IEA Bioenergy

Accomplishments from IEA Bioenergy Task 36: Integrating Energy Recovery into Solid Waste Management Systems (2007-2009)

End of Task Report

Lakeside Energy from Waste Plant, UK

CONTENTS

INTRODUCTION

IEA Bioenergy

IEA Bioenergy is an international collaborative agreement set up in 1978 by the International Energy Agency (IEA) to improve international co-operation and information exchange between national bioenergy RD&D programmes. IEA Bioenergy aims to accelerate the use of environmentally sound and cost-competitive bioenergy on a sustainable basis, to provide increased security of supply and a substantial contribution to future energy demands. The work within IEA Bioenergy is structured in a number of Tasks, which have well-defined objectives, budgets, and time frames. Further information on IEA Bioenergy can be found on www.**ieabioenergy**.com.

IEA Bioenergy Tasks

During the period 2007-2009 there were 12 ongoing Tasks:

Task 29: Socio-economic Drivers in Implementing Bioenergy Projects
Task 30: Short Rotation Crops for Bioenergy Systems
Task 31: Biomass Production for Energy from Sustainable Forestry
Task 32: Biomass Combustion and Co-firing
Task 33: Thermal Gasification of Biomass
Task 34: Pyrolysis of Biomass
Task 36: Integrating Energy Recovery into Solid Waste Management Systems
Task 37: Energy from Biogas
Task 38: Greenhouse Gas Balances of Biomass and Bioenergy Systems
Task 39: Commercialising Liquid Biofuels from Biomass
Task 40: Sustainable International Bioenergy Trade - Securing Supply and Demand
Task 41: Project 3 - joint project with the Advanced Motor Fuels Implementing Agreement
Task 42: Biorefineries: Co-production of Fuels, Chemicals, Power and Materials from Biomass
Task 43: Biomass Feedstocks for Energy Markets

Task 36: Integrating Energy Recovery into Solid Waste Management Systems

Task organisation

In October 2006, the Executive Committee of IEA Bioenergy approved a three-year work programme (for the period 2007 to 2009) on Integrating Energy Recovery into Solid Waste Management Systems - referred to as Task 36. The Task objectives included the maintenance of a network of participating countries as a forum for information exchange and dissemination. The participating countries in this current phase of the Task were: Canada, the EC, France, Germany, Italy, the Netherlands, Norway, Sweden and the United Kingdom.

The National representatives of the Task are noted below and their contact details are listed in Appendix 1.

Canada	Rene-Pierre Allard, NRCanada
EC	David Baxter, JRC the Netherlands
France	Elisabeth Poncelet, ADEME
Germany	Prof Dr-Ing. Helmut Seifert, Karlsruhe Institute of Technology
Italy	Giovanni Ciceri, ERSE
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The Chair of the Task (Task Leader) was Dr Niranjan Patel (Waste Infrastructure Delivery Programme, Defra, UK).

The Operating agent was Kieran Power from the Department of Energy and Climate Change (UK).

The principal contributors to the four chapters that comprise this report were:

Chapter 1	Rene-Pierre Allard, NRCanada; David Baxter, JRC; Elisabeth Poncelet, ADEME; Helmut Seifert and Juergen Vehlow, KIT; Giovanni Ciceri, ERSE; Timo Gerlagh, NL Agency; Michael Becidan, SINTEF; Evalena Blomqvist, SP; Pat Howes and Jim Poll, AEA
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Chapter 3	Judith Bates, AEA
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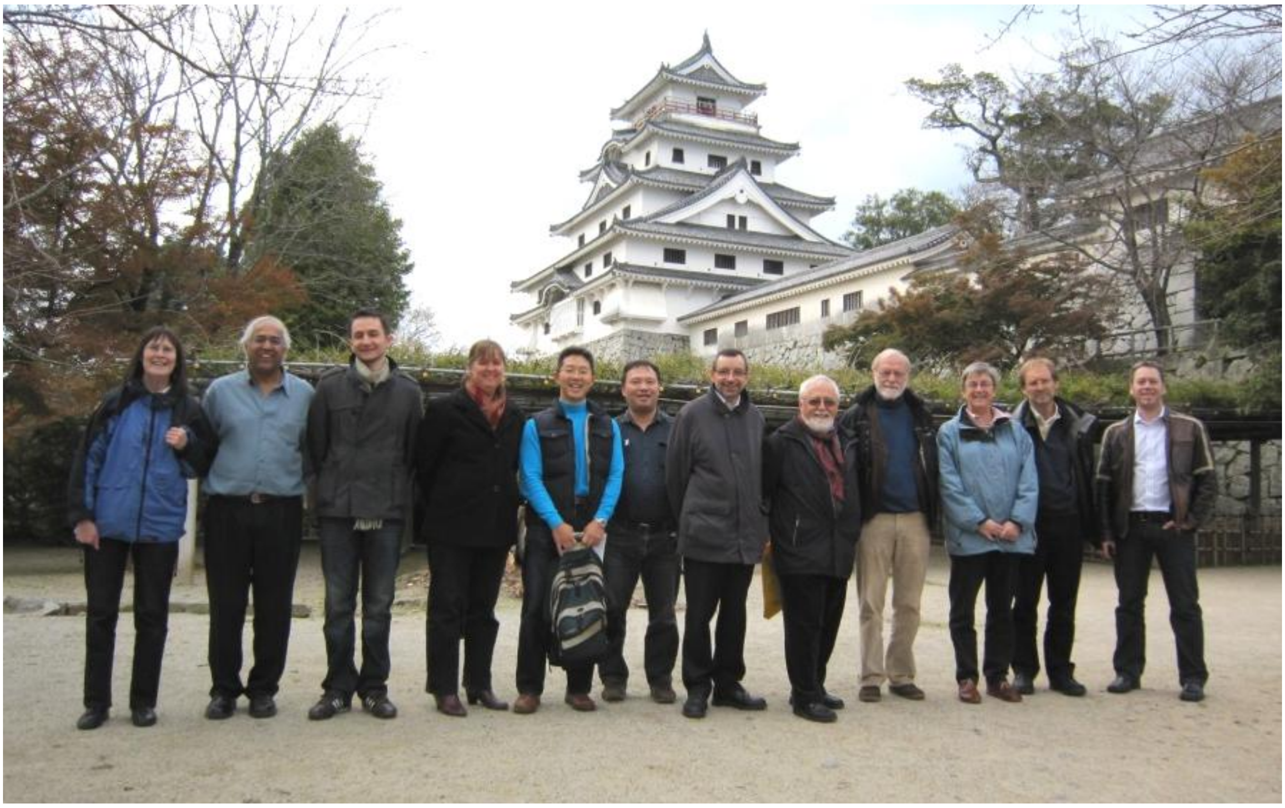


Task 36 Members in Fukuoka, Japan

Aims and objectives of Task 36

The potential for exploiting Municipal Solid Waste (MSW) as an energy resource is at a crossroad. Within the EU, the main driver for diverting waste from landfill is the Landfill Directive. The waste can either be recycled (so recovering its inherent energy value) or energy can be extracted directly from the remaining residual waste. In terms of meeting the Landfill Directive, EU member countries fall into one of two groups: those that already meet the requirements of the Directive - because they have highly developed waste management infrastructure and so consign the minimum to landfill; and those that do not meet the Directive and so provide the greatest opportunity for energy recovery. The former group of countries include Germany, Denmark and the Netherlands. The latter group includes the southern European nations, Scandinavia, the UK and Ireland.

Internationally, developed nations such as Canada, USA and Australia continue to rely on landfill and do not as yet have policy measures such as the EU Landfill Directive. Rather, they rely principally on the economic driver for waste diversion. The potential for energy recovery in these countries is therefore high, though institutional and other non-technical barriers pose considerable challenges.

The last decade has seen considerable efforts in research work on waste management - including policy development, environmental systems analysis, technology development and economic drivers. Whilst this has assisted in the development of waste management systems in many cases, it has also delayed deployment of energy recovery systems in particular due to confused policy making, public awareness (and opposition) and uncertainty over environmental performance and technology performance. Policy makers require guidance and information on all these aspects if waste and resource management systems that are environmentally and economically sustainable are to be developed. It is the aim of this IEA Task to collate some of the most relevant recent research work and to produce a concise report for the benefit of the waste and resource management sector.

The Task has focused on four key areas:

1. The MSW resource
2. Waste and resource management policy
3. Environmental considerations
4. Technology

This report provides a summary of the work undertaken by the Task.

The future

IEA Bioenergy Task 36 will continue to promote information exchange and deployment of environmentally sound energy recovery technologies and to stimulate interaction between RD&D programmes, industry and decision makers.

Further information

For further information on Task 36, contact the Task Leader for the next phase of work (2010 - 2012):

Dr Patricia Howes
e-mail: pat.howes@aeat.co.uk
and visit the Task 36 website at www.ieabioenergytask36.org

For further information on IEA Bioenergy, contact the IEA Bioenergy Secretary:

John Tustin
e-mail: jrtustin@extra.co.nz
and visit the IEA Bioenergy website at www.ieabioenergy.com

EXECUTIVE SUMMARY

Summary of chapter 1: status of solid waste management in task member countries

Introduction

This chapter details the solid waste management practices in the IEA Task 36 member countries in terms of policy, actual practice, and trends for the future (to 2020). The country specific reports include details on:

- national policy/strategy on waste management and the recovery of energy from waste;
- data on the historical arisings and management of solid waste;
- factors affecting waste growth, and estimates the solid waste arisings in the future;
- the potential for increasing the amount of energy which is recovered from solid waste.

The summary below draws on data from a wider source (i.e. from more than just the Task 36 Membership) in order to give a more global perspective where relevant and also focuses on the treatment of the residual waste stream for energy recovery (energy from waste - EfW).

Definition of MSW

The key for designing waste management systems for countries, regions, or municipalities is knowledge of the amount and quality of waste arising. Data are found in various statistics on all levels, collected by local, regional, national, and international organisations like UNEP, OECD, or Eurostat. The problem with these statistics is the inconsistent basis of the data sources, which makes comparison between regions difficult.

Most national and international statistics contain generation and, rarely, composition data for MSW. Unfortunately, there is no common definition of this type of waste and hence, for example, the OECD statistics are characterised by numerous footnotes indicating which waste fractions are included in the actual data. The following illustrates some of the definitions used for MSW:

OECD: 'In general, municipal waste is waste collected and treated by or for municipalities. It covers waste from households, including bulky waste, similar waste from commerce and trade, office buildings, institutions and small businesses, yard and garden waste, street sweepings, the contents of litter containers, and market cleansing waste. The definition excludes waste from municipal sewage networks and treatment, as well as municipal construction and demolition waste.'

'Household waste is waste generated by the domestic activity installations of households. It includes garbage, bulky waste and separately collected waste.' [OECD 2002].

U.S. EPA: 'EPA includes those materials that historically have been handled in the municipal solid waste stream and sent to municipal landfills. MSW includes wastes such as product packaging, newspapers, office and classroom papers, bottles and cans, boxes, wood pallets, food scraps, grass clippings, clothing, furniture, appliances, automobile tires, consumer electronics, and batteries.' [U.S. EPA 2004]

'Household Waste (Domestic Waste): Solid waste, composed of garbage and rubbish, which normally originates in a private home or apartment house. Domestic waste may contain a significant amount of toxic or hazardous waste.' [U.S. EPA 1997]

'Residential Waste: Waste generated in single and multi-family homes, including newspapers, clothing, disposable tableware, food packaging, cans, bottles, food scraps, and yard trimmings other than those that are diverted to backyard composting.' [U.S. EPA 1997]

From the definitions it is obvious that household waste and domestic waste are the same material. Another synonym is often 'residential waste', but the EPA definition makes no clear statement in that case.

'Commercial Waste: All solid waste emanating from business establishments such as stores, markets, office buildings, restaurants, shopping centers, and theaters.' [U.S. EPA 1997]

IEA: For the IEA, waste is only of interest in view of its energy inventory and - for IEA Bioenergy - also for its biogenic energy fraction. The definition for MSW is: 'Municipal waste consists of products that are combusted directly to produce heat and/or power and comprises wastes produced by the residential, commercial and public services sectors that are collected by local authorities for disposal in a central location. Hospital waste is included in this category.' [IEA 2007]. Here again, the last waste type is excluded in most definitions.

EU: The European Commission issued a waste list in 2000 which defines under code 20 'Municipal wastes and similar commercial, industrial and institutional wastes including separately collected fractions.' Code 20 01 'Separately collected fractions' lists paper, wood, textiles, glass, metals, and organic kitchen waste and also hazardous fractions like acids, photo chemicals and others. The latter ones, however, are typically summarised as hazardous household waste in Eurostat or OECD statistics. Code 20 02 'Garden and park waste' comprises compostable waste, soil and stones, and other non-compostable waste. 20 03 'Other municipal waste' covers mixed municipal waste, often called 'residual waste', and waste from markets, street cleaning, and septic tanks. [European Commission 2000]

Eurostat, the statistical office of the European Commission, and the national statistical offices of the EU member states compile annual statistics on MSW and household waste, but do not always indicate which waste fractions are separately collected. Commercial waste is only included as long as the material is similar to household waste. Such waste is under the regime of the public waste management system, other waste from commerce, trade, and industry has to be taken care of by the producer himself.

According to the above listed definitions, MSW comprises waste from various sources. Some of these waste streams, like yard and garden waste, are more uniform in composition than others such as waste from commerce and trade or from office buildings. From this perspective, residential waste, the waste generated in private homes, should be the most inhomogeneous and hence, for the purposes of treatment, probably the most difficult type of waste to manage.

