (Figure 29.). The largest fractions collected are paper, food and garden waste. There are, however, large differences in the separate collection between northern, central and southern Italy. (EEA Report No 7/.,2009)

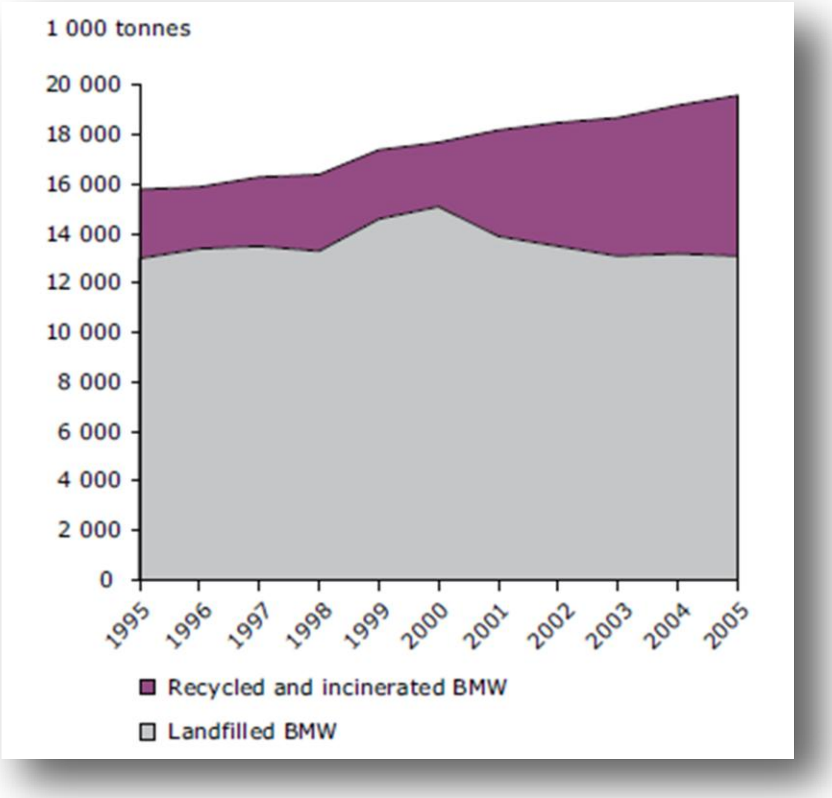


Figure 29.: Management of biodegradable municipal waste 1995–2005
(EEA Report No 7/,.2009)

Instead of transposing the percentage based targets set out in the Landfill Directive, Italy adopted targets based on the quantity (kilograms) of BMW produced per capita. That decision was based on two core reasons: the lack of reliable data on the quantity of biodegradable municipal waste landfilled in 1995 and the need to implement improved monitoring at the local level. Moreover, every province is supposed to meet these targets and the per capita targets aim to ensure even implementation throughout the country. Targets have been defined for 2011 and 2018. Italy transposed the Landfill Directive into national law in January 2003, i.e. 18 months after the deadline. As such the targets follow the intervals of the directive with a delay of two years.

Italy also set targets for collecting municipal waste separately. The first set of targets were agreed in 1997 and aimed at 35 % separate collection by 2003. The targets were ambitious in the light of the fact that separate collection at the time was only 10 %. Even though Italy had not yet met the 2003 target, a second set of targets was set in 2006, aiming at a progressive improvement in the separate collection rate, from 40 % in 2007 to 65 % in 2012.

Targets on recycling packaging waste were first introduced in 1997 and then updated in 2006 concurrent with the targets on separate collection those in the revised Packaging Directive, except for those relating to plastic and wood, which have higher values than the ones set in the directive. The Italian legislation provides for targets of 26 % for plastic and 35 % for wood, rather than the 22.5 % and 15 % respectively stipulated in the directive. (EEA Report No 7/.,2009)

6.2. Italian waste policy

Italy has four administrative levels: national, regional, provincial and municipal. Each has responsibilities for waste management. The Ministry of Environment outlines the overall waste management strategy by establishing the legislative framework, setting targets at national level and drawing up the 'National Waste Management Plan'. The regions prepare regional waste management plans based on criteria defined in the national legislation and the provinces develop waste management plans in conformity with the regional plans. (EEA Report No 7/.,2009)

The regions issue regulations in compliance with the national legislation and define the 'optimal areas for the management of waste' (ATOs) that are responsible for meeting the targets on landfilling BMW and separate collection of municipal waste. The ATOs are supposed to represent a geographical entity where waste management is economically feasible and generally correspond to province boundaries. Other countries have a similar approach of joining forces but there it is usually the municipalities themselves who decide if and with whom they cooperate. Every region must also formulate a plan for reducing landfilling of biodegradable waste. The regions define the waste streams to be collected separately and issue permits on constructing new treatment capacity and upgrading existing plants. (EEA Report No 7/.,2009)

The provinces coordinate the municipalities' waste management and identify instruments for separate collection, enhancing implementation of the regional waste management plan. Municipalities are in charge of municipal waste collection and disposal and collect charges for managing waste. (EEA Report No 7/.,2009)

6.3. Policy instruments

The framework for waste policy instruments is often introduced at national level leaving the actual implementation of practical measures to the lower levels of administration. The charge for waste collection and management is based on households' floor space per capita in the vast majority of municipalities. To provide an incentive to prevent waste and increase recycling, some municipalities are developing a new system where in the waste collection charge also depends on the amount of waste generated per person in the household. The coverage of costs has improved in recent years, with the charge now covering around 90 % of waste management costs. (EEA Report No 7/.,2009)

Italy introduced a landfill tax in 1996. The national regulation defines the upper and lower level of the tax but the regions determine the precise level within these limits. The regions also decide the destination of the tax revenues. The tax has an environmental dimension as regions can spend up to 20 % of the revenue on improving the waste management system, financing regional environmental protection agencies or protecting natural areas. In 2003, the national Parliament announced that it would introduce a landfill ban for waste with a calorific value exceeding 13 megajoules per ton but the ban was not enacted until 2006 and took effect in December 2008.

Some Mediterranean soils are undersupplied with organic matter and others are at risk of desertification. Compost can help restore the organic content and for this reason many regions have introduced individual measures to promote soil restoration of farming areas using organic soil improvers. For instance, the Emilia-Romagna region provides farmers with subsidies of EUR 150–180 per hectare to promote the use of compost. The Italian Composting Association has developed a quality assurance system and label to guarantee good compost quality and some regions have introduced a regional quality label for compost. (EEA Report No 7/.,2009)

The main composted waste fractions originate from domestic food wastes, green wastes from gardens and parks, agro industry wastes and sewage sludge

(Figure 30.). The quality of compost that can be sold as a product is prescribed by legislation (legislative decree 217 of 2006), which defines the different typologies of compost, setting precise agronomical parameters, microbiological standards and pollutants limit values. Compost can also be used for organic agriculture if it meets specific standards. (EEA Report No 7/.,2009)

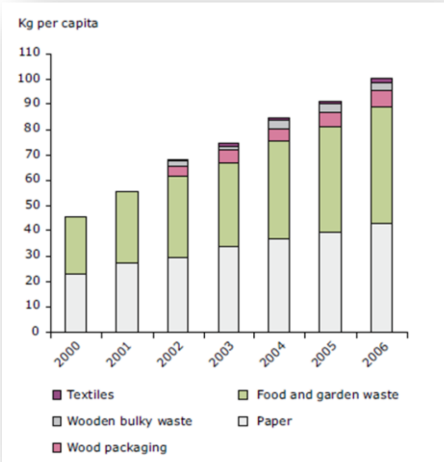


Figure 30.: Separate collection of biodegradable waste in Italy
(EEA Report No 7/.,2009)

The output of composting plants is primarily marketed:

- ❖ by sale via the floriculture sector (mainly mixed with peat and then sold to the public in supermarkets;
- ❖ By direct sale to the public (currently only in small quantities);
- ❖ By sale to agricultural businesses to cultivate open field crops.

In order to help develop a market for recycled products, green public procurement regulation requires public bodies and companies to buy goods made of recycled materials to meet at least 30 % of their annual demand.

6.4. Best practices

6.4.1. The Montanaso plant, Italy

The Montanaso plant (Picture 10.) is designed to treat residual MSW in a single process module. The plant has a capacity of 60,000 tpa and a building footprint of 80m x20m x 14m high. It was constructed in 1999 and started operations in June 2000 taking the MSW, after source segregation (kerbside), of glass, paper, plastics and in some cases the organic waste fraction from districts in Milan where there is 40% recycling. There is a plant nearby at Lacchiarella which has twin units, one at 60,000 tpa taking MSW and the other 40,000 tpa unit taking organic fraction for compost. It started operating in December 2002. The system outputs are:

- 50% solid recovered fuel as fluff – landfilled or used as fuel for industry (in the case of the Montaso Plant – sent to the fluidized bed boiler at Corteolona)
- 25% water and carbon dioxide
- 3% ferrous_ 11% glass and stone
- 10.5% fines – compostable/landfill
- .5% non-ferrous

Picture 10.: *Waste is shredded at Ecodeco's Montanaso Plant in Italy* (Wastesum project Del 3A., 2010)

The process (Figure 31.) takes place in a fully enclosed building where negative air pressure is maintained to minimize environmental impacts. Waste is unloaded from refuse collection vehicles into a tipping pit which takes place in a controlled environment with water sprays and airflow management to control emissions to the atmosphere. The reception pit has sufficient storage capacity to contain more than 1 day supply of waste and has an elevated perforated floor. Waste is picked up automatically by a programmable crane operated from the control room and transported to a shredder. The shredded waste (exit size 200-300 mm) is then transported into a buffer storage pit to produce a homogenous material. The material is then moved by crane to the aerobic fermentation area where the waste is placed in contiguous windrows. (Wastesum project, Del 3A., 2010)

The area is divided into a virtual grid on the computerized control system which controls the crane movements and records when and where materials have been stockpiled. According to the pre-set computer programme the crushed and homogeneous material is formed into heaps of up to 6 m height. The perforated floor and ductwork system allows air which is sucked in by fans, to be drawn through the waste and the void beneath the raised floor. This air is transferred to the bio-filters (a bed of woody material) mounted on the roof which neutralizes odors before release. The air flow is controlled automatically by a computer system to ensure optimum temperature range (50-60^{o}c) is maintained so that material is apparently stabilized, sanitized and practically odor free in 12-15 days.

By providing air the activity of micro organisms is stimulated and heat is released, causing the evaporation of water present in the waste (biodrying). The most easily putrefied portion of the organic waste is decomposed, whilst the remaining material has a heating value of between 15 MJ/kg and 18 MJ/kg. Once the material has been aerated for 12-15 days it is automatically transported by crane to the recycling and recovery process area where the dried waste is separated into fractions by using a combination of sieving, weight separation and metal extraction and secondary shredding. The stabilized waste fraction (approx 50%) can be landfilled or sent for conversion into energy as a secondary fuel. For use as Solid Recovered Fuel (SRF) the material is shredded to a suitable size i.e. dimension of around 100-150 mm.

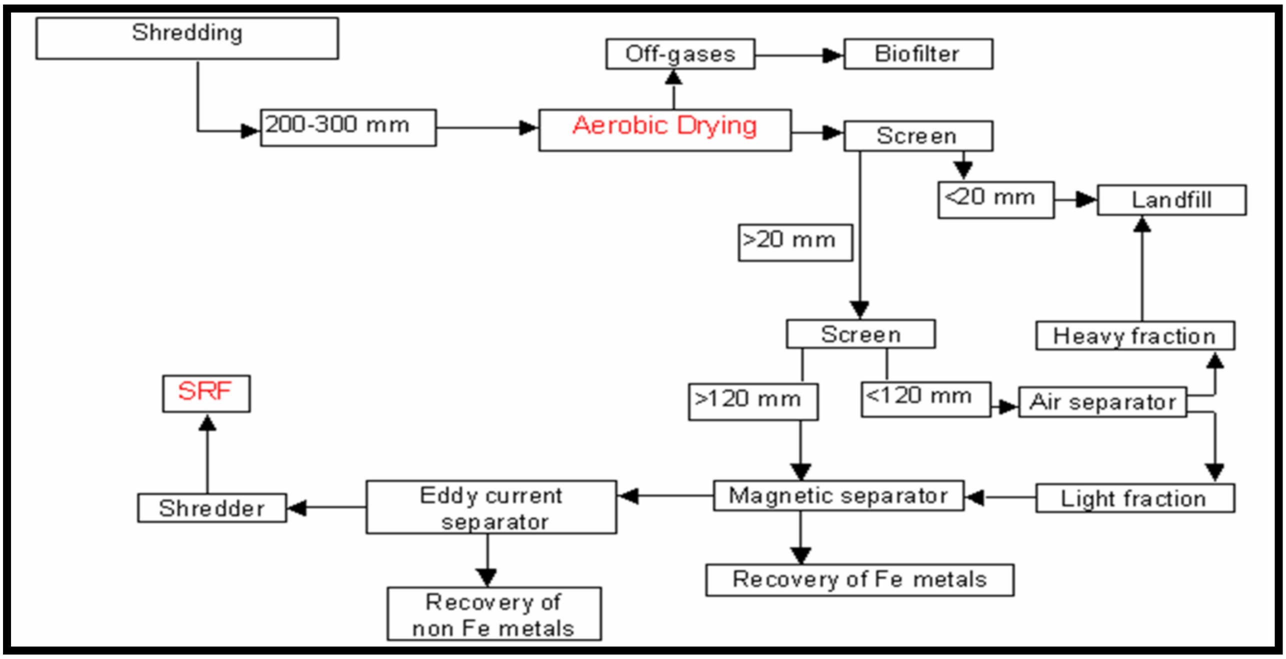


Figure 31.: Schematic operation of Montanaso plant in Italy.
(Wastesum project Del 3A., 2010)

6.4.2. The Corteolona plant in Italy

The Corteolona plant (Picture 11.) is an integrated waste management facility with sludge treatment, industrial waste treatment area, mechanical and biological treatment plant, fluidized bed plant for power generation from RDF and landfill. The site is in a rural area surrounded by trees. The waste facilities are all painted green to blend in but the chimney from the fluidized bed plant, although slim, does stand out from the surroundings even though the plant has been built 5 m below the ground level. The plant has a capacity of 60,000 tpa. The SRF from the MBT is fed directly into the fluidized bed plant via a conveyor and burnt to produce electricity (9.0 MWe). It also takes RDF produced by some of the other mechanical and biological treatment plants. (Wastesum project Del 3A., 2010)

The power plant started operating at the beginning of 2004 and is owned by Ecoenergia, a subsidiary of Ecodeco. It has a footprint of 120m x 45m with the boiler completely contained in a 32m high building, while the gas cleaning section is outdoor. The tallest equipment is the stack that reaches 60 m. (Wastesum project Del 3A., 2010)

***Picture 11.**: The Corteolona plant in Italy.*
(Wastesum project Del 3A., 2010)

Flue gas treatment has been foreseen to get de-acidification and dust elimination of flue gas coming from the bed fluid kiln manufactured by KVAERNER and from boiler to produce 40 ton/h of steam at 40 bars - 400 °C, steam necessary to get the required electrical production. Flue gas treatment is carried out in the following stage of treatment:

- Pre-dedusting using cyclones
- Conditioning tower used as 1st stage of acid reduction using NaOH and meantime as temperature correction to get 130 °C, optimized temperature for acid reduction using lime.

- Deacidification with double possibility of injection:
- Wet injection of NaOH in conditioning tower
- Dry injection of lime in the flue gas flow
- Additional possibility of lime recycling in excess
- Micro-pollutants of organic origin (PCDD +PCDF, PCB + PCN+ PCT, IPA, etc.) and inorganic (Hg, Cd, Tl, other heavy metals) mixing activated carbon in reaction tower
- Elimination from flue gas of dusts and reaction products using bag filter system.
- Extraction fan to get negative pressure in the system
- Final chimney, 60 m high
- Chemical silo stockage and chemical transport up to venturi for injection in the

flue gas flow.

- Ash transport and stockage with pneumatic transport from cyclones and bag filter

to get filling of two silos, 150 cum of capacity each.

6.4.3. The Tufino plant, Italy

The Tufino plant can be seen in (Figure 4.9) This plant is well engineered and housed in relatively substantial buildings. It has to be mentioned that the mechanical pretreatment stage is housed in separate building. During the mechanical stage two fractions are produced:

- One that is more than 100mm. This fraction is baled as RDF (Figure 4.10) and
- One fraction that is less than 100mm and is sent for the composting process

The building in the foreground houses the waste reception and mechanical pretreatment parts of the process and the larger building in the background houses the composting process. The main output is a bio-stabilized product which is used for landfilling. The composting process uses a patented compost turning machine which is called as the 'CTM' system (Picture 12.).

The waste material to be composted is loaded into bays that are aerated from below and housed in a closed building. It takes 4-6 weeks to complete this process and a further three weeks for the maturation of compost. The compost is turned automatically by the 'CTM' system, which is essentially a bucket wheel and conveyor system, which incorporates compost irrigation that traverses each composting bay about five times during the initial 4-6 weeks cycle.

***Picture 12.**: The Tufino plant in Italy.*
(Wastesum project Del 3A., 2010)

Leachate from the composting process is collected and re-circulated as process water. The off-gases from the composting process and the fugitive emissions from the mechanical separation stage are collected and sent for treatment. The off-gases are first scrubbed to reduce the levels of ammonia (NH_3) and then passed through a biofilter before being emitted to the atmosphere. Moreover, the off -gases from the process and the fugitive emissions from the mechanical pre-treatment plant were piped to separate scrubbers before they were treated by bio-filtration. At the Tufino plant, no further mechanical separation of the bio-stabilized materials is carried out and this output is being landfilled. (Wastesum project Del 3A., 2010)

Picture 13.: *Part of the 'CTM' compost turning machine at Tufino plant in Italy*

6.4.4. The Cupello composting scheme

Cupello is a small town located in the Abruzzo region of southern Italy. The municipality population is approximately 4 695 inhabitants and covers an area of 48 km^2. The local Municipality of Cupello manages the composting management sceme described in this section.(Success stories on composting and separate collection., 2000)

The Cupello composting scheme began to operate in 1998. Until then, only 1% of the biodegradable household waste was collected. The scheme added a totally different way of bio waste treatment in this small city. The management plan included of the following actions:

- **door-to-door collection of biodegradable waste three times a week**
- **door-to-door collection of paper and plastic once a month**
- **collection of dry non-recyclable waste twice a week**

(Success stories on composting and separate collection., 2000)

In the industrial region of the village operates a collection centre but only food waste is collected separately. The reason for this is the need for the public to compost their garden waste. The biodegradable fraction is delivered for composting at a cost of approximately 28 euros/ per tone. The attained separate collection level is 35 %, with a 25 % biodegradable waste separation (approximately 75 kg/year/inhabitant). The biodegradable fraction which is collected separately is considered to be of high quality for the production of compost. Italy needs of this fraction because of the dry climate and the need of the farmers for better quality soil. (Success stories on composting and separate collection., 2000)

Biodegradable waste collection takes place three times a week (other waste is collected twice a week). Bulk lorries are used, with a capacity of 3 m^3 each. The lorries (Picture 14.) are managed by two operators (one is the driver). The operator empties the household buckets or bins, which are placed along the roads in front of the buildings on collection days, directly into the bulk lorries. Wheeled carts are hung on the lorries and emptied automatically. Compacting is not required, due to the high bulk density of food waste. The bulk lorries then carry the waste directly to the composting plant, which is located about 10 km from the area covered by the scheme. (Success stories on composting and separate collection., 2000)

Picture 14.: *Organic waste-collection lorry*
(Success stories on composting and separate collection., 2000)

The plant where the composting process takes place, is owned by many Municipalities. It accepts municipal solid waste but the organic fraction is treated separately. The unit now because of this scheme produces high quality compost. (Success stories on composting and separate collection., 2000)

At present, the source separated biodegradable fraction from Cupello is treated in a dedicated line (separated from the non-separated waste); biodegradable waste is mixed with screened garden trimmings and tipped on a covered and aerated platform. The composting process takes 90–100 days. With the implementation of the pilot project of separate collection of biodegradable waste (The plant throughput is approximately 40 000 tones/year. (Success stories on composting and separate collection., 2000)

The quality compost produced is called Civeta and is currently produced in small quantities, although these are expected to rise. The consortium managing the plant has drawn up an agreement with the local consortium for irrigation aimed at carrying out experiments on compost use in agriculture. (Success stories on composting and separate collection., 2000)

6.4.5. The Bacino Padua composting scheme

The composting management scheme is located in Padua which is the capital of the province of Padua and the economic and communications hub of the area. Padua's population is 212,500 (as of 2008). Padua stands on the Bacchiglione River, 40 km west of Venice and 29 km southeast of Vicenza (Wikipedia.,2010)

The scheme covers 26 Municipalities in 'Bacino Padova' . These Municipalities have formed a consortium for the management of their waste (sewage system, water treatment, waste collection). The consortium is a public utility company financed by the municipalities, and through revenue obtained from its service functions. (Success stories on composting and separate collection., 2000)

Since 1996, a door-to-door collection scheme has been in place in the district, with a recycling rate of 50.8 % in 1998. The following waste streams are separately collected:

- biodegradable waste (food and garden Waste);
- paper and board;
- glass;
- plastic;
- Other (mixed waste)

The total amount of waste produced in 1998 was 64 000 tones (approximately 320 kg/inhabitant); in 1998, 7 571 tons of food waste (meat and fish, as well as vegetable and fruit peelings), and 8 876 tones of garden waste were separately collected. Each household received a 6.5–10 l bucket and biodegradable bags of the same volume for food waste. Further biodegradable bags have to be purchased in main markets. Multi-occupant buildings, canteens and fruit shops have been provided with a trolley bin (120/240/360 l, according to user request) where food waste is stored until the next collection round. (Success stories on composting and separate collection, 2000)

Garden waste has to be collected separately and preferably taken directly by the producer to an eco-centre. In the district there are 14 eco-centers, which are equipped collection areas, where there are large containers for storage of waste prior to disposal or recycling. (Success stories on composting and separate collection., 2000)

Households who ask for door-to-door collection of garden waste have to pay an additional tax. In all, 35 % of householders home compost their garden waste and are allowed to ask for a reduction of waste tax. Householders can purchase heap systems, mesh-wire bins, and plastic bins from the municipality, which sells the composters at the manufacturing cost. (Success stories on composting and separate collection, 2000)

House-to-house biodegradable waste collection takes place twice a week, although in summer, food waste may be collected three times a week. Buckets are placed on roadsides on collection days, which are emptied directly into the bulk lorries, and then into compaction vehicles for long distance transport. The scheme vehicles are owned by the contractor employed to collect the waste. The estimated total amount of waste recovered through composting (Figure 4.12) in 1998 was approximately 110 kg/inhabitant. Home composting accounted for an estimated 30 kg/inhabitant a year; the rest was food and garden waste. (Success stories on composting and separate collection., 2000)

The district has its own composting plant for garden waste and sewage sludge. The plant and the water treatment facility are managed directly by the Consorzio Tergola and are located in Vigonza, near Padua. The plant has been recently renewed and treats about 30 000 tons a year. The composting process lasts about three months and involves the following.

- **Pre-treatment:** open air shredding of waste, mixing with sludge and transport to the composting hall.

- **Fast thermophilic decomposition:** piles are placed over an aerated floor where pipes connected to a blower supply the air needed for composting. Piles are turned and mixed every 3–4 days, for one month, to homogenize the compost and promote rapid oxygen transfer.

- **Curing in outdoor windrows:** to guarantee the necessary oxygen, windrows are turned every 8–10 days. The area is paved and leachate is collected.

- **Screening:** two sizes of screen are in use, the finer for compost to be used for pot cultivation (< 10 mm), the other for agricultural users. Coarse rejects are sent to landfill.

Storage of the final product under a roofed area. In order to reduce the visual impact, the border of the composting site has been provided with a vegetation curtain. (Success stories on composting and separate collection., 2000)

Food waste is not taken to this composting plant, but relies on many different composting plants, according to their availability and tipping fees. At present, the composting plant which is mainly used is the SE.SA. s.p.a. plant, which is located about 50 km from the district area. The garden waste composting plant produces: high nutrient compost, which is sold to homeowners and farmers; the average selling price is about 7,5 euros/m^3; a compost lower in fertilizing value, to be used for topsoil and soil amendment, fruit and vegetable farming, land reclamation, etc., which has so far been given away free. The benefits of compost use have been extensively publicized with letters and flyers sent to all households in the district.

Picture 15.: *Final storage of compost at the plant*
(Success stories on composting and separate collection., 2000)

7. Germany

7.1. Waste management situation

The German strategy

Germany focuses on three ways of waste management: separate collection and recycling of secondary raw materials (paper and biowaste), pre-treatment of mixed household waste in mechanical-biological treatment plants and dedicated incineration with energy recovery of mixed household waste.

A ban on landfilling waste with an organic content of more than 3 % was adopted already in 1993 but due to several problems it was not implemented properly. The difficulties encountered, were dealt with the Waste Landfilling Ordinance (2001), which re-established a deadline of 1 June 2005 for implementing the landfill ban. Special limit values for the organic content of waste that has undergone mechanical-biological treatment were introduced. Since the deadline, the amount of municipal waste landfilled has fallen to 1 %.

In Germany each federal state has its own targets in waste management. Some states try to minimize the negative impacts of the biodegradable fraction by treating it separately. Others incinerate their waste for energy production,etc. (EEA Report No 7/.,2009)

In the mid-1960s the national government and the federal states started to analyze waste disposal and disseminated the findings to municipalities, which were responsible for disposing of municipal waste. Due to a substantial increase in industrial production and private consumption, waste generation grew rapidly at the beginning of the 1970s. At that time, waste was primarily disposed of in 50 000 small dumpsites and interest concentrated on them and the need to build appropriate waste management facilities. (EEA Report No 7/.,2009)

Germany is one of the first countries which adopted the diversion of waste for landfilling in the early 90s. Measures included schemes for collecting packaging waste, biowaste and waste paper separately. As a result, by 1995 Germany already recycled a relatively large proportion of municipal waste and landfilled approximately 40 %.(EEA Report No 7/.,2009)

German waste policy follows the EU's waste hierarchy, with prevention as the first priority, followed by material recovery and energy recovery, depending on which is better for the environment. Objectives for managing municipal waste also focus on avoiding contamination of waste and ensuring treatment and landfilling of waste that is not recovered. (EEA Report No 7/.,2009)

The two most important fractions of waste are (paper and biowaste). Among the most efficient actions for the treatment of these types of waste, are: composting or anaerobic biological treatment; and limiting the organic content of landfilled waste. (EEA Report No 7/.,2009)

Germany set a target in 1999 for stopping landfilling and treating residues by 2020. This is an ambitious and very difficult to achieve objective and includes, recovering waste incineration residues and further developing treatment technologies such as sorting and MBT. (EEA Report No 7/.,2009)

Except for recycling targets for packaging waste, very few quantitative targets have been set at federal levels. Those that exist generally apply to paper and cardboard. In addition to the targets of the 2004 Packaging Directive, the paper industry has committed itself to recycle around 80 % of waste paper in a voluntary agreement. (EEA Report No 7/.,2009)

7.2. The German policy

Germany is a federal republic made up of sixteen federal states (Bundesländer). Responsibility for waste management and environmental protection is shared between the national government, the federal states and the local authorities. The national Ministry of Environment sets priorities, participates in the enactment of laws and oversees strategic planning, information and public relations and defines requirements for waste facilities. Each federal state adopts its own waste management act containing supplementary regulations to the national law, e.g. concerning regional waste management concepts and rules on requirements for disposal. There is no national waste management planning in Germany. Instead, each federal state develops a waste management plan for its area. (EEA Report No 7/.,2009)

According to the producer responsibility principle, which is a core tenet of German waste legislation, the producer of a product generally still has responsibility for the product when it becomes waste. However, this principle has been specified only for some product types such as packaging and waste electric and electronic equipment. For waste generated by households, the Recycling Management and Waste Act assigns responsibility to the local public waste disposal authorities (in most federal states these are the districts and towns). Their responsibility covers collecting and transporting waste, measures to promote waste prevention and recovery, and planning, constructing and operating waste disposal facilities. Municipalities have more practical tasks such as providing sites for waste collection. (EEA Report No 7/.,2009)

One of the key means of diverting waste from landfills is limiting the organic content of landfilled waste. A landfill ban was introduced to achieve this goal. It was introduced in two steps and using three pieces of legislation because the initial statute contained severe loopholes.

The first step was an administrative regulation (TASi) in 1993, which limited the organic content in waste going to landfills to less than 3 % total organic carbon (TOC). Achieving such a low organic content necessitated thermal treatment of the waste. The debate concluded that incineration should be the only pre-treatment method but it was agreed to extend the transition period from 8 to 12 years so the final deadline would be 1 June 2005. The aim was to allow enough time to establish treatment capacity especially in the federal states formerly situated in East Germany. Moreover, it was agreed to permit exemptions in exceptional cases to allow some flexibility. Finally, the Bundesrat (the body at which the federal states are represented) called on the Ministry of Environment to define the criteria for environmentally sound landfilling of residues from mechanical-biological treatment. (EEA Report No 7/.,2009)

In some cases states expanded the use of incineration as a method of waste treatment in order to achieve the targets set by TASi, whereas others invested in MBT as the main pre-treatment method and made use of extensive exemptions from the provisions.

Separate collection of biowaste and paper is also regulated mainly through legislative measures. In 1983 the Federal State of Hesse initiated separate collection of biowaste to divert waste from landfill. Between 1985 and 1993 the number of inhabitants with a collection system for biowaste increased from 400 000 to 7.6 million. Intervention at national level came in 1993 with TASi, which requires the competent waste authorities to set up separate collection schemes for biowaste from households and garden waste from public parks. (EEA Report No 7/.,2009)

According to the Commercial Waste Ordinance, biodegradable waste, as well as other secondary raw materials (e.g. paper) from commercial activities, has to be separated at source and recovered.

Packaging waste is regulated by the Packaging Ordinance (1991), which introduced producer responsibility. In this case, that implies that producers and retailers are obliged to take back used packages and to contribute to their further management. The implementation of this ordinance led to the 'Green dot' system. (EEA Report No 7/.,2009)

In Germany, waste collection charges on households have to cover the full cost of collection and management of waste. Such tariffs vary between municipalities, depending on the waste management situation and the service offered to citizens. Separate collection of biodegradable waste has realized a considerable decrease in biodegradable waste in the residual waste stream. Separately collected paper waste and biowaste show almost the same development.

In 2005 around 190 kilograms of biodegradable waste was collected per person, including waste from public parks. Paper comprises the largest waste stream and has increased from 20 to 96 kilograms per capita between 1990 and 2005. In the same period, the collection of biowaste from households arised from 30 kilograms per capita to 46 kilograms per capita (Figure 32.).

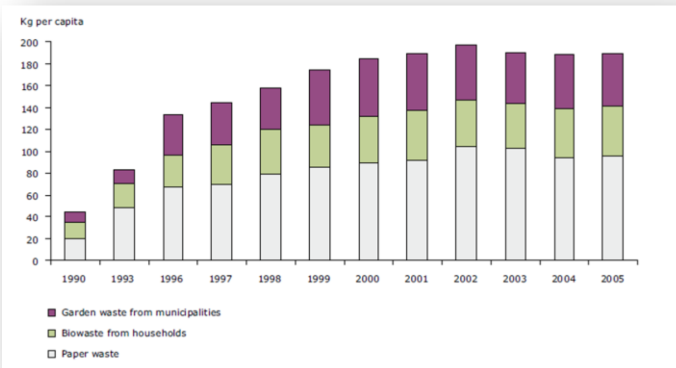


Figure 32.: Separate collection of biodegradable waste fractions in Germany
(EEA Report No 7/.,2009)

7.3. Best practices

7.3.1. The sludge wastewater treatment and sludge drying plant in Heimertingen/Memmingen

Heimertingen is a municipality in the district of Unterallgäu in Bavaria very close to Memmingen. **Memmingen** is a town in the Bavarian administrative region of Swabia in Germany. It is the central economic, educational and administrative centre in the Danube-Iller region.

Heimertingen wastewater treatment facility, is located in Memmingen approximately 20 minutes drive from the main train station in Memmingen. The facility is covered with very tall trees all around and it is placed in a spot away from residences (the first residence is located approximately 3 kilometers of the facility).

It is a sewage treatment facility that treats wastewater from the city of Memmingen and suburbs. The facility has a primary treatment tank, a nitrification system, a denitrification system and a phosphorous removal system. The sewage goes to the secondary treatment tank where the separation between the sludge and water takes place. After the separation process ,the sewage sludge is taken to a sludge drier operating inside the facilities.

The sludge drier operating in the facilities, is manufactured by the «ANDRITZ GROUP» which is a manufactory company for customized plant, systems and services for hydropower, pulp and paper, steel and other specialized industries (solid/liquid separation, feed and biofuel).

Sewage sludge from the Wastewater treatment plant is treated in the following steps after digestion process:

- dewatered by centrifuges to a dry substance content of > 28%
- pumped after dewatering directly into a dosing silo
- pumped from the dosing silo (capacity 50 m^3) directly into the Fluid bed Dryer
- dispersed and dried in the fluid bed to a dry substance content of > 90%
- fed to a product silo (capacity 100 m3) and stored for truck loading

Thermal energy for the drying process is generated by burning Biogas which is produced by an anaerobic digester (Picture 16.). operating in the sewage sludge facilities or if necessary oil in a Boiler. Usually from Monday-Friday the energy is produced by burning biogas and during the weekend or in case some malfunction occurs to the anaerobic digester, a thermal oil method is used.

Picture 16.: *Anaerobic digester fully operational inside the facilities*

The facility is usually closed during the weekend but electronic equipment (sensors) for the monitoring of the drying process operate inside the facility and the staff can access the control system from their houses so if anything goes wrong everybody communicate with each other so that the potential problem is solved with no significant cost.

Thermal oil (Picture 17.). will be used as media to transfer the heat to the heat exchanger of the drier. Excess heat from the condensation process is also available to heat up the digesters transferred by a heat exchanger (60/40°C).

Picture 17.: *Power generator*

The installation has different options for the handling of the sludge/product:

- discharge of the mechanical dewatered sludge to containers
- production of partially dried granules with 65 – 90% dry substance
- production of fully dried granules with 90% DS (main product route)

A diagram with the drying process is shown in (Figure.33)

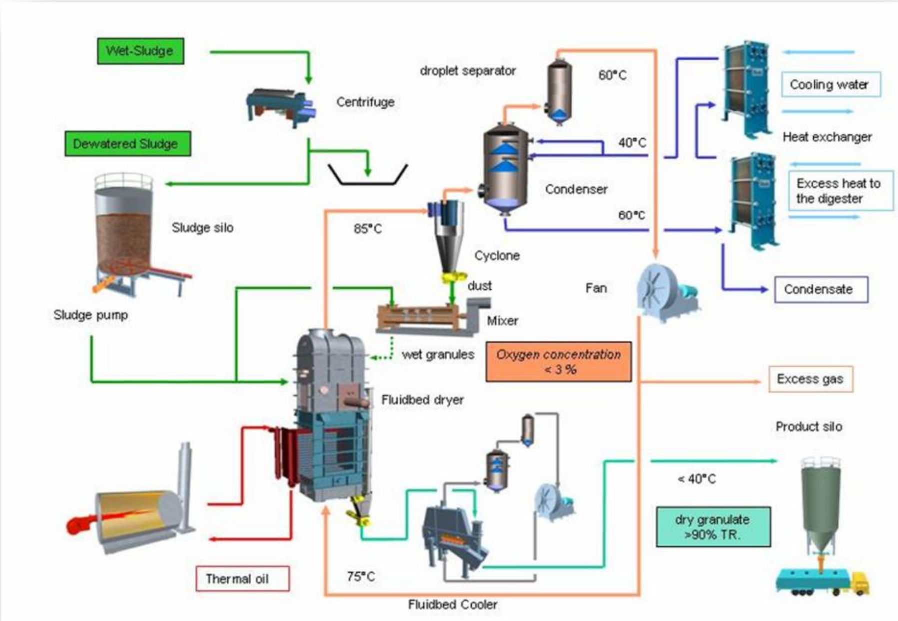


Figure 33.:Drying process description diagram

The plant dries 3500 tons/year of treated sludge and the total cost of the drying facility is approximately 16 000 000 euros while the total sewage treatment plant facility cost is 42 000 000 euros. The final product without the excess moisture and without the polluting odors is transported to incinerators for burning.

7.3.2. The (EDZ) technology sludge drying facility in Augsburg

Augsburg is a city in the south-west of Bavaria in Germany. It is a College town and home of the Regierungsbezirk Schwaben and the Bezirk Schwaben. Augsburg is an urban district and home to the institutions of the Landkreis Augsburg. It is, as of 2008, the third-largest city in Bavaria with a population exceeding 264,000 citizens. After Trier, Augsburg is Germany's second oldest city.

Augsburg sludge drying facility, is located in Augsburg approximately 30 minutes drive from the main train station of the region. The facility is 500 meters away from residences while the operator's residence is just outside the facility for 24 hours facility monitoring. It is a sewage drying facility that dries sludge from 4-5 small sewage sludge facilities that operate near the city of Augsburg.

The EDZ-drying method makes effective use of solar heat radiation in a solar house equipped with floor heating and the waste heat available in many locations for instance from block heating stations makes it possible, to produce fuel out of sewage sludge in a cost effective way. The product obtained using the EDZ- drying method is a fuel granulate with > 90% dry substance contents and an energy content between 9 –12 MJ/kg (Å 2.5 - 3.3 kWh/kg).

In the facility operates a small scale anaerobic digester (Picture.7) (Fermentation Process) which uses grass and woodchips for the production of biogas the burning of which is used for heating the water which is in turn used for the heating of the drying facility.

Picture 18.: *Anaerobic digester*

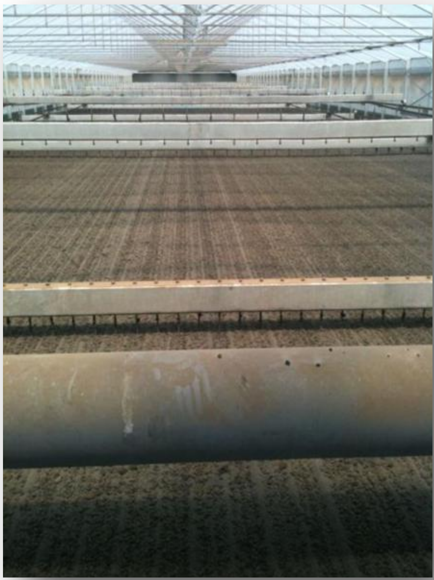
The sludge is placed into a large box (Picture 19.) which is connected to the main drying facility with a pushing floor and then pushed automatically inside the solar house where the drying process takes place.

Picture 19.: *Box for incoming sludge*

Approximately 120 Water pipes (Picture 20.) with the use of the thermal energy produced by the biogas burning process and water, heat the concrete floor at a temperature of about 55°C and produce the final dry organic product.

Picture 20.: *Heat water pipes*
(Lazaretos.,2009)

The sludge height inside the solar house is no more than 10cm for the drying process to be effective. It also mixed during the whole process with the use of a special mixing mechanism 'WendeWolf' (Picture 21.) for the drying process to be even faster.



Picture 21.: *Sludge mixing mechanism*

Drying is accelerated and condensation formation prevented through guided supply (Picture 22.) and exhaust air. The Performance of this mechanism, depends on the air humidity involved. A programmable logical control governs the air exchange and waste heat supply. Optimum drying results are achieved as a result.

Picture 22.: *Air mixing mechanism*

A programmable logical control (Picture 23.) governs the air exchange and waste heat supply. Optimum drying results are achieved as a result.

Picture 23.: *Programmable logical control system*

The excess moisture is being removed through a chimney (Picture 24.) which is installed at the top of the solar house where the drying process takes place.

Picture 24.: *Air removal chimney*

The sludge keeps moving (from one way of the greenhouse to the other) with the help of the pushing floor until it dries out completely. Then the dried sludge is been disembogue into a sump (Picture 25.).

Picture 25.: *Sump for dried sludge*

Finally the dried sludge is been transferred automatically to a temporary storage (Picture 26.).

Picture 26.: Temporary storage

The sludge is been collected by tracks and sold to the market for incineration for a price of about 30 euros/ton.

Picture 27.: *Hole where the sludge is been tipped of to the tracks*

It must be mentioned that everything takes place automatically and no personnel is required to carry out the process. Only one person is enough for the management of the whole operation.

The facility needs approximately 30 KWH/ton of water of energy to operate while the performance of it depends on the weather. In the winter approximately 15 ton/day of sludge is been dried while in the summer (when the greenhouse performance is higher) almost 25-30 tons/day of sludge is been processed. Finally, the facility takes about 1000 m^2 of space and its cost is approximately 600.000 euros.

7.3.3. The Kaiserslautern plant in Germany

The plant (Picture 28.) is located near the municipal landfill. Gas engines produce electricity by the combustion of the landfill gas and the biogas produced by the anaerobic digestion plant. The waste heat of the gas engines is utilized to evaporate the excess waste water.(European Commission.,2010)

Picture 28.: *The Kaiserslautern plant in Germany*
(Wastesum project Del 3A,. 2010)

The DRANCO process is a patented thermophilic one phase digestion system with external inoculation. There is no mixing apparatus in the digester. The process treats the wastes as concentrated as possible, resulting in a total solids content inside the digester between 15 and 40%, depending on the waste composition. Most of the DRANCO plants are treating source separated bio-wastes. However, the DRANCO installation can also handle grey waste (the residual organic fraction of MSW). The plant has a capacity of 20.000 tons per year municipal solid waste. (European Commission.,2010)

The waste is dumped in a bunker which can be closed off in order to limit odour emissions. A pushing floor at the bottom of the bunker is transporting the waste to the pre-treatment station. The pre-treatment station consists of a cascade mill, a screen of 40 mm and an over-belt magnet. The oversize of the screen is landfilled or sent for thermal treatment. The undersize, about 18.000 tons per year, is sent to a 200 m³ buffer. (European Commission.,2010)

The pretreatment is functioning five days a week. The buffer allows the feeding of the digester during the weekend so that a continuous gas production is secured. Before being pumped into the fermentation reactor the substrate is mixed with digested residue and a small amount of steam, in order to heat up the substrate to about 50 °C. (Figure 4.15) shows the schematic flow of the Kaiserslautern plant in Germany. (European Commission.,2010)

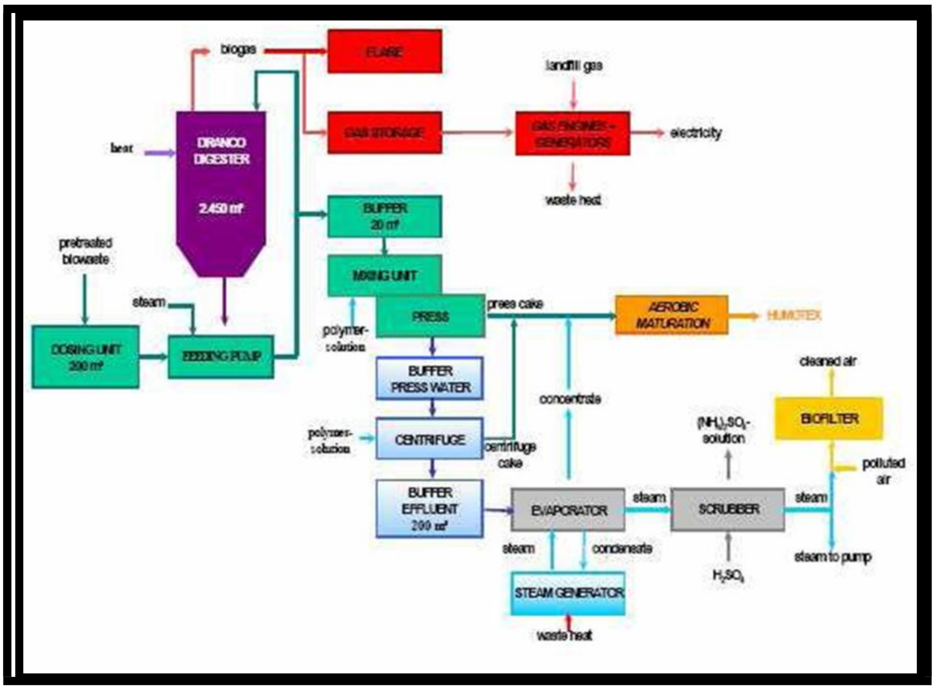


Figure 34.: The schematic flow of the Kaiserslautern plant in Germany.
(Wastesum project Del 3A., 2010)

The digestion takes place under thermophilic conditions, i.e., in the range of 50- 55 °C. The fermentation reactor itself is heated by a hot water spiral in order to minimize the amount of steam needed for maintaining the operating temperature in this range. The digester has a total volume of 2450 m^3. The mean retention time of the substrate in the reactor varies in the range of 20 to 30 days. The waste heat is used to evaporate waste water. Due to the evaporation of the process water the installation is operating free of any effluent. (European Commission.,2010)

The gas production is about 110 Nm^3 per ton of waste fed to the digester. The collected gas is stored in a 170 m^3 gas bag and is used, together with landfill gas, to fuel biogas engines with a total installed electrical power of 1400 kWe. The surplus of electrical energy is sold to the grid. A high temperature torch is installed in order to flare off excess biogas. The digester has a semi-conical bottom with a sliding frame of 3 m diameter. (European Commission.,2010)

The digested residue is extracted and either recycled together with fresh substrate back into the reactor or pumped to a 20 m^3 buffer in order to be dewatered. Before the dewatering process, the residue is dosed to a mixing unit and mixed with a polymer solution in order to improve the dehydration. A screw press is dewatering the residue to 50% total solids. The resulting press cake is sent to a post-composting system in order to produce mature compost. (European Commission.,2010)

The water effluent from the press is centrifuged and the effluent of the centrifuge is stored into a 200 m^3 buffer before being evaporated by utilizing the waste heat of the gas engines. The evaporating capacity is 1100 l/h. The concentrate of the evaporator is mixed with the press cake and the centrifuge cake in order to be stabilized aerobically. The steam is sent to an acid scrubber which is capturing the evaporated ammonia and producing an ammonium sulfate solution. After the scrubber the steam is mixed with process air, and eventually clean air, and treated in an insulated container with a biofilter. (Wastesum project Del 3A,. 2010)

To avoid fluctuations as regards the biogas production, additional inoculums material is added in order to accelerate overall start up of the installation and to stabilize the performance of the digester. The methane concentration is around 55% which is the expected biogas quality. The plant has been designed to generate 5.2 x106 kWh per year electricity derived from the biogas. The plant consumption is about 0.7 x106 kWh per year resulting in a net electricity production of 4.5 x106 kWh per year. (European Commission.,2010)

7.3.4. The Dresden plant, Germany

Mixed MSW, commercial waste as well as residual waste from source segregated recycling is brought to the delivery area. There are four handover shafts (Picture 29.) in the delivery area with a hydraulic closing system, in which the waste is unloaded directly into the bunker. The delivery shafts are automatically controlled by the control room computer using information supplied from the entry weighbridge. A fully automated delivery crane operates in the bunker area, which ensures both the optimum utilization of the bunker volume by moving the waste and also that the downstream crushing machines are filled. The crushing takes place via slowly running rotary shredders, which condition the residual waste to a particle size of < 150 mm. The crushed residual waste is free of coarse ferrous metal fractions by a magnetic conveyor belt running above it and passes into a buffer bunker. A second process crane, also fully automated, passes the crushed waste from this buffer bunker to the composting boxes. (Wastesum projectDel 3A., 2010)

To prepare the filling process, the process crane uses an ancillary lifting system to raise the lid of each empty composting box and then places it on a neighboring box. Each of the 9 composting boxes has an effective volume of approximately 600 m^3 and can take approximately 280 tons of waste. During the filling process, the level of the composting box is automatically monitored by the crane system. Once the composting box is full, the crane lifts the lid and closes the box rendering it air tight. Due to the fully automated operation no manual activities are required in the bunker and decomposition hall. (Wastesum projectDel 3A., 2010)

Picture 29.: Delivery in the handover shafts (left) and inner view of the bunker (right) of Dresden plant in Germany (Wastesum project Del 3A., 2010)

Due to an automatic control system adjusted to the requirements of the biological conversion process, the easily degradable organic substances in the composting boxes are converted into heat during a brief six-day aerobic biodegradation process. This heat is used to evaporate the moisture resulting in a dried waste. No external heat is required for the **drying process**. The condensate which is removed from the waste air of the decomposing material is mostly circulated via a heat exchange system and then fed to the wastewater treatment plant. (Wastesum projectDel 3A., 2010)

Then the easily degradable organic substances in the composting boxes are converted into heat during a brief six-day aerobic biodegradation process. This heat is used to evaporate the moisture resulting in a drier waste. No external heat is required for the drying process. The condensate which is removed from the waste air of the decomposing material is mostly circulated via a heat exchange system (Picture 30.) and then fed to the wastewater treatment plan. (Wastesum project Del 3A., 2010)

Picture 30.: *The heat exchanger system of Dresden plant in Germany*
(Wastesum projectDel 3A., 2010)

Due to the individual control of each composting box and the segmental air supply, it is possible to guarantee even and efficient drying. The relevant data such as heat quantity, temperature curve, and CO2 discharge are entered into the process control as is the air permeability of the waste. In an optimum bioconversion process, the mass is reduced by up to 30% in only 6 days.

The dried waste then has only a residual moisture content of less than 12% and thus very good properties for the subsequent mechanical separation treatment. The pre-treated waste is moved by a process crane to a buffer bunker equipped with a "walking floor" conveyor. From here the waste is automatically transferred in batches to the separation machinery.

The biological drying to a residual water content of <12 % decisively improves the ease with which the waste is mechanically separated. This is the essential prerequisite for the efficiency of the automated waste separation and for the sorted quality of the fractions extracted. (Wastesum project, Del 3A. 2010)

The material separation separates the dry waste flow into 3 basic fractions:

- Solid Recovered Fuel (SRF)
- Ferrous and non-ferrous metals
- Inerts (stones, sand, glass)

An important characteristic of the material separation, especially the separation of the light-weight fraction, is that due to the well positioned use of several air classification and sieving processes matched to each other, a very precise separation between light (combustible) and heavy waste components (metals, inert materials) is achieved and thus a high fuel quality is guaranteed.

The remaining ferrous and non-ferrous constituents are removed from the dry, light weight material using magnetic and fluidized bed separators. This treated lightweight fraction now consists of virtually 100% combustible materials such as wood, paper, plastics, textiles and organic matter. The average composition of this SRF fraction is shown in (Figure 35.). The renewable energy fraction contained in the stabilate is around 2/3 and could be beneficial for renewable energy generation. (Wastesum projectDel 3A., 2010)

The calorific value of the SRF lies within the range of 15–18 MJ/kg and thus represents the energy equivalent of treated, dried lignite coal. Due to its dry consistency, SRF is very easy to store and can thus be used as a secondary fuel in industrial processes when it is required and independent of the amount of waste generated. The removal of heavy metals associated with the removal of metal parts and batteries is of decisive importance for the use of SRF as a secondary fuel. It reduces the heavy metal load by up to 90% compared to that of residual waste.

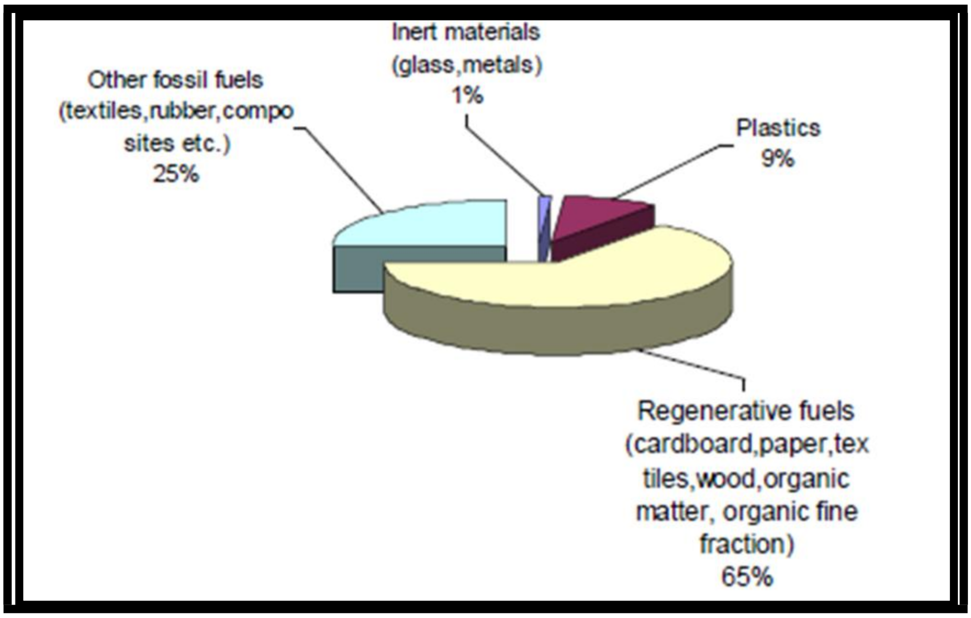


Figure 35.: Average composition of SRF of Dresden plant in Germany
(Wastesum project Del 3A., 2010)

The heavy fraction gained from the initial density sorting process is subjected to further treatment stages. With the separation of the combustible residues (organic matter, plastics), the overall organic content (expressed as ignition losses) are reduced and a material quality is achieved that can for example be used for the construction of landfill sites. The combustible fractions separated out are added to the SRF.The separation of electronic scrap, iron and non-ferrous metals using magnetic and eddy current separators produces a marketable product, the income from which helps to reduce the overall treatment costs.

The SRF is passed over four pelleting presses (Figure 4.19) to form around 20 mm sized pellets for reuse in the Methanol Plant. The pellets are mixed with a small quantity of coal and are then supplied to gasification reactors. There the organic components of the input materials react with a mixture of steam and oxygen at a pressure of 25 bar and temperatures well above 1000 °C to form synthesis gas. (Wastesum project Del 3A,. 2010)

The synthesis gas produced primarily consists of carbon monoxide, carbon dioxide and hydrogen. Following thorough cleaning, the synthesis gas passes into a plant that produces methanol. At a pressure of 45 bars, a temperature of 500 °C and in the presence of a catalyst, the gas constituents react to form methanol. Annually, approx. 16,600 t methanol are produced in the SVZ using the 42,500 t of pelleted SRF produced in the Dresden Waste Recycling Plant and 15% coal. This equates to 21.5 million liters. This can then replace around 16.5 million liters of petrol.

Picture 31.: *Pelleting machine of the Dresden plant in Germany*
(Wastesum project Del 3A., 2010)

The Dresden plant has been equipped with the thermal-regenerative waste air treatment technique. A prerequisite for the efficient use of this cleaning technology is the reduction of the waste air flow to be treated to the technically feasible minimum with simultaneous concentration of the TOC content contained in the waste air.

In the thermal-regenerative waste air cleaning process, the process air loaded with hydrocarbons is first heated using a ceramic heat exchanger module and then fed to the heating chambers situated above it, in which complete oxidation of the hydrocarbons to form carbon dioxide and water is ensured by a defined temperature level (>850 °C) and a defined retention time (>2 sec.). (Wastesum project Del 3A., 2010)

During the subsequent passing of the second ceramic heat exchanger, 98% of the heat energy taken up is returned to the heat exchanger. By cyclically switching over the 3 heat exchangers present, associated with intermediate flushing cycles for the prevention of "switching peaks", continuous operation that conforms with the requirements is guaranteed, even for the varying input concentrations that typically occur in the treatment of residual waste. (Figure 36.) shows the schematic flow of the Dresden plant in Germany.

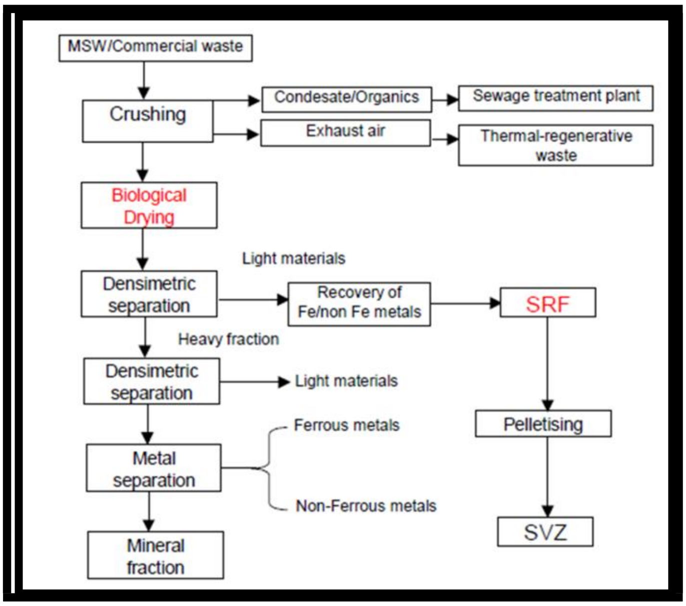


Figure 36.: Process diagram of the Dresden plant in Germany.
(Wastesum projectDel 3A., 2010)

7.3.5.TW Eldena grass drier

In Germany operates a grass drier facility in Eldena. The facility has been supplied with a VADEB DDD grass dryer, model DX-2000 by ' Vandenbroek

International'. In the **D**rum **D**rying system the product is **directly heated**. The exhaust gas flows directly into the rotating drum.

Picture 32.: *Grass drier facility*

The maximum drum inlet temperature is 650^0 Celsius. The total volume of the dryer exhaust is treated by de-dusting equipment and if needed, scrubber/condenser equipment. By recycling a part of the dryer (Figure 37.) exhaust gas to the dryer, the amount of airborne gas to the stack is strongly reduced.