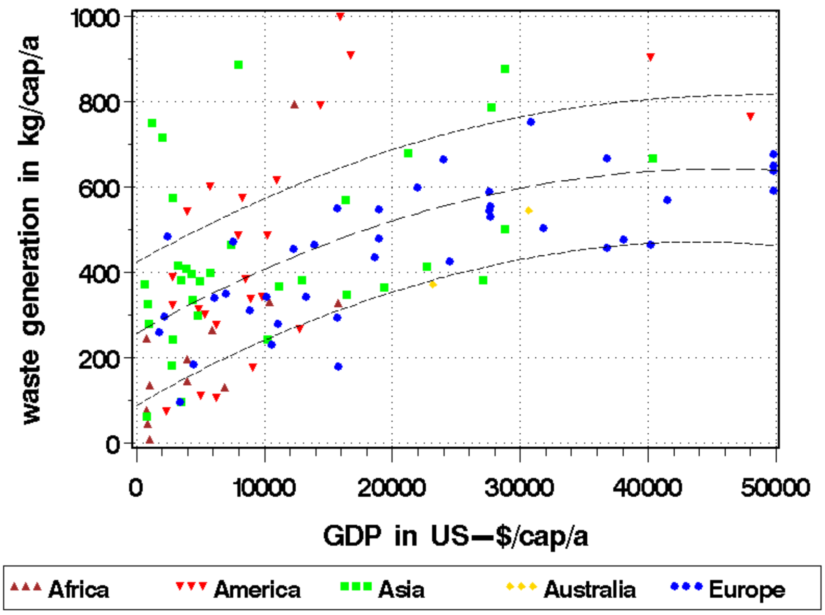
Our focus in this report has been on examining the management of MSW and more specifically on *residual* MSW. MSW is the waste typically collected and managed by local municipalities, i.e. it is predominantly the waste generated by households and collected from households or from areas to which households have access to deposit their waste. It also includes wastes of a similar nature derived from the commercial and industrial waste sector.

Residual MSW is the waste remaining after recyclable materials have been extracted - typically by the householder taking part in source segregated collections.

Generation and composition of MSW

The huge variation of waste data at local level does not mean that regional and national statistics should be regarded as pure guesses. In evaluating the available information, it would appear that the single (MSW) statistics do bear some correlation with other parameters - particularly with the economic situation of a country. On a global level, a good correlation appears to exist between the generation of MSW and the gross domestic product (GDP) of a country. The data plotted in Figure 1 have been collected from several public statistics and scientific publications. European figures date from 2006 or 2007; those from other industrialised countries may go back to 2000 - 2005 and, for some developing countries, data before 2000 are included.

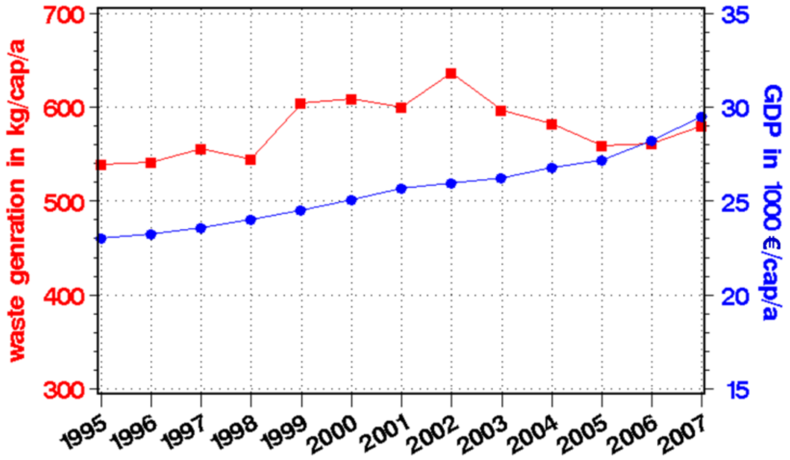
Figure 1: Waste generation versus GDP in 111 countries (fit with 70% confidence limit)



The calculated correlation between the waste generation data and GDP is surprisingly good. This positive correlation leads to the conclusion that economic growth changes consumption patterns and results in higher rates of per capita waste generation.

Decoupling of economic development and waste generation is a major objective in industrialised countries. Policy is driven towards the aims of reducing the amount of waste and diverting reactive waste from landfill. The EU with its many Directives regulating waste disposal is a forerunner towards such goals. Some successes can be noted in terms of reducing landfill, but few countries have been successful at reducing or at least to keeping their waste generation figures constant over the past years. One example where waste reduction has been achieved is Germany (Figure 2).

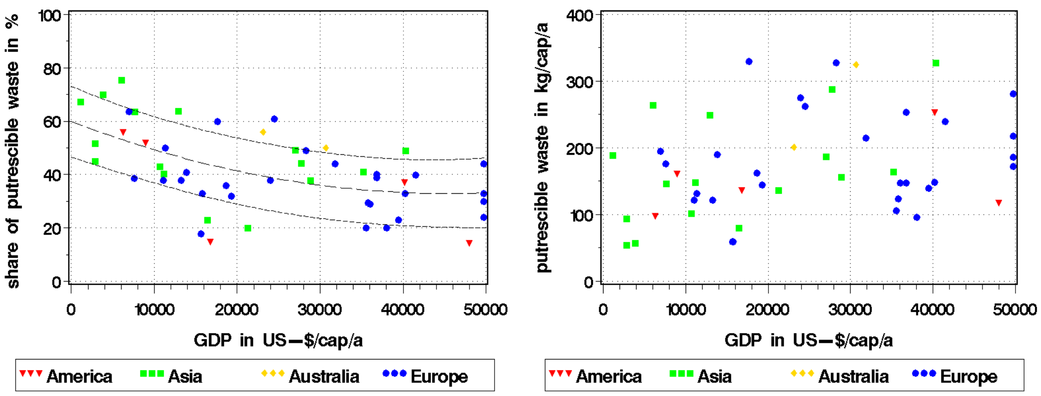
Figure 2: Decoupling of waste generation from economic output in Germany [Umweltbundesamt 2008 - data from Statistisches Bundesamt Deutschland]



A rather good correlation with the GDP is also reflected in the share of food or biodegradable waste in MSW as can be seen in the left hand graph of Figure 3. This correlation is usually explained by reference to the different ways of preparing food: poorer countries live less on prefabricated food and prepare their meals more from fresh food, which causes higher amounts of waste in residential homes. However, keeping in mind that MSW usually also comprises waste from restaurants, small businesses (including food preparing enterprises), canteens, etc. this argument is not necessarily convincing.

In reality, this explanation does not hold if the absolute amount of this waste is considered. The right hand graph in Figure 3 shows the per capita generation of food and other biodegradable waste plotted against the GDP for 52 countries. The result is a broad scattering of values without any discernable trends. The data for all countries from all continents seem to vary in the same broad range which means that the poor countries do not discard more food waste, but - and this makes much more sense - have not much else to throw away.

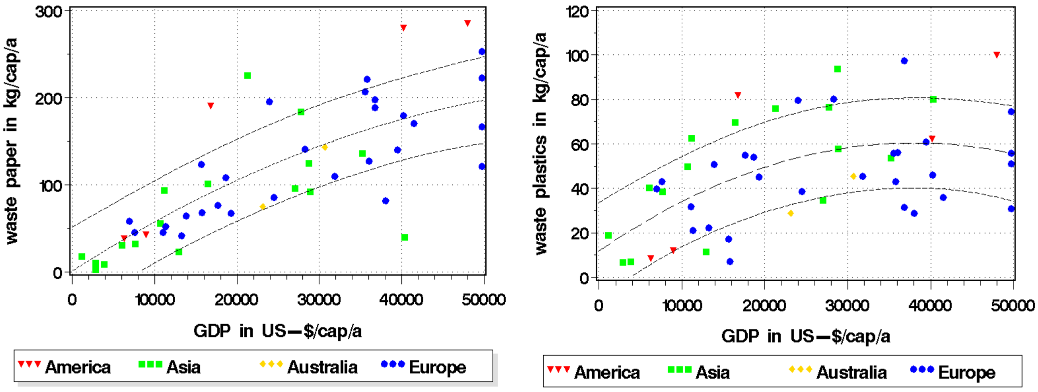
Figure 3: Percentage of biodegradable waste fraction versus GDP (left) and per capita generation of biodegradable waste (right) for 52 countries



This fact is underlined by the characteristics of paper and plastic generation data which are depicted again against GDP in Figure 4. The amount of paper correlates rather well with the

GDP whereas the correlation for waste plastics is much weaker. The almost uniform distribution of plastics indicates the extent of their use across the globe.

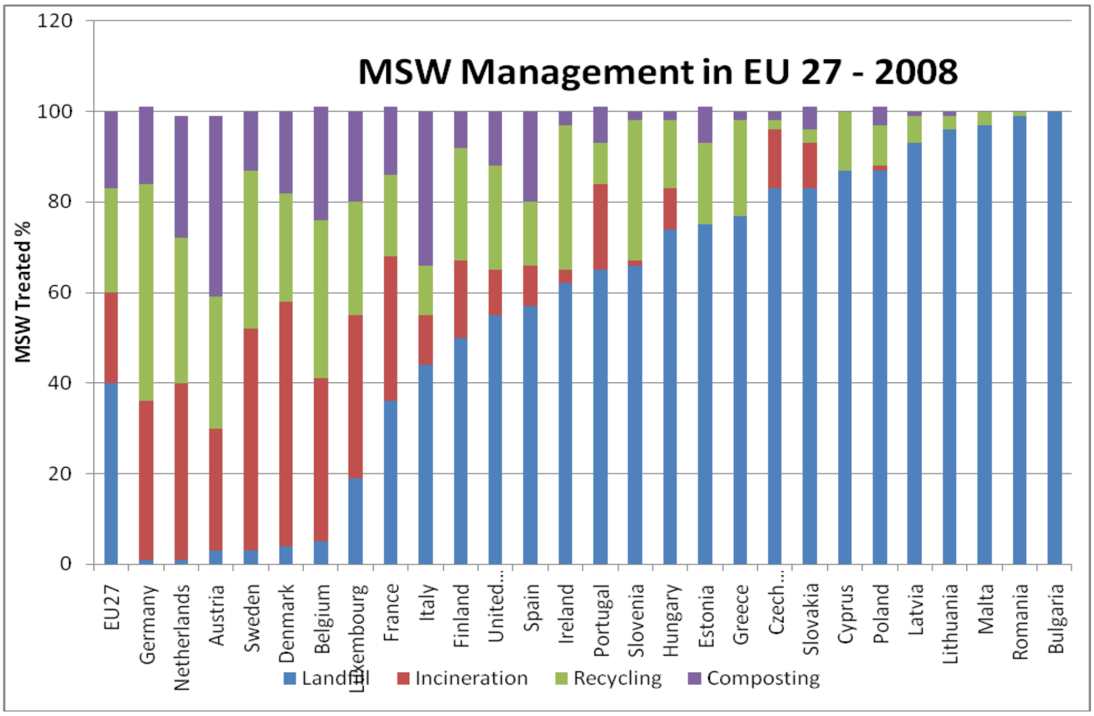
Figure 4: Per capita generation of waste paper (left) and waste plastics (right) versus GDP for 52 countries



Management of MSW

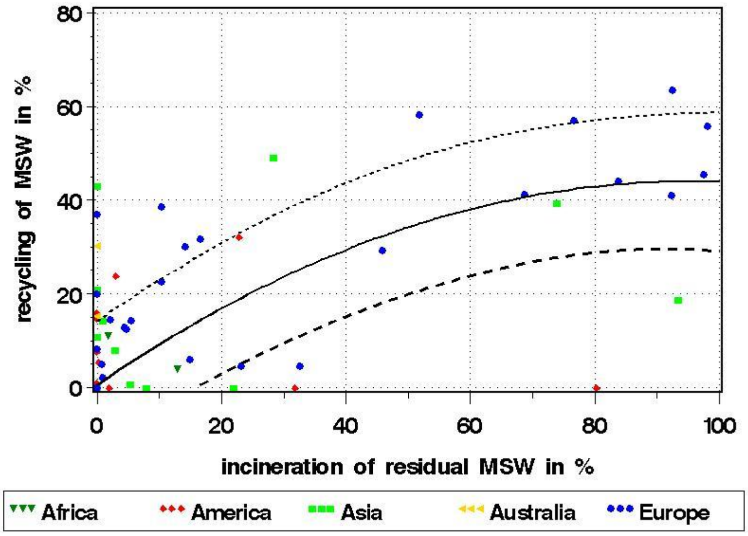
Figure 5 collates (Eurostat) 2008 data for EU27 and shows the destination of MSW to either recycling/composting (or similarly recovered), incineration (energy recovery) and landfill. The EU27 countries are ordered in terms of increasing landfill usage and show Germany at the top with the least tonnage to landfill and Bulgaria at the bottom with virtually all waste consigned to landfill. Norway and Canada are of course not included in these statistics but with landfill levels of approximately 25% and 80% they would appear above France and the Czech Republic respectively.

Figure 5: MSW management in EU27 (2008)



The level of incineration in EU27 was approximately 20% with the highest level recorded by Denmark (50%). Some have argued that waste incineration impedes recycling. However, an evaluation of data in Figure 5 and other wider statistical data does not support such arguments. Figure 6 correlates the incinerated fraction of residual waste - that waste which is left over after all material recovery activities - with the recycled and composted fraction of the total MSW stream. It is evident that most countries with high recycling also tend to have high levels of waste incineration (in almost all cases with energy recovery) for their residual waste prior to its final disposal.

Figure 6: Recycling and incineration of MSW

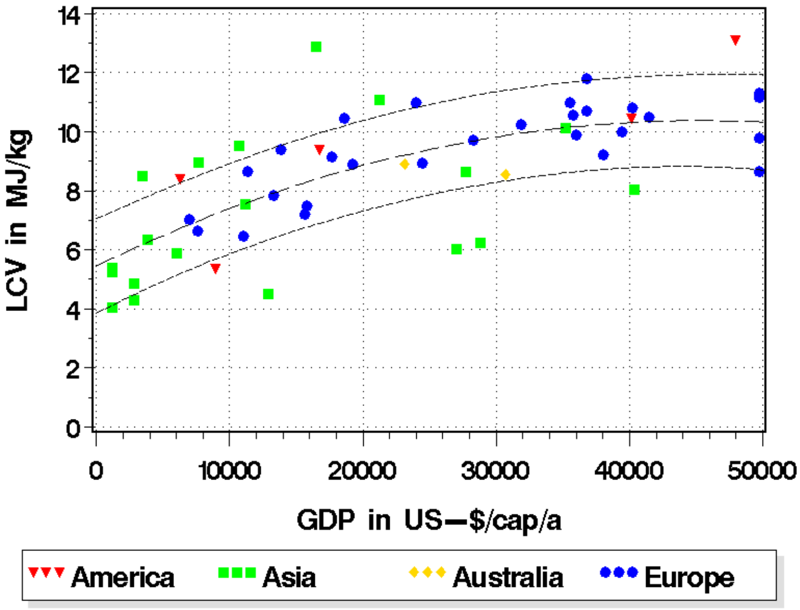


Energy recovery

Feedstock

The feedstock for thermal EfW systems can be the residual MSW as received or a processed product (SRF - Solid Recovered Fuel - meaning waste treated to produce a fuel fraction that can be transported to an off-site user) derived from residual MSW. The energy content of the feedstock is expressed as the lower calorific value (LCV) and covers a wide range. For residual MSW, in developing countries, it is of the order of 2 - 5 MJ/kg and in industrialised countries of the order of 8 - 12 MJ/kg. A good correlation exists between the LCV of MSW and the GDP of a country (Figure 7). A LCV of 6 MJ/kg is needed for the safe operation of thermal EfW systems and this is a level that is reached in many countries.

Figure 7: Correlation between LCV and GDP



SRF is characterised by higher LCV, lower contamination, and better homogeneity. SRF is produced in a number of industrialised countries to substitute fossil fuel in industrial furnaces, or for use in other high efficiency combustion systems. SRF is mainly produced in mechanical biological treatment (MBT) or mechanical treatment (MT) plants: metals are separated for recycling, organics are diverted for composting or anaerobic digestion, the high calorific fraction is separated for SRF, and residual inert materials are consigned to landfill or used in low value recovery processes such as landfill cover.

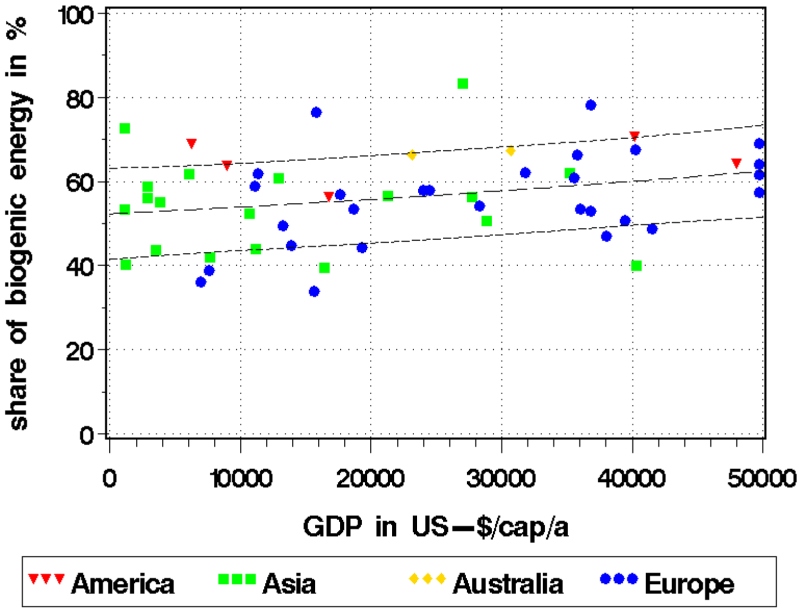
Various types of SRF are on the market to comply with process requirements and applicable legislative requirements. The conversion rate from MSW to SRF is typically 20 - 55% depending on product quality. Some plants produce a high-grade SRF together with a low calorific combustible residue, which is destined for waste incineration. In some countries, quality labels for special SRF types have been established, and on an EU level, EN-standards are under development. The main problem in utilisation of SRF from mixed MSW is the presence of pollutants, especially chlorine and heavy metals. Hence SRF, is mainly produced in countries with well developed MSW source separation and recycling.

The LCV of SRF from MSW is of the order of <15 - 20 MJ/kg. SRF/RDF with LCV >20 MJ/kg is virtually only produced from well-defined residue streams from trade and industry. SRF production and utilisation figures are vague in many countries due to rapid on-going changes in the waste management industries. In the US, approximately 6 Mt out of 30 Mt of incinerated MSW is SRF. Japan operates approximately 50 MBT or SRF plants with a capacity of 4.2 Mt/a. The exported material for incineration is of the order of only 0.4 Mt/a. In the EU, 3 - 4 Mt/a SRF is produced in more than 50 plants with a total capacity of >6 Mt/a.

Biogenic content

A significant fraction of the municipal solid waste stream is of biogenic origin: food and garden waste, wood, paper and to a certain extent, also textiles and diapers. Assessing the waste composition data with the amount of biogenic energy per waste fraction allows an approximate calculation of the share of biogenic energy in the waste. The results of such calculations are depicted in Figure 8. For most EU countries (and all of the Task 36 countries) the biogenic energy content is about 50%.

Figure 8: Share of biogenic energy in waste as a function of GDP (quadratic fit, 70% confidence limit)

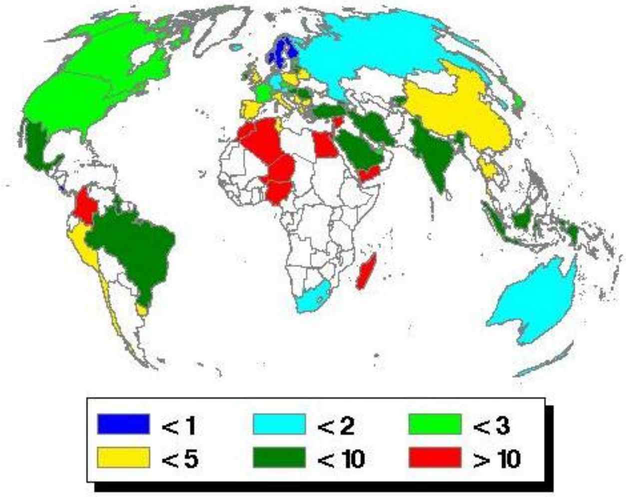


The fact that a certain fraction of the energy in waste is of biogenic origin has been acknowledged by some European countries, such as the Netherlands, Denmark and Finland. In these countries, power generated in waste incineration plants is rewarded by tariffs partly subsidised according to the national renewable energy acts. In other countries (e.g. UK, France, Sweden, Italy, Canada, Norway and Germany) even if the energy generated from waste is not supported by such tariffs, it is acknowledged in the collation of national and EU statistics for renewable energy.

Apart from the revenue support that may flow from the recognition of the biogenic energy inventory in MSW there is also beneficial consequence of the fact that the CO_2 emitted during combustion of this fraction is climate neutral.

The potential for MSW to replace fossil fuel in the power market for selected countries is shown in Figure 9. Even in highly industrialised countries, MSW can supply 1 - 2% of the power demand, a share that should not be underestimated. For the time being, this potential is far from being exhausted in any country. The actual number for Germany is in the order of 0.7% [CEWEP 2008], but it has to be expected that here, and at least in other EU countries, much higher values will be reached in the near future.

Figure 9: Potential of residual MSW to replace fossil fuel in the power market for selected countries, given in % of power supply



Task 36 member country reports

From the individual country reports, a number of common themes can be identified:

1. All countries are guided by a waste hierarchy in their policy - in broad terms, this is waste prevention, reuse, material recovery, material recycling and energy recovery, all of which take priority above final disposal (landfill). The waste hierarchy informs policy development aimed at decreasing waste to landfill and setting out the role of energy recovery (energy from waste).

2. In line with the waste hierarchy, the principal waste management policies are built around the desire to decrease landfill and improve resource recovery - whether materials and/or energy. These policy measures include a combination of fiscal incentives, such as taxes on materials destined for disposal to landfill, and regulatory measures, such as landfill bans on specific waste streams, for example biodegradable (food) and combustible and/or recyclable wastes.

3. At both national and local level, waste policy is frequently targeted at supporting separation, recycling and recovery activities. All of the IEA T36 Member countries have set targets for recycling and all (except Canada) have reported declining levels of waste to landfill and progressively increasing rates of recycling. Some countries (Germany, Netherlands) have clearly managed to break the link between GDP and waste growth.

4. Public perception of incineration (energy from waste) remains a concern in many countries. However, where there is a proactive programme of communications and public participation in decision making, much of the negative perception of EfW (and residual treatment technologies in general) can be mitigated. There has been a strong policy emphasis in response to public concern by, for example, applying more stringent emissions regulations and also to improving energy utilisation, i.e. improving energy efficiency through the generation of electricity and/or heat (combined heat and power).

5. Energy from waste makes a significant contribution to renewable energy in many countries. Increasingly, renewable policy is designed to encourage the recovery of energy from biodegradable wastes that cannot be recycled, composted or digested

and to encourage efficient recovery of this energy. Hence the utilisation of heat should be promoted wherever possible, although negative public perception sometimes results in facilities being sited away from urban areas where there is the demand for heat.

6. There is an increasing trend towards the use of separation technologies for mixed waste followed by composting or anaerobic digestion of the biodegradable fractions - sometimes driven by public opposition to direct combustion of waste. Pre-treatment of residual waste often results in a final fraction of waste that is usually not recyclable/reusable but nevertheless contains residual energy value. Pre-treatment can also produce a paper/plastic combustible fraction sometimes referred to as solid recovered fuel (SRF). Increasingly, waste management systems are required to treat this waste; options include co-incineration in cement kilns, co-firing in power stations (this option depends on the design of the power station) or incineration in a dedicated facility.

7. The European nations are obliged to comply with various EU Directives, e.g. the Waste Framework Directive and the Waste Incineration Directive. These Directives provide a common framework for the EU nations, but when transposed to national policy, there remain wide diversions in the way in which that national policy has developed and in the management of waste in each country. Perhaps, not surprisingly, it is the local conditions, policy priorities and economics that determine the development of the waste management systems and the uptake, in particular, of energy from waste technology.

In terms of future trends, it is possible to conclude that:

- There will be less biodegradable (and combustible?) waste consigned to landfill in the future.
- Most Member countries project that waste production will continue at current or slightly increased levels, indicating that measures to reduce waste arisings are starting to make a gradual impact.
- For those countries that currently rely on landfill, it is likely that the utilisation of energy from waste will expand but that the final deployment rate achieved is uncertain as there are still significant barriers to overcome, e.g. cost effectiveness, public concern, development timescales and planning/facility location issues.
- The utilisation of heat (for heating or cooling purposes) is likely to play a greater role in the future, but this potential will depend on siting issues (developing plants close to heat users) and overcoming other barriers, such as developing infrastructure (heat networks) and cost.
- Anaerobic digestion (AD) is likely to play a greater role in the future as many countries look to segregate this waste stream (food waste) at source.
- Further debate on the biogenic nature of MSW is likely to influence policy making and have practical consequences, for example, in the measurement and monitoring of wastes for this parameter.

Summary of chapter 2: energy recovery from MSW (one step further)

Within the current phase of the IEA Bioenergy Task 36, special attention has been paid to the subject of how to optimise, and thus extend, the application of energy recovery from MSW from the point of view of policy makers. An assessment of drivers and barriers to energy recovery was carried out in each of the countries of Task 36. Based on these assessments, a workshop, organised by Umweltbundesamt, IEA Bioenergy Task 36 and NL Agency (formerly SenterNovem), was held at DECHEMA on April 14 2008 in Frankfurt, Germany.

At the workshop, the experiences in the different countries were shared and recommendations for the promotion of energy recovery from MSW were discussed. Chapter 2 summarises the results of the country assessments and the workshop and recommendations on how to promote energy recovery from MSW in a more effective way are presented. It is not the intention of Chapter 2 to present the outcome of scientific-based research, but more to reflect the results of the workshop presentations and discussions.

The ten most significant lessons learned from the workshop may be summarised as follows:

1. In the countries assessed, the introduction of the EU Directive on the landfill of waste has resulted in a reduction of the amount of waste being sent to landfill and an increase in recycling and EfW.

2. In the waste hierarchy, recycling is given higher priority than EfW - EfW must complement and not displace recycling activities.

3. Drivers for the promotion of EfW (the Landfill Directive and the desire to reduce CO_2 impacts) are the same throughout the countries assessed.

4. Barriers to EfW vary from country to country, as does the rate of EfW utilisation.

5. Policies can change quicker than EfW project development time, thus frustrating projects.

6. Policies need to address the tension in the market between solid recovered fuels (SRF), mechanical-biological treatment (MBT) and EfW.