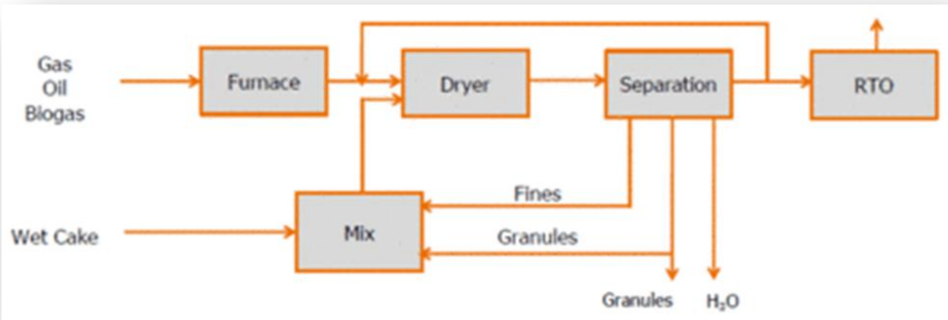


Figure 37.: The DDD drying system

The facility has an Evaporation capacity of16.000 l/h, a grass input capacity of 20.000 kg/h at 20% DS and a grass output capacity of 4.500 kg/h at 90% DS. Finally the facility has a need for thermal energy consumption of: 3,4 Mjoule/kg

H_2O and a temperature drum inlet range of: 200-650°Celsius. (Vandenbroek International., 2010)

7.3.6. The Rennerod plant, Germany

The delivery area of the Rennerod plant (Picture 33.) is divided into a deep bunker for household waste and a flat bunker for commercial wastes. Thus, an initial pre-sorting into fractions to be treated mechanically and/or bio-mechanically as well as a sorting out of the contaminants can take place in the latter using a wheel loader. During delivery the quantity and position of the waste is automatically transmitted to the crane system to feed the bunker.

Picture 33.*: The Rennerod plant in Germany*
(Wastesum projectDel 3A., 2010)

An automated delivery crane (Picture 34.) removes the residual waste from the deep bunker and feeds the downstream shredder. After the initial separation of ferrous metals, the residual shredded waste is passed via a conveyor belt system to a buffer bunker. At the same time, it is the interface or the handover point with the second process crane. The second process crane lifts the lids of the composting boxes and places them on a neighboring box. Then it fills the opened composting box with the shredded residual waste, re-lifts the box cover and sets it precisely on the filled box by means of a guide rail system. The Rennerod plant consists of 7 1/2 boxes.

Picture 34.: *Delivery crane in Rennerod plant in Germany*
(Wastesum project Del 3A. ,2010)

Then the aerobic decomposition takes place in the closed, air and liquid boxes (made of thermally insulated reinforced concrete) for 6 days. Moreover, it has to be mentioned that the residual waste is also sanitized during this time. As the air supply is adjusted to suit the biological needs of the decomposing microorganisms, the easily degradable organic substance is microbiologically converted in a very short time. The heat produced during this process is used to remove the moisture (condensate) and thus for drying the residual waste. The drying of the waste is the prerequisite for a separation of the waste mixture into clean fractions of its recyclables like metals/ inert materials/ glass and energetically usable SRF components. Condensate is separated out of the moist waste air via a heat exchanger system, which is then fed into a water treatment plant.

Following the completion of the drying stage, the composting boxes are emptied using the automated process crane analogue to the waste delivery. A condensate treatment (Picture 35.) is integrated in the Rennerod plant. The moisture contained in the waste is removed from the waste air in the cycle via a heat exchanger system. The condensate separated out is fed into a 2-stage cleaning plant, consisting of a high-performance biological stage and a downstream ultra filtration stage. Following this treatment process, the cleaned condensate (permeate) is fed into the cooling circuit of the system as service water and evaporates via an open evaporative cooler. In this way, the plant can operate without producing wastewater.

***Picture 35.**: The condensate treatment in Rennerod plant in Germany*
(Wastesum projectDel 3A., 2010)

The different materials are sorted out during the downstream process steps. Several process steps to separate the materials into their combustible and noncombustible materials are followed. The efficiency of these separation steps and the sorted quality of the different separated fractions depends from the dry state of the material. The materials are separated into:

- Solid Recovered Fuel (*Stabilat*)
- Mixed plastics fraction (as an option)
- Usable materials (Ferrous and non-Ferrous metals, inert substances/ glass)
- Contaminants (e.g. batteries)

The multiple stages, dry density sorting used initially separates the output from the composting boxes into the heavy and light fraction material flows. The dry, lightweight material virtually consists of 100% combustible constituents (such as wood, paper, plastics, textiles and organic materials). The calorific value of the *Stabilat* lies within the range of 15–18 MJ/kg and therefore represents an energy equivalent to processed and dried lignite coal. Due to its dry consistency, it can be easily stored and therefore used as a secondary fuel in industrial processes, where and when it is needed independent of the time and the region of waste production.

Before the heavy materials are recycled, they are subjected to additional treatment stages. However, these do not take place in the Rennerod plant but they are sent in the Asslar plant. The metal fractions separated out are sorted profitable into pure their materials and are fed into the used metal recycling system thereby. The separated batteries are recycled in a feedback.

The proportion of dust separated out over the whole process stage by fibrous filters is approx. 10% of the inert fraction. It is formed into pellets and due to its high calorific value it can be added to the *Stabilat*. The remaining material flow (mainly consists of ceramics, stones, porcelain and glass fragments) is subjected through the glass separation stage.

The glass fragments contained in the mixture are automatically identified by an electro-optical sorting device. With the aid of compressed air, they are diverted from their path and into a specific drop shaft. Following several runs of these steps of optical identification and separation using compressed air, four separate pure fractions are available for reuse:

- clear glass,
- green glass,
- brown glass and
- a mixture of ceramics, stones and porcelain.

The separation of the glass fractions contributes to a noticeable increase in the recycling proportion. The quality of the remaining mineral fraction approximately 35% complies with the requirements for use in road construction and as a result can be recycled accordingly. The RDF (*Stabilat*) produced in the Rennerod plant is fed into an energetic/material reuse in the:

- Cement kilns (Ruedersdorf)
- Methanol Plant (SVZ)

The process diagram of the Rennerod plant in Germany is shown in (Figure 38.)

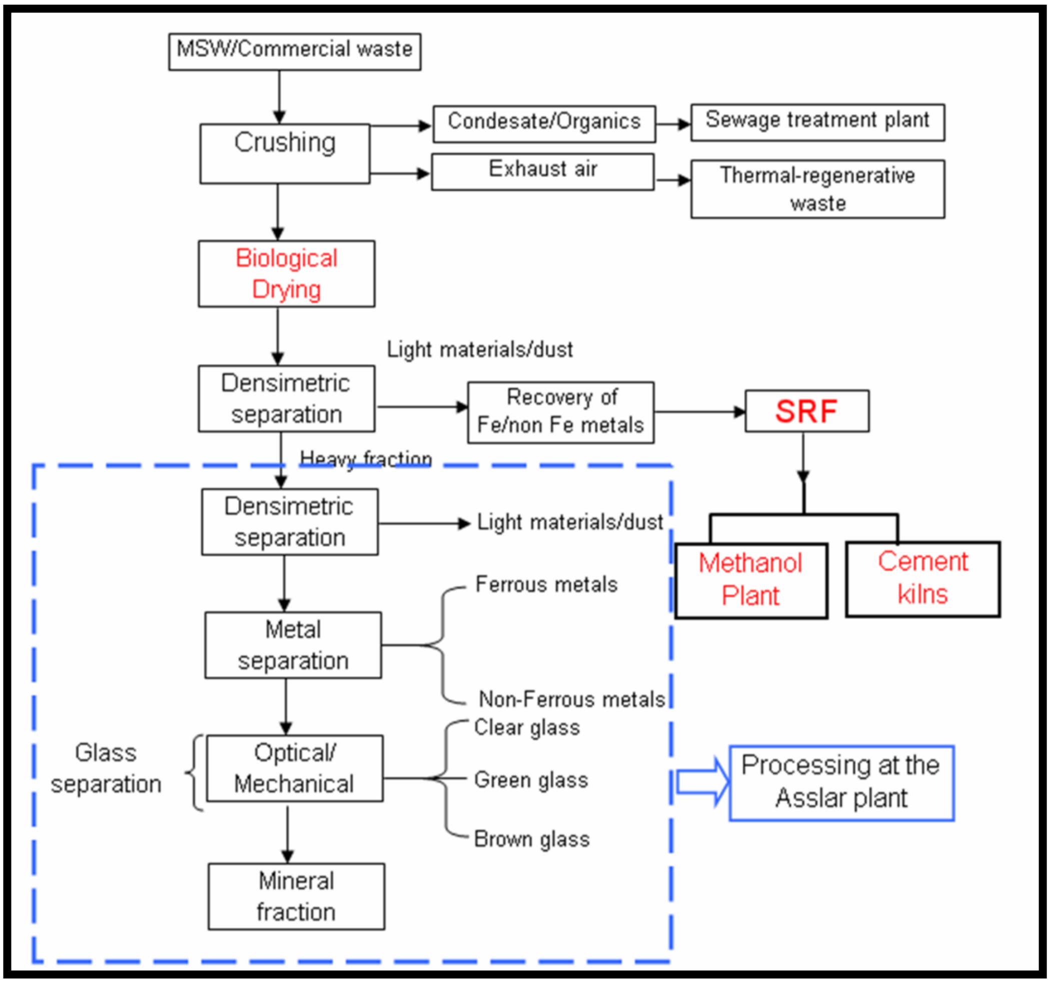


Figure 38.: Process diagram of the Rennerod plant in Germany.
(Wastesum project Del 3A. ,2010)

7.3.7. The Ludwigslust flexible compact system in Germany

Although the Ludwigslust (Picture 36.) is a small facility, with a maximum waste throughput of just 6 Mg/h, its capabilities measure up to those of large plants in terms of efficiency and environmental impact. Use of standardized components keeps waste disposal prices competitive. What is more, the plant's interfaces can be optimally adapted to the anticipated waste streams and regional circumstances. The single-train compact plant comprises a great combustion system, a steam generator with thermal system and energy recovery, and a flue gas treatment system.

The facility has interim storage for incoming waste as well as outgoing residues (slag and residues from flue gas treatment). Unlike other plants, Ludwigslust does not have a pit for waste unloading, but a separately situated building at grade. A remote controlled frontend loader, the first in the waste treatment industry, mixes the waste and conveys it to an area at one end of the building. From this head area, an automated crane draws the waste to charge the incineration system.

The reciprocating grate, made up of four zones, two of them with water cooling, ensures complete burnout of the waste. The steam generator is situated above the grate system to recover thermal energy for further utilization. Downstream of the combustion system is the flue gas treatment unit, which keeps the plant in compliance with government emission limits at all times.

Treatment takes place in two stages: destruction of nitrogen oxides by SNCR (selective no catalytic reduction) followed by semi-dry treatment for safe removal of gaseous pollutants as well as heavy metals and dioxins. Residues comprise slag for subsequent processing as well as residue from flue gas treatment for disposal. The 16 MW thermal output of the facility is used in a cogeneration scheme to produce electric power, which is fed into the local grid after plant service power is drawn.

What is striking about the Ludwigslust plant is its compact construction. After passing through the steam generator, the flue gas stream is deflected so that the flue gas treatment unit can be located next to the process building in order to save space. The stack is integrated into the building, and from outside the plant it is visible only as a short pipe above the roof.

Picture 36.: *The Ludwigslust plant in Germany (Wastesum project, Del 3A. 2010)*

(Figure 39.) presents schematically the operation of the Ludwigslust plant in Germany.

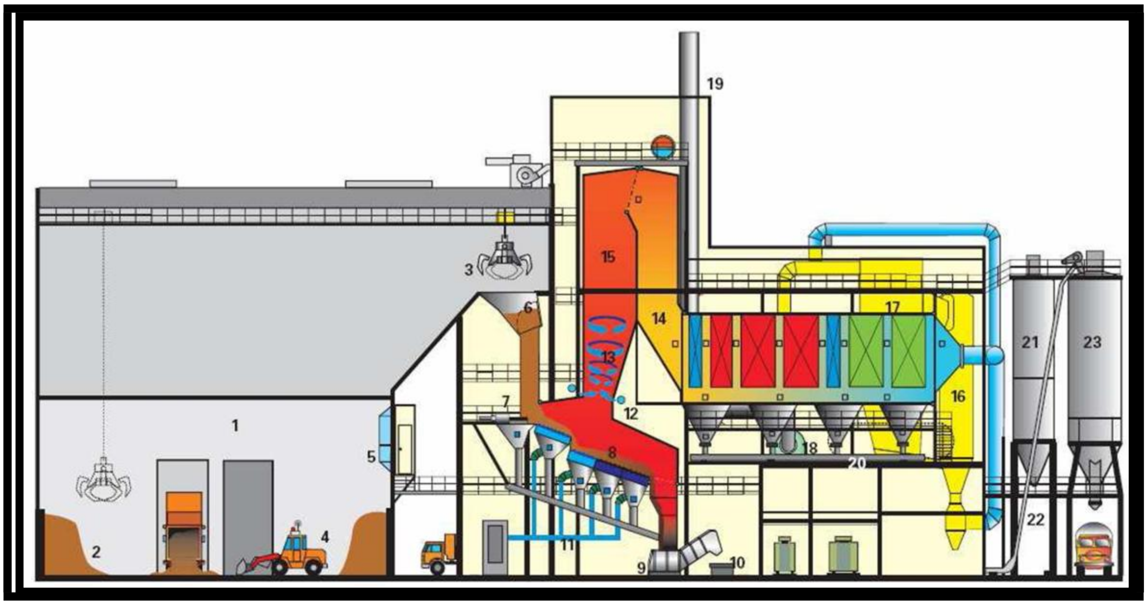


Figure 39.: Schematic operation of the Ludwigslust plant in Germany.
(Wastesum project, Del 3A. 2010)

Waste receiving and storage
1. Waste receiving area
2. Waste storage
3. Waste crane
4. Front-end loader
5. Loader control cabin

Grate incineration and steam generator
6. Feed hopper
7. Ram feeder
8. Reciprocating incineration grate
9. Ram slag extractor
10. Slag conveyor
11. Primary air distribution
12. Secondary air injection
13. Auxiliary burner
14. Three-pass steam generator

Flue gas treatment
15. SNCR injection levels
16. Reactor
17. Bag filter
18. Induced draft fan
19. Stack

Consumables and residues
20. Ash removal
21. Silo for hydrated lime/lignite coke mixture
22. Residue transport
23. Residue silo

8. Sweden

The Swedish strategy

All parties participate in this work – from producers to households. The producers are responsible for their various product groups, the local authorities are responsible for the household waste, and the operators in the sector are responsible for taking care of all waste which is not household waste. The households have the responsibility to separate paper, packaging, electric waste, batteries, and bulky waste and to leave this waste for the collection systems available. Households also have the responsibility to follow the regulations for waste management within their municipality. (AÖS., 2009)

The EU waste hierarchy characterizes the Swedish waste management system: waste prevention, reuse, material recycling, recovery – for example energy recovery – and last, disposal. EU decisions set the frameworks for Swedish waste management. The environmental objectives of the Swedish Parliament govern the waste management and its environmental aspects. By 2015, at the latest, at least 60 percent of phosphorus pollution in effluent shall be treated and used on productive lands, of which at least half should be used on arable land. (AÖS., 2009)

8.1. Waste management situation

The most important environmental objectives set in Sweden (refer to 2010) are:

- By 2010, at the latest, a minimum of 50 percent of household waste shall be recovered through material recycling, including biological treatment.
- By 2010, at the latest, a minimum of 35 percent of food waste from households, restaurants, large-scale kitchens, and stores shall be recycled through biological treatment. The objective refers to sources separated food waste for both home composting and central treatment.

- By 2010, at the latest, food waste, and consequently also equivalent waste from food industries etc., shall be recycled through biological treatment. The objective refers to waste not mixed with other types of waste, which subsequent to treatment is of sufficient quality that it is suitable for crop production. (AÖS., 2009)

The most important treatment methods for waste are:

- Material recycling
- Biological treatment
- Waste-to-Energy
- Landfill

Hazardous waste as a special type of waste can be treated with anyone of the above methods. Either one or a combination of them can be used . Biological treatment can be implemented only through anaerobic digestion or composting. The Anaerobic digestion process produces the biogas which in turn can be used as vehicle fuel. The total quantity of biogas produced from waste treatment with the (AD) process, is equivalent to 30 million liters of petrol. The final product of the (AD) called digestate comprises an excellent nutrient. The composting process produces a high quality fertilizer called (the compost) which is used as a soil improver in parks, gardens and ground installations. (AÖS., 2009)

The Waste incineration process is also widely used in Sweden. It is used for producing energy from waste (thermal energy and electricity). Every year it produces heating which corresponds to the need of 810,000 households, approximately 20% of all the district heating produced. It also produces electricity in a quantity which corresponds to the need of more than 250,000 houses. Finally the landfilling treatment method is still been used for these waste which cannot or should not be recovered or treated in another way (such as some types of hazardous waste or ash). Through landfilling, waste is kept in a long-term safe way, and the treatment method is controlled by a strict regulatory framework. (AÖS., 2009)

The choice of the organization of a waste management system, represents a decision of the local authorities . This possibility of municipal self-government is laid down in the Swedish constitutional law. The local authorities can choose management mode or municipal undertakings, separate or joint with other municipalities. Cooperation among the Municipalities, is also possible with a joint committee or local government federation. There are also local authorities who collaborate on specific matters, such as joint procurements. To many local authorities collaboration is a natural solution to attain the best possible environmental and social benefits, to achieve cost-efficient treatment and to guarantee the competence required. In 75% of the municipalities the collection of household waste is managed by external actors, private companies, while the rest is managed by the municipalities themselves. In the same way, waste treatment is effected either by the municipalities themselves or by an external actor, often a municipal enterprise or sometimes a private company. (AÖS., 2009)

8.2. Collection and transport

Bulky and Hazardous waste are transferred by the householders to one of the recycling centers operation in each of the Municipalities. Bulky waste is household waste that is too heavy, too bulky or for other reasons inappropriate for collection in bags or bins. It may be for example broken furniture, toys, bicycles, or baby prams, but can also include garden waste or certain demolition waste. There are about 650 recycling centers in the country. These can handle the main part of household bulky, hazardous and waste from electronic or electric equipment. During 2008 approximately 1,400,000 tons of waste was handed to the municipal recycling centers, which corresponds to 154 kg per person. Each recycling center received on average 8,240 visitors that year, or 5,3 million visitors in total. (AÖS., 2009)

The only serious problem encountered in the recycling centers is burglaries from thieves and sometimes problems with people coming to the centers such as (arguments, lack of communication,etc). The measures taken in order for the thieves to be stopped is electric fences all around the facilities so that no one can have access to them without permission. Another meter introduced by several of the municipalities is a barrier gate system at recycling centers to improve the safety, to get a functional system for access control and to obtain more accurate visiting statistics. This system is often combined with an entry card which gives households the right to a certain number of free visits. For a fee, small entrepreneurs also have the possibility to use the services offered at the recycling centers in several of the municipalities. (AÖS., 2009)

The producers' system, with approximately 5,800 unmanned recycling stations for packaging and paper, are located around the country. The collection systems should be formed in consultation with both producers and local authorities. The recycling stations have separate containers for newspaper and different types of packaging materials. Several municipalities have implemented curbside collection of material which falls under producers' responsibility, from apartment blocks and detached house properties, a collection system which is becoming more common. (AÖS., 2009)

Almost half of all municipalities in the country now have collection systems for source separated **food waste**. The most common collection systems are collections with separate containers, one for bio-waste and one for combustible waste, collections with a multi-compartment system, or through optical sorting of different colored bags that are placed into the same container. The most common ways to collect the household waste in bins and bags is either as a mixed waste fraction intended for waste-to energy incineration, or through two separated waste fractions – one for food waste and one for combustible waste.

Collection in bags constitutes a working environment risk and has therefore become considerably less common. Mixed combustible waste from single-family houses is in most cases collected in 190 liter wheelie bins and emptied every other week. Other than this, there are a number of different bag and bin sizes which are collected and emptied in various intervals. Waste from apartment blocks is normally collected weekly. Traditional back loading vehicles are still the most common when it comes to waste collection, but the technology for multi-compartmented vehicles is developing and becoming more and more popular, while side-loading vehicles account for a more constant share of the operators' vehicle fleet. An increasing number of vehicles use biogas as fuel, which the local authorities may control through purchasing requirements. (AÖS., 2009)

Today collection of waste with bags has been reduced. Manual handling of waste is being replaced by new technology and automated systems, such as refuse vacuum pipes and underground container systems. Both of these systems are becoming more common, particularly in bigger cities. One of several advantages is that they do not require heavy manual handling. From the point of view of health and safety at work, vacuum collection systems are good since they are sealed and completely automated. This type of collection system reduces the need for waste transportation, especially in residential areas.

There are two kinds of vacuum collection systems, a stationary system and a mobile system. With the stationary system the waste is collected using air in an automated vacuum system. It is thereafter transported through underground tubes, which connect the inlets with big containers placed in a terminal. With this technique the waste can be transported up to a distance of two kilometers from the inlets. The number of containers varies and depends, on the one hand, upon the number of collected fractions, and on the other hand, on the waste volumes. The containers are collected by hook-lift vehicles.

The mobile vacuum collection system also uses air to collect the waste. However, here the vacuum technique originates from the vehicle. Positioned under each input is a storage tank. The tanks are connected, via an underground pipe system, to a so called docking point which could be placed at a maximum distance of 300 meters from the tanks. The vehicle connects to the docking point for emptying, the vacuum system is turned on and air transports the waste from the different storage tanks to the docking point and further onto the vehicle. Mobile vacuum collection systems require specialized vehicles. (AÖS., 2009)

Another collection system that is on the rise is the underground container (Picture 37.) system. By placing containers underground, the need for space on the street level is reduced. The temperature below the street level, where the waste is contained, is relatively low, which prevents odor, and the containers can be easily emptied with a crane truck. There are also underground containers which are emptied with front-loading vehicles. Since the underground containers can hold bigger volumes, the level of transports is reduced. (AÖS., 2009)

Picture 37.: *Underground container*
(AÖS., 2009)

8.3. Waste quantities 2008

In 2008, approximately 4,731,660 tons of household waste was treated, a small increase of 0.3 percent compared to 2007. According to the population, this means that every Swedish resident produces 511,2 kg of waste per year. There have not been any significant changes regarding the division of waste between different treatment methods over the last years**. 97 % of household** waste is recovered, while only 3 percent goes to landfills, a reduction of close to 25 percent compared with 2007. (AÖS., 2009)

Material recycling has decreased somewhat, and is now at 35 %, while incineration with energy recovery has increased, and is now 48.5 %. Biological treatment, anaerobic digestion or composting, has also increased and now represents 12.6 percent. 597,280 tons of household waste was treated biologically last year, which is an increase of close to 36,000 tons or 6.4 percent. Park and garden waste as well as food waste are included in those figures. (AÖS., 2009)

Material recycling, excluding biological treatment, has decreased by close to 80,000 tons or 4.6 %. 1,657,840 tons of packaging, paper, electric waste and metal from the municipal recycling centers was taken care of through recycling. 2,292,970 tons of household waste was treated through incineration with energy recovery, an increase of 4.7 percent and more than 100,000 tons.

Landfill disposal continues to decrease. 140,250 tons of household waste went to landfills in 2008. This is a decrease of 46,000 tons from the previous year, or 24.8 percent.

Hazardous waste still represents 0.9 percent of treated household waste. 43,320 tons was collected last year. Almost half of that waste was impregnated wood, 21,380 tons, a fraction which has increased considerably in the last years. (AÖS, 2009)

	2004	2005	2006	2007	2008
Hazardous waste	2.9	2.9	4.3	4.5	4.7
Material recovery	153.7	162.9	181.9	189.2	179.1
Biological treatment	48.1	50.2	51.6	61.1	64.5
Incineration with energy recovery	215.8	241.2	231.3	238.6	247.7
Landfilling	42.2	23.2	24.8	20.3	15.2
Total	462.6	480.5	493.8	513.7	511.2

(Table 5.): *Quantity of treated household waste 2004-2008 (KG/Person)* (AÖS, 2009)

In 2008, 597,280 tons of household waste was biologically treated (Figure 40.). An increase of 6.4 percent compared to 2007. In total that means that 64.5 kg of food waste and green waste per person was biologically treated in 2008. The biological treatment now stands for 12.6 percent of the total quantity of treated household waste. 133 of 290 municipalities already have more or less implemented systems for collection of food waste. 22 of these only collect food waste from restaurants and large-scale kitchens, while the remaining 111 municipalities have systems for households as well.

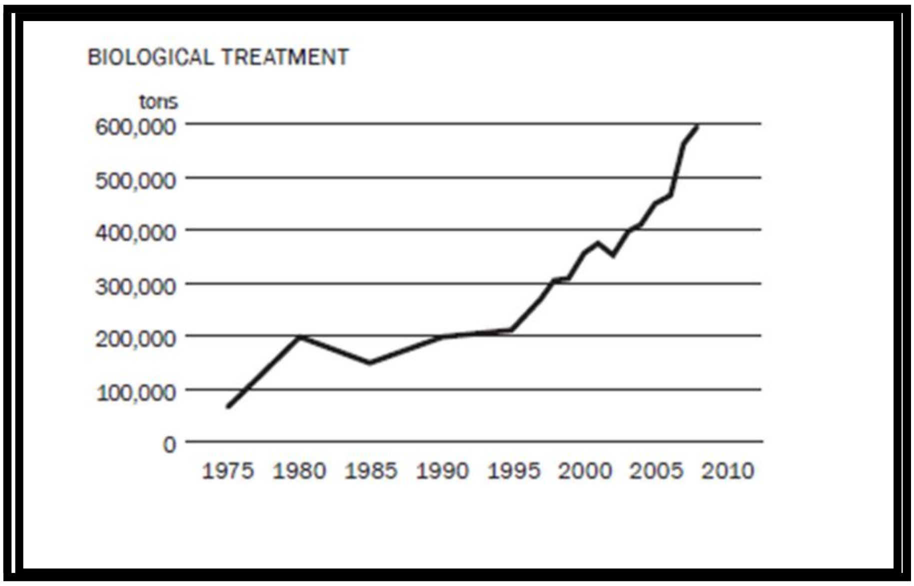


Figure 40.: Biological treatment through decades in Sweden
(AÖS., 2009)

These municipalities represent half of the Swedish population. According to a study carried out by Avfall Sverige, an additional 90 municipalities are planning to introduce systems for source-separation of food waste. The same study shows that all municipalities need to act in order to reach the environmental objective. According to Avfall Sverige calculations, an estimated 20% of the food waste was biologically treated in 2008.

Waste analysis (Table 8) shows that every Swedish resident produces close to 100 kg of food waste every year, mainly from fruit and vegetables. The most common system used for source separation of food waste in single-family houses is two separate bins, one for food waste and one for combustible waste. There is also a system where different fractions are separated into separate containers. Another collection system, which is used, is optic sorting of different colored bags that are put into the same container. Through anaerobic digestion of biological waste, biogas, consisting of methane and carbon dioxide, is produced. (AÖS., 2009)

Biogas is renewable and the most environmentally sound fuel available, and can be used for vehicle fuel, heating and electricity generation. In order to use biogas as vehicle fuel it needs to be upgraded. In 2008, 280,000 MWh of biogas was produced, which is equivalent to 30 million liters of petrol. Biogas is today primarily used as vehicle fuel, a market which is developing quickly.

Anaerobic digestion also produces digestate, which is an excellent fertilizer. 389,350 tons of digestate was produced in 2008, of which 96 percent was used in farming. The remaining 4 percent was either dehydrated and/or processed with after-composting.