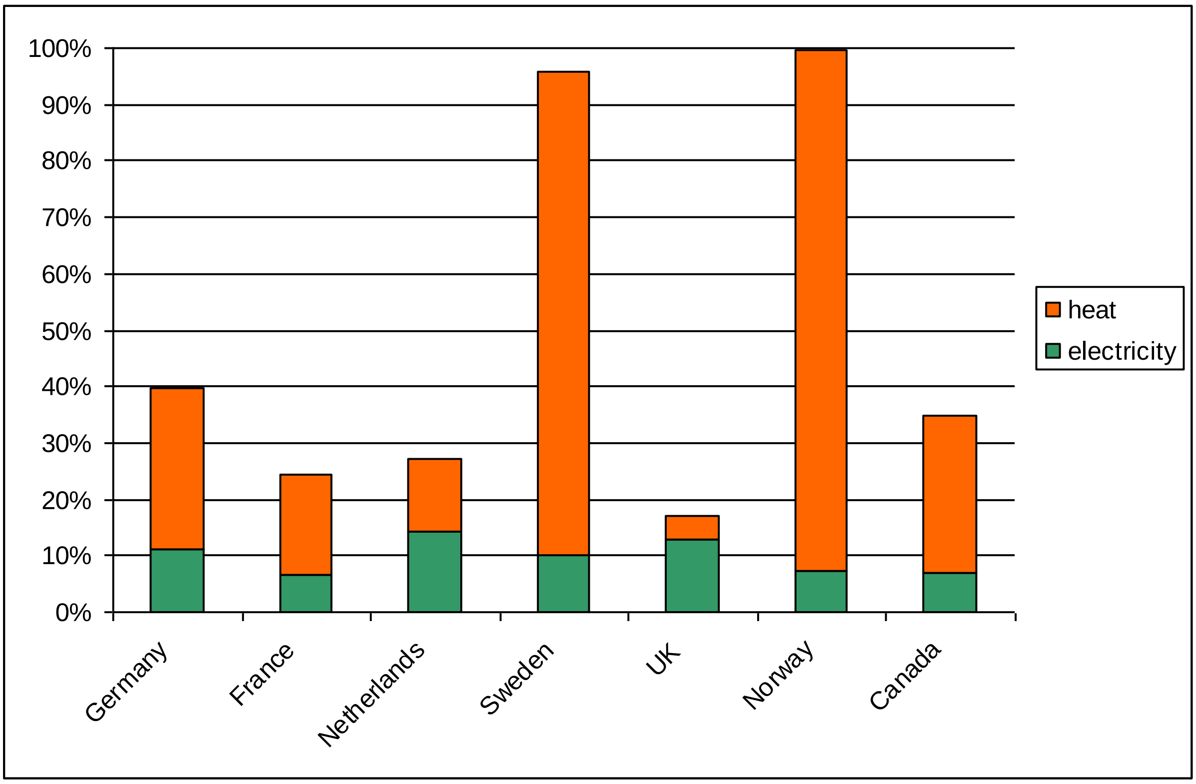
7. Political will on utilisation of waste heat is often high, but doesn't always lead to subsequent market development; Figure 10 demonstrates the differences in heat utilisation between the Scandinavian countries (high utilisation) and others.

8. Since waste management systems are capital (investment) intensive, long-term (contract) security is crucial.

9. More consideration is required to spatial planning (i.e. making room for EfW) -this is a significantly underestimated policy element.

10. There is a lack of trust between the proponents of EfW and non-governmental organisation (NGOs) and interaction between them is often problematic.

Figure 10: Energy recovery from waste incineration as a percentage of the heat content of the input



Summary of chapter 3: impacts of managing residual municipal solid waste

A wide range of options are available for treating the residual component of MSW, i.e. the waste that remains after source separation of recyclable fractions. These range from combustion based techniques to biological processes, such as anaerobic digestion and composting. There are also systems which combine elements of both, using sorting techniques to recover recyclable materials such as metals, and splitting the waste into an organically based component which can be biologically treated and another fraction - a refuse derived fuel (RDF also sometimes referred to as SRF) - which can be combusted.

A life cycle waste management software tool was used to see whether different types of options for managing residual waste offer particular environmental benefits and whether it is possible to establish a hierarchy of environmentally preferred options. The assessment was carried out using WRATE (Waste and Resources Assessment Tool for the Environment), an integrated waste management life cycle analysis tool developed for the Environment Agency in the UK, which has been peer reviewed and is publicly available.

The following options for the management of residual waste were examined:

- EfW plant.
- Mechanical Biological Treatment (MBT) plant where recyclable materials such as metals are first separated out and the remaining waste is:
    - biodried to produce a refuse derived fuel (RDF) which is burnt in an energy from waste plant (MBT biodrying);
    - sorted into an organic component which is anaerobically digested and a fraction which is burnt in an energy from waste plant (MBT AD);
    - sorted into an organic component which is composted and a fraction which is burnt in an energy from waste plant (MBT IVC).
- Landfill with energy recovery.

The effect of recovering heat at the EfW plant was also evaluated, as were the effects of improving the levels at which energy and materials were recovered, of introducing plastics recovery into the MBT processes and of changing the type of electricity production avoided when energy is recovered.

Four key environmental impacts for which robust evaluation methodologies are available were considered: climate change, resource depletion, acidification and eutrophication. As elements of waste management common to all options (e.g. collection of the waste) were not modelled, the results can only be used to compare treatment options and do not give an absolute indication of the environmental impacts of managing the waste.

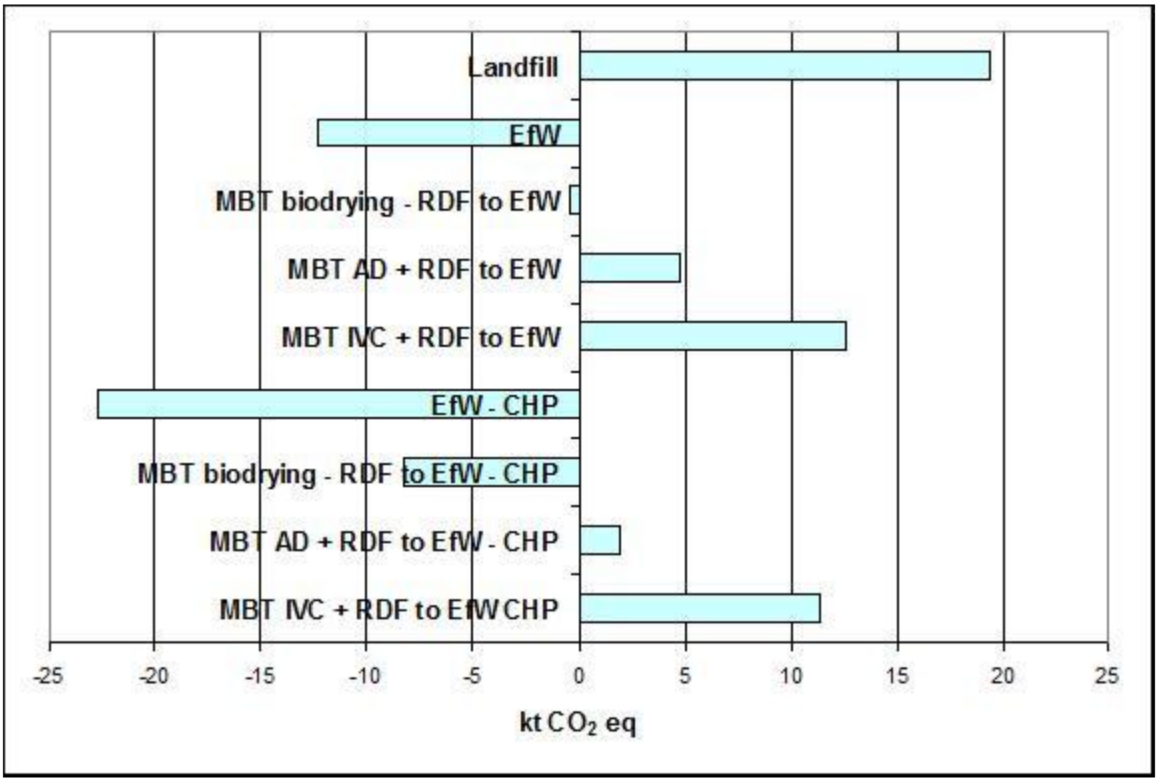
Some general conclusions can be drawn for the work undertaken:

1. All the treatment options considered had, for a typical coal/gas electricity mix, lower environmental impacts than landfill. The ranking of the non-landfill options depends on the environmental impact considered and, for some options, was also affected by the electricity mix that is displaced. While no treatment option performed best under all the cases for all impacts evaluated, overall, the EfW - CHP plant had the best environmental performance. Where there is no opportunity to utilise heat, the EfW plant had the best environmental performance overall.

2. Energy recovery and materials recovery of energy intensive materials such as metals and plastics, have significant benefits for all the environmental impacts evaluated, reducing emissions of pollutants and use of resources. They should be maximised in any waste management option that is implemented. If EfW is part of the option, whether burning MSW directly or RDF, then making the plant a CHP one reduces environmental impacts, in most cases significantly, particularly if heat utilisation is high.

3. Climate change is often a key concern and if this is the case, then an EfW plant (or EfW - CHP plant if heat can be utilised) is likely to be the best choice, whenever the electricity displaced is based on coal or gas or a coal/gas mixture, see Figure 11. However, if the energy recovered is displacing very low carbon electricity (e.g. predominantly from hydro or nuclear), then there is much less differentiation between the waste management options, and the MBT - IVC option performs best, having a slightly lower impact than the EfW plant. An EfW - CHP plant, however, has a lower climate change impact than an MBT - IVC CHP option.

Figure 11: Greenhouse gas impacts



4. In the case of depletion of resources, the EfW and EfW - CHP plant have the lowest impact, although the difference between these and other options is less pronounced for a very low carbon electricity mix. EfW also has the lowest impact when eutrophication is considered, and (together with the MBT biodrying option) has a significantly lower impact than other options even if there is improved material recovery at MBTs, or a low carbon energy mix is evaluated.

5. The environmental impact category where EfW does not perform as well is acidification, where emissions of acidifying pollutants from the process are higher than from the MBT treatment options, and the higher metal recovery rates in the MBT processes deliver substantial savings in emissions of acidifying pollutants. The MBT biodrying process generally has the lowest acidification impact, although if gas or a

low carbon electricity mix is being displaced, then the MBT - IVC process which involves the lowest amount of combustion of waste has the lowest impact.

The results of the modelling suggest that, for locations where electricity generation that is displaced comes from fossil fuels, then a waste management option based on EfW is likely to have the lowest environmental impacts overall. However, for locations where the electricity that is displaced comes mainly from non-fossil fuel sources, then an environmental hierarchy is less clear cut. While an EfW and, in particular, an EfW - CHP option still performs well in some environmental areas, MBT treatments which biologically treat most of the waste (such as MBT - IVC), can offer benefits and a more detailed analysis and decisions on the relative importance of impacts may be necessary to define which option is environmentally preferable.

Summary of chapter 4: overview of technologies used for energy recovery

Chapter 4 provides a brief description of the principal technologies applied for the treatment of residual MSW. It also covers some of the newer technologies, such as pyrolysis and/or gasification, that have been demonstrated at large scale (>100,000 t/y capacity).

In the summary below, a synopsis is provided of the current status of energy recovery technology for managing residual MSW in terms of the processes used and their cost.

Processes

Various processes are in use for energy recovery from MSW, but only the principal EfW processes with actual or future significant potential are described in Chapter 4. The most common and well-established technology (over 130 years operation) is waste incineration on inclined moving grates. Pyrolysis and gasification are practised, but are not as widely used as grate incineration. Various novel processes based on combined pyrolysis/gasification have been developed and implemented, especially in Japan. As well as direct combustion of MSW, it is also possible to co-combust MSW, or more appropriately SRF, with fossil fuel in dedicated plants or in industrial furnaces (e.g. power plants, cement kilns).

Excess air combustion processes: A modern waste incineration plant comprises a furnace, a boiler, the power generation island and an efficient gas cleaning system to meet stringent air emission standards. The most common combustion system with approximately 800 installations worldwide is based on the moving inclined grate furnace that treats MSW in an essentially unsorted state. Grates of various designs (reciprocating, roller, travelling, etc.) and size (typically 5 - 30 t/h) are in use. In some new plants, water cooled grates are used when burning MSW with a high heating value.

The furnace can also be of the fluidised bed type (stationary or bubbling, circulating, revolving systems) -there are over 100 such systems operating on MSW, mainly in Japan. Fluidised beds have special requirements concerning the particle size of the fuel and hence the MSW needs, as a minimum, shredding or some other form of pre-treatment. The throughput of fluidised bed furnaces is typically smaller than that of grate furnaces. Other types of furnaces can also be used - batch type furnaces, rotary or oscillating kilns, combinations of grates and rotary kilns, but these have a minor share of the EfW market.

The boiler efficiency of state-of-the art MSW incineration plants is typically >75% and can reach values around 85%. The boiler steam temperature and pressure (typically 400^{o}C and 40 bar respectively) are lower than in conventional power plants in order to avoid corrosion problems. As a consequence, the efficiency of power generation rarely exceeds 22% (net). European state-of-the-art MSW incineration plants report an average power generation of 0.55 MWh/t of MSW, which equates to an energy recovery efficiency of about 20% (typically 0.4 - 0.65 MWh/t). The electrical consumption for plant operation varies between 0.06 and 0.15 MWh/t with a strong dependence on plant size. Modern European plants export 0.4 - 0.5 MWh electricity per ton MSW. This figure has to be reduced by approximately 0.25 MWh/t if the bottom ashes are melted. If only heat is generated, as is widely done in North European countries, approximately 2 MWh/t MSW can be exported, which equates to 70% energy recovery efficiency. An optimised total efficiency can be accomplished if CHP utilisation is possible. A new and promising heat utilisation route is district cooling.

New boiler designs using nickel base alloys allow increased steam temperature and pressure and allow power generation efficiencies >30%. Such plants have recently been commissioned in Europe and Japan. One option to increase the power efficiency to 30 - 40% involves integration with a combined cycle natural gas turbine. At the moment, approximately 15 such plants are in operation worldwide.

Combustion and co-combustion of SRF: SRF is used as fuel in dedicated combustion plants (grate and fluidised bed furnaces), cement kilns, power plants, district heating plants, blast furnaces, and sometimes also in waste incinerators. SRF gained some interest in Germany in the last few years, especially after the EU Landfill Directive set limits for the direct landfill of combustible waste. Energy recovery from SRF is seen as an alternative to conventional (direct combustion) waste incineration. In most countries, combustion or co-combustion is regulated in the same way as for waste incineration.

Cement kilns are the main consumers of SRF with approximately 2.3 Mt/a in European cement kilns. Cement kilns accept (baled) SRF with a maximum chlorine content <1%. High quality SRF is needed for co-combustion in coal fired power plants. Particle size, halogen concentration, and concentration of abrasive inert materials are critical parameters. In Europe, approximately 0.6 Mt/a of SRF go to the power sector, 90% of this in eight German power plants. Energy recovery in dedicated combustion plants typically configured for CHP with grate or fluidised bed technology and with power efficiencies >30%, is a rapidly expanding sector in some EU countries.

The total SRF production in the EU was according to ERFO, the association of European SRF producers, in 2008 4 - 5 Mt. The market outlook talks about a potential of 24 - 41 Mt, however, the actual discussion about the quality of the production plants as well as of the quality of the SRF does not allow to speculate about the market in future.

Pyrolysis: This is an endothermic process in which organic matter decomposes in the absence of oxygen at temperatures of 450 - 700°C. The products of pyrolysis are a combustible gas, a liquid, and a carbon rich solid residue (pyrolysis coke) that can be utilised for energy recovery.

The preferred pyrolysis reactor is a heated rotary drum. For application to MSW, pyrolysis is currently used as the first stage in a combined process where the pyrolysis coke is separated from inert materials (minerals, metal scrap) and then burnt together with the pyrolysis gas in a high temperature combustion chamber. About 15 of these combined systems with a total capacity of approximately 2,500 t/d are in operation in Japan.

In general, the energy efficiency of pyrolysis systems is lower than that of waste incinerators, especially when the fuel is SRF and the energy used for its production is considered. However, advantages for the operator are easy combustion control, high metal scrap quality and a molten slag. The latter feature is important in Japan. Like waste incinerators, these processes require an efficient gas cleaning system.

Gasification: This is the high temperature reaction of organic matter in an oxidising agent, in most cases air or oxygen, with insufficient oxygen to result in combustion. The gasification product is syngas, a mix of CO and H_2, which is burnt in a connected combustion chamber or fed into another furnace for energy recovery. Alternatively, the syngas can feed a gas engine which would offer a higher conversion efficiency. The syngas from MSW gasification contains waste-born pollutants (particles, HCl, NH_3, H_2S, COS, etc.), which have to be removed, especially if a gas engine is used.

Gasification processes with direct syngas combustion are most commonly found in Japan. The low-ash content Japanese waste seems especially suited for this technology. Reactors are typically shaft furnaces (totally of about 40 plants, 5,500 capacity t/d) and fluidised beds (about 30 plants, 4,700 t/d capacity).

A different design concept starts with a degassing stage in a compacting channel followed by high temperature gasification in a chamber. The syngas is either burnt in a combustion chamber or fed into a gas pipeline. Five plants are in operation in Japan (capacity 1,575 t/d). A plant in Germany with a capacity of 225 t/d was shut down because it could not reach the design throughput. The complex technology employed and energy consumed for gas cleaning and ash melting results in very low energy efficiency.

Economics of waste combustion

A cost assessment for waste combustion systems is difficult since most technologies are primarily implemented for waste treatment/inertisation and energy recovery is a by-product, albeit a mandatory requirement of the legislation in many countries. There is no real competition of waste or SRF with fossil or biomass fuels. A thermal waste treatment plant is financed primarily on the basis of the income from the gate fee for processing MSW - typically 80% of the income is derived from this source. The income from power sales makes up the remaining 20%. MSW and SRF have a negative market price which means the producer has to pay a fee to have it accepted by a processor.

Investment (capital) costs are country specific and depend strongly on the configuration of the plant, particularly with respect to the heat recovery and gas cleaning systems deployed and the capacity or size of the plant. The specific investment cost for a 25 t/h MSW incinerator in the EU is of the order of 700 - 1,100 US-$ per tonne of annual throughput. Similar costs are expected in the US and Japan for waste incinerators without ash melting. Unit costs are typically higher for smaller scale systems, i.e. an economy of scale does apply.

Operating costs are highly variable and again depend on plant configuration and site specific conditions. In European plants they range from 55 US-$/t (at a Swedish heat generating plant) to 460 US-$/t (at a German power generation plant); the average cost range if of the order of 110 - 160 US-$/t. It has to be noted that most published costs are gate fees which may, on one hand, include other costs of the MSW management system, while on the other hand, also be influenced by externally imposed taxes.

Published SRF production costs, usually quoted as gate fees, for MBT plants are in the range 70 - 130 US-$/t for Europe. The figures have to be taken with caution since they are site specific and it is not always clear whether they include the expenses for the energy utilisation (at the lower end almost certainly not). In some EU countries, an extra payment of approximately 25 - 55 US-$/t is required for SRF utilisation in cement kilns. The fee for power plants is in the range 40 - 80 US-$/t, while that for dedicated CHP plants, is up to 130 US-$/t in Germany.

CHAPTER 1: STATUS OF SOLID WASTE MANAGEMENT IN TASK MEMBER COUNTRIES

Canada

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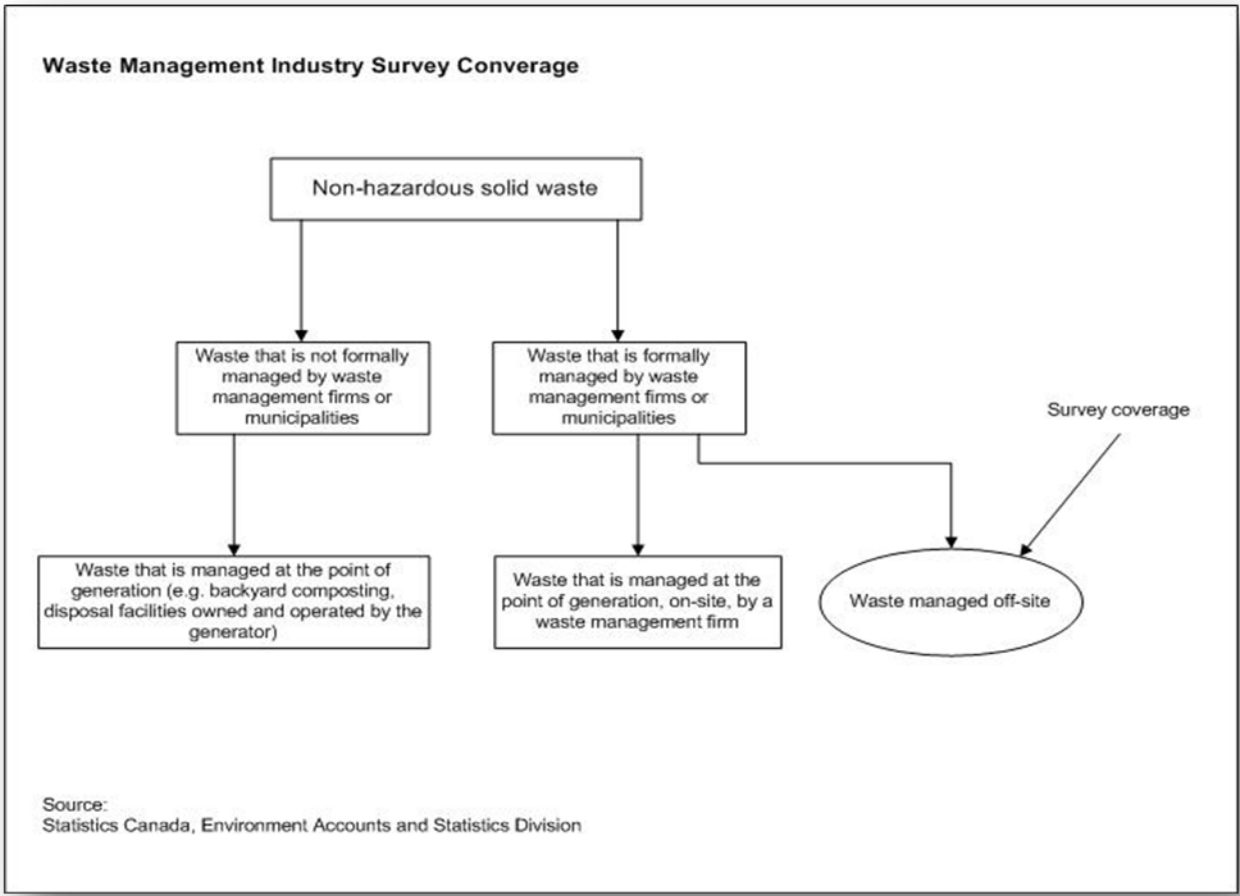
Definition

The definition of waste in Canada is still evolving. The common thread among definitions developed over the last years is that a waste is a material that is unwanted by its producer. Canada identifies municipal solid waste in two sectors, residential and non-residential.

- Residential waste is solid waste that is produced from residential sources (households) and that is either picked up by municipalities or brought to depots and landfills by the generators.
- Non-residential waste consists of non-hazardous waste generated by industrial, commercial and institutional sources as well as waste generated by construction and demolition activities. In more detail:
    - Industrial waste is generated by manufacturing, primary and secondary industries, and is managed off-site from the production operation.
    - Commercial waste is generated by commercial operations (such as shopping centres, restaurants, offices, etc).
    - Institutional waste is generated by facilities such as schools, hospitals, government facilities, etc.
    - Construction and demolition waste is waste that is generated by construction, renovation and demolition activities.

Figure 1.1: Waste management industry survey coverage



National waste policy

The responsibility for municipal solid waste (MSW) management in Canada is shared among the municipal, provincial/territorial and federal governments. The daily MSW management activities such as collection, diversion (recycling and composting) and disposal operations are the responsibility of municipal governments, while the provinces and territories are responsible for approvals, licensing and monitoring of operations. The federal government is involved in management issues related to sustainable development, toxic substances, trans-boundary movement (inter-provincial and international) of hazardous waste, hazardous recyclable material, federal lands and operations, air emissions including greenhouse gas emissions and the Fisheries Act.

All three levels of government cooperate in developing national initiatives, collecting statistics and disseminating the information to the public. Due to the lack of a centralized regulatory body however, regulations vary on a provincial basis based on regional and political dissimilarities. To address this concern, the Canadian Council of Ministers of the Environment was created in the 1980s to provide a forum for a national effort on environmental and resource related issues. It is made up of environment ministers from each province and territories as well as from the federal government. It developed and issued guidelines for MSW incinerators, established waste diversion targets and developed a National Packaging Protocol. The waste diversion targets of 50% diversion of waste from landfill by 2000 were based on the 4Rs approach of reduction, reuse, recycling and recovery. The National Packaging Protocol set a 50% reduction target on packaging sent for disposal by the year 2000 based on source reduction and reuse. The objective of those initiatives was to significantly reduce the reliance of Canadians on landfill. While a few communities have reached this goal, Canada as a whole still disposes of more than 78% of its waste to landfill.

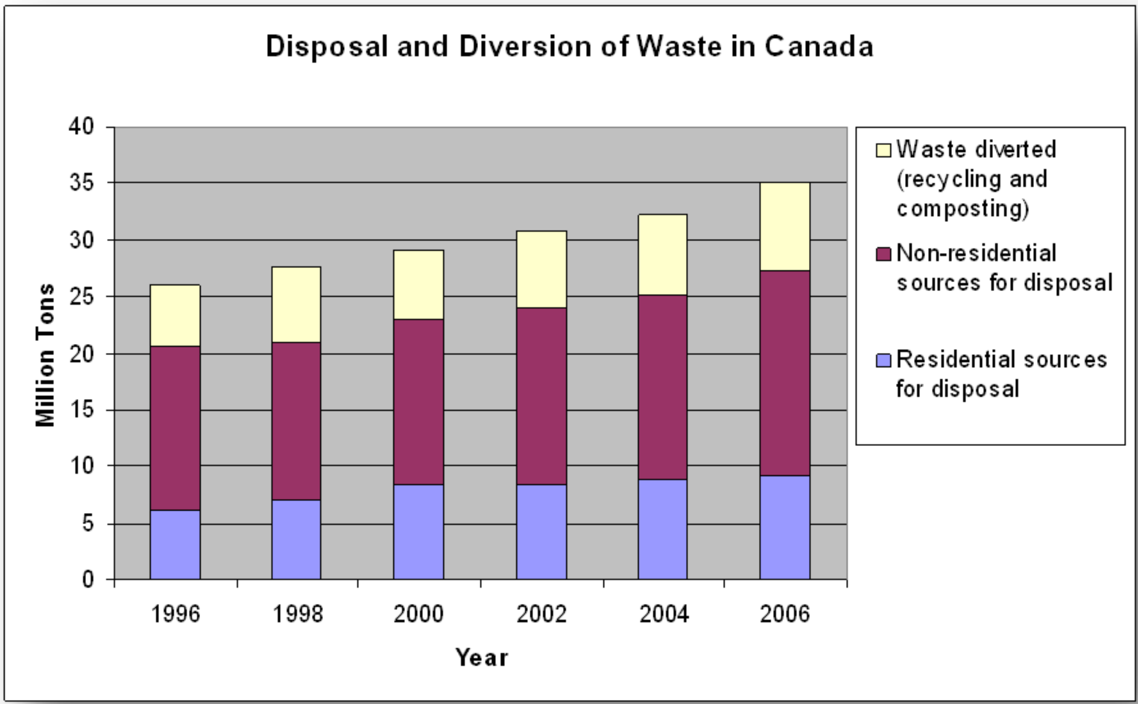
Quantities of waste generated

Waste generation in Canada in 2006 reached 35 million tonnes (Mt), an 8% increase over 2004 figures. Of this 35 Mt, 27 Mt were landfilled or incinerated while 8 Mt were diverted to material recovery or centralized composting facilities. Landfills have been to this day the preferred method of disposal in Canada where nearly 97% of the wastes have been sent; the balance represents the incinerated portion. The non-residential wastes made up approximately 22 Mt of the total while the remaining 13 Mt came from residential sources. There was no change in the residential (1/3) to non-residential (2/3) ratio of waste for disposal from 2004 to 2006.