The compost produced at plants (Table 6.) is mainly used as soil improver or in soil mixtures. Plants which produce compost or digestate from source separated bio-waste, including food waste from the food industry, can have their product quality marked. The quality assurance system has been developed by Avfall Sverige, among others. (AÖS., 2009)

	2004	2005	2006	2007	2008
Anaerobic digestion	244,374	258,071	283,729	356,087	405,580
Composting	389,384	459,827	452,388	515,294	568,700
Total biological treatment	633,758	717,710	736,117	871,380	974,280
of which food waste	107,028	118,960	134,994	166,807	162,680
Total quantity of household waste treated biologically	433,830	454,450	469,877	561,303	597,280

(Table 6.): *waste treatment statistics*

(AÖS., 2009)

Certification places requirements on the entire waste management chain, from the incoming waste to the final product. A number of plants are currently going through the process of having their products certified. Eight biogas plants and three composting plants have obtained certificates. A voluntary undertaking to minimize the emissions from biogas and upgrading plants was initiated by

Avfall Sverige and further developed throughout 2008. Air emissions may arise from different stages of biological treatment through anaerobic digestion of organic material and in biogas upgrading processes in treatment plants. Even though the emissions from biogas plants are low, they should be minimized for several reasons. They can be attended to by putting a larger focus on operational issues. Approximately 30 biogas and upgrading plants have signed up for the voluntary undertaking. (AÖS., 2009)

Composting	Total (tons)	of which household waste
Alingsås	3,620	3,510
Borlänge	12,400	11,810
Borås	8,950	2,670
Eslöv	16,310	12,010
Fagersta	4,090	780
Gällivare	6,920	560
Göteborg	25,430	24,410
Habo	790	290
Halmstad	25,420	1,760
Helsingborg	55,320	39,940
Huddinge	12,900	12,900

Hässleholm	12,300	10,120
Karlshamn	12,240	9,740

(Table 7.): *Compost produced in some Sweden's compost plants*
(AÖS., 2009)

8.4. Best practices

8.4.1. Stockholm concept

The substrate used today for biogas production in Stockholm is sewage sludge from the wastewater treatment mainly. Other substrates co-digested with the sewage sludge are grease trap removal sludge from restaurants and institutional kitchens and some pumpable food waste from restaurants, institutional kitchens and market halls. *(Chemical Engineering and Technology department KTH., 2007)*

The wastewater treatment plants are Henriksdal and Bromma, both owned by *Stockholm Water Company*, SV in (Figure 41.).

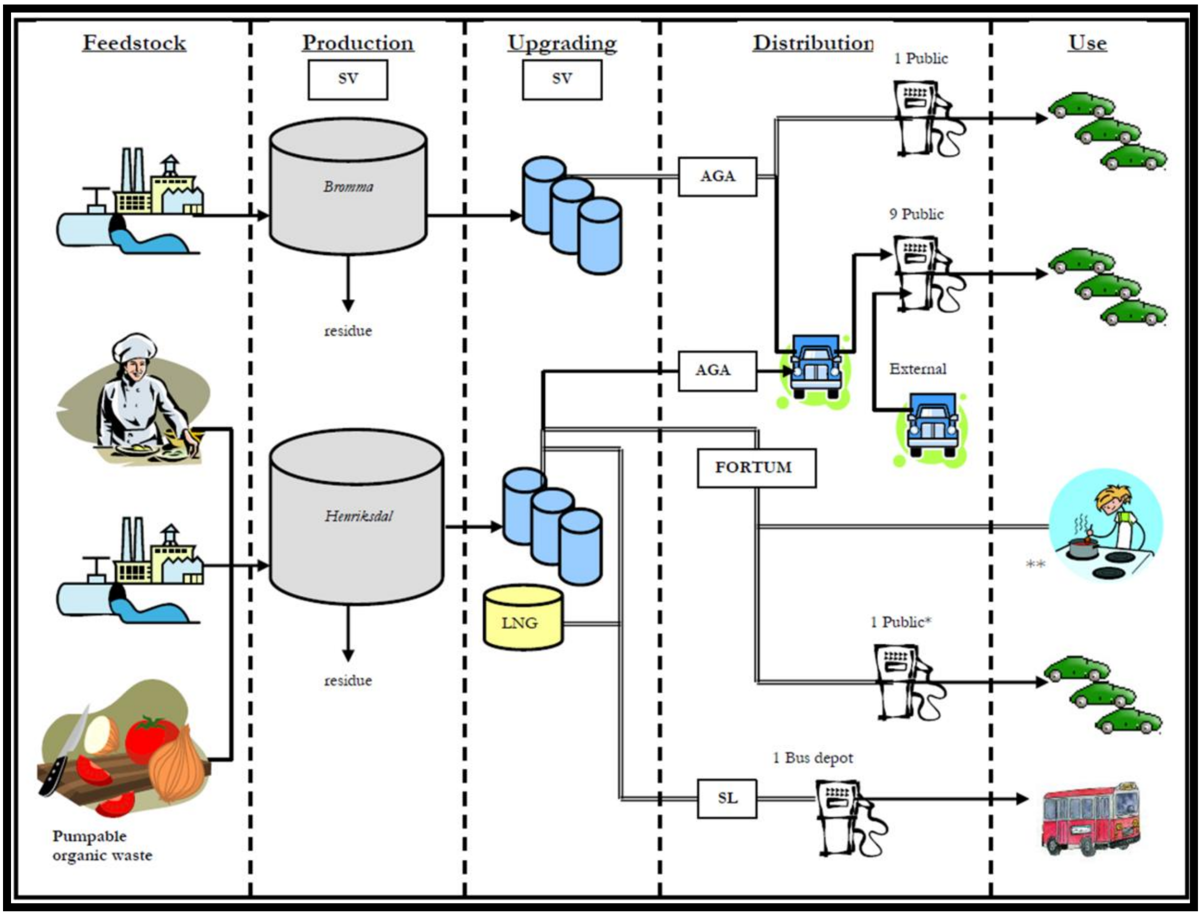


Figure 41.: Stockholm concept
(Chemical Engineering and Technology department KTH., 2007)

The Henriksdal WWTP was built in the 1940s and it is, as well as the digesters, mainly located inside a rock. The upgrading plant is placed on the top of the rock. The plant was built inside the rock due to the risks for bacteria and odor diffusion, since there was a mill located not far from the area. A residential area is located on top of the rock. The safety distance for localization of a biogas plant is 50 meters from residential buildings and premises hard to evacuate, such as schools, hospitals etc.

The external organic material received at the plant is as mentioned earlier grease trap removal sludge and small amounts of other pumpable organic waste from restaurants, institutional kitchens and market halls. The sludge is transported to the plant by special slurry exhauster vehicles and since the plant is located within the city of Stockholm, the distance is not very long. The central location also facilitates a future possibility of household waste treatment at the plant. The produced gas is upgraded at each plant and distributed either through gas pipe or by vehicles with swapbody units. From Henriksdal there is one gas pipe providing the local transport buses and one providing a public refueling station at Hammarby Sjöstad. The distribution to the fast-filling bus depot is made by SL, *Stockholm Transport*, and to Hammarby Sjöstad by the energy company *Fortum*. At Hammarby Sjöstad, the gas from Henriksdal is used for residential cookers as well. *(Chemical Engineering and Technology department KTH., 2007)*

The remaining gas is purchased by the company *AGA*, and distributed by vehicles to the public refueling stations within Stockholm County. There are as mentioned 11 public refueling stations and 3 to be built in 2007 within the region. In addition, there are 3 refueling stations used only by the producers themselves, for their service vehicles. The production plant at Bromma has one public refueling station, which is provided by a gas pipe, although most of the gas is distributed by vehicles. Practically all gas produced at Bromma is purchased and distributed by *AGA*.

Some of the biogas supplying the public refueling stations in Stockholm is imported from Linköping and Västerås. The quality of the digestion residue is, according to (2005) environmental report, sufficient for use in the agriculture. But still, practically the entire amount of residue, 69 000 tones, was used for after-treatment at mines, whereas 3000 tones was used as fertilizer on arable land, in 200519. The residue can also be used for end covering of landfills. *(Chemical Engineering and Technology department KTH., 2007)*

Municipal organic waste separation

The municipal organic waste separation for households is voluntary and it is up to each household if they want to have the special containers and bags for the organic waste. If you decide to receive the service you will have a special container, bags made of cornstarch and a bag holder delivered to you. The food waste is then placed in the bags, which are placed inside the special container. The waste is picked up every 14 day by a particular vehicle, which transports the organic waste to a treatment plant in Huddinge, south of Stockholm. The plant is a composting plant and the waste is turned into soil. The bags made of cornstarch cannot be digested, consequently they have to be specially treated, or replaced by another type, before a future digestion process is possible. This kind of separation is only made to a very limited extent.

The restaurants can also have a special container for the food waste delivered. The food waste is placed in a bag inside the container, which is stored cold. These types of bags are compostable and digestible. The waste is picked up by a waste vehicle, particularly designed for the wet food waste, and transported to the treatment plant n Huddinge, but to their digesting plant Ecoferm, (Picture 38.).

***Picture 38.**: The Ecoferm biogas plant in Huddinge*
(Chemical Engineering and Technology department KTH., 2007)

The Ecoferm plant is a pilot plant, receiving 4 000 tones of organic waste yearly. The gas produced is not upgraded to fuel quality, but used for district heating. The grease trap removal sludge from restaurants, cafés, institutional kitchens etc is collected by slurry exhauster vehicles and delivered to the wastewater treatment plant at Henriksdal. The sludge is digested there and Biogas is produced and upgraded to vehicle fuel.

At Henriksdal liquid food waste from market halls in Stockholm is treated as well. The waste is collected by slurry exhauster vehicles and pumped into the plant for co-digestion with the sewage sludge. An increase of the separation and biological treatment of municipal organic waste is a project suggested in Stockholm. The aim, set by *Stockholm Waste Management Committee* in 2003, is to treat 33 000 tones of food waste biologically in 2010. This represents 35 % of the total food waste from households, restaurants, institutional kitchens and grocery stores in Stockholm, and is a measure to reach the national 35%-goal mentioned in earlier. *(Chemical Engineering and Technology department KTH., 2007)*

By biological treatment, digestion as well as composting is intended. The quantity of biologically treated waste in 2005 was 2 720 tones, and additionally 500 tones by home composting. Accordingly only 10 % of the total goal amount was fulfilled in 2005. The collection has to be greatly increased to reach the 35 %-goal.

As mentioned earlier, *Stockholm Traffic Office* together with the *Stockholm Water Company* has an experiment in progress. The purpose is to increase the separation of food waste and treat it biologically. Waste mills will be placed in restaurants, grocery stores and school kitchens. The food waste placed in the mill will be ground and transported to a tank, which is emptied by a slurry exhauster vehicle. *(Chemical Engineering and Technology department KTH, 2007)*

8.4.2. Linköping concept

In Linköping the production of biogas has come a long way and the company *Svensk Biogas*, subsidiary to the regional company *Tekniska Verken*, produces biogas in three different plants, whereas two of them apply solely for biogas production. The substrates used at the Åby plant are slaughter house waste, organic waste from industries, restaurants and institutional kitchens and a quantity of manure. The waste water treatment plant Nykvarn uses some grease trap removal sludge in addition to sewage sludge. The gas produced at Nykvarn is lead through a gas pipe to the Åby plant, where it is upgraded. The concept is illustrated in (Figure 42.)

The produced gas is distributed to refueling stations and to the local bus depot in Linköping by gas pipes. One of the local refueling stations, located close to the production plant and the bus depot, can be seen in (Figure 4.36). The buses are slow-filled over the night. Distribution to surrounding cities, without their own CBG production, is made by vehicles with swap-body units. The refueling stations in Norrkoping have been supplied by gas from Linköping earlier, but since the new plant Händelö is in operation the stations are locally supplied. Except distribution to other surrounding cities, some of the CBG produced in Linköping is purchased by *AGA* and distributed to Stockholm.

The new plant Händelö in Norrkoping uses refuse from ethanol production and residue from crop production in the agricultural industry as substrates. The produced gas is upgraded at the plant and distributed to refueling stations in Norrkoping by vehicles with swap-body units. Distribution of gas to surrounding cities also takes place. A gas pipe in Norrkoping was constructed in August 2007. *(Chemical Engineering and Technology department KTH., 2007)*

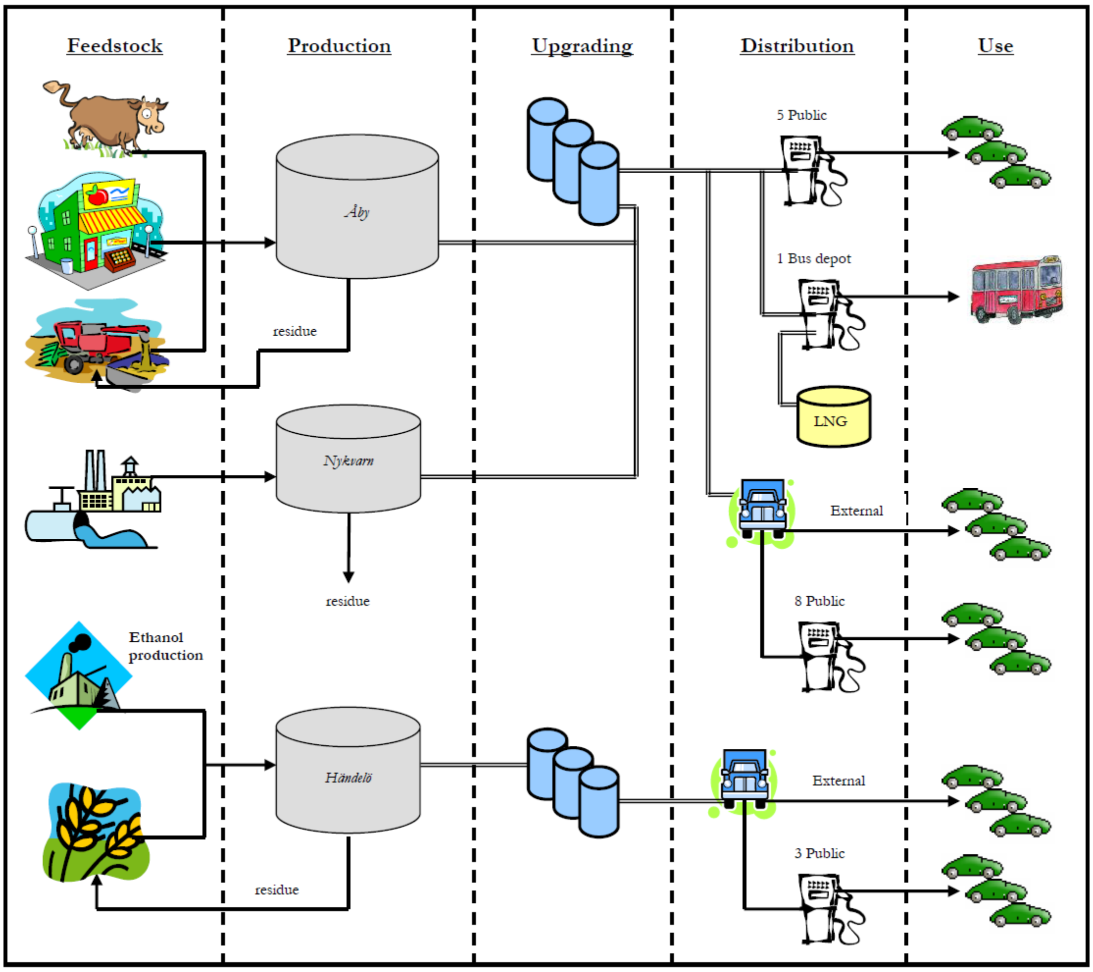


Figure 42.: Linköping concept
(Chemical Engineering and Technology department KTH,. 2007)

***Picture 39.**: Public fuelling station in Linköping*
(Chemical Engineering and Technology department KTH., 2007)

The residue produced at Händelö, as well as Åby, is used as fertilizer in the agriculture. The fertilizers produced at Händelö is KRAV-labeled, and therefore certificated for organic farming. KRAV is an organization working with the organic market in Sweden. They are active members of IFOAM – International Federation of Organic Agriculture Movements and they promote the KRAV-label. The fertilizer produced at Åby plant is certificated for conventional farming.

The Åby biogas plant is located close to the wastewater treatment plant Nykvarn, which was an important reason for the location since the biogas produced at the Nykvarn plant could be upgraded at the same upgrading plant. Another important advantage with the location was the distance to the substrate, i.e. the slaughter house, which was located nearby as well. Some of the liquefied waste from the slaughter house is actually transmitted to the plant by pipes. *(Chemical Engineering and Technology department KTH., 2007*)

The Åby plant (Picture 40.) is located only 1 km from the city of Linköping, which is an advantage when distributing the gas to refueling stations. The location is also close to the waste treatment plant Gärstad, at which the municipal household waste is incinerated and all different kinds of waste is treated.

***Picture 40.**: The Åby plant in Linköping*
(Chemical Engineering and Technology department KTH,. 2007)

The organic waste from households in Linköping is delivered to the waste incineration plant Gärstad. The municipality of Linköping is responsible for the waste treatment and the company *Tekniska Verken*, owned by the municipality, is the owner of the incineration plant as well as the Åby biogas plant. By charging the waste treatment by weight, the households are encouraged to do their own home composting. The biogas plant Åby receives organic waste from restaurants, institutional kitchens, slaughterhouses and other industries. But due to the safe quality policy of *Tekniska Verken* the household waste is not received in the plant. It is difficult to secure the quality of household waste, and it needs to be quality assured to be used as fertilizer.

The Gärstad treatment plant is owned by *Tekniska Verken* as well. There is a farm located close to the production plant, but the closest residential buildings are those in the city, 1 km away. In the other directions the distance are 1,5 and 3 km to the nearest residential building areas.

The pumpable organic waste is brought to the plant by biogas fuelled slurry exhauster vehicles. The other organic material is transported in container vehicles, which are not biogas fuelled. The transport distances of substrates are in some cases very long, since industrial waste from cities in a wide region is utilized. If the biogas production is extended over a wider region the distances of transports could be shortened.

The new biogas plant at Händelö is strategically located close to the substrate since the bio ethanol plant, from which the refuse is used, is located next door. The residue from the agricultural crop production is easily available here as well. *(Chemical Engineering and Technology department KTH., 2007)*

8.4.3. Västerås concept

Växtkraft (Figure 43.) is a project in Västerås with the purpose to treat source separated household waste with (Figure 44.) ley crops and other suitable organic waste. The partners in the project are *Vafab-Miljö*, *Mälarenergi* (the local energy company), *LRF* (the National Federation of Swedish Farmers), and 17 farmers living in the surroundings. *(Chemical Engineering and Technology department KTH,. 2007)*

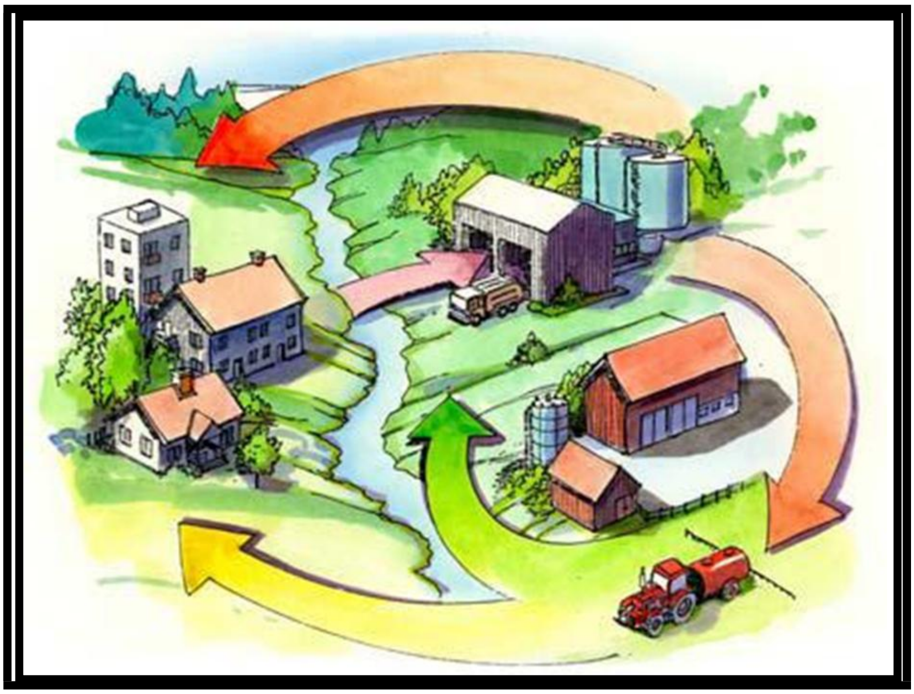


Figure 43.: The life-cycle of the Växtkraft project in Västerås
(Chemical Engineering and Technology department KTH., 2007)

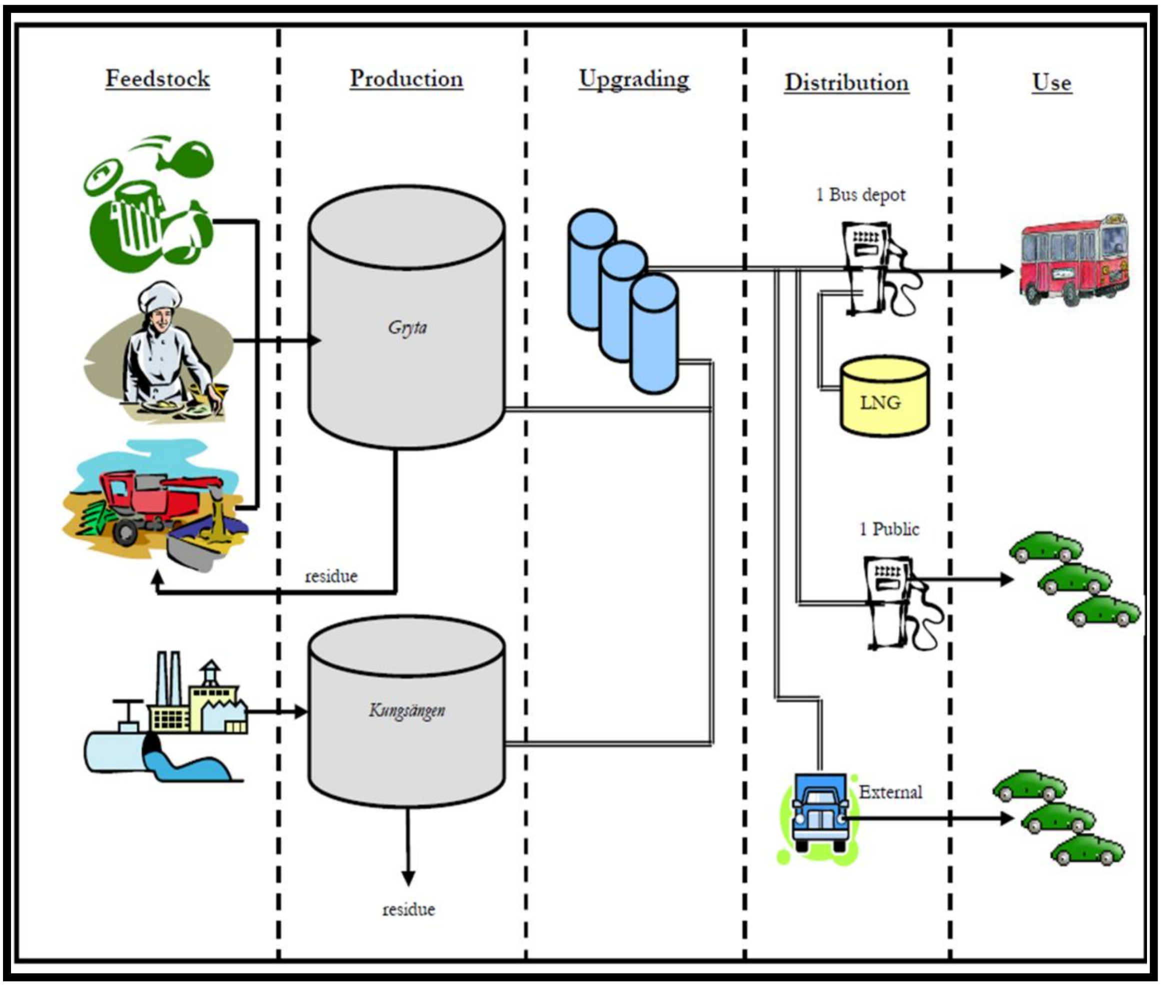


Figure 44.: Västerås concept
(Chemical Engineering and Technology department KTH., 2007)

The municipal organic waste is source separated and used as a substrate together with grease trap removal sludge from institutional kitchens and restaurants and ley crops from the agriculture in the biogas plant Gryta. The sludge in the wastewater treatment plant in Västerås is not co-digested with other substrates, since there are difficulties holding a high-quality residue when sewage sludge is used.

Hence there are two production plants, but only one upgrading plant. The biogas produced at the wastewater treatment plant is lead through an 8,5 km long gas pipe to the upgrading plant at Gryta. The upgraded biogas is distributed through gas pipes to the only public refueling station in Västerås and to the fast filling bus depot, (Picture 41.). Some of the produced CBG is purchased by *AGA* and distributed to Stockholm. *(Chemical Engineering and Technology department KTH, 2007)*

Picture 41.: *The fast filling station for busses in Västerås*
(Chemical Engineering and Technology department KTH, 2007)

The residue produced is KRAV-labeled and accepted in organic farming according to EC-regulations. It is used as agricultural fertilizer by farmers, who are also part of the Växtkraft project.

The idea to cooperate with the farmers started in the end of 1980s when politicians and employees realized that a new treatment system for the organic waste was needed. At the same time the local farmers considered an improvement in the soil structure, as the region has a very sensitive soil. Together with the Agricultural University in Uppsala the idea of digesting ley crops to produce fertilizer and biogas was examined. The cooperation between the farmers and *Vafab* started in the middle of the 1990s. Plans to build an organic treatment plant for co-digestion of agricultural crops and household waste started. *(Chemical Engineering and Technology department KTH., 2007)*

A condition for the Växtkraft project (Picture 42) is that the digestion residuals are accepted as a fertilizer. The farmers does not accept the residuals if the purchasers of the crops does not. Therefore the farmers must be ensured the purchasers accept the digestion residuals. A lot of work has been done to guarantee that the residuals produced are accepted as fertilizers for conventional farming, as well as organic farming. The participation by *LRF* (the National Federation of Swedish Farmers) has been important for the agricultural side of the project. They have contributed with economical security and legitimacy. *(Chemical Engineering and Technology department KTH., 2007)*

Picture 42.: *The Växtkraft biogas plant in Västerås*
(Chemical Engineering and Technology department KTH,. 2007)

Bio-waste

In Västerås there are three alternatives of handling the bio waste:

1. You can participate in the source separation scheme, which means that you put the bio waste in particular paper bags, see (Picture 43.) below. The bags are kept in the kitchen and placed in a ventilated plastic bin when it is filled. They are collected separately and treated at the biogas plant.

2. Another alternative is to have home composting in the backyard.

3. The last alternative is to not separate the waste at all. The bio waste is treated with residual kitchen waste, which means that it is incinerated. *(Chemical Engineering and Technology department KTH., 2007)*

***Picture 43.**: Paper bag with household waste at the input station at the biogas plant in Västerås*
(Chemical Engineering and Technology department KTH,. 2007)

There are lower fees for those who are source separating and the quantity of participants in the source separation scheme is very high – approximately 90 % of the households participate in the scheme. The bins are placed outdoors in residential districts and indoors, in separate refuse chambers or recycling houses, in apartment buildings. The bio waste is collected biweekly in residential districts and once a week in apartment building areas.

The bio waste from institutional kitchens is handled in the same way. Slurry exhauster vehicles collect the grease trap removal sludge from restaurants and institutional kitchens and deliver it directly to the biogas plant.

The *Waste Management Administration of Västerås* is responsible for the collection of the waste from households and restaurants and the transport to the treatment plant. *Vafab*, which is a regional company founded by the municipality of Västerås together with surrounding municipalities, has the responsibility to treat the municipal waste. The waste must be quality controlled, and *Vafab* is responsible for the quality control as well. At the quality control foreign materials are separated and tests are made to ensure the quality demands are fulfilled. *(Chemical Engineering and Technology department KTH, 2007)*

8.4.4. The Ljungsjöverket plant in Sweden

(Picture 44.) Presents the waste incinerator plant in Sweden. The plant incinerates household waste from Ljungby and the surrounding municipalities and has an annual capacity of up to 35,000 tons of unsorted waste. The maximum boiler effect is 18 MW. The fly ash from the plant is collected in big-bags and deposited at the local refuse dump where a class 1 deposit has been established. The slag from the plant is driven to Malmö for screening, following which the main portion (80-85%) is transported back to Ljungby for re-use or depositing.

***Picture 44.**: The Ljungsjöverket plant in Sweden*

Since December 2000 the plant has, by and large, supplied Ljungby with district heating throughout the winter period. During the summer, when heating requirements are low, the town receives its heat from an old wood chip fired plant. The waste generated during the summer is therefore pressed into bales and stored until needed again for heating during the winter. (Table 8.) shows the plant data while (Figure 45.) represents schematically the plant's operation.