The result is a per-person waste generation of 1,072 kg in 2006, up 8% from 2004. The portion disposed of was 835 kg and the diverted portion was 237 kg.

Many factors such as population growth, rising incomes and increased economic activity can influence the production of waste. Not only the goods themselves but their packaging must be disposed of, recycled or reused. During the period 2004-2006 the national GDP increased by 6% while the population of Canada increased by 2%.

Figure 1.2: Disposal and diversion of waste in Canada



The average waste disposed of per Canadian was 835 kg in 2006. Across the country the range spreads from a low of 430 kg/capita (kg/cap) in Nova Scotia to a high of 1133 kg/cap in Alberta. The population increased by 5% in Alberta since 2004 and the waste disposal increased by 24% over the same period. This was largely influenced by the non-residential portion which increased by 33% in 2006 while the residential portion increased by 3%. The residential portion is on par with a national increase of 3% while in comparison, the national non-residential waste generation increased by approximately 11%.

Figure 1.3: Disposal of residential and non-residential waste per capita

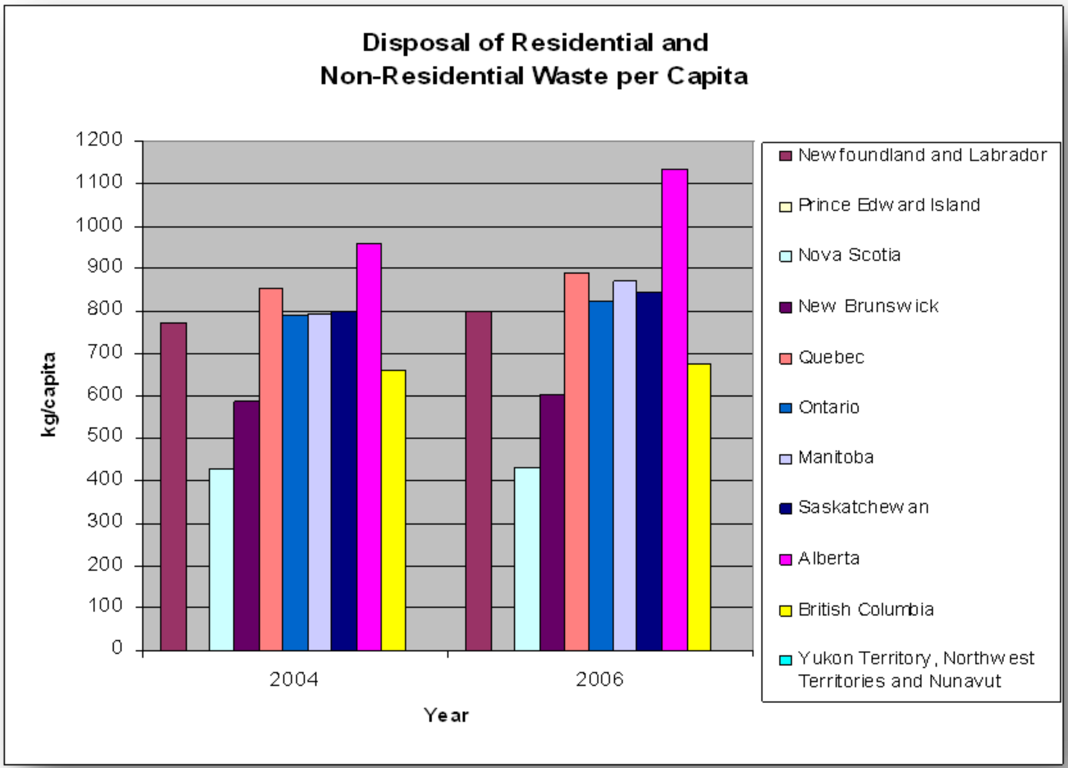


Table 1.1: Disposal of waste material in Canada in 2006

Disposal of Waste Material (Residential and Non-Residential) in 2006			
Region	**Population**	**Waste Managed (Mtons)**	**Waste per capita (kg/cap)**
Alberta	3,370,600	3.82	1,133
British Columbia	4,320,255	2.92	675
Manitoba	1,178,492	1.02	869
New Brunswick	749,225	0.45	600
Newfoundland and Labrador	509,940	0.41	799
Nova Scotia	935,050	0.40	429
Ontario	12,705,328	10.44	821
Prince Edward Island	138,027	na	na
Quebec	7,651,033	6.81	889
Saskatchewan	987,520	0.83	844
Yukon Territory, Northwest Territories and Nunavut	104,012	na	na
Canada	**32,649,482**	**27.1**	**834**

Waste diversion - recycling and composting

The national diversion rate from landfill remained constant at 22% from 2004 to 2006; a few provinces exceeded the average as can be observed in Table 1.2.

Table 1.2: Waste diverted from landfill in Canada

Waste Diverted (Residential and Non-Residential) in 2006				
Region	**Population**	**Waste Managed (Mtons)**	**Diverted Material (Mtons)**	**Diversion Rate (%)**
Newfoundland and Labrador	509,940	0.41	na	na
Prince Edward Island	138,027	na	na	na
Nova Scotia	935,050	0.40	0.28	40.72
New Brunswick	749,225	0.45	0.25	35.90
Quebec	7,651,033	6.81	2.46	26.51
Ontario	12,705,328	10.44	2.40	18.67
Manitoba	1,178,492	1.02	0.15	12.98
Saskatchewan	987,520	0.83	0.11	11.36
Alberta	3,370,600	3.82	0.65	14.59
British Columbia	4,320,255	2.92	1.37	31.89
Yukon Territory, Northwest Territories and Nunavut	104,012	na	na	na
Canada	**32,649,482**	**27.25**	**7.75**	**22.14**

Overall the materials processed for recycling increased 9% to just over 7.7 Mt in 2006. There has been a steady increase in the quantity of materials processed since 2002 especially with organics and plastics. Paper fibres are still the main contributor to diverted materials with 44% of the share, while organics made up 26% of the total in 2006.

Figure 1.4: Diverted waste by type

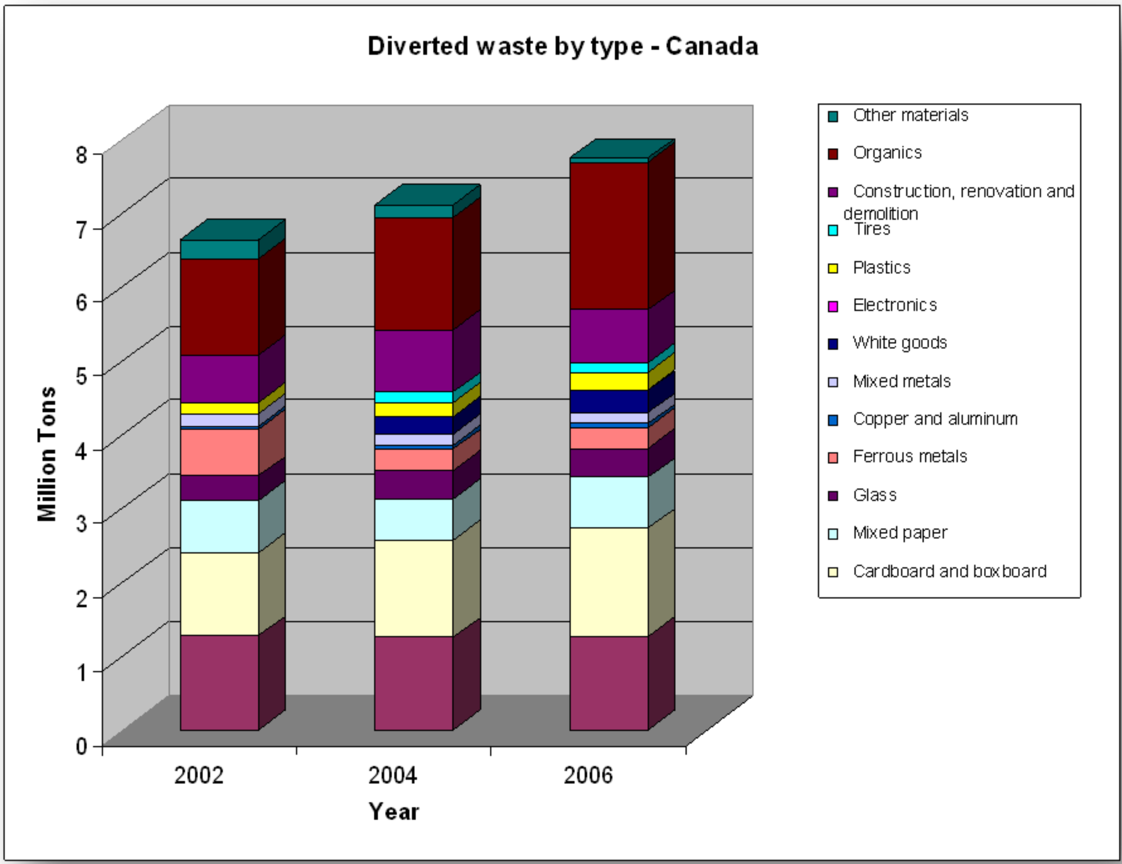
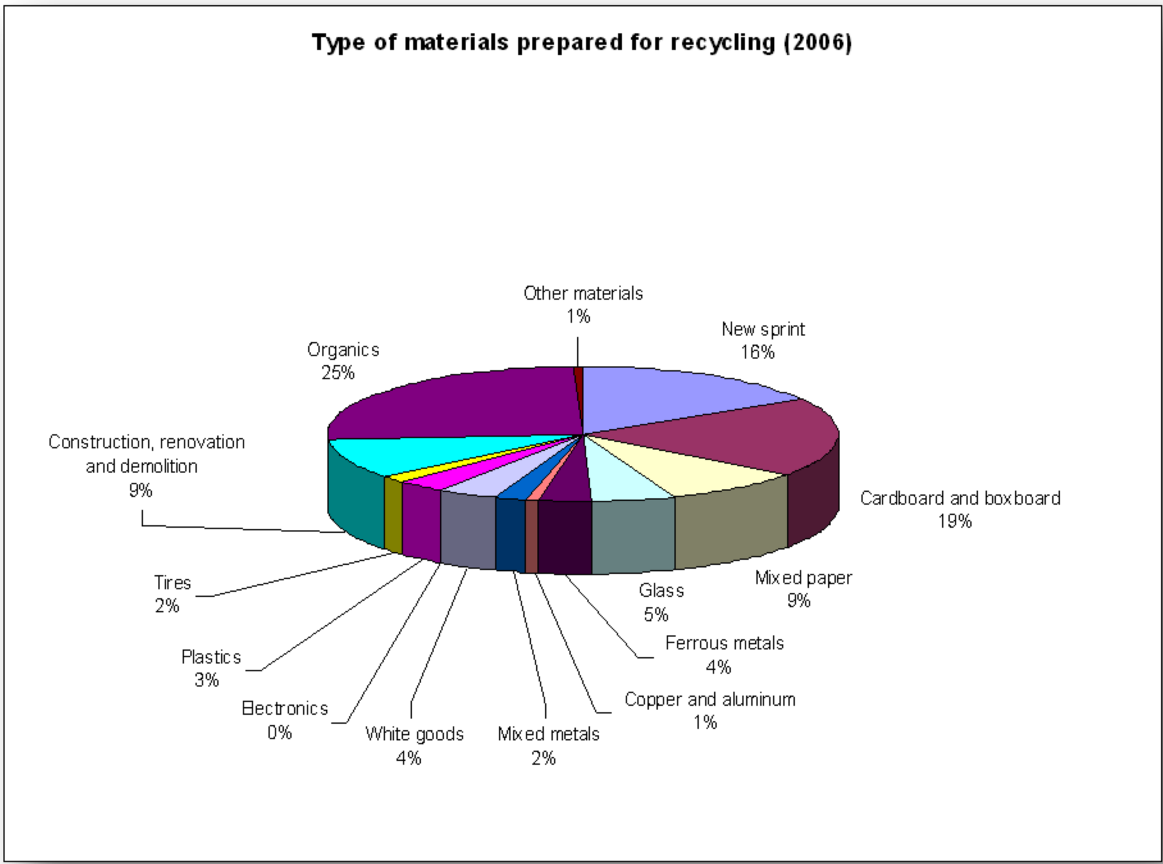


Figure 1.5: Type of materials prepared for recycling in Canada (2006)



Thermal conversion facilities in Canada

There are seven main thermal treatment facilities currently in operation in Canada that have a waste processing capacity of more than 25 t/day. Four of those facilities use mass burn technologies while the other three use a modular multi-stage technology. In 2006 nearly 773,000 t (up from 761,000 t in 2005) were thermally processed to produce 5.23 PJ of energy, of which 2.75 PJ were sold in the form of electricity, steam and hot water.