Nominal capacity	8.2 t/h at 9.0 MJ/kg
Max. continuous capacity	10.5 t/h at 7.0 MJ/kg
Steam data	16 bar, 217°C
Steam production	28.3 t/h
Electricity generation	1.7 MW
District heating production	18.9 MW
Flue gas cleaning	Semi-dry scrubber with bag filter

(Table 8.): The Ljungsjöverket plant in Sweden data

(Wastesum project Del 3A., 2010)

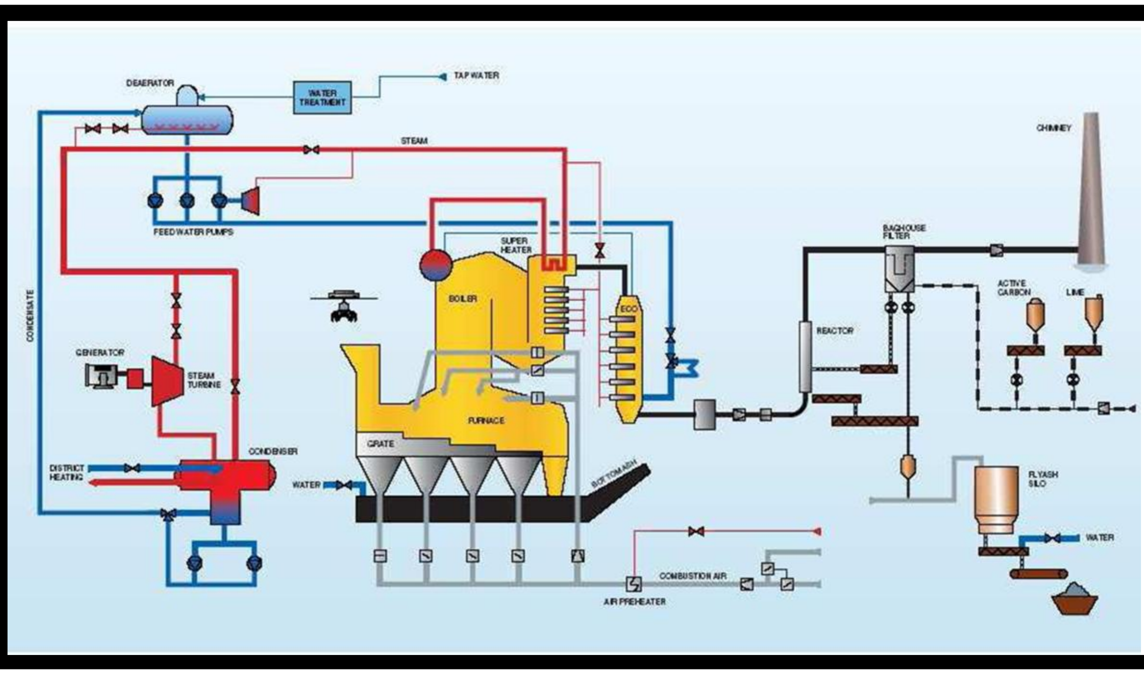


Figure 45.: Schematic operation of the Ljungsjöverket waste incinerator plant in Sweden.

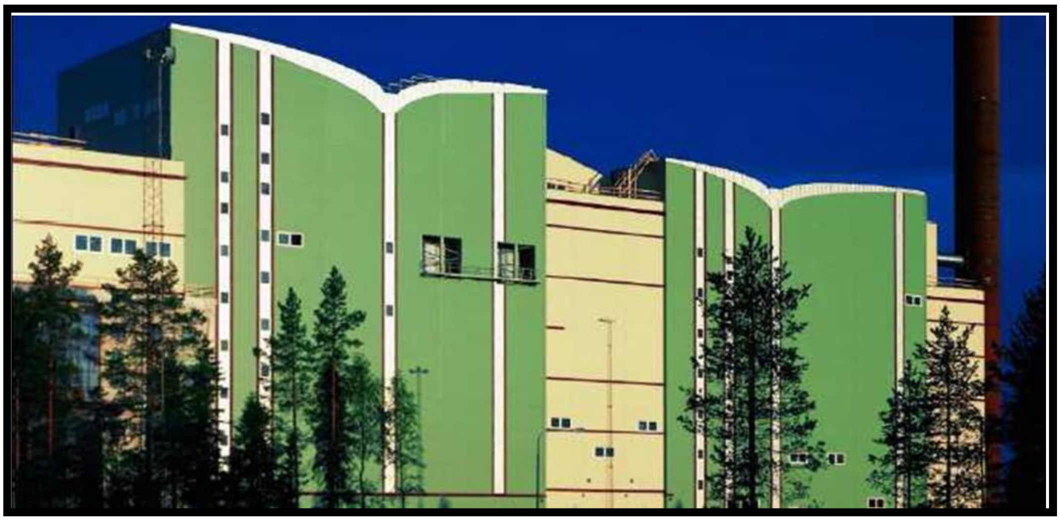
(Wastesum project Del 3A., 2010)

8.4.5. The Dåva district heating and power station in Sweden (Umeå).

The Dåva plant (Picture 45.) generates heat and electricity by burning presorted waste and residues from the wood products manufacturing industry –chiefly biofuel. The efficiency is fully 99.5% thanks to effective recovery of excess heat from power generation and in flue gases.

Located at Dåvamyran, four kilometers outside the city, the new plant has a much smaller impact on the environment than the old one, not least because a more efficient cleaning system has been added to the remaining old steam generator. What is more, the content of oil in the fuel mix has been greatly reduced. The new facility offered an opportunity to expand the Umeå district heating network, thus helping minimize the consumption of high-priced electricity.

The plant consists of one process incorporating a grate combustion system, a steam generator, a fabric filter, a flue gas treatment system with condensation, and a wastewater treatment system. The design will readily lend itself to expansion with a second train. (Figure 46) presents schematically the operation of the Dåva plant.



***Picture 45.**: The Dåva district heating and power station in Sweden.*
(Wastesum project Del 3A., 2010)

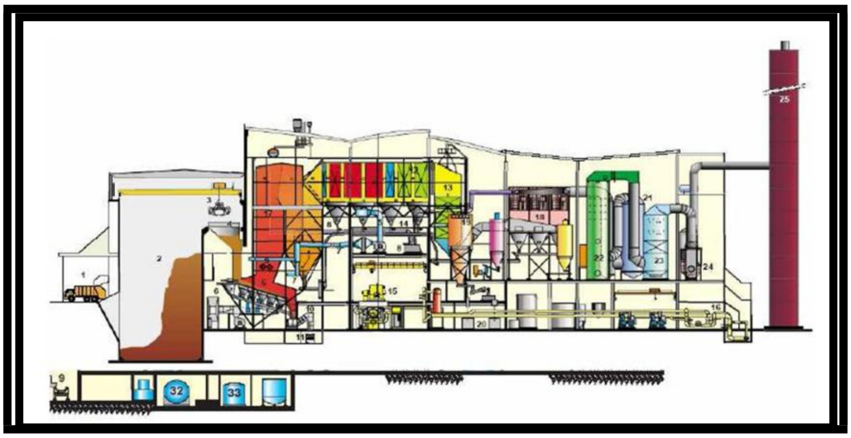


Figure 46.: Schematic operation of the Dåva district heating and power station in Sweden.
(Wastesum project Del 3A,. 2010)

9. United Kingdom

The British Strategy

England has a continuous increasing performance in integrated waste management since 1996, Recycling and composting of waste has nearly quadrupled since 1996-97, achieving 27% in 2005-06. The recycling of packaging waste has increased from 27% to 56% since 1998. Less waste is being landfilled, with a 9% fall between 2000-01 and 2004-05. Waste growth is also being reduced with municipal waste growing much less quickly than the economy at 0.5% per year.

*Measures such as the landfill tax escalator and the introduction of the Landfill Allowance Trading Scheme (LATS) has created sharp incentives to divert private finance initiative, has led to a major increase in kerbside recycling facilities and new waste treatment facilities. New delivery arrangements have helped to drive the strategy, including the Waste Implementation Programme (WIP), the Waste and Resources Action Programme (WRAP) and the Business Resource Efficiency and Waste (BREW) programme .(Defra.,*2009)

9.1. Objectives and targets

The role of central government such as in the case of Italy, is to enable each part of society (Municipalities, private companies, general public,etc) to take responsibility, and show leadership through reducing its own waste. This new strategy builds on Waste Strategy 2000 (WS2000) and the progress since then but aims for greater ambition by addressing the key challenges for the future through additional steps.

The Government's key objectives are to:

- Decouple waste growth (in all sectors) from economic growth and put more emphasis on waste prevention and re-use;

- Meet and exceed the Landfill Directive diversion targets for biodegradable municipal waste in 2010, 2013 and 2020;
- Increase diversion from landfill of non-municipal waste and secure better integration of treatment for municipal and non-municipal waste;
- Secure the investment in infrastructure needed to divert waste from landfill and for the management of hazardous waste; and
- Get the most environmental benefit from that investment, through increased recycling of resources and recovery of energy from residual waste using a mix of technologies.*(Defra*.,2009)

The basic target is to reduce the amount of household waste not re-used, recycled or composted from over 22.2 million tons in 2000 by 29% to 15.8 million tons in 2010 with an aspiration to reduce it to 12.2 million tons in 2020 – a reduction of 45%. This is equivalent to a fall of 50% per person (from 450 kg per person in 2000 to 225 kg in 2020). *(Defra*.,2009)

Higher national targets than in 2000 have been set for:

- ✓ Recycling and composting of household waste – at least 40% by 2010, 45% by 2015 and 50% by 2020; and
- ✓ Recovery of municipal waste – 53% by 2010, 67% by 2015 and 75% by 2020.

Because lower levels of waste growth are expected than when the consultation document was published, meeting these targets implies lower levels of residual waste than were previously assumed. The Government will review the targets for 2015 and 2020 in the light of progress to 2010 and future forecasts, to see if they can be even more ambitious. The Government will be setting a new national target for the reduction of commercial and industrial waste going to landfill. On the basis of the policies set out in *Waste Strategy for England 2007*, levels of commercial and industrial waste landfilled are expected to have fallen by 20% by 2010 compared to 2004.

9.2. Waste quantities 2008

The main target of the English government is to reduce household waste after reuse, recycling and composting (Figure 47.) from over 22.2 million tons in 2000 by 29% to 15.8 million tons in 2010 with an aspiration to reduce it to 12.2 million tons in 2020 – a reduction of 45%. This is equivalent to a fall of 50% per person (from 450 kg per person in 2000 to 225 kg in 2020). Quarterly reporting gives an early indication of performance in 2008/09. Residual household waste was 15.5mt (or 306kg per head) in year to end December 2008, a decrease of roughly 1 million tons (6.3%) compared to 2007/08. *(Defra*.,2009)

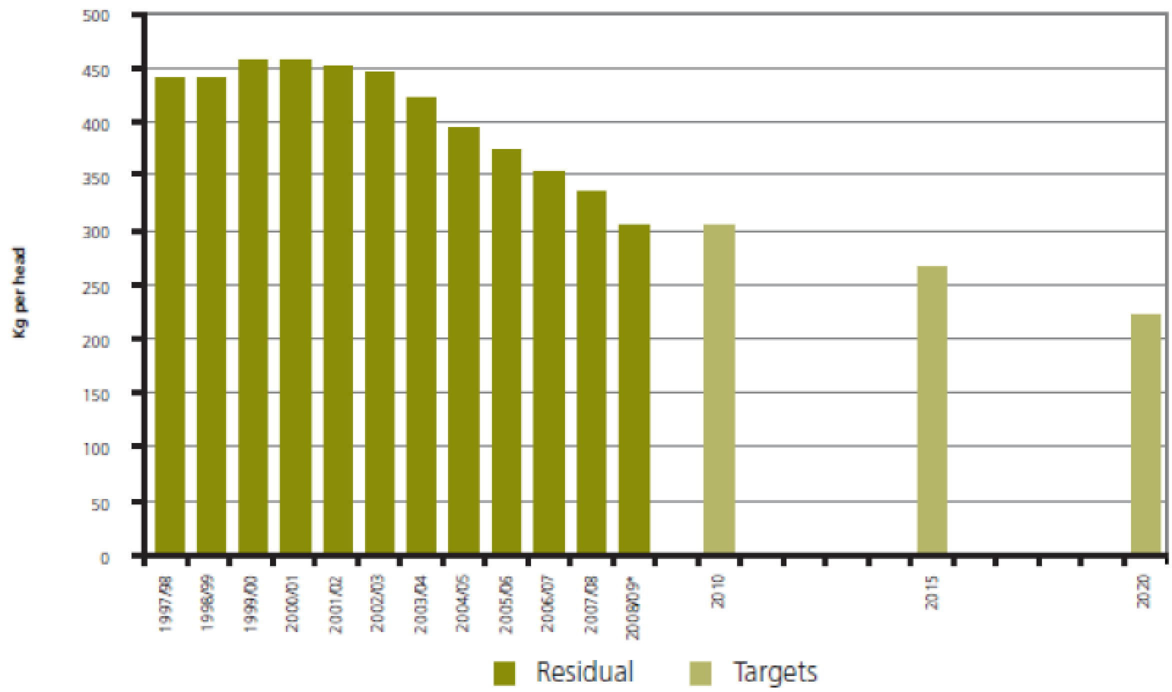


Figure 47.: Household waste per head after recycling and composting (kg) including targets in 2010, 2015 and 2020 *(Defra*.,2009)

Total waste to landfill in England (Figure 48.) has decreased over time, by 19% (15mt) from 80mt in 2000/01 to 65mt in 2006. Non-municipal/non-inert waste to landfill is a proxy for commercial and industrial waste. This is calculated by subtracting municipal and inert waste landfilled from total waste going to landfill.

The BIS Strategy for Sustainable Construction set a target for a 50% reduction of Construction, Demolition and Excavation (CD&E) waste to landfill in 2012 compared to 2008. This excludes aggregates used for backfilling quarries, site restoration and spreading on exempt sites. The total amount disposed via landfill is estimated at around 25 million tones, but data will be developed further to assess the baseline and progress. *(Defra.*,2009)

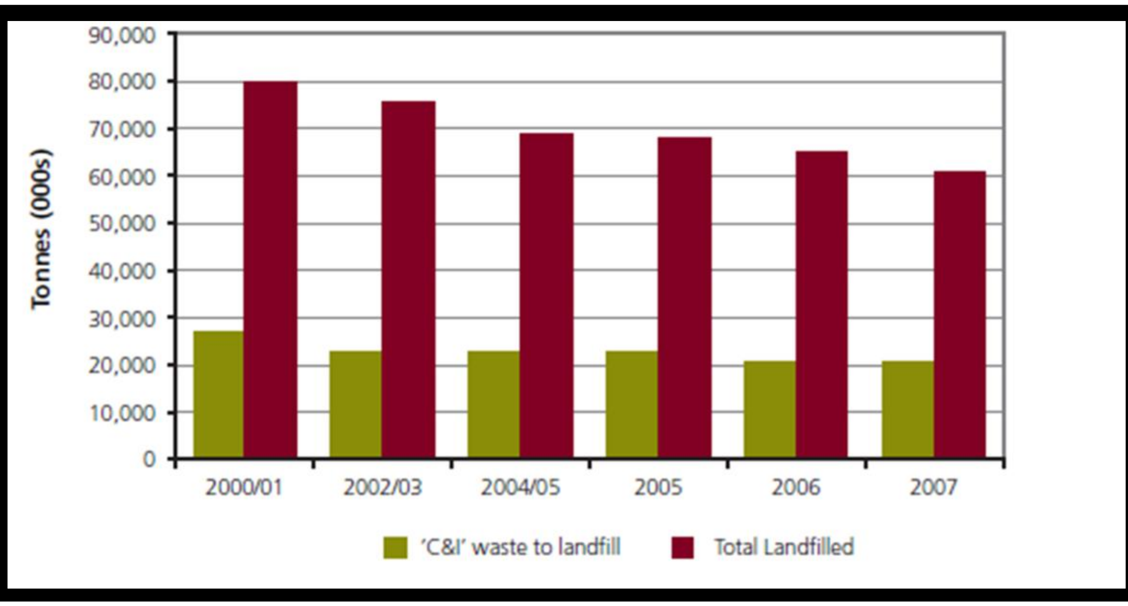


Figure 48.: Total non-municipal/non-inert waste landfilled (tones) (Target) *(Defra.*,2009)

The EU Landfill Directive requires biodegradable municipal waste (Figure 49.) to landfill in England to be reduced to 11.2 million tons in 2010, 7.5 million tons in 2013 and 5.2 million tons in 2020. 2007/08 out-turn figures, calculated by the Environment Agency, are 10.6 million tones, 78% of the total allocation. The proportion of total recycling and recovery accounted for by incineration with energy recovery ranged from 0% to 88% in 2006/07.

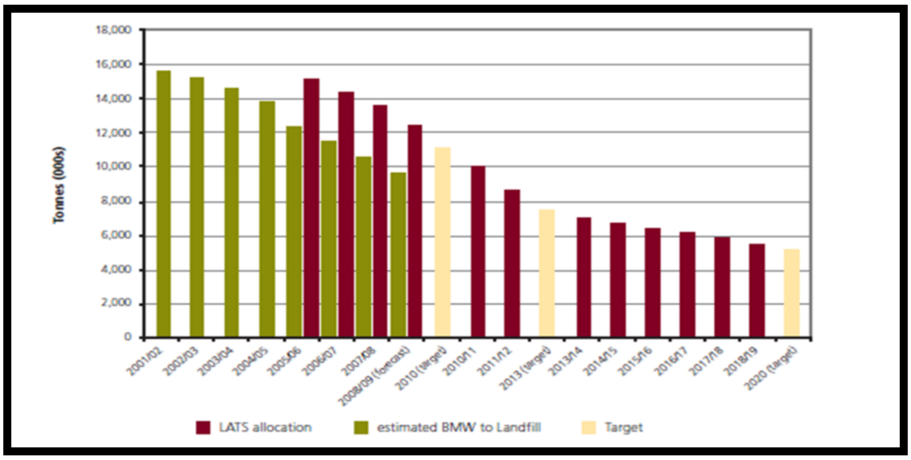


Figure 49.: Biodegradable municipal waste landfilled (Target) and Landfill Allowance Trading Scheme (LATS) (tones) *(Defra.*,2009)

9.3. Best practices

9.3.1. Project Integra in Hampshire

Project Integra is a partnership working to provide an integrated approach to the collection, treatment and disposal of municipal waste in Hampshire. This covers around 740,000 households and over 800,000 tons of waste a year.

The project originates back to the early 1990s when the need to move away from the landfilling of most waste was recognized. The approach developed in Hampshire was one of partnership between the 14 local authorities in the area and plans for change were developed together. This way of working continues to this day and the partnership is now joined by the private company that secured the long-term disposal contract. (Hampshire County council., 2009)

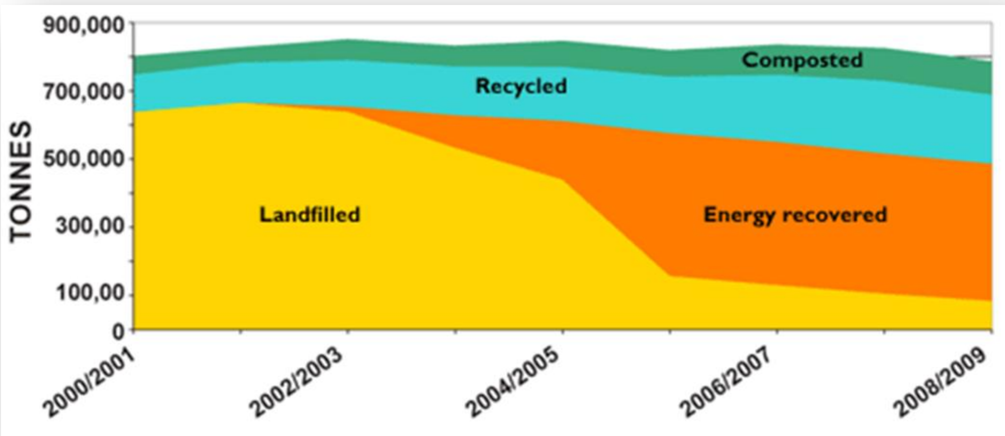


Figure 50.: Project Integra Household Waste Treatment: 2000/01 to 2008/09
(Hampshire County council., 2009)

Project Integra is the partnership of;

- the 11 district/borough authorities in Hampshire (Waste Collection Authorities (WCAs),
- Hampshire County Council (Waste Disposal Authority (WDA),
- the unitary authorities of Portsmouth and Southampton (responsible for both collection and disposal) and
- Veolia Environmental Services (VES), the main waste disposal contractor

All partners work together to provide an integrated solution to Hampshire's municipal waste (Table 9.)

(Project Integra) Partners	**Basingstoke & Deane Borough Council**
	East Hampshire District Council
	Eastleigh Borough Council
	Fareham Borough Council
	Gosport Borough Council
	Hampshire County Council
	Hart District Council
	Havant Borough Council
	New Forest District Council
	Portsmouth City Council
	Rushmoor Borough Council
	Southampton City Council
	Test Valley Borough Council
	Veolia Environmental Services (formerly HWS)
	Winchester City Council

*(**Table 9.**): Project Integra Parners*

(Hampshire County council, 2009)

The partners collect around 840,000 tons of waste per year. The Project Integra Partnership provides an integrated network of facilities to manage this:

- Waste collected by collection authorities that are not close to an appropriate facility is deposited at one of 8 transfer stations from where it is transported in bulk to the appropriate facility;
- Two material recovery facilities (MRFs) sort the co-mingled recyclables into the different materials and sell them for reprocessing;
- The materials analysis facility (MAF) undertakes the analysis of co-mingled recyclables to identify individual contamination rates for each authority. Other analysis is also undertaken to support projects by Project Integra and its partners;
- A glass reprocessing facility handles all the glass collected by the partners – ensuring that it is processed to standards that ensure that almost all of it can be sold for re-melt into glass containers;
- Three composting sites process the garden waste collected at the kerbside and at HWRCs into branded compost called Pro-Grow. Pro-Grow is sold back to local households and businesses as a soil conditioner;
- All kerbside waste not collected for recycling or composting is sent to one of the three energy recovery facilities (ERFs) where it is burned – enough energy is recovered from the facilities annually to power 50,000 homes;
- Ash from the ERFs is processed to recover metals which are recycled and also to create an aggregate substitute that is used locally in road construction;
- Small amounts of residues from processing facilities as well as material that is not suitable for energy recovery are sent to a landfill site. (Hampshire County council, 2009)

Hampshire was hailed as an example of good practice for its partnership approach to waste management in the 2002 government strategy report 'Waste NotWant Not'. In addition, in 2000-2001, Project Integra was attributed 'Beacon Council Status' in the first year of the awards, in the category 'sustainable development – dealing with waste'.

Hampshire's population of 1.64 million comprised around 738,500 households in 2008/9. The Project Integra collection authorities retain the freedom to decide on the details of the collection services they provide to their residents – standardized approaches and protocols are used only where necessary for the efficient functioning of the collective infrastructure:

- All authorities collect the same combination of recyclable materials co-mingled at the kerbside (paper and cardboard, cans and tins, plastic bottles). Coverage of households by this key service is now 98%;
- The majority of authorities provide a collection of garden waste for composting;
- Glass is collected through bottle banks by all authorities and at the kerbside by four;
- Six authorities provide commercial waste collections to local businesses.

In addition to the kerbside collection and other services provided by the collection authorities, the disposal authorities provide 26 Household Waste Recycling Centers (HWRCs) which accept a wide range of materials for reuse, recycling, composting or disposal.

Additional collection arrangements are made with households for bulky household waste and healthcare waste. Cleansing services provided by the authorities include litter bins, street cleaning, removal of litter, graffiti, abandoned vehicles and fly tipping – the resulting waste is also managed through the collective infrastructure. (Hampshire County council., 2009)

The quantities of waste composted during the integra project are shown in (figure 51.)

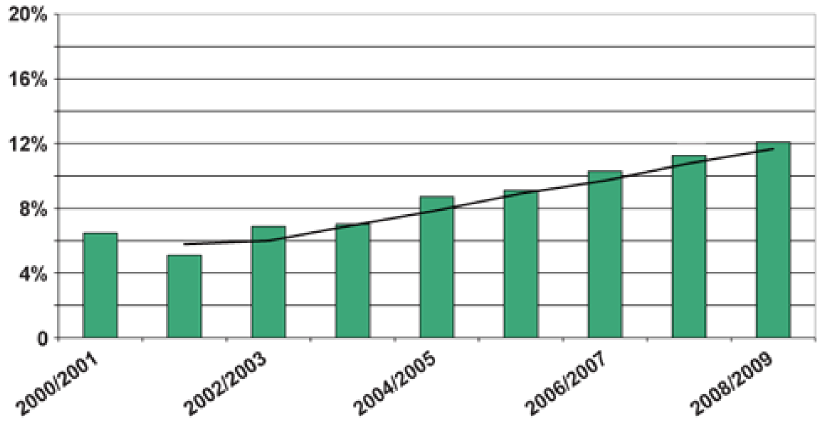


Figure 51.: Quantity of waste composted since 2001
(Hampshire County council., 2009)

9.3.2. West London Eco Park

The EcoPark is a 43-acre site owned by London Waste Ltd. It offers a range of waste services recycling, composting, clinical treatment, recovery and disposal - primarily to the North London Waste Authority (the Authority responsible for organizing the disposal of waste from seven North London Boroughs), but also to businesses in and around London and the south east. (Picture 46.)

***Picture 46.**: London EcoPark*
(Londonwaste., 2009)

The sites owned and managed by London Waste provide recycling, composting and electricity generation operations in the North London area. The license capacity of the Compost Centre has been increased from **30,000 tons** to **45,000 tons** per annum, where the compost material matures under a covered maturation area to reduce the risk of odor impact.

The company recycles wood, metals, waste timber, aggregate and green waste. During 2008, the company recycled **86,301** tons of waste aggregates, which is used in the construction industry and reduce the demands upon raw materials.

The EcoPark contains a Recycling Centre for bulky waste which enables the segregation and recycling of a wide variety of materials that would otherwise end up in landfill (Picture 47.). Bulky items such as office furniture, wood pallets, skip waste and builders' rubble can be delivered into this centre or collected by London Waste, using its own fleet of Vehicles.

Picture 47.: *Lorries unloading rubbish*
(Londonwaste., 2009)

Untreated wood such as wood pallets, off cuts, some furniture, decking and fencing can be delivered or even collected by special arrangement. This material can be shredded into chips, which can be used for animal bedding, new wood based products or as a fuel.

In-Vessel technology takes mixed food and green wastes and turns it into high value compost that meets the requirements of the PAS quality protocol. A proportion of the compost produced by the Centre is returned to agricultural land, reducing the need for chemical fertilizers. EcoPark compost is available for sale and is used in parks, gardens, allotments and other developments within north London, effectively providing a closed loop solution.

The Energy Centre processes waste at temperatures of up to 1000°C ensuring ABP wastes are effectively destroyed. The heat is then converted to electricity and fed into the national grid, providing sustainable green energy for London. A comprehensive service is on offer and includes transport through to disposal, ensuring duty of care obligations are met.

The Energy Centre complies with all relevant UK and European legislation and is fully licensed by the Environment Agency. It provides safe, economic and reliable disposal of residual waste and, since commencing operations, has diverted almost 20 million tons of waste from landfill.

The Energy Centre operates five boilers producing superheated steam that is fed into turbines to generate green energy and is not reliant on fossil fuels. LondonWaste produces enough electricity every year to power around 66,000 homes and makes a valuable contribution to meeting the UK's ever-increasing energy needs.

Civic amenity sites and household waste recycling centers operated by London Waste collected over **8,365.92** tons of waste, which was sent for recycling. The company's composting operations recycled over **31,225** tones of green waste and kitchen scraps in 2008 and created over **9,000** tones of compost for reuse.

London Waste plans to expand its organic waste treatment capacity by investing in new Anaerobic Digestion facilities which will divert more waste from landfill and enable additional green energy generation(Londonwaste,. 2009)

9.3.3. Warwickshire Waste Partnership Composting scheme

Warwickshire is a landlocked non-metropolitan county in the West Midlands region of England. The county town is Warwick, although the largest town is Nuneaton in the far north of the county. The northern tip of the county is only 5 km (3 miles) from the Derbyshire border. An average-sized English county covering an area of almost 2,000 km^2, it runs some 96 km (60 mi) north to south. The population of the county according to 2008 statistics is 530500 and their density is approximately 269/km^2. The weather in the region is the typical UK weather. (Wikipedia.,2010)

Since the Warwickshire Waste Partnership began promoting home composting in March 2003, some 19,221 have been sold. It is estimated that this has diverted some 4,228 tones away from the green waste stream service per year. One of the county's targets for home composting is to have a minimum of 12.5%

(26,650) of all households across the County using home composters. Since 2004 the Waste Partnership have been working in partnership with WRAP (Waste Resource Action Programme) who have been providing home composters at a very competitive rate to the residents of the county. Each household receives leaflets outlining the promotion every year and the Waste Partnership sents out press releases, as well as promoting this scheme within the A to Z of Recycling and on the County Council's website.

This partnership has benefited from the following contribution from WRAP:

(i) The provision of a range of home compost bins and accessories to be sold at subsidised rates in partnership area. This year's prices have been £6.00 for a 330ltr and £4.00 for 220ltr including delivery, and each household can purchase up to 3 bins.

(ii) Storage, order processing and delivery of the home compost bins to the individual households.

(iii) Organisation of one day sale events.

(iv) Promotional material, advertising, advice and support services for home composting activity.

(v) Additional materials and events such as videos, seminars, training as agreed appropriate to support the schemes.

(vi) Access to a free helpline for residents.

(vii) Home Composting Advisors dedicated to support us in our area.