Table 1.3: Major thermal conversion facilities in Canada 2006

Major Thermal Conversion Facilities in Canada in 2006					
Installation	**Capacity (kton/y)**	**Energy Product**	**Energy Generated (GJ)**	**Energy Exported (GJ)**	**Date Commissioned**
Greater Vancouver Regional District Waste to Energy Facility	263	Steam & electricity	2,756,638	867,429	1988
Algonquin Power Peel Energy-From-Waste Facility	166	Electricity	214,600	151,528	1992
L'incinérateur de la Ville de Québec	336	Steam	1,725,870	1,150,115	1974
PEI Energy Systems EFW Facility	361	Steam and hot water	531,655	474,802	1983
Ville de Lévis, Incinérateur	292	None	-	-	1976
MRC des Iles de la Madeleine	113	None	-	-	1995
Wainright Energy From Waste Facility	99	Steam	na	115,023	1994
TOTAL	**1,630**		**5,228,763**	**2,758,897**	

There is currently one thermal processing facility planned for the York-Durham region near Toronto, Ontario. The plan is for an initial design capacity of 140,000 t/yr with a scale-up plan to 400,000 t/yr. The project is now in Phase 1 where advanced architectural designs must be submitted and environmental approvals must be obtained. The stack emissions will have to meet EU2000/76/EC and MOE A-7 guidelines. The Final Draft EA document was submitted to the Regional Council in June 2009. The RFP process which was started in June 2007 was expected to reach project approval status by June 2009.

Landfill gas

Landfill gas is produced from the anaerobic decomposition of organic waste in a landfill and is mainly composed of methane and carbon dioxide. Both these gases are greenhouse gases although methane is deemed to possess a global warming potential 23 times that of carbon dioxide.

It is estimated that 24 MT in carbon dioxide (CO_2) equivalent (eq) were emitted from municipal solid waste landfills in Canada in 2005, accounting for 22% of the total national man-made methane emissions. The most recent data (2005) shows there are 47 landfills involved in capturing landfill gas throughout Canada for a total quantity of 6.4 Mt CO_2eq. From this amount, 52% (3.3 Mt CO_2eq) was utilized and 48% (3.1 Mt CO_2eq) was flared. Of the 47 sites, 8 utilized the captured methane, 26 flared it, and 13 both utilized and flared the gas. Table 1.4 shows the breakdown of use and output for the use of captured methane.

Table 1.4: Breakdown of use and output for captured methane from landfill sites in Canada

No of facilities	Methane Utilization	Facility Output
26	Flared	Nil
13	Utilized and flared	67 MWe
8	Utilized	• Space & hot water heating • Fuel for gypsum manufacturing plant, steel refinery, greenhouse and recycling plant

Landfill gas capture and combustion increased by 50% over the 1990-2005 period, however landfill gas emissions from MSW landfills increased by 24% over the same period.

The European Union policy landscape

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In the EU, the policy on waste management has been rationalised and consolidated over the last five years and new legislation has come into force since 2006. In addition to specific waste management policy and legislation, new energy and climate change policies have assumed a growing role in waste management practices. The major components of the EU legislative portfolio with an impact on waste management are described below.

Direct waste legislation

The directive 75/442/EEC (1975) was the EU first waste framework legislation that defined categories of waste and approaches to waste treatment. In the years following, a number of directives were introduced to cope with specific waste streams. These included, amongst others, waste electrical and electronic equipment, packaging waste, waste oils and end of life vehicles. During the early stages of this century there were a number of legal cases involving transport of waste and classifications of waste for recovery and disposal. The final opinions of the judge in two cases in particular in 2002, involving waste sent for recovery to cement kilns and waste exported for waste incineration, led to a complete overall of waste policy and to the formulation of the new waste framework directive (WFD): **Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste.** Introduction of the new WFD resulted in repeal of a number of obsolete directives, including 2006/12/EC on waste. One directive that remains in place is the **Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste**, which has probably had the biggest single impact on waste management practices over the last 35 years. The landfill directive requires major reductions in the disposal of biodegradable municipal waste, which accounts for approximately 70% of the mass of MSW. The reductions are given as:

- By 2006, a reduction to 75% of the amount of biodegradable municipal waste landfilled in 1995.
- By 2009, a reduction to 50% of the amount of biodegradable municipal waste landfilled in 1995.
- By 2016, a reduction to 35% of the amount of biodegradable municipal waste landfilled in 1995.
  (These dates can be extended by up to four years for Member States which landfilled over 80% of their municipal waste in 1995)

The landfill directive (Article 16) is supplemented by **COUNCIL DECISION of 19 December 2002 establishing criteria and procedures for the acceptance of waste at landfills.** Until the start of implementation of the landfill directive, there were great differences in the proportion of biodegradable waste landfilled in different member states. These differences were in large part due to how well developed recycling and energy recovery practices are across the EU. Countries like Sweden, Denmark, Germany and the Netherlands made large scale efforts in the 1990s to implement recycling and waste-to-energy into national waste management strategies. As a consequence, landfilling in those countries was already low on implementation of the landfill directive. On the other hand, countries like Greece, Ireland and the UK relied heavily on landfilling of all waste. The new member states that joined the EU in 2004 (10 countries) and 2007 (2 countries) were granted prolongations until 2020; their targets will be reviewed in 2014.

The Waste Framework Directive reinforces the five-step waste hierarchy (Article 4) that had been established previously. The waste hierarchy applies as a priority order in waste prevention and management legislation and policy:

a) prevention;
b) preparing for reuse;
c) recycling;
d) other recovery, e.g. energy recovery;
e) disposal.

The WFD takes a fresh look at waste prevention (Article 29 of 2008/98/EC) and requires member states to set up programmes to address waste prevention in order to stem the seemingly endless rate of increase in waste creation. At the same time, the directive sets new recycling targets (Article 11) as follows:

a) by 2020, reuse and recycling of waste materials such as paper, metal, plastic and glass from households and possibly from other origins similar to waste from households, will be increased to a minimum of overall 50% by weight;
b) by 2020, reuse, recycling and other material recovery, including backfilling operations using waste to substitute other materials, of non-hazardous construction and demolition waste excluding naturally occurring material will be increased to a minimum of 70% by weight.

Concerning recovery operations, there are two key issues that could have a significant impact on waste management practices in the future. These are end-of-waste and energy recovery efficiency of waste-to-energy plants.

End-of-waste criteria are addressed in Article 6 of the WFD. The Article states that when something (a material/substance) is recovered from Municipal Solid Waste (MSW) and:

- the material/substance is commonly used for specific purposes;
- a market or demand exists for such material/substance;
- the material/substance fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products;
- the use of the material/substance will not lead to overall adverse environmental or human health impacts;

the material/substance shall cease to be classified as waste. As a consequence, a waste license and transport restrictions will no longer apply. The situation concerning Solid Recovered Fuel (SRF) or Refuse Derived Fuel (RDF) could change in the future as a consequence of this rule. Application of the end-of-waste criteria should be considered, among others, for aggregates, paper, glass, metal, tyres and textiles.

Energy efficiency is now considered as the key parameter to determine whether a waste-to-energy plant can claim recovery status, or whether combustion of the waste will be classified as disposal. A number of calculation methods for efficiency of energy recovery were considered in the Waste Incineration BREF [2006]. One of these methods, after modification, was selected for inclusion in the WFD; the equation is to be found in Annex II of the Directive. The equation does not give energy conversion efficiency in the true physical sense, but energy conversion performance. Thresholds are set for waste-to-energy plants, where a performance level of 0.6 (for installation permitted and in operation before end 2008) and 0.65 (for installations permitted and in operation after 2008) to claim ’recovery‘ status. A rough evaluation of operating plants in the EU suggests that about one-third will exceed the threshold immediately, but that hardly any of those exporting only electricity will be included in the recovery group. Allowances are available to account for climate factors so that plants operating in warm regions will not be penalised.

Emissions from waste incinerators (waste-to-energy plants) continue to be covered by **DIRECTIVE 2000/76/EC of the European Parliament and of the Council** of 4 December 2000. However, this directive is in the process of review (expected date of completion is mid-2010) and there is a possibility of changes to emissions limits. The proposal, contained in Commission Communication, COM(2007) (of 21.12.2007), is to combine seven industrial emissions directives into one 'recast' directive [EC 2007] based on the requirements of the**Integrated Pollution Prevention and Control (IPPC) directive, 96/61/EC** of 24-09-1996 and its associated best available techniques documents (BREFS) from the seven industries concerned.

The WFD also requires (in Article 22) the Commission to address specific issues related to bio-waste from households, restaurants, etc; that means:

> a) the separate collection of bio-waste with a view to composting and digestion;
> b) the treatment of bio-waste in a way that fulfils a high level of environmental protection;
> c) the use of environmentally safe materials produced from bio-waste.

As a consequence, DG Environment produced a **'green paper' (COM(2008) 811, on the management of bio-waste in the European Union**, 3.12.2008) and in 2009 is carrying out life cycle assessment work on different bio-waste treatment pathways. The assessment is examining the opportunity of setting minimum requirements for bio-waste management and quality criteria for compost and digestate from bio-waste, in order to guarantee a high level of protection for human health and the environment. A separate directive is one possible option for dealing with bio-waste in the future.

Legislation with indirect impact on waste management

The biodegradable fraction of waste, about 70% of the weight or 50% of the energy content of municipal solid waste, is counted as biomass according to new renewable energy directive [EC 2009] of the EU. The definition of biomass in the new EU renewables directive is given as:

> 'biomass' means the biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste".

As a consequence, energy recovered from the biodegradable component of waste can be considered as renewable energy and counted towards renewable energy targets. Since 2005 the European Commission has been promoting energy from biomass according to the **Biomass Action Plan (Commission Communication COM(2005) 628,** of 7.12.2005). The new renewable energy directive also focuses on sustainability of biomass production and its conversion to energy. While the criteria for sustainable biomass have yet to be established, criteria are included in the new directive for biofuels for transport. Importantly, as far as waste materials and residues are concerned, CO_2 emissions associated with production of wastes and residues are given as zero in any life cycle assessment. This means that only emissions produced during the energy conversion process, and in the disposal of residues such as ashes, will be counted so that CO_2 savings from energy from waste should be high enough to safely exceed any future threshold. The WFD energy efficiency criterion should nevertheless push waste incinerator operators to maximise the efficiency of energy recovery.

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EC (2007) Proposal for a Directive of the European Parliament and of the Council on industrial emissions (integrated pollution prevention and control) (Recast), COM(2007) 844, of 21.12.2007

EC (2009) DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the promotion of the use of energy from renewable sources

France

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National policy/strategy

Fundamentals on waste strategy

First waste management acts

The first waste management act in France came into force on July 15th 1975. This was driven by sanitary rather than environmental considerations. However the act encouraged recovery over disposal and required that strategies were put in place for the disposal of hazardous and non-hazardous waste. Waste could only be treated in permitted facilities. Waste collection was also extended to all householders (at this time only 50% of the population was covered by waste collection).

A new act came into force in 1992, with the purpose of achieving sound environmental waste management and improving the sustainability of waste management. The Act established the waste hierarchy (prevention, reuse, recycling, recovery and disposal). Recycling and recovery were strongly encouraged. Landfill was restricted to 'ultimate' waste, meaning waste that cannot be technically and economically recovered for the time being. This act showed a voluntary approach by establishing tools: waste management plans, tax regulation, and waste fund. The act set up the landfill tax regulation for Municipal Solid Waste (MSW).

Waste fund

From 1993 to 2003, part of the landfill tax was dedicated to the improvement of waste management, in particular for increasing the recycling rate and for diverting waste from landfill. The fund was managed by ADEME. Subsidies were allocated to help the investment in separate collections, drop off centres, sorting units and recycling units. Energy from waste units received grants for pilot schemes and for combined heat and power investment. Research related to waste management processes, sanitary and heath impact, waste recovery schemes and pilot scale projects was funded.

Table 1.5: Evolution of waste management from 1993 to 2002

	1993		2002	
	%	Mt	%	Mt
Separate collection for packaging and paper	6	1.3	13	3.4
Separate collection for organics	6	1.3	6	1.6
Energy from waste plant	28	6.2	33	8.6
Incineration without energy recovery	12	2.6	3	0.8
Landfill	48	10.6	45	11.7
Total		22		26

Table 1.5 above shows the developments in waste management in France from 1993 to 2002. By 2002, there was an increase in material recycling and energy recovery, a slight decrease in materials sent ton landfill, a significant reduction in incineration without energy recovery and a stabilisation of biodegradable recycling. The developments were partly due to the subsidies received for increasing the recycling rate. The level of the landfill tax was not high enough to divert waste from landfill. Also no landfill ban was issued. Stricter regulation on emission limits led to the closure of many small, obsolete incinerators.

The 'Grenelle'

A national strategy for France was drafted in 2003. The strategy promoted waste minimisation (waste prevention, home composting), and public acceptance. One of the key drivers of the strategy was to divert waste from landfill and in 2007 the 'Grenelle' was put in place to speed up the process.

The 'Grenelle' was a multi-stakeholder forum of environmentalists, business representatives, trade unions, local authorities and state bodies which gathered together to discuss environmental causes. The aim was to reach an agreement on the ways of tackling climate change and to draw a roadmap for sustainable management and development. Several working groups were organised (health, energy, governance). The waste strategy group presented its conclusions in December 2007. The conclusions were related to France's commitment to fight climate change and to preserve resources and to decrease greenhouse gas emissions fourfold by 2050. Of the 268 'Grenelle' measures, 25 were concerning waste. On 3 August 2009, the first Grenelle law was adopted by the parliament, setting up the Grenelle requirements and allowing implementation of the decisions.

Grenelle waste objectives

To achieve the objective of minimizing the impact of waste on climate change and on resource depletion, the following main actions were proposed:

Strengthening waste prevention

- Waste prevention was put at the top of the list of priorities in compliance with the Framework Directive 2008/98/EC. Besides resource and energy saving, waste prevention impacts the overall cost of waste management. Waste management was estimated to have cost €11.6 billion in 2006 of which €7.4 billion was dedicated for household waste management, meaning €116 per inhabitant. These costs have doubled in the last ten years (data from MEEDDAT/IFEN). Part of this increase is due to more sophisticated technology in order to get better environmental and sanitary protection, but part of it is due to the increase in the amount of waste produced.
- Developing organic and material waste recycling. ADEME assessed that, in 2005, waste recycling (municipal solid waste and non-hazardous industrial waste) avoided the consumption of 17 million tons of raw material and reduced CO_2 emissions by 15 million tons. Recycling stimulates more jobs - ten times more than landfilling.
- Increasing diversion from landfill and incineration. Today 75% of the household and assimilated waste is going to landfill or incineration. To promote recycling, this waste route should be limited.