All six of the Warwickshire authorities exceeded their statutory recycling and composting targets for 2005/06 with **30%** being attained countywide, (30% is Warwickshire County Councils recycling and composting rate, each of the district councils has met or exceeded their 2005/06 target

The county has made progress with the recycling and composting targets set by reaching 30%, however the target for 2010 is (40-45% by 2010) . Compared to other Shire Counties and Unitary authorities Warwickshire is still lagging behind and has some way to go particularly with respect to increasing levels of recycling. (Warwick District Council., 2010)

9.3.4. The City and County of Swansea waste management scheme

Swansea is a coastal city and county in Wales. Swansea is in the historic county boundaries of Glamorgan. Situated on the sandy South West Wales coast, the county area includes the Gower Peninsula and the Lliw uplands. Swansea is the second most populous city in Wales after Cardiff and the third most populous county in Wales after Cardiff and Rhondda Cynon Taf. The city covers an area of 145.9 sq mi (378 km^2) and has a population within (Unitary Authority area: 228,100) and (Urban area within Unitary Authority: 169,880). The density of the population is approximately 1,556.6/sq mi (601/km^2) (Wikipedia.,2010)

Nearly every house in Swansea receives a kerbside collection. The items collected depend on where someone lives.

There are green bag collections for glass, paper and cans, pink bag collections for plastics, white (or green) cloth bags for garden waste and green bins for kitchen waste cardboard from the kerbside are also collected, and for £15 for three items the bulk waste can be collected.

A specialist collection for people living in flats also runs. The way the collection of recycling from flats takes place, is slightly different to how they are collected from other households. There are three main collection methods from flats in Swansea:

- Recycling banks which are usually found outside high rise tower blocks. The bank is split into 3 sections, one for paper, one for glass and the other for can.

Picture 48.: *Recycling banks*

- Recycling Bins which are emptied every fortnight. These bins are for green bags only. If the bins contain general waste the entire contents of the bin ends up in landfill

Picture 49.: *Recycling bins*

- In some cases green bags from compound/storage areas are collected. Most management companies prefer to use bins to keep the compound/storage areas tidy but as some compound/storage areas are not large enough to contain bins, the green bags have to be collected loosely.
-

Every household in Swansea can recycle paper, glass and cans. The way we collect recycling from flats is slightly different to how we collect it from other households as most flats have bin store rooms or compounds.. Green bags are for paper, glass and cans only. Green bags containing materials that we do not currently collect for recycling are not collected.

The waste in Swansea is collected in 6 kerbsites.

- Glass, paper, cans and card are collected on a fortnightly basis from the kerbside in a green semi-transparent bag. The collections are made on the GREEN WEEK collection.
- Plastics are collected on a fortnightly basis from the kerbside in a pink semi-transparent bag. The collections are made on the PINK WEEK collection.
- Garden waste is collected on a fortnightly basis from the kerbside in a white bag. The collections are made on the GREEN WEEK collection.
- Kitchen waste is collected weekly from the kerbside in a green bin. The collections are made EVERY WEEK.

Cardboard and card are collected on a fortnightly basis from the kerbside. The collections are made on the GREEN WEEK collection.

- Finally Household rubbish is collected from the kerbside in a black bag.

The people in Swansea have been provided with 2 bins; a larger bin to keep outside and a handy caddy to keep in the kitchen. Collections of kitchen waste are now made weekly on the same day as the black bags.

Picture 50.: Woman collecting kitchen waste

Free caddy liners to help keep the caddy clean as well as a special tag to request more bags are also available to the citizens. These liners are made from a special compostable plastic.

For garden waste, the public has been provided with 2 reusable garden waste bags. The bags are collected on a fortnightly basis on the same day as your green bags. Up to an additional 4 bags at £2 each can be purchased from the Civic Centre. Once collected, these materials are shredded and composted. This soil enhancer is available free of charge from the Tir John Community Recycling Site, Danygraig Road at St Thomas throughout the year.

A home composting campaign (**Swansea Home Composting Campaign**) is also in progress and provides compost bins to the public from **£12.00.**

9.3.5. Waste Management in Northumberland

Northumberland is a ceremonial county and unitary district in the North East of England. It borders Cumbria to the west, County Durham to the south and Tyne and Wear to the south east, as well as having a border with the Scottish Borders council area to the north, and a North Sea coastline with a 103 km long distance path. Since 1981, the county council has been located in Morpeth, situated in the east of the county. The population of the county is (311000.,2008 statistics) and the density of the population is (62 /km^2). (Wikipedia.,2010)

Ten years ago, Northumberland sent 96% of its mixed waste to landfill and only about 3% % of residents received a kerbside recycling service. Only six Household Waste Recovery Centres (HWRCs) were provided for the whole of Northumberland. Ten years after, Northumberland sends to landfill only 12 % of household waste while 100% of households receive a kerbside recycling service. Thirteen state of the art HWRCs recycle 64% of the waste delivered to them while great investments in energy from waste plants and recycling facilities, prevent waste from been buried to the landfills.

In Northumberland operates a composting scheme for household garden waste and kitchen waste. Anyone can **compost garden waste at home** by purchasing a home compost bin. This is the most environmentally sustainable option and it provides each one of the civilians their own supply of compost. The compost bins can be ordered for home delivery or pick-up and are available in two sizes:

- **'Garden King' 220 liter home composter at £21**
- **'Garden King' 330 liter home composter at £23**

(Northumberland County Council.,2010)

Residents can save the delivery charge by **buying a voucher** which enables them to pick up a **330 liter bin** from their chosen household waste recovery centre, **at a cost of £16.50**.

Garden waste can also be transported by someone to the nearest **Household Waste Recovery Centre**. There is no charge for the use of these facilities. There are 13 Household Waste Recovery Centers (HWRCs) across the county of Northumberland. They are provided in order that Northumberland residents may reuse, recycle, compost or dispose of their own household waste free of charge. (Northumberland County Council.,2010)

Finally, the **council arranges to collect the garden waste** from the edge of everyone's property. Kerbside collections (figure.5) from a wheeled bin is now the only option for garden waste collection in Northumberland. Bags are not used anymore for health and safety reasons. The annual charge for this service is £20. The biodegradable waste is been collected from early March until late November. In the winter no collection takes place because of the limited amount of material available which results in high collection costs. The residents though can still take their biodegradable waste to the Household Waste Recovery Centers all year round free of charge.

Figure 52.: Collection bin

To increase recycling and to reduce the reliance of the county on landfill disposal, Northumberland County Council and waste Management Company SITA UK Ltd signed up to a 28 year waste Private Finance Initiative (PFI) contract in December 2006 in order for more investments in new waste recovery facilities to be made. (Northumberland County Council.,2010)

9.17.6. Wyecycle community composting scheme

The scheme is located in the south-east of England near Ashford, within the county of Kent. The scheme operates throughout the two parishes of Wye and Brook. The areas covered by the scheme are predominantly rural, and the majority of residents are considered to be upper middle class. There is also an agricultural element present within the area. The climate is quite dry in comparison with other areas in the UK, and the average temperature slightly higher.

The scheme began as part of a research project in May 1990 with students from Wye College. A composting site was initially shared with the College, but in 1995 funding from the College ceased and the scheme relocated to its current site.

The scheme in operation in Wye was the first community compost scheme to be established in the UK, and covers 950 households. Collections from Brook began in January 1999, and the number of householders covered in this area is 70. The scheme is operated by Wyecycle, a community business which is separate from the local council. Ashford Borough Council's only involvement in the scheme is for the payment of the recycling credits. Householders are given a 10 l bin for use within the kitchen for indoor waste, including vegetable, meat and fish waste. This is then emptied by the householder into an 80 l green wheel bin. The waste entering this bin consists of both kitchen biodegradable waste and, in the case of Brook, cardboard.

Garden waste, which is collected separately, is collected in second-hand potato paper sacks, which are supplied by Wyecycle free of charge. These paper sacks are obtained free by Wyecycle from a local potato chip manufacturer. The green wheel bins for kitchen waste are collected weekly. A grey 120 l bin is collected fortnightly for mixed waste by the local council. In addition to the collection of kitchen and garden waste, Wyecycle collect glass, paper, metal and textiles on a weekly basis in a black recycling box.

The collection of recyclables is believed to be vital for the success of the kitchen and garden waste scheme. Without a comprehensive collection scheme, i.e. recyclable wastes as well as kitchen and garden waste, it is believed that residents would be less likely to participate.

The green bins (Picture 51.), although the same size as the grey bins, have a false floor and hence a smaller capacity. The bins were purchased in this way so that a paper bag could be used as a liner within the bins. This has since been found not to be required, due to the bins not getting very dirty. Future bins will be purchased without a false floor and will hence have a 120 l capacity. (Success stories on composting and separate collection., 2000)

Picture 51.: *Resident with green kitchen waste bin and brown garden waste sacks*
(Success stories on composting and separate collection., 2000)

Vehicles used for the scheme include a tractor and trailer which are used for the collection of the garden waste, and a van, which is used for the collection of the kitchen and recyclable wastes. All three waste streams (kitchen waste, garden waste and recyclable wastes) are collected on the same day of the week, although they are all collected separately

The majority of residents participate in the scheme as the grey bin of mixed waste is collected only fortnightly and this provides an incentive to segregate compostable and recyclable wastes. Using a figure of one tone per year as the average quantity of waste produced per household, Wyecycle claims to have reduced the amount of waste being sent for landfill by 78 % as the average quantity of waste now being sent for landfill per household is 220 kg. Of the green waste collected, approximately a quarter by weight is kitchen waste and three quarters is garden waste.

The scheme is currently running at a capacity of around 250 tons per year. The quantities of kitchen waste arising are fairly consistent all year round, and so any variations in the quantities collected are due to a varying quantity of garden waste. The minimum quantity of waste collected during the last 12 months was in February when only two tones of garden waste were collected (plus the four to five tones of kitchen waste). The maximum quantity of waste collected during the last 12 months was in September, when 20 to 25 tons of garden waste were collected (plus the kitchen waste).

The method of composting the garden waste is that of a static pile/aerated windrow system. The waste is heaped in a pile and left for one month. This is then turned and moved to the next heap space and left again for another month, and water is added if the heap has got too dry. This is done a total of nine times, after which it is ready to be sieved, bagged and sold. There is no shredding involved and any large pieces are simply put back into the system and go around again.

The kitchen waste is placed in a secondhand shipping container, before being added to the garden waste composting system. Here it undergoes partial composting and digestion within a fairly anaerobic environment. After three weeks the waste is transferred to another shipping container where it is left a further three more weeks before being added to the garden waste. This process reduces the risk of nuisance from fly and vermin.

The plant is located 1.6 km from Wye and 0.8 km from Brook. The collection of kitchen waste is undertaken by one visit to each of the villages. The number of trips carried out by the tractor for the collection of garden waste is dependent on the quantities of garden waste to be collected. The trailer on the rear of the tractor holds approximately one tone of waste, and hence if there are five tones to collect then five trips are made. The end product of the process is marketed as a soil conditioner and mulch, and not as a high-grade product intended for growing seeds in.

Research into its composition, along with growing trials, has been undertaken by students at Wye College. The compost is sold back to the residents within the two small parishes of Wye and Brook. It is either bagged up and retailed from a local hardware store, which takes the orders for Wyecycle which then delivers the compost, or the compost is sold in bulk from the site.

Compost is bagged within old fertilizer bags and is then sold as a 30 kg product. It costs GBP 3 (EUR 4.5) per bag or GBP 10 (EUR 15) for four bags. It can be bought in bulk for GBP 10 (EUR 15) per cubic meter. In general, it is the householders and landscape gardeners that buy the compost and Wyecycle has not experienced any difficulties in selling the product.

The scheme is publicized using leaflets to householders which inform the residents of the scheme, and act as a memory jogger for what can and cannot be put into the various containers. (Success stories on composting and separate collection, 2000

10. Netherlands

The Dutch Strategy

The present waste management strategy for the Netherlands has its main foundation in the 1988-1991. The publication of the 'Memorandum on prevention', the producer responsibility introduction, the creation of the waste consultation body, etc comprise some of the meters taken for preventing waste from landfill. A number of waste accidents and researchs forced the government to create a new management programme.

The policy now focuses on preventing the generation of waste at source , When prevention cannot occur then recycling of waste is the second choice. Finally materials that cannot be recycled should be treated in such a way that there won't be additional environmental negative impacts. According to 'Landsink Ladder' (named after the person who proposed it) , prevention stands as the most preferred option and landfill as the last option for waste management. The 'Landsink Ladder' is presented at the figure below. (Ministry of spatial planning and the environment., 2009)

10.1. Netherland policy objectives

The Dutch government's aspect is in general the same as the European Union. The National Waste Management Plan uses European terms and definitions such as: Waste, Management (of waste), Recovery, Prevention (of waste), Disposal, Minimum standard, etc.

The key points of the government position regarding the opinion of the CTOA are:

- The collection and disposal (incineration as a method of disposal and landfilling) of household waste are a utility function. The government must ensure that facilities for performing this utility function are present and, in the last resort, must provide them itself. In principle, parties other than the government may also exercise the utility function, but this must not jeopardize the continuity of waste management or the government's responsibility for it;

- Responsibility for controlling waste is becoming more centralized and there is a shift in powers from the provincial to the national level. This change is mainly a consequence of the changing scale of the facilities required for waste management and the expected increasing disappearance of geographic borders. Producer responsibility means that producers or importers are responsible or share responsibility for the management of the products they have or will put on the market and that have reached the end-of-life stage. This responsibility may be expanded into a chain responsibility, in which other links are also given responsibilities.

- There will be one waste management plan covering both hazardous and non-hazardous waste that will apply to the entire waste management chain. The individual parts will be formulated in or following consultation with the parties concerned. The Minister for Housing, Spatial Planning and the Environment will lay down the plan, for which a legal basis will be created;

- Provincial boundaries for waste management can be abolished if certain conditions are met. Provided the environmentally sound management of waste is not jeopardized, there is no objection to elimination of the national boundaries;

- Efforts will be made to restructure the landfill sector;

- Rate-setting for landfilling and incineration will be brought into line with the preferred sequence for waste management.

- If the function of a waste management company no longer fully accords with the policy objectives of the authority owning the company, steps must be taken to avoid a conflict of interests;

- The waste sector must endeavor to achieve an optimum effect from certification by joining up with European developments in this regard (EMAS);

- Attention to optimizing licensing and implementation schemes, e.g. via a license on essentials and collection licenses with nationwide coverage.

- The following waste has to be separated by consumers: organic household waste, paper and board, glass, textiles, white and brown goods, minor chemical waste and components from bulky household waste (such as bulky garden waste and household construction and demolition waste, including impregnated wood).

- The sub-streams tin, plastic waste and drink cartons do not have to be separated at the source. Tin is separated for recycling at the waste incineration plant either from the residual waste before incineration or from the incineration residues after incineration. Plastic and drink cartons are generally heterogeneous in composition and heavily contaminated. Consequently, separate collection and recycling is complex and expensive. Mechanical post-separation of household residual waste with a view to using these components as fuel is a more logical processing route and one that is increasingly being used. This method avoids the need to dispose of these types of waste. Naturally, local initiatives that do provide for separation at the source of these components are permitted.

- Litter prevention can also be a reason for introducing a system of separation at the source for certain products that are not currently separated at the source. This will mainly involve small packaging. (Ministry of spatial planning and the environment., 2009)

Kitchen and garden waste accounts almost half of the total household waste in the Netherlands. Since 1994 Municipalities are obliged to collect the specific waste fraction separately in order to be treated separately. In 1999 almost half of the biodegradable waste were collected separately (1441 ktons over 2671ktons of garden and kitchen waste). Nowadays almost 77% of the total population separate their garden and kitchen waste at source. An increasing number of businesses also separate the waste they produce.

The Biowaste is treated with the 2 well known processes (AD and Composting). The second method is used more than the AD process. This can be seen in 1998 statistics which show that kitchen and garden waste were processed in 25 composting plants and in only two anaerobic digestion facilities. (Ministry of spatial planning and the environment., 2009)

10.2. Present situation

The present situation regarding waste management has both strong and weak points. Strong points are the relatively high level of environmental protection in the processing of waste and the high degree of recovery. The fact that for around 77% of waste, which is the waste that is recovered, government involvement can be confined to setting conditions and enforcement is also positive. The increase in the landfill tax has made the landfilling of waste less attractive. This provides a financial incentive that encourages reuse and utilization of the energy content of waste.

A weak point in current waste management is that there is still insufficient grip on the quantity of waste produced, particularly consumer waste and to a lesser extent trade, services and government waste, which is still increasing. The situation is being exacerbated as these are also the waste streams for which the level of recovery is lagging behind the targets. A great deal of combustible and recoverable waste is consequently still being disposed of in landfills because, when planning incineration capacity, it had been assumed that the waste supply would be smaller and the degree of separate collection higher.

A further observation is that the degree to which waste management costs are incorporated in the product price, thus doing greater justice to the 'polluter pays principle', is still fairly limited. Regulations governing waste management are seen by industry to be complex and sometimes to hamper waste recovery. This complexity of the regulations sometimes also proves to be an obstacle to effective enforcement.

Market forces are still having a limited impact on the collection of household waste and the incineration and landfilling of waste, which may be resulting in less than optimum efficiency. Besides the strong and weak points of present waste management outlined above, there are various developments that demand attention if the objectives of waste management policy are to remain whole. (Ministry of spatial planning and the environment., 2009)

10.3. Waste quantities

According to the Netherlands statistics agency, the latest information about the waste situation in the Netherlands, refer to 2006 and 2007.

In 2006, total waste quantities (Table 10.) decreased by approximately 3-4 % from 2000. However, the figures shows that the situation regarding the waste management has been almost the same in the years that passed by and that is something that the Dutch government should consider in the future.

In 2007, a total of 9,303 *(mln kg)* of household waste was produced, a small increase of 1.47% compared to 2006 (Table 11.). There have not been any significant changes regarding the division of waste between different treatment methods over the last years. The numbers show that there are light changes each year with no significant achievements. (Netherlands statistics., 2009)

	2000	2004	2005	2006
Total	63,242	60,783	61,008	60,005
Recycled	50,925	50,424	50,950	49,834
Incinerated	7,083	7,904	7,178	6,823
Dumped	4,832	1,783	2,232	2,763
Other	402	672	648	585

(Table 10.): *Generation and treatment of waste in the Netherlands (mln kg)*
(Netherlands statistics, 2009)

	2000	2005	2006	2007
Total	8,986	9,158	9,166	9,303
Non-separated collected waste	4,827	4,784	4,790	4,759
household waste	3,935	3,958	3,961	3,965
bulky household waste	794	716	716	685
Separated collected waste	4,159	4,374	4,385	4,544
compostable waste	1,457	1,362	1,296	1,317
hazardous household waste	21	21	21	21
bulky garden waste	359	406	407	452

wood	225	318	341	348

(Table 11.): *Household waste by waste category (mln kg)*
(Netherlands statistics., 2009)

10.4. Best practices

10.4.1. South Holland waste management scheme

South Holland is a province situated on the North Sea in the western part of the Netherlands. The provincial capital is The Hague and its largest city is Rotterdam. It has a total population of 3,458,875 inhabitants according to 2006 stats and their density is 1,227/km². (Wikipedia.,2010)

Collection of household waste is supported by Community & Neighborhood Services, Waste Services. For refuse collection a weekly kerbside black sack collection to all households in South Holland is provided. A weekly kerbside recycling collection to all properties in South Holland is also provided. Materials for recycling may be presented in SHDC green sacks, carrier bags, cardboard boxes or a suitable rigid container for collection. Each household is entitled to 52 black sacks and 52 green sacks per year (deliveries are made twice a year).

Figure 53.: (Above) Bag and bins for recycling (different types for each waste stream)
(Below) home composting bin

All domestic waste/recycling collections are made from the cartilage of each ones property. This is the point at which the property joins the public highway. In most instances this may be at the end of a garden path or driveway. However for properties on a shared private drive waste must be put at the end of the drive. (South Holland district Council.,2010)

Garden waste can be either:

- Composted at home
- Taken it to the West Marsh Road, Spalding recycling centre or a Saturday Morning Service
- Or they can be put out on your refuse day and collected by the refuse freighter as long as customers have bought the special sacks from the council. Garden Waste Bags are £1.50 each. This includes collection and disposal fee to landfill.

The charge for these green waste bags is to encourage residents to try to use other means of disposal that are more environmentally friendly. For example, home composting rather than landfilling.

On the other hand, home composter can be bought from £13.50 (a one off £5 delivery charge applies on orders) and the public can buy them from 'The Lincolnshire Get Composting Website'. (South Holland district Council.,2010)

10.4.2. Susteren sewage treatment and drying plant

The main parts of the Susteren facility is the treatment plant and the sludge dryer unit which supplies waste sewage sludge to the ENCI cement plant throughout the year. The drying system is a (Fluid Bed Drying System FDS) manufactured by Altritz.

Picture 52.: *Susteren sludge drying facility*

The drier gives a water evaporation rate of approximately 8.300 kg/h and a sludge output of 11.000 kg/hr.. The plant operates 7 days a week and 24 hours a day and the total material is (> 92 % DS).

The drying plant at Susteren works by conveying (7 m^3/h max). The next step is the heating of the sludge in a boiler before agitating the mixture to breakdown large agglomerations and the removal of any metal contaminants. Sludge is then transferred for drying with the help of an oil heat exchanger (max 225°C). Air is induced by two 85,000 m^3/h fans through the vat's bottom lining plates, mixing air through the sludge which has an average depth of 4-5m.

This process continues while dust and moisture is driven off through the cyclone system which has an air stream performance of 59,000 m^3/h. The dust and air is sent back to the (FD) This gives a 60% secondary mix in the vat. Sludge cooling is aided by the exhaust gas taken from the oil boiler to bring sludge temperature down to below 40°C.

The end product is made into a pellet 0.5-2mm wide with a low moisture content consisting of around 92% suspended solids for ENCI's needs.

Picture 53.: *The Susteren vat*

The Storage capacity of the facility is 280m^3. There are about one or two deliveries by tanker of the dried sewage sludge to the Maastricht cement factory every week.

10.4.3. The Zeeasterweg Lelystad plant in Netherlands

The Zeeasterweg plant at Lelystad of Netherlands is an aerobic tunnel composting plant and is the most up-to-date of its kind. The plant has been designed and constructed by the Dutch company Orgaworld. It processes a variety of waste including industrial waste, green waste, residual waste and sludge from the food-processing industry and has an annual capacity of 75,000 tones. It receives organic waste from the Municipality of Lelystad which has around 70,000 inhabitants. The garden and kitchen waste is collected separately at source and transferred by the Municipalities at the facility.

In (Figure 54.) the flow diagram of the processes is shown. Waste is received and is placed inside the parallel compost tunnels where the composting process takes place. The input waste does not receive any pre-treatment. The compost mix remains inside the composting tunnels for 10 days. The aeration system is that of forced aeration; via thousands of under-floor nozzles pressurized air is passed through the material to be processed, thus initiating the composting process. During this process part of the organic matter is degraded and water vaporizes, resulting in stable compost as the end product.

The tunneling system does not have any leachate collection system or water provision system. The material is then screened. The reject stream (i.e. course material) is mixed together with the new input material and is thus composted again. The material that passes the screen (i.e. fine material) is the final compost that is packaged accordingly. The energy required for the whole process is low (approximately 15 kWh/ton of incoming waste). This facility is a simple low cost facility.

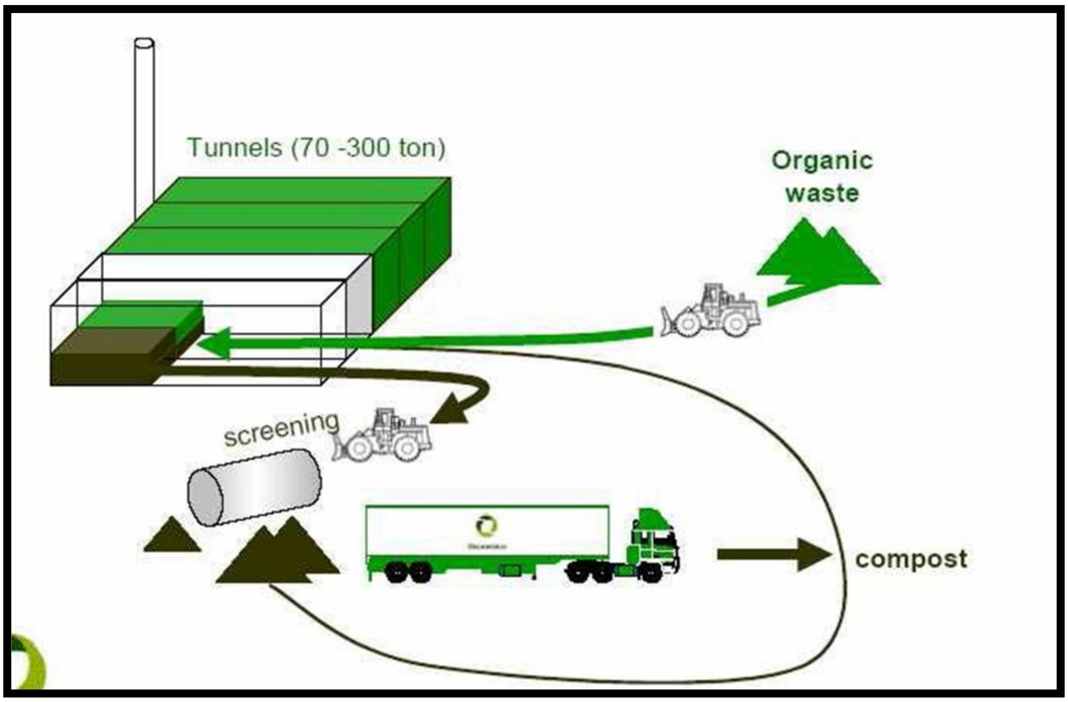


Figure 54.: Flow Diagram of the Composting Process in Lelystad Plant in Netherlands
(Wastesum project Del 3A,. 2010)

10.4.4. The Moerdijk incineration plant in Netherlands

The Moerdijk plant *(*Picture 54.) is unique in being the first waste incineration plant linked to a thermal power plant. The design results in a very high energy yield. Waste heat generated in a year amounts to 2,000,000 tons of high-pressure steam at a temperature of 400 °C and a pressure of 100 bars. The facility consists of three separate lines, each with a grate furnace, a boiler, a fly ash collector, and a flue gas purification plant. A slight vacuum is maintained in the waste pit and feed building to prevent releases of odors to the surroundings.

The plant has a design capacity of 600,000 Mg/year of municipal, bulky and comparable industrial waste. *(*Figure 55.) presents schematically the operation of the Moerdijk incineration plant in Netherlands.

Picture 54.: *The Moerdijk incineration plant in Netherlands*(Wastesum project Del 3A., 2010)

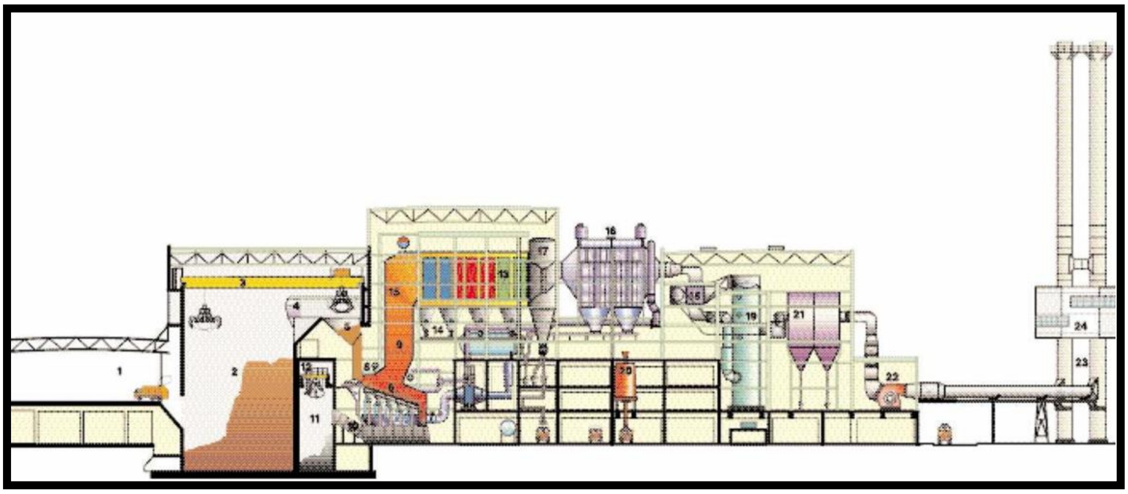


Figure 55.: Schematic operation of the Moerdijk incineration plant in Netherlands(Wastesum project Del 3A;. 2010)

Waste delivery and storage

1. Tipping hall
2. Waste pit
3. Overhead crane
4. Crane pulpit

Incineration, slag, energy output

5. Feed hopper
6. Reciprocating grate
7. Primary air supply
8. Secondary air supply
9. Auxiliary burners
10. Wet deslagger
11. Slag pit
12. Slag crane
13. Two-pass boiler
14. Boiler ash removal

Flue gas purification, disposables and residues

15. SNCR DeNOx system
16. Electrostatic precipitator
17. Ash silo
18. Gas-to-gas heat exchanger
19. Wet scrubber
20. Gypsum silo
21. Fabric filter with activated carbon injection
22. Induced draft fan
23. Stack
24. Emission monitoring

11. Greece

The Greeks Strategy

Waste management on Greece seems to be one of the most difficult problems to be solved. Greece has been condemned several times by the European Court of Justice for failing to follow the European Waste Management framework including a judgment under Article 228(2)(b) EC1. More than 1000 unauthorized dumping keep existing within the mainland while 2 years ago more than 3000 existed. The method used in Greece today for waste treatment is unfortunately landfill. More than 90% of the MSW is still landfilled or thrown away in illegal dumps.

In comparison to all the other countries mentioned before (Sweden, Netherlands, Germany, Uk,etc) Greece seems to be unable to comply with the EU official waste policy which is diverting waste from been landfilled. Even worse is it estimated that the existing authorized and controlled landfill sites cover only almost 60% of the total population while the other 40% is covered by unauthorized landfill sites currently in operation in Greece. Even worse there are more than 1000 abandoned illegal waste tips all over the Country.

The negative impacts of this kind of policy are severe for Greece's environment and public health. Fortunately Greece existence in the EU quaranties the change in policy which shall be followed by a rapid development in waste management and treatment.

11.1. Greek framework directive

The basic legal instruments on waste management in Greece are the following:

- Article 12 of Law 1650/1986 on the Environment which lays down the principal obligations in relation to waste management.
- Joint Ministerial Decision 50910/2727/2003 on the management of waste - which transposes the Directive into national law and includes the National Waste Management Plan - introduces the

tool of Regional (and Inter-regional) Waste Management Plan as the operational tool for waste management planning, determines the obligations of the management authorities and the Regions, regulates the permits of waste management operators and sets a time limit for the eradication of uncontrolled dumping.

- Joint Ministerial Decision 29407/3508/2002 on sanitary landfill of waste, transposing Council Directive 99/31 on landfill of waste. The Decision *inter alia* sets strict operational guidelines for Sanitary Landfill Sites; mandatory processing of waste both at a national and at Landfill Site level, establishes targets for reducing the amount of waste deposited by landfill and provides for planning and licensing.

- Law 2939/2001 and associated Presidential Decrees for the recycling of packaging waste, transposing Council Directive 94/62/EC on packaging waste and related Directives on other wastes (used tires, end of life vehicles, waste oils, electrical and electronic waste and batteries). Quantitative targets are set for recovery and their enactment is primarily an implementation of the 'polluter pays' principle, since producers of products and producers of waste are obligatorily involved in the set up and management of relevant Alternative Management Systems. (MEEC.,2010)

It must be emphasized that Greeks policy does not have complete waste management plan for green garden waste and kitchen waste. The instruments policy focuses in the use of landfills for waste disposal and some recycling for a small part of the recyclable waste stream. The recycling centers though are very little in Greece today and this is a great difficulty for the public that has the will to participate. It must be also noted that incineration and anaerobic digestion are not widely used today in Greece for the treatment of waste

11.2.Greece policy objectives

Along with the measure of Article 3 and 5 of the Directive, which they appear in the Directive, the 2003 Joint Ministerial Decision adds:

- The environmentally acceptable and safe disposal of waste that is not subject to recovery and waste remnants processing, with the aim of sustainability,

- The encouragement of rational organization and integrated waste management, and

The drawing up of national waste statistics, in accordance with Regulation 2150/2002/EC, so that with the complete registering of the quantities of waste the maximization of recovery and safe disposal is secured.

(Sifakis A. Haidarlis. M., 2009)

It should be mentioned that all the measures have a target of forming a suitable for Greece waste management policy. Emphasis to the articles concerning specific waste fractions is not given by the government until now. As such, until the replacement of this instrument in 2003, the dominant waste management approach in Greece was the 'appropriate disposal site' approach.

Now, disposal has been downgraded in terms of priority and been placed as the fifth recital, rather than the second, and the measures envisaged in the Directive (i.e. development of clean technologies, product design, recovery and energy) have been upgraded to the first paragraph. Article 4(a) of the Directive is included in the 2003 Joint Ministerial Decision but it is provided for that the conditions envisaged in the Directive for recovery and disposal are applicable to waste management in general. (Sifakis A. Haidarlis. M., 2009)

11.3. Waste quantities

According to Greece statistics agency, the latest information about the waste situation in Greece, refers to 2006 but the existing statistic information is unfortunately pure because there is no accurate measure for all kind of waste quantities and the way they are treated, maybe because of the fact that MSW treatment is Greece is pour in addition to other EU countries. Another reason is the existence of a large number of unauthorized dump sites which makes it difficult to estimate the actual quantities of MSW.

The only useful data is that of Household waste in Greece, which is steadily increasing and the latest official data for 2006 estimated it at 4,133 thousand tons, whereas today it is estimated to have reached 5 million tons/year. (Hellenic Statistical Authority., 2009) Of the total waste generated in Greece it is estimated that some 8.8% is recovered while the remaining 91.2% is deposed of, legally or illegally. The records on the recovery of waste in Greece are not so clear so there is little information about the exact quantities of garden waste and kitchen waste treated in Greece. (Waste Management in Greece National Report., 2009)

11.4. Best practices

11.4.1. The Ano-Liosia plant in Greece

The Ano-Liosia Integrated Waste Management Scheme *(*Picture 55.) comprises of a landfill, an industrial unit of incineration of hospital waste and a mechanical recycling scheme for waste. The latter includes a large composting facility. The plant is situated in the Western suburbs of Athens in Greece. The factory of mechanical recycling of waste was designed and constructed after an international tender, which was procured by the Association of Communities and Municipalities of the Attica Region (ACMAR). The Scheme is one of the two largest waste treatment facilities in Greece. The other facility is the wastewater treatment plant in Psyttaleia which serves a population of 3,000,000. (Morocomp.,2010)

Furthermore, the Factory for mechanical recycling of waste is the largest one in Europe and one of the largest ones in the world. It receives waste from the Attica region. Currently, the population of Attica exceeds 4.5 million people. ACMAR is the Public Authority responsible for the management (treatment, recycling and disposal) of Solid Waste of about 95% of the population of the Attica Region. The construction of the factory of Mechanical Recycling was funded by the European Union and by the Greek government.

The factories capacity is the following:

- 1,200 tons/day of refuse
- 300 tons/day of sewage sludge generated from the Wastewater Treatment Plant of the Attica Prefecture
- 130 tons/day of green waste (leaves) and tree braches

Picture 55.: *Panoramic View of the Ano-Liosia Integrated Waste Management Scheme* (Morocomp.,2010)

The useful material that is produced in this factory is compost, refuse derived fuel (RDF), ferrous metals and aluminum. The by-products of the whole process are directed to the Ano-Liosia landfill which is located nearby. The Factory of Mechanical Recycling of Waste Consists of the following components:

A. Entrance Facilities – Weighting of waste

B. Unit for the Reception of Waste

(Morocomp.,2010)

The Ano Liosia waste management factory, consists the following facilities:

Three (3) waste reception facilities (i.e. lowered reservoirs).

In each reservoir eight (8) garbage trucks can unload waste simultaneously. Therefore, in total there are 24 positions from where waste can be unloaded simultaneously. Each waste reception facility comprises the following:

- ✓ One crane and one electrical hook which feeds with waste the waste collection hopper (Picture 56.)
- ✓ Three (3) hoppers for receiving waste. Each hopper corresponds to a conveyor, upstream of which there is a device that rips the bags that contain waste
- ✓ The three (3) aforementioned devices that rip the waste bags

- ✓ One receptor of grass, greens and tree cuttings into which the trucks unload their content. A mechanically operating loader feeds the shredder with leaves and tree cuttings
- ✓ Three (3) receptors of sludge (i.e. elevated reservoirs) into which the trucks unload sludge (Morocomp.,2010)

Picture 56.: *Waste Reception Trench at Ano-Liosia in Greece* (Morocomp.,2010)

<u>Unit of Mechanical Separation</u>

This unit (Picture 57.) comprises the following components: Three lines of mechanical separation; each line is fed with waste from its respective receptor. Each line of mechanical separation consists of:

- ✓ Primary rotating screener
- ✓ Secondary screener
- ✓ Electrical magnets
- ✓ Bioreactor in the last compartment of which there is a tertiary screener.
- ✓ Conveyor belts

Line for the dry fraction of waste consisting of:

- ✓ Four (4) ballistic separators in order to sort out the light weight fraction which is then shredded, the biodegradable fraction which is fed to the mixer and the remaining residues
- ✓ Four (4) shredders of the light weight fraction of waste; each shredder is fed by a conveyor belt
- ✓ Electrical magnet ballistic separators
- ✓ Conveyor belts (Morocomp.,2010)

***Picture 57.**: Unit of Mechanical Separation at Ano-Liosia in Greece*
(Morocomp.,2010)

One Refuse Derived Fuel (RDF) line which is composed of the following components:

- ✓ One compressor which is fed by the shredded light weight waste through conveyor belts. The light weight fraction is compressed and packaged
- ✓ Conveyor Belts

One Residuals Line which has:

- ✓ One silo for storing the ferrous metals with are then fed to the compressor of ferrous metals

- ✓ One compressor for compressing the ferrous metals into cubes
- ✓ Conveyor belts

One Aluminum Line which consists of:

- ✓ Layout for aluminum recycling which employs eddy currents in order to recover aluminum material from the rest
- ✓ One silo where the recovered aluminum is stored. Then it is fed to a compressor
- ✓ Aluminum compressor where the recovered aluminum is formed into cubes
- ✓ Conveyor belts

One homogenization line with:

- ✓ Three (3) homogenization layouts; each one corresponds to one mechanical layout and to one sludge reception system. Each layout is fed with waste through the exit of the corresponding bioreactor (after the tertiary screening, with the screener which is incorporated in the bioreactor). Furthermore, it is fed with sludge from the respective sludge receptor and with shredded tree cuttings and leaves.
- ✓ Conveyor belts

Furthermore, the Factory of Mechanical Recycling of Waste has equipment which assures the protection of the environment and of the personnel. This equipment includes cyclones, air ducts and air ventilators for the suction of air etc. (Morocomp.,2010)

<u>The Composting Unit</u>

The composting unit (Picture 58.) of Ano-Liosia employs the technology of tunnel composting to treat the organics of Municipal Solid Waste sorted out through the Mechanical Separation System, sludge and green waste. More specifically, the plant comprises of the following:

Picture 58.: *View of Composting Tunnel at Ano-Liosia in Greece*
(Morocomp.,2010)

Three (3) feeding lines: each line feeds 16 composting tunnels with biodegradable material. The total number of composting tunnels is 48. The transportation of the biodegradable material is conducted via conveyor belts. The tunnels are fed with the following material:

- ✓ The mixture exiting the homogenization unit
- ✓ The biodegradable fraction that is recovered from the ballistic separator
- ✓ The recycled material from the screening process

The recycled compost material. As it will be described later, the end compost is screened. The reject stream is then recycled through an elevated conveyor back to the composting unit, as a product that has not been fully composted. It is split into three streams in order to be fed to the 3 lines of the composting unit. The compost mix is placed inside the tunnels up to a height of 2.1 m. Six (6) electrical agitation devices. Each couple (2) of agitation devices is used to mix 16 composting tunnels, corresponding to one feeding line. Each day the agitator agitates 4 tunnels. Overall, 24 composting tunnels are agitated each day. As the agitators proceed inside the composting tunnel they displace the compost mix forward towards the exit of the composting tunnel. Therefore, every 2 days, the agitator completes one displacement of the compost mix towards the exit of the compost tunnel. This way the compost mix is gradually 'pushed' towards the exit of the composting tunnel. (Morocomp.,2010)

The residence time of the compost mix inside the tunnel is 46 days. Each agitation device is equipped with sprinklers for providing water to the compost mix. This is important in order to ensure that the compost mix will not dry out from the high temperatures that develop inside the compost heap. This way the moisture level of the mix is controlled and maintained at desirable levels.

Thirty six (36) blowers provide the required air for the composting process to take place. This corresponds to 12 blowers for each feeding line of the composting unit. Aeration is achieved (apart from agitation) with air suction from the floor of the compost tunnels. The tunnel floor has a grid; air is sucked through aeration pipes placed beneath the grid and ends up in a main pipe. In total there are six (6) main pipes; the air that is sucked is fed to each central pipe through eight (8) tunnels. Therefore, 2 main pipes correspond to each feeding line of the composting unit.

At the floor of each tunnel there is a collection pipe in order to collect the produced leachate. The top part of the collection pipe is perforated so that leachate can enter inside it. All the collection pipes converge to a centralized pipe which ends up at the wastewater treatment unit of the facility. At the end of each composting tunnel there is a conveyor belt which has been installed vertically to the composting tunnels. This conveyor belt transports the end compost to the screening unit. At last, there is a Shredder for shedding the green waste (Morocomp.,2010)

The refinery unit

The compost from the tunnels is fed to the refinery unit (Picture 59.) through the conveyor belt of the composting tunnels. The compost is received at the reception unit. In the reception unit the compost is agitated and grinded. Agitated screws with blades speed up the simultaneous feeding, distribution and dosing of the material. Two rotating drum screens are utilized that produce three different streams of output material. The finest material is directed through a conveyor belt to the waste residuals. The coarser material, which is mainly comprised of material that has not been fully composted, is directed to a densimetric table. The middle sized stream is directed to another densimetric table. The screening unit has in total three (3) densimetric tables.

Picture 59.: *Refinery Unit at Ano-Liosia in Greece*
(Morocomp.,2010)

In two of these tables, the separation of the middle sized stream takes place. The separation is achieved through air and through ballistic separation. Each one of the two densimetric tables produces 3 different streams. The lightest and heaviest streams are directed through conveyor belts to the residual waste stream that is disposed. The third stream is directed to two flat, vibrating screens for further refinement.

As mentioned earlier, the third densimetric table receives the coarse material from the rotating drum screens for further refinement. This third densimetric table also produces three new streams: the lighter and heavier streams go to the waste residuals in order to be disposed off; the remaining stream is directed through an elevated conveyor back to the composting tunnels in order to be composted again. Finally, the screening unit has a vibrating screen that produces two streams; the coarse stream is directed to the waste residuals while the finer one goes for curing after it passes the stage of magnetic separation. 85% by weight of this stream is directed to an open-air curing place and the other 15% to a curing warehouse. (Morocomp.,2010)

Curing Unit

The curing unit consists of the open-air curing system and the warehouse where curing takes place:

a. In the open-air curing place, the screened compost is placed into windrows with the use of loaders. The maximum height of the windrows is 3.5 m. The residence time of the compost in the windrows is 1 month. Curing is essential in order to fully stabilize the end compost. 85% of the compost is cured in this facility

b. Inside the warehouse where the compost is cured, the material is placed in windrows. The warehouse protects the compost from the outside environmental conditions. The windrows have a maximum height of 3.5 m. The residence time is 1 month. 15% of the compost is cured in this installation.

Following the curing stage, the loaders feed the packaging unit, in order to package the end compost. (Morocomp.,2010)

Packaging Unit

The packaging unit consists of the following:

a. Smoothening sub-unit for ameliorating the texture of the end product

b. Sub-unit for placing the end compost inside bags and for sealing these bags

c. Sub-unit of palletizing the packaged end compost

Wastewater Treatment Unit

The wastewater that is treated in this unit is generated from:

a. The reception unit for the trucks

b. The unit of mechanical separation

c. The composting unit (leachate collected from the floor of the composting tunnel)

d. Wastewater from all the sanitation areas of the factory

A two-stage aerobic biological process takes place for the treatment of wastewater. The final effluent is used for irrigating the grass facilities of the installation

Unit for Treatment of Air Emissions from the Mechanical Separation Unit

This unit treats the air emissions resulting for the Unit of Mechanical Separation. The treatment unit consists of three (3) biofilters for treating air exhausts from the unit of mechanical separation. Each biofilter corresponds to one reservoir of the unit of waste reception and to one line of mechanical separation. Biofilters are made up of end compost.

Unit for Treatment of Air Emissions from the Composting Unit

The unit consists of six (6) sub-units for the treatment of air emissions resulting from the composting process. The treatment is performed by employing chemical means; more specifically chemical scrubbing is performed. Each sub-unit is fed by one of the 6 main pipes that collect the air exhaust from the composting unit. Two sub-units correspond to one line from the composting unit. Each sub-unit consists of:

- ✓ One (1) tower for the removal of NH_3 with the addition of H_2SO_4.
- ✓ One (1) neutralization tower where NaOH is added
- ✓ One (1) tower for controlling the pH value and the Red/ox potential through the addition of hypochloric acid
- ✓ Six (6) chimneys

Furthermore, the Ano-Liosia plant has supplementary facilities (e.g. fire fighting facilities, water and acid reservoirs etc), green installations, road facilities (e.g. roundabouts) and control buildings for most units. Each building is controlled through its Local Control Building. However, the whole operation of the facility is controlled from the Main Administration Building. (Morocomp.,2010)

11.4.2.The MBT plant in Chania

The **Solid Waste Recycling & Composting Plant (SWRC)** and the Space for Sanitary Burial of Solid Waste (SSBSW) of the Prefecture of Chania was designed to collect and treat waste produced by the Municipalities of Chania, Akrotiri, Souda, Keramies, Eleftherios Venizelos, Therisos, Kydonia, Platania and Mousouri, although it has a much larger capacity. For that reason, it currently collects urban waste from the entire Prefecture of Chania, except for waste from Sfakia, Armeni, Pelekanos and Anatoliko Selino.

The production of **municipal solid waste** by the Municipalities mentioned above is estimated to be 70,000 tons annually (based on the design) and the production of **green waste** is estimated to be 10,500 tons. 65% of the treated waste can be exploited as tradable recyclable and soil improvement material and the remaining 35% is buried in the SSBSW as residue.

The project was constructed in an **area covering 235 dectares** near the dump of "Kouroupito", where untreated waste of the Prefecture used to be disposed of. The plant is designed to operate **six (6) hours per day, 5 days a week (260 days per year)**. It will have approximately eighty (80) employees when fully developed. **Its total installed power is 2.3MW**.

The plant's total **operational costs,** when it has been fully developed, are estimated to approach 40€/ton. Revenues expected from the sales of soil improvement and recyclable material are expected to reach approximately 15€/ton. The net operational cost is estimated to be 25-30€/ton.

The facilities combine modern, innovative and environment and human friendly technologies and comprise an **integrated and effective solution** for the management of household waste which is produced in the broader area of Chania.

With respect to the construction of the Project, the first cell of the SSBSW was completed and set into operation within the first six (6) months from the signature of the contract, when the sanitary burial of mixed waste began in February of 2003. (P.A.C., 2009)

The statistical data of the plant can be seen in (Table 12.).

(Table 12.): Chania waste management plant statistical data(P.A.C., 2009)

Incoming	Tons/year
Municipal solid waste	70000
Branches and grass	10500
Production	Tons/year
Compost	20000
paper	9000
plastic	5200
Iron metals	1800
aluminum	600

Picture 60.: *Chania MBT plant*
(P.A.C., 2009)

ENTRY OF WASTE - Scale Urban waste is brought to the plant in closed sanitary collectors which take the waste to the scales where it is weighed to determine the nature of the load. The waste is then led through an internal road to the waste collection building or to the SSBSW (if waste is suitable for immediate disposal).

Picture 61.: *sanitary collectors*
(P.A.C., 2009)

Waste is unloaded into collector tanks in an area where the emission of odors and dust is fully under control (Picture 62.). From the collection and through the bridge crane and the claw, the waste is transported on a moving floor so that portions are measured for ripping of bags and then it is transported to the moving belts for its final destination, which is the recycling plant.

Picture 62.: *Area where the emission of odors and dust is fully under control*
(P.A.C., 2009)

Collection building

A mechanical sorting (Picture 63.) of dry matter (paper, plastic) from fluid matter (organic) takes place at the recycling building and then a manual separation is made, from which the lanes of recyclable material may be sorted for utilization and re-use. The sorted recyclable material is packaged and ready for sale. A fraction is left from the treatment, which is rich in organic matter and which, when mixed with the lane of "green" waste, is led to the rapid composting plant for further treatment. (P.A.C., 2009)

Picture 63.: *Mechanical shorting*
(P.A.C., 2009) Rapid
Composting Unit

The rich organic fraction is compressed (after it has been separated from mixed waste) in a reactor with a concurrent aerobic fermentation and infusion of air.

A biological stabilization is then performed within an environment that has controlled temperature and humidity. The composting process (Picture 64.) takes place in two treatment lanes which lie between two similar buildings. Composting. (P.A.C., 2009)

Picture 64..: *Composting organic fraction*
(P.A.C., 2009)

The compressed material is churned once daily and is forwarded on a system of bolts which are placed on a reversible bridge. After it has remained there for a period of six (6) weeks under constant ventilation and churning, so that the composition of the biodecomposite organic load and the production of very fine-grained material may be achieved, it is led for refining.

Refining Unit

The compost material is led to the refining unit (Picture 65.) for final treatment, which is the process of refining, during which unwanted material (glass, hard plastic, gravel, plastic sheets, etc.) that pollute the material may be removed. The final product that emerges from this treatment is the refined soil improvement material (compost), which is a stabilized form of an organic fraction of waste.

Picture 65.: *refining unit*
(P.A.C., 2009)

The refined compost is lead on a moving belt for humification where it is piled up for maturation. 15% of the composite produced is standardized and packaged in sacks while the remainder may be utilized as fill in material. Of the sorted material, the unusable material that is produced from the Refining unit is collected into a container and transferred by vehicle for final disposal at a nearby SSBSW. (P.A.C., 2009)

11.4.3. Project LIFE03 ENV/GR/205 (Comwaste)

The beneficiary/coordinator of the project was the National Technical University of Athens (NTUA) while the associated beneficiaries were the Municipalities of Kifissia, Acharnes and Nea Halkidona. 90 composting systems (Figure.) were installed in 90 selected households (30 in each Municipality), 8 systems were installed in the households of 8 members of the NTUA scientific team and 2 systems run in the Laboratory of Environmental Science and Technology of NTUA. (Comwaste.,2010)

Picture 66.: *Prototype composting unit*
(Comwaste.,2010)

The project lasted 3 years and involved the Promotion and implementation of a prototype system for the production of high quality compost from biodegradable household waste separated at source. The householders were provided with the prototype system as well as with additives that were used for the efficient development of the process. In particular, the householders fed the system with the appropriate biodegradable waste generated at their kitchen together with Greek zeolite of a specific particle size and dose in order to eliminate the odor and improve the quality characteristics of the final product. (Comwaste.,2010)

Picture 67.: *Waste fraction to be composted*
(Comwaste.,2010)

Moreover, a low quantity of mature compost was added to the system in order to support the composting process as well as a specific quantity of sawdust (in order to increase the carbon content that was available for the development of the biochemical actions in the composting compartment by the microorganisms as well to optimize the aeration conditions of the material that was subjected to composting). The product obtained was temporarily stored by the householders in appropriate biodegradable bags. The bags had the capacity to store the quantity of compost that produced during a period of three months for each household. Finally the final product was used in their gardens as a soil improver with great success. (Comwaste.,2010)

Picture 68.: *Final product (compost)*
(Comwaste.,2010)

11.4.4. Psitallia Sludge Drying Facility

The psitallia sludge drying facility started operating in 2007. The facility was installed by the International Technology Group Andritz and is part of the psitallia sewage sludge facility in Athens. Psitallia had a problem coming from (wet sludge odours). The sludge processing capacity of the facility was so big that the excess sludge stayed outside to dry. The result was intolerable odours coming from the facility. The drying sludge facility came to solve this problem. (EYDAP.,2010)

Picture 69.: *Psitallia sewage sludge treatment facility*
(EYDAP.,2010)

The drum drying system (DDS) provides today one of the largest sewage-sludge drying capacity in all of Europe.

Picture 70.: *Drum Drying System*
(EYDAP.,2010)

The process of drying starts after the sludge from the sewage treatment facility, enters the DDS system. The evaporation capacity of the system is approximately 10,000 kg of water per hour and line while almost 350000 tons of sludge can be treated in the plant every year. The dried sludge is used as a high calorific value fuel. heating of the plant is almost exclusively done with off-heat from a gas-turbine and the biogas produced in the sewage system. The final product is 90% dry. The offgas from the drying system is treated in a thermal post-treatment station, where odours and harmful substances are removed. (EYDAP.,2010)

12. International best practices

12.1. The SUMTER plant in South Carolina, USA

In the city of Sumter two are existent problems in waste management. These are sewage sludge and waste wood, mainly tree bark from industry operating in the region.

Picture 71.: *Sumpter drying plant*

The problem was solved by producing energy from the woodchips in order for the sewage sludge to be dried. The sludge is used in agriculture as a fertilizer. The plants specification are:

- ✓ storage area for wood and bark waste
- ✓ shredding equipment for waste wood
- ✓ front loader and weighing device
- ✓ buffer silo for wood/bark
- ✓ combined grate firing with lean gas combustion (1000°C hot gas) with automatic ash discharge
- ✓ directly fired standard drum drying plant for evaporation of 4 t liquid/hour, approx. 5,500 tones d.s. annually, with sewage sludge pre-dewatered to 15% d.s. (digested). Alternatively, the drying plant can be operated partially or entirely with primary energy.

At the following figure the process that takes place in the plant can be seen (Figure 57.):

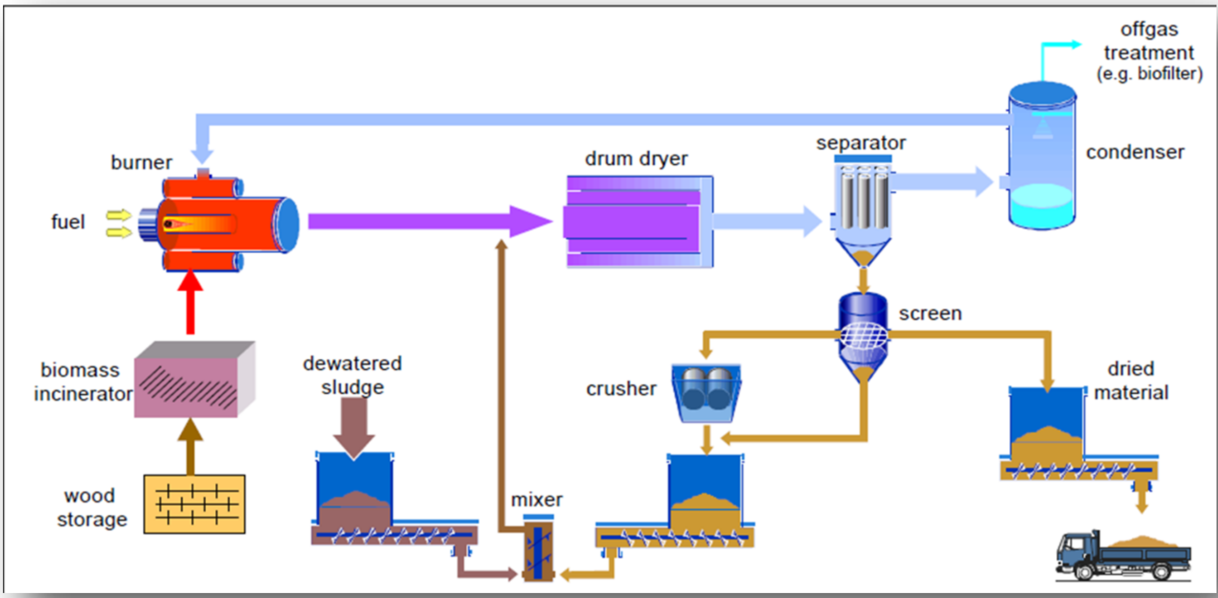


Figure 56.: Process description

12.2.The ARTI Compact Biogas System used in Tanzania and Uganda .

The ARTI (Figure 58.) Compact biogas system (CBS) is made from two cut-down standard high density polyethylene (HDPE) water tanks and standard plumber piping. The larger tank acts as the digester while the smaller one is inverted and telescoped in to the digester and serves as a floating gas holder, which raises proportional to the produced gas and acts as a store room of the biogas. The CBS is designed for treating 1-2kg (dry weight) of kitchen waste per day. The gas can directly be used for cooking on an adjustable gas stove whereas the liquid effluent can be applied as nutrient fertilizer in the garden. Space of about 2 m^2 and 2.5 m height is needed for a CBS of 1000l.(Riuji., 2009)

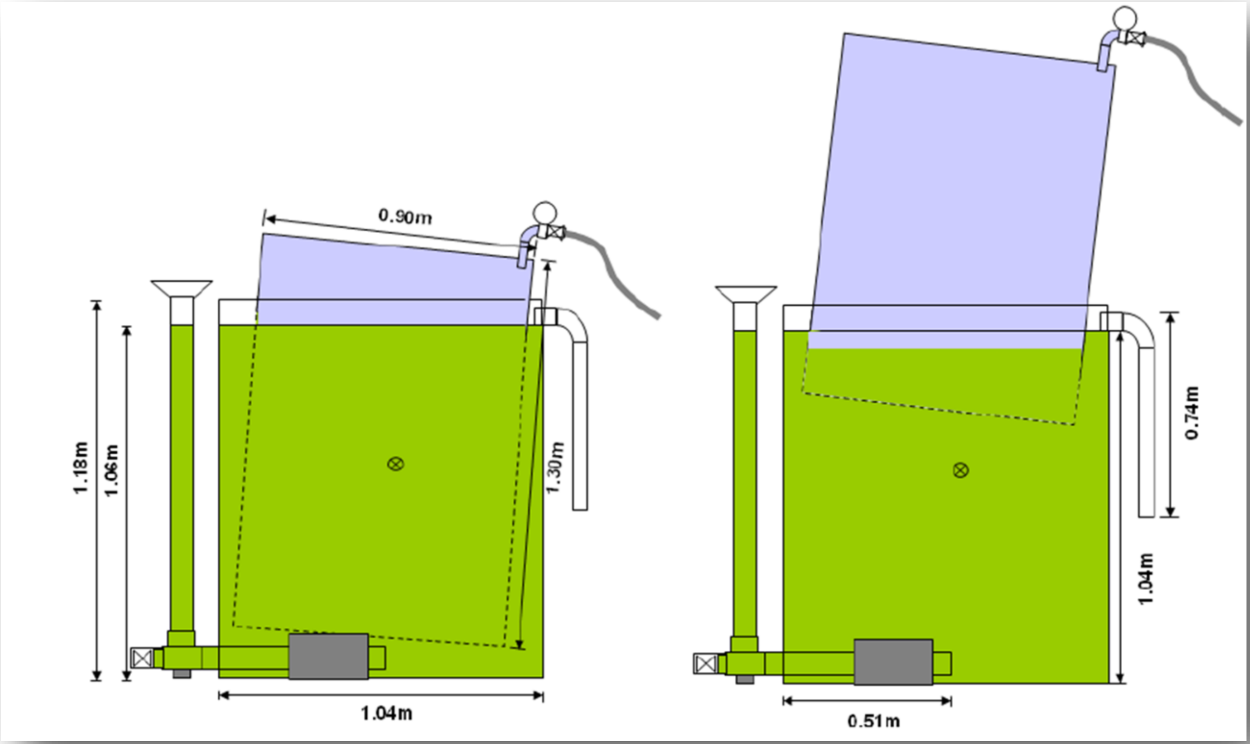


Figure 57.: ARTI Compact biogas plant scheme (gasholder empty and gas - filled)

The effective volume of the digester is approximately 850l, given by the dimension of the 1000l-water tank (inner radius: 51.5cm) and the position of the overflow-pipe (1.04 m above ground level) . The total surface area of the digester ($0.83m^2$) is covered by roughly $0.65m^2$ (78%), in other words the gas released through 22% of the digester surface is lost to the atmosphere without utilization. The usable gas volume of the 750 l - gasholder is 400l. The Hydraulic Retention Time (HRT) suggested by ARTI-TZ, which describes the ratio of the reactor volume ($0.85m^3$) to the f low rate of t he influent substrate ($0.02m^3$/day) , is 42.5 days. The seeming lyrather long period of time that digester liquid spends in the reactor is justified by the appearances of sinking and floating layers. (Riuji., 2009)

Since ARTI-TZ started disseminating CBS in November 2006 until November 2008, 31 ARTI Compact biogas units have been installed in Tanzania and Uganda (Table.13)

Country	Digester size	Quantity	Location	Level
Tanzania	1.0m3	10	9 in DSM, 1 in Mbeya	Household
	1.5m3	1	Kyela	Household
	2.0m3	3	DSM	Household
	3.0m3	2	Saadani (Safari Lodge), Mbagala (Kinasi Lodge)	Institutional
	2.0m3	4	2 on Mafia Island (Kinasi Lodge) 2 in DSM (army campus)	Institutional
	3.0m3	3	DSM (Azania Secondary School)	Institutional
	4.0m3	1	DSM (Bethsaida Sec. School)	Institutional
	1.0m3	1	DSM (ARTI-office)	Demonstration
	1.0m3	1	DSM (ARDHI-university)	Research
Uganda	2.5m3 5.0m3	2 1	Kitende (St.Mary's Sec. School)	Institutional
	1.0m3	2	Kampala (JET-office, ARTI-office)	Demonstration

(Table 13).: Household AD installations in Tanzania and Uganda

12.3. Chinas household anaerobic digesters

China is a country of 1.3 billion people and almost 97% live in villages. The most common waste found there are: sweet potato vines, human wastes, animal wastes, and food waste. Nowadays in China operate more than 5000000 household anaerobic digesters. These digesters produce biogas (Picture 72.) essential for each house and fertilizer also essential in agriculture. Simple composting systems are also used for processing waste.

Picture 72.: *Household biogas use for kitchen appliances*

The wastes used for the anaerobic digestion process differ between regions according to the type of agricultural production. These could be human and animal wastes, and agricultural by-products such as grain stalks (primarily rice), sweet potato vines, and weeds. The basic (AD) household reactors comprise of a cylinder (Picture 73.) shaped main reactor with a domed top. Waste material is fed into the reactor through a port that is connected into the bottom of the reactor.

***Picture 73.**: Household (AD) under construction*

Nowadays these reactors have been developed. The effluent chamber and reactor are connected, and generally, toilets and pigsties are connected directly to the influent port something that didn't happen earlier. The effluent is removed from the reactor at the top of the water column. Thus supernatant is collected rather than sludge. Additionally, no mixing of the system occurs when effluent is removed. In some systems, a vertical cylindrical pull-rod port is added at the side of the effluent port. The pull-rod port connects into the base of the effluent port. Effluent is removed by moving a pull-rod up and down in the port. The pull-rod is simply a wooden shaft with a metal disk on the bottom. In addition to simplifying effluent removal, as a bucket can be placed directly under the pull-rod port, removing the effluent provides some mixing in reactor. In the standard reactor design, the head space volume above the reactor is essentially fixed, although the volume increases slightly with increasing pressure since the effluent port liquid level moves up and down with pressure changes. If in any case effluent is not removed from the AD system, the of it volume in the reactor and the head space volume is reduced. As a result, gas pressure delivered into the home varies. (Henderson.,2010)

The construction of these reactors is made by experienced local technicians trained by the Country for this job. (Picture 74.)

Picture 74.: *Construction of AD systems by technicians*

The biogas comprises of 60% methane and the biogas production is approximately 0.25 to 0.3 m^3 biogas/kg total solids something that depends on temperature which varies during the year and even the day. Gas pressure from the systems ranges from 0 to 80 centimeters of water, and each system has a pressure meter to measure the pressure. The biogas is used for cooking and electricity and covers almost 60% of a house energy needs. Finally the effluent of the AD process is used as a fertilizer or as a feeding supplement for pigs, worms,etc.

12.4. The Tel Aviv plant in Israel

A full-scale Municipal Solid Waste transfer station (Picture 75.) at the pre-existing Tel Aviv opened in early 2003.

Picture 75.: *The ArrowBio plant at the Tel Aviv, Israel, transfer station*.

(Wastesum project Del 3A,. 2010)

The physical separation/preparation element of the plant is under the roof at the left, and the biological element is beyond the roof at the right. In the background is the Hiriya dump, now closed and being remediated as part of the future Ayalon Park. The design capacity of a standard ArrowBio module is 200 tons/day or 70,000 tons/year. However, lack of space at the preexisting transfer station imposed two constraints. First, the two elements had to be apart, though this is not a major drawback as they are connected by pipelines. Second, there was space for only one 100 ton/day separation/preparation line rather than two lines as in a standard module. The biological element shown is sized for two lines as in a standard module.

The physical and biological elements of the Process are integrated such as to make possible the recovery of both material (e.g., non-compliance food containers) and energy (methane-rich biogas) resources in a single facility. Typically, about 70% of unsorted MSW mixtures consist of biodegradable organics (food preparation wastes, plate wastes, diapers, incidental vegetative material, food tainted paper), yielding methane. Source separated waste streams might be up to 90% biodegradable. Both types of input must undergo separation and preparation prior to anaerobic digestion. Not only must the biodegradables be isolated and prepared for energy recovery, but the nonbiodegradables must be sub-fractionated into the various types of secondary materials for recycling to the extent practicable, as well as residual to be landfilled.

Water has significant role in the operation of the plant. It has to be mentioned that water in the vat is in circulation with water newly freed from the waste through biological action at the back-end. That is, the source of the water in both elements is the moisture content of the waste, typically comprising around 30% of the weight of MSW [Finstein, M.S. 2003. "Operational Full-Scale ArrowBio Plant Integrates Separation and Anaerobic Digestion in Watery Processing, With Near-Zero Landfilling." *Proceedings of WasteCon 2003, SWANA's 41st Annual International Solid Waste Exposition*, October 14-16 2003 St. Louis, Missouri, p. 290-296]. The biological gasification of organic solids leaves behind the water in liquid form.

The non-biodegradable and biodegradable fractions are separated gravitationally in the water vat. Separation in water is far more efficient than in air, owing to the comparative densities (relative buoyancies) of the two fluids. Thus, depending on their specific gravity and tendency to absorb water, items sink, float, or become suspended in the water. Other benefits of tipping into water include dust suppression and the neutralization of odors. Neutralization is immediate because odorous compounds are soluble in water. Their biodegradation soon follows in enclosed digesters, preventing downstream generation of nuisance odors. Also, being watery evens-out surges and regulates the rate of progression through the processing train, contributing to the system's overall resiliency.

The exterior of the physical element is depicted in (Picture 76.).Traditional recyclables (e.g., non-compliance bottles and cans) and other non-biodegradables are removed while the biodegradable for UASB digestion 1 are isolated. In this Figure, the following are presented:

- ✓ the settling tank (Figure (2a))
- ✓ the cyclone at the terminal end of a plastic film plastic removal system (Figure (2b)) which leads to a baler (Figure 3)
- ✓ the trommel screen (Figure (2c))
- ✓ the office and control room (Figure (2d))

Picture 76.: *The exterior of the physical element in the Tel Aviv plant in Israel.*
(Wastesum project Del 3A., 2010)

In the separation/preparation vat, the watery flow carrying the heterogeneous mixture of MSW materials follows multiple pathways that are, by design, complex, overlapping, and repetitious. As such, the agencies of solubilization, size reduction, screening, and gravitational separation are given diverse and repeated opportunities to complete their work. The multiplicity of pathways makes it impossible to describe events in a linear fashion. The interior of the physical element is shown in (Picture 77.). In this Figure, the following are presented:

Picture 77.: *The physical separation/preparation element in the Tel Aviv plant in Israel.*
(Wastesum project Del 3A, 2010)

- ✓ the walking floor (Figure (4a))
- ✓ the rotating paddle (Figure (4b))
- ✓ the main body of water paddle (Figure (4c))
- ✓ the bag breaker (Figure (4d))
- ✓ the magnetic pickup (Figure (4e))
- ✓ the eddy current device (Figure (4f))
- ✓ the pneumatic (vacuum/forced draft) station (Figure (4g))
- ✓ ductwork (Figure (4h))
- ✓ trommel screens (Figure (4i))
- ✓ settlers (Figure (4j))
- ✓ lifters (Figure (4k))
- ✓ shredder (Figure (4l))

- ✓ large trommel screen (Figure (4m))

The load is tipped onto a walking floor (4a), from which it falls into the water vat immediately upstream of a partially submerged rotating paddle (4b). The paddle urges floaters and buoyancy-neutral items forward into the main body of water (4c). Sinkers are diverted to the left and passed sequentially to a bag breaker (4d), magnetic pickup (4e), eddy current device (4f), and a pneumatic (vacuum/forced draft) station (4g) from which film plastic is swept into ductwork (4h). Ducts from several such stations converge on the cyclone. Thereby, metals and film plastic are removed. Items that escape this processing train the first time around re-enter the water vat (4c) for another chance to dissolve, float or sink or, if buoyancy-neutral, be suspended in the forward-moving water column.

Overflow from the water vat, screened to exclude large items, passes though smaller enclosed trommel screens (4i) and thence, according to partitioning criteria, to large and small (4j) settlers. In the settlers grit is separated from organics and removed from the system. Meanwhile, larger floaters and buoyancy-neutral items are lifted (4k) to a slow speed shredder (4l) and thence to the large trommel screen (4m). The "overs" from this trammel consist mostly of film plastic and are removed at a pneumatic station. The "unders" (material that passed through screen) are washed into a non-mechanical device for further solubilization and size reduction. Non-soluble substances are thus reduced to a suspension of fine particles whose surfaces are roughened to favor microbial colonization.

Thus non-biodegradables are recovered for recycling as secondary material commodities, and soluble and particulate organics come into solution or fine suspension, including food sticking to containers and the contents of unopened diapers. Insoluble biodegradable organics (e.g., non-source-separated food-tainted paper products, tough fruit rinds) get increasingly soggy and fragmented, ultimately to the point of passing screens of selected sizes. The organics, now in watery isolation, are pumped to the biological element. In turn, return water from the biological element refreshes the separation/preparation water vat. Within half an hour after tipping the last load of the day, the work of the physical separation/preparation element is complete. This part of the plant is then shut down until deliveries resume the next working day.

The organic flow first enters acidogenic bioreactors for several hours of preliminary treatment. There, readily metabolized substances already in solution are fermented (e.g., sugars fermented to alcohols), while certain complex molecules are biologically hydrolyzed to their simpler components (cellulose to sugar, fats to acetic acid). The overflow, rich in such intermediate metabolites, then enters the UASB bioreactor. Then, they are transferred to a settling tank. Supernatant is pumped to the physical separation/preparation element as needed for makeup water, or to an aerobic tank for polishing if necessary.

Water may be stored or used immediately as in irrigation. The solids are dewatered for use as stabilized organic soil amendment. Some of the biogas is used to fire boilers to maintain UASB digestion at its optimum temperature of ~35°C. Otherwise, depending on site-specific circumstances; the gas fuels an electrical generator via a storage tank. Waste heat from the generator contributes to the maintenance of digestion temperature.=

12.5. The Rapid City, South Dakota plant in USA

Composting of yard trimmings in Rapid City began in 1993. In (1994) no landfilling of yard trimmings was allowed. "A waste composition study done in 1993 showed that yard waste was 10 to 15 percent of the total MSW generated," In The city three dropoff sites were built, and 20 cubic yard rolloff containers at each for collection were placed. Curbside collection is available to these receiving city service (about 16,500 households); citizens must place yard trimmings in kraft paper bags, which are collected the same day as garbage and recyclables (during the season when yard trimmings are primarily generated). Yard trimmings also can be brought to the landfill at no charge. About half of the annual tonnage received (about 13,000 tons in 2002) comes from the dropoff sites; the remainder arrives either through the curbside program or self-hauling to the landfill.

Leaves, grass, tree limbs brush, and some manures are also accepted. All materials are ground in a Peterson Pacific 5400 horizontal grinder before being placed into windrows. A Scarab turner mixes and aerates the piles once a week initially. The composting process varies and depends on the weather, composting material, temperature, etc.. Finished compost is screened to either three-eighth or three-quarter inches, depending on the end use. The three-eighth inch compost is sold for $30/ton; three-quarter inch sells for $25/ton, and the three-eighth inch rejects, mostly wood chips, sell for $10/ton. "The production of the facilities is approximately 4000 tons per year.

The Rapid City composting plant (Picture 78.) in South Dakota was built in three stages. It is a facility that treats both Municipal Solid Waste (MSW) and sewage sludge. Partnering enabled Rapid City to complete the third and final phase of its biosolids and municipal solid waste (MSW) co-composting facility on time and within budget.

The first phases of the solid waste program which consisted of the Material Recovery Facility and the two rotating bioreactors was completed in 1997. Economic concerns prompted the City to put the final phase composting project on hold. Interest was renewed in 1999 when Rapid City decided to upgrade its Water Reclamation Facility and discovered that biosolids land application would require purchasing an additional 1,100 acres of land. Co-composting biosolids with MSW would achieve greater economic benefits, meet the recycling goals and preserve landfill space. However, problems surfaced again in 2002 when the first round of bids for the co-composting facility exceeded the project budget. US Filter presented an approach that the City accepted.

The technical team conducted an intense design workshop to achieve the project and budget objectives. Within six months the design was completed, the project was successfully rebid and construction was underway. Finally, the facility started to operate at May 2003. It has the capacity of processing 355 cubic yards per day of municipal solid waste with biosolids at 9 tunnels, each 10 feet wide x 8 feet high x 280 feet long. The solids retention time is 29 days, while the area of the composting building is 47,000 square feet. The facility consists of the active composting facility, aerated curing (20,000 square feet compost aerated curing shelter with a retention time of 30 days) and a refining building with a screener and destoner. The product is stored at a 3 acre area. The compost product is used in land reclamation and landscaping projects.

Picture 78.: *Transportation of Municipal Solid Waste and the Final Product after cocomposting of Solid Wastes with Biosolid in USA(*Wastesum project Del 3A,. 2010)

13. Commercialized household waste drying systems

Household waste drying is an innovative technology that has never been used before for the management and treatment of household organic waste. There are no EU and International reports showing that household waste dryers have been used in the past in either small or large scale for the treatment of this type of waste. An extensive World Wide Web research revealed that there are some commercialized household organic waste drying systems that could be used as a single device without being part of a wider waste management concept. No publications have been found though showing the research results of the use of these household appliances. It must be mentioned that all the household waste dryers found were for indoor use only and made in Korea mainly.

This Section aims to provide a brief description of the existing commercialized household waste drying systems.

13.1. Loofen household waste dryers

Loofen Lee Co., Ltd was established in 2003 in Korea. The company has been developing innovative household and commercial waste drying systems since then. A series of household and commercial waste drying systems have already been constructed and have obtained many national certifications. The company's waste dryers though have not been widely distributed internationally up until now.

The company has created many series of household waste drying models with different capacities and capabilities but they all have the same philosophy. They all use heated air for the drying process. In the following picture, some of the 5L capacity models are shown:

Picture 79.: *Loofen company's household waste drying systems, 5L capacity*

(Loofen., 2010)

The following picture shows some of the 4L capacity models distributed by the company:

Picture 80.: *Loofen company's household waste drying systems 4L capacity*

(Loofen., 2010)

In the pictures that follow, some of the 10L capacity models distributed by the company are shown:

Picture 81.: *Loofen company's household waste drying systems 10L capacity*

(Loofen., 2010)

Picture 82.: *Double layer 10L waste dryer*

(Loofen., 2010)

13.2. Loofen household waste dryers technical specifications

In the following table the main household models of the company are presented along with the technical specifications of each model:

Utility	Household Appliances				
Model No.	LF-07	LF-01	LF-02	LF-03	10Liter New
Standard Feature					
Dimension (WxLxH / mm) (exclude Filter Holder) (Main Body only)	270 x 292 x 350	270 x 275 x 350	270 x 309 x 355	360 x 250 x 438	280 x 420 x 440
Waste Basket Capacity	5L	4L	4L	7L	5L x 2 basket
Product Weight (exclude Filter & Filter Holder)	6kg	6kg	6kg	8kg	undecided
Advantageous Characteristics	Moisture Detecting Sensor			*Standard drying mode * Rapid drying mode	Same as LF-07,01,02
	Touch Sensor Button (Power On/Off & Operation)				
	Coated with antifungal substance / easy-washable Basket				
Process Type	Dehydrating : Heated Air circulation in chamber			Dehydrating : Air circulation in chamber	Dehydrating : Air circulation in chamber
	Deodorizing : Coated activated carbon filtration			[illegible]	Deodorizing : Activated carbon filtration
Power Source	Varies to suit each country Voltage / Hrz / (Phase) standard				
Power Consumption	Ventilation mode 10W/Hr ~ Operation mode 90W/Hr(average 60W/Hr)			Ventilation 20W / Standard 90W / Rapidity 150W	2 Basket operation 700g input 145~150W
Option	*pearl coated red body with yellow circle *pearl coated black body with green circle	N/A	N/A	N/A	N/A

Table 14.: Loofen company's household waste drying systems specifications (Loofen., 2010)

In the following table the main commercial waste drying systems are presented:

Utility	Commercial Equipment
Model No.	LF-25/50/100
Standard Feature	
Dimension (WxLxH / mm) (exclude Filter Holder) (Main Body only)	LF-25: 750 x 650 x 940 LF-50: 900 x 750 x 1,050 LF-100: 1,050 x 900 x 1,050
Waste Basket Capacity	Max treat.capa : 30kg/60kg/100kg
Product Weight (exclude Filter & Filter Holder)	LF-25: 150kg LF-50: 220kg LF-100: 440kg
Advantageous Characteristics	On touch operation / Condensed water drainage after filtration / Desiccation by heated air circulation
Process Type	Air circulation in chamber and condensed water drainage
Power Source	Varies to suit each country Voltage / Hrz / (Phase) standard
Power Consumption	LF-25 : 2.5KW/HR LF-50 : 4.0KW/HR LF-100 : 7.0KW/HR
Option	N/A

Table 15.: Loofen company's commercial waste drying systems specifications (Loofen., 2010)

The interior parts of both the commercial and the household models are presented in the figure that follows:

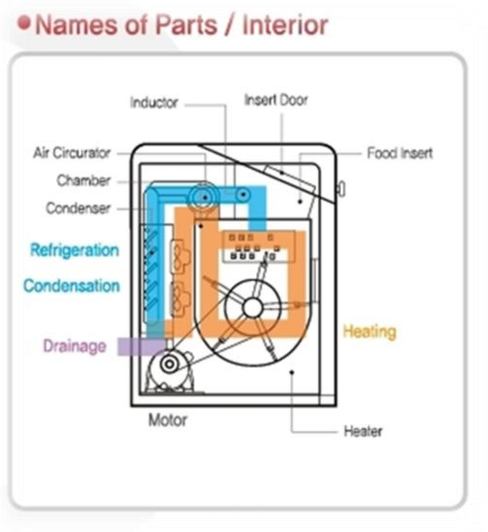


Figure 58.: Loofen company's systems interior parts (Loofen., 2010)

A feature that *characterizes* all *of* the company's waste dryers is the activated carbon filter for the odors minimization at the back of the device. The air which contains the removed waste moisture passes through a thick layer of activated carbon pellets for the odors removal. Most of The odors are removed from the moist air and thus the air does not have negative impacts to the environment and the human society in general. The figure below shows the operation of the filter:

Figure 59.: Loofen company's activated carbon filter (Loofen., 2010)

A different point of view of the activated carbon filter is shown at the picture that follows:

Figure 60.: Loofen company's activated carbon filter (Loofen., 2010)

13.3. Coway household waste dryers

Coway *cooperation* was established in 1989 in Korea. The company has been creating products such as: air purifiers, water filtration devices, digital bidets, megasonic cleaning devices and other home appliances since then. As some of Coway's products had a quite high initial cost to consumers when they first hit the market, Coway adopted a rental business model in 1998 to make them more accessible to the public. As the cost to consumers decreased over time, people began adopting the products more and more. In 2003, Coway enlarged its business to go global with the first overseas business starting in Japan. Coway then expanded to Thailand, China, and Malaysia. On May 2010, Coway also opened its first U.S. subsidiary in Los Angeles, signaling its commitment to the U.S. market.

As for the European market, Coway has set up a number of logistics bases and is planning to establish subsidiaries shortly. In the global market, Coway makes localization its top priority.

The company has created a small series of household waste drying models with different capabilities but they all have the same philosophy just like the Loofen models. In the following picture, the high capacity model (WM05-A) of the company is shown in the following picture:

Figure 61.: Coway high capacity model (Coway., 2010)

A smaller waste capacity model (WMD-01) is shown in the picture below:

Figure 62.: Coway small capacity model (Coway., 2010)

The third small capacity model (WM03) is shown in the following picture:

Figure 63.: Coway small capacity model
(Coway., 2010)

Finally the third small capacity model (WM06) which is ready to be released is shown in the following picture:

Figure 64.: Coway small capacity model ready to be released
(Coway., 2010)

13.3.1. Coway model (WM05-A)

In the following *diagram,* the operation of the model is presented in brief:

Figure 65.: Coway (WM05-A) operation diagram (Coway., 2010)

The technical specifications of the model are shown in the following table:

Specification

Model	WM05-A
Disposal Method	Heat and Grind
Volume Reduction	90 % (Varies depending on the moisture contents of food wastes)
Capacity	1.5 kg per session (Max. 3kg)
Processing Time	Approx. 3 hrs/cycle * Varies depending on the types of food wastes
Deodorization	Composite Filter (AC + Zeolite + Oriental herb)
Power Consumption	800 W
Dimensions (W X H X D)	12.5 X 15.3 X 26.2 inch 320 X 397 X 668 mm
Net Weight	47.3 lb (21.5 kg)

Table 16.: Coway (WM05-A) technical specifications

(Coway., 2010)

13.3.2. Coway model (WMD-01)

In the following *diagram* the operation of all three small capacity models is presented in brief:

1. The food leftovers are put in the food receptacle, 2.The food waste is dried naturally with the operating fan inside the dryer, 3.the waste is heated and the pulverization takes place, 4. The bad odor is removed with the use of an activated carbon filter, 5. The pulverized food is removed from the waste dryer.

Figure 66.: Coway small capacity dryers operation diagram (Coway., 2010)

The technical specifications of the (WMD-01) model are shown in the following table:

Specification

Model	WMD-01
Disposal Method	Heating + windy drying
Deodorization Filter	Dual stage deodorization filter (2 EA)
Disposal Capacity	Maximum 1KG
Operating Time	About 8 hours *Operating time varies depending on the type of food
Dimension(mm)	311(W)*368(D)*319(H)
Weight	7kg(15.4lb)
Power Consumption	285W

Table 17.: Coway (WMD-01) technical specifications

(Coway., 2010)

13.3.3. Coway model (WM03)

The technical specifications of the (WM03) model are shown in the following table:

Specification

Model	WMD-03
Disposal Method	Heat and Grind
Volume Reduction	90 % (Varies depending on the moisture contents of food wastes)
Capacity	1kg per session
Processing Time	Approx. 4 hrs/cycle * Varies depending on the types of food wastes
Deodorization	Composite Filter (AC + Urethane)
Power Consumption	485 W
Dimension (W x H x D)	11.5 X 15.3 X 12 inch 293 X 389 X 307 mm
Net Weight	28.7 lb (13 kg)

Table 18.: Coway (WM03) technical specifications

(Coway., 2010)

13.3.4. Coway model (WM06)

*T*he technical specifications of this model *are* not available since it has not been released *until now*.

13.4. Kitchen smile household waste dryers

Samoh NK was established in Korea. The company has been developing innovative household waste drying systems along with other kind of environmental friendly technologies. The company's waste dryers though have not been widely used internationally up until now just like the Loofen ltd. Waste dryers.

The company has created two series of household waste drying models named "Kitchen Smile" with different capacities and capabilities but they all have the same philosophy.

In the following picture, the first released model of the company which is now out of the market, is *presented*:

Figure 67.: Kitchen smile first released model
(Samon NK., 2010)

The second released model is shown in the following picture:

Figure 68 .: Kitchen smile second released model
(Samon NK., 2010)

13.4.1 Kitchen smile household waste dryer technical specifications

The technical specifications of the second released waste dryer are *recorded below*:

Specifications:

- Voltage : 220V
- Power Consumption : Approximately 90W
- Weight : 6.6kg
- Dehydrating Method : Air Circulation
- Size : 240mm x 667(697)mm x 429/240mm x 717(747)mm x 429

13.5. DUO Enterprise Ltd Food garbage evaporator

DUO Enterprise Ltd., was established in 1998, and has manufactured & *exported general* goods (especially cotton knitted underwear, socks, etc.). The company has started exporting internationally *in the recent years*.

The company besides the other products that *produces* has released one household waste dryer *model* (garbage evaporator) which is *presented* in the following picture:

Figure 69.: DUO Enterprise Ltd. released model
(DUO Enterprise Ltd., 2010)

13.5.1 DUO Enterprise Ltd. household waste dryer's technical specifications

The drying *process takes place* with a Dual Dry & Sterilization by Far-Infrared Ray & Ceramic Heater. It is a patented product. The *specific* application dries food waste by using wave-length of Far-infrared ray which gives huge advantage according to the company of time saving as it dries food waste sufficiently internally & externally at the same time.

The Wave-length of Far-infrared ray penetrates the inside of the food waste and thus it is believed to be more effective than heated air drying.
The company has adopted a 4-stage multi-filter for the odor removal. It can be used more than 6 months according to the company.

Finally the drying basket at the bottom of the waste dryer has holes a *characteristic* which makes the food waste *drying process more efficient*.
The technical specifications of this waste dry*ing system* are *recorded below*:

Specifications:

- Weight : 11 Kgs
- Input Volume : 6.5L
- Power : AC 220~240V 50/60Hz
- Size : 270(W) * 450(D) * 380(H)

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