National targets were set up for each of those objectives

To show a voluntary approach, targets were set up. A national committee with all main actor representatives will monitor yearly achievement of the objectives.

- Waste prevention. Households should reduce their waste by 5 kg/h each year over five years to achieve 25 kg reduction by 2014 (decrease of 7% per capita over the next five years).

- Waste recycling.
    - 35% of municipal solid waste should be recycled or composted by 2012 (24% in 2006) rising to 45% in 2015;
    - increase recycling from 60% in 2006 to 75% by 2012 for household packaging waste;
    - increase recycling from 68% to 75% by 2012 for industrial waste.

- Organic waste. The amount of organic waste treated by composting or anaerobic digestion should double in the future.

- Landfill and incineration. To reduce the amount of waste landfilled and incinerated by 15% by 2012. To promote these targets, regulations are being introduced to limit the capacity of any new incinerator, thus allowing the recycling target to be reached.

Main measures

- Tax regulation on landfill and incineration.
  Currently the tax level on landfill is too low to be an incentive to divert waste from landfill. At €10/t, the tax in France is one of the lowest in EU. The average cost of landfill of €53/t (€63 with tax) can be compared with €70 to €90 for composting and incineration.
    - The Landfill Tax will increase from €15/t in 2009 to €40/t in 2015. The tax is lower when the site carries out high efficiency recovery of the collected landfill gas (> 75%) and has been awarded an environmental certificate.
    - A new tax will be set up for incineration with a level depending on the energy efficiency from €7/tonne in 2009 to €14/tonne by 2013. The tax is lower (from €2/tonne in 2009 to €4/tonne in 2013) when two of the following criteria have been satisfied: (a) the plants have been awarded an environmental certificate, (b) the energy efficiency is high (in accordance with the French formula calculation), or (c) the NOx emission is less than 80 mg/Nm3.

The level and the scope of the tax is still being debated within parliament.

- Local prevention plan.

  In 2004 the Environment Ministry adopted a National Waste Prevention Plan, with three major lines of action:
    - mobilising stakeholders;
    - implementing action over the long term;
    - ensuring follow-up on measures taken.

  This plan aims to "raise awareness of waste prevention to the same level as for recycling", with the prime objective of holding down waste generation and achieving growth in GDP without increasing waste.

  This law calls for:
    - across-the-board application of rate incentives;
    - development of green fiscal measures to tax products that generate large quantities of waste, provided alternate products with the same functional properties are available;
    - country-wide application of Local Waste Prevention Plans;
    - general implementation of Extended Producer Responsibility.

Financial assistance should help to draft and implement the Local waste prevention Plan. Considering that implementing the plan will cost an average of €2/h/a, a grant of €1/h/a could be attributed if the objectives have been reached. 80% of the population should be covered by such a plan by 2015.

- Develop the principle for extended producer responsibility (EPR) to more products.

Stewardship, or responsible management based on environment and resource, requires industry to assume a greater responsibility for ensuring that its products have a minimum impact on environment during their lifetime. Grenelle emphasizes this concept strongly and promotes the extension of the principle for more of the waste stream. In the first place, the EPR will be applied to hospital waste, furniture and household hazardous waste stream.

- Generalize the pay as you throw tax by 2020

A pay as you throw tax (PAYT) or at least an incentive tax should be established for householders within ten years. To improve the recycling record, the PAYT seems to be a valuable concept. Traditionally, residents pay for waste collection through property taxes regardless of how much - or how little - trash they generate. Pay as you throw breaks with tradition by treating trash services just like electricity, gas, and other utilities. Households pay a variable rate depending on the amount of service they use. Currently, as an experimental measure, 25 municipalities have set up a pay as you throw tax. They charge residents a fee for each bag or can of waste they generate or on the weight of their trash. Despite administrative difficulties and a little non civic behaviour, the results are positive. To avoid illegal tipping a fixed amount will be charged for an amount of waste at first then a fee will be charged depending of the amount collected.

Transversal measure

Waste management remains a concern among the population. To improve public acceptance, transparency and public involvement needs to increase. The Grenelle proposed the following measures to tackle this problem:

- Draw an environmental and sanitary impact assessment of the different waste treatment options.
- Set up a more ambitious research, information and monitoring policy.
- Strengthen waste management planning.
- A new national campaign for information on environmental issues.

Measures concerning waste incineration

At the beginning of the debate, some participants wanted a moratorium on waste incineration. They argued that incineration is a sink for waste and slows down waste minimisation and recovery. They agreed to reconsider their point of view due to prevention and recycling considerations within the Grenelle but also due to a limitation on waste incineration development.

As the EU waste directive 2008/98/EC requires, the residual waste stream will be treated only in waste to energy (WtE) plants with high environmental standards and high energy efficiency. Modernisation of the WtE plant will be encouraged. Within a territory, the capacity of the WtE plants and landfill will be capped at a maximum of 60% of the relevant waste production.

To try to improve heat recovery rate a fiscal measure is proposed. Municipalities applying their own tax system could exempt buildings (using the heat from the WtE plant) from the requirement to pay property tax for a period of five years. The amount of heat used should be a significant part of the energy produced by the unit.

Fundamentals on renewable energy policy

Objectives

Energy was the centre of the Grenelle debate as the major source of climate change.

- The first measured trends concern energy efficiency on new construction, on refurbishment of existing buildings and on transport by increasing the role of railways and public transport and by decreasing vehicle consumption.
- The second measured trend is related to renewable energy. The French commitment goes beyond the EU energy-climate package and targets 23% renewable energy by 2020, instead of 20%. A rise of 20 Mtep production from

renewable energy is mandatory. Biomass and wind power will be the main source of renewable energy with a contribution of 16 Mtep. Energy from waste from incineration, co-combustion or anaerobic digestion will be included within this.

Tariffs for energy from biomass

Since 2000 (law 2000-108 of the 10/02/2000) EDF has the obligation to buy electricity from renewable energy.

In 2001 (law of the 02/10/2001), the tariffs were fixed for MSW plant as incineration. For new units, the tariff is established to a level of c€4.6/kWh with a prime of c€0.3/kWh for high efficiency units (>60% calculated on the basis of the R1 formula). For existing units the tariff is set up to c€3.9/kWh.

New tariffs were established in 2006 for biogas from landfill and aerobic digestion: c€7.5-9/kWh, with a bonus of c€2/kWh for aerobic digestion and up to circa €3/kWh for high efficiency. But for incineration the tariffs did not change. The French government clearly wants to support anaerobic digestion rather than incineration.

Current situation on MSW management

MSW Production in 2006

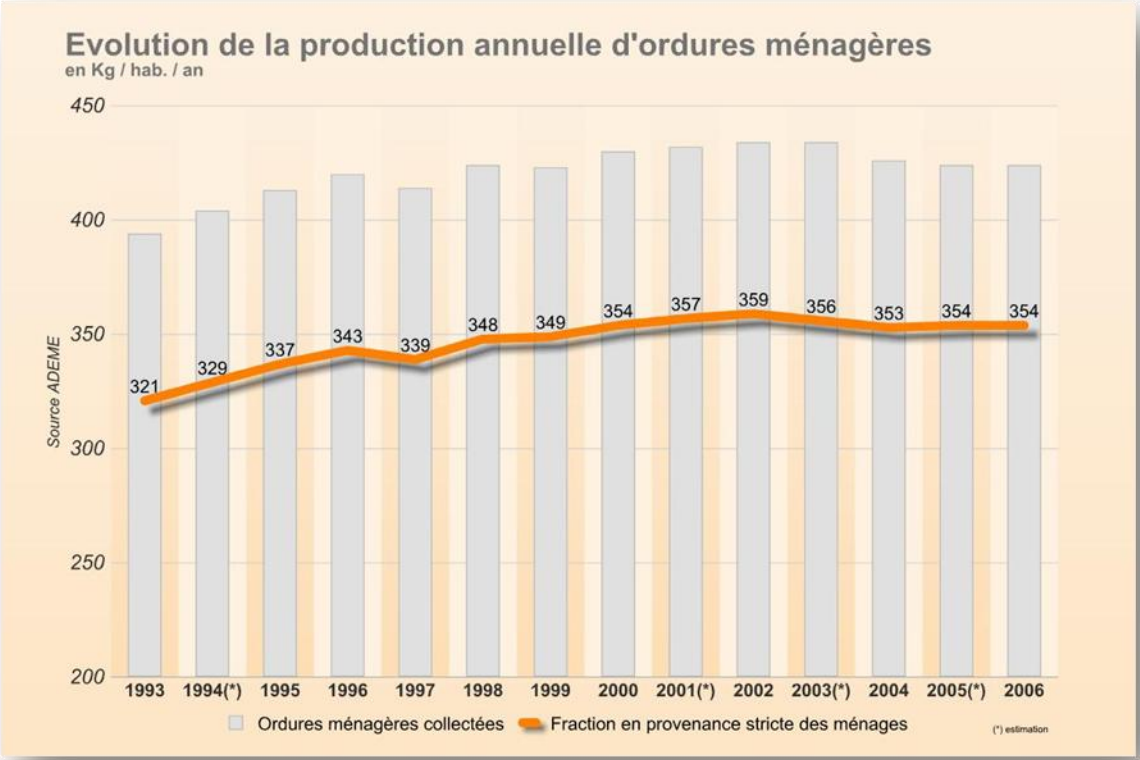
In 2006, the total production of waste was estimated at 849 Mt, of which 28 Mt (3%) was produced by householders.

Table 1.6: Waste production in 2006 in Mt (ADEME-IFEN)

<table>
<tr><td>Waste from municipalities</td><td colspan="2">Household waste</td><td colspan="3">Industrial waste : Factories & industrial plants</td><td>Agriculture and forestry waste</td><td>Infectious waste</td><td colspan="2">Construction and demolition waste</td></tr>
<tr><td>14 Mt</td><td colspan="2">31 Mt</td><td colspan="3">90 Mt</td><td>374 Mt</td><td>0.2 Mt</td><td colspan="2">359Mt</td></tr>
<tr><td rowspan="4">Street sweeping, garden waste, waste water treatment sludge</td><td>Bulky waste, garden waste</td><td>Household Collection rounds</td><td colspan="2">Non hazardous</td><td>Hazard-ous</td><td rowspan="4"></td><td rowspan="4"></td><td>Non hazard-ous</td><td>Hazard-ous</td></tr>
<tr><td rowspan="3">11</td><td rowspan="3">20</td><td colspan="2">84</td><td>6</td><td rowspan="3">356</td><td rowspan="3">3</td></tr>
<tr><td>Collected with household</td><td>Private collect</td><td></td></tr>
<tr><td>5</td><td>79</td><td></td></tr>
</table>

In 2006, the production of household waste was estimated at 354 kg/h/a. The production doubled in the last forty years but started to have a smaller increase since the 1990s with an average rate of growth of 4% a year. However, since 2002 there has been a slight decrease (1%), but the trend is weak.

Figure 1.6: Evolution of household waste production (ADEME)



MSW management in 2006

ITOM is a survey of household and assimilated waste treatment facilities carried out by ADEME every two years. It considers all types of treatment and all throughput of waste; including waste from waste treatment plants as bottom ash going to landfill or sorting refuse into an incinerator. As is common with such statistics, the quantity treated appears to be greater than the quantities collected at times. This is due to discrepancies in the statistics due to collection techniques.

Table 1.7: Quantity of waste treated in waste treatment units managed by the public waste management system in 2006 (ADEME, ITOM 2006)

Treatment type	Number of plants	Waste treated kt/a	Percentage %
Sorting units	320	6 438	13.4
Composting	511	5 051	10.7
Anaerobic digestion	3	147	0.3
Energy from waste facilities	110	12 372	26.0
Incineration without energy recovery	18	579	1.2
Landfill	303	22 938	48.3
Total	**1 263**	**47 526**	
Bottom ash treatment facilities	50	2 006	

The MSW units treat 46% of household waste collected on kerbside and 21% of non-hazardous waste coming from retail and small enterprises. Incineration and landfill together represented 80% of the treatment, a stable position since 2003.

Table 1.8: Waste treated in waste treatment units managed by the public waste management system (ADEME, ITOM 2006)

Waste treated by the MSW units	Percentage %
Household strict	46
Waste from retail and small business	21
Dry waste from separate collection	9
Organic waste	8
Refuse from sorting unit	5
Rubble	2
Waste water treatment sludge	3
Hazardous waste	1

Role of EfW Plants

In December 2008, 116 energy from waste plants were in operation. Over the past 20 years the number of incinerators has decreased from 300 in 1993 to 113 today, but the quantity of waste treated has increased slightly.

The average capacity of a new unit is 110,000 t/a, for a population of 260,000 inhabitants.

France used to have a lot of small incinerators without energy recovery. The new regulations led to the closure of several units of less than one t/h.

Several reasons can explain the shut downs:

- the drafting of departmental plans with the objective of optimising the waste management options;
- the establishment of inter-municipal bodies with centralised units instead of one small unit per municipality;
- the strengthening of regulations that were difficult to apply technically and economically for small units;
- the problem of public acceptability and the perceived threat of toxic emissions.

Table 1.9: Thermal waste treatment plants with energy recovery in France in July 2008 (ADEME, Sinoe, www.sinoe.org)

Note: The capacity is calculated by multiplying the hourly capacity by 8,000 hours. Sometimes the permits given by the authority is for less than the real capacity. This could explain some of the discrepancies between the two numbers.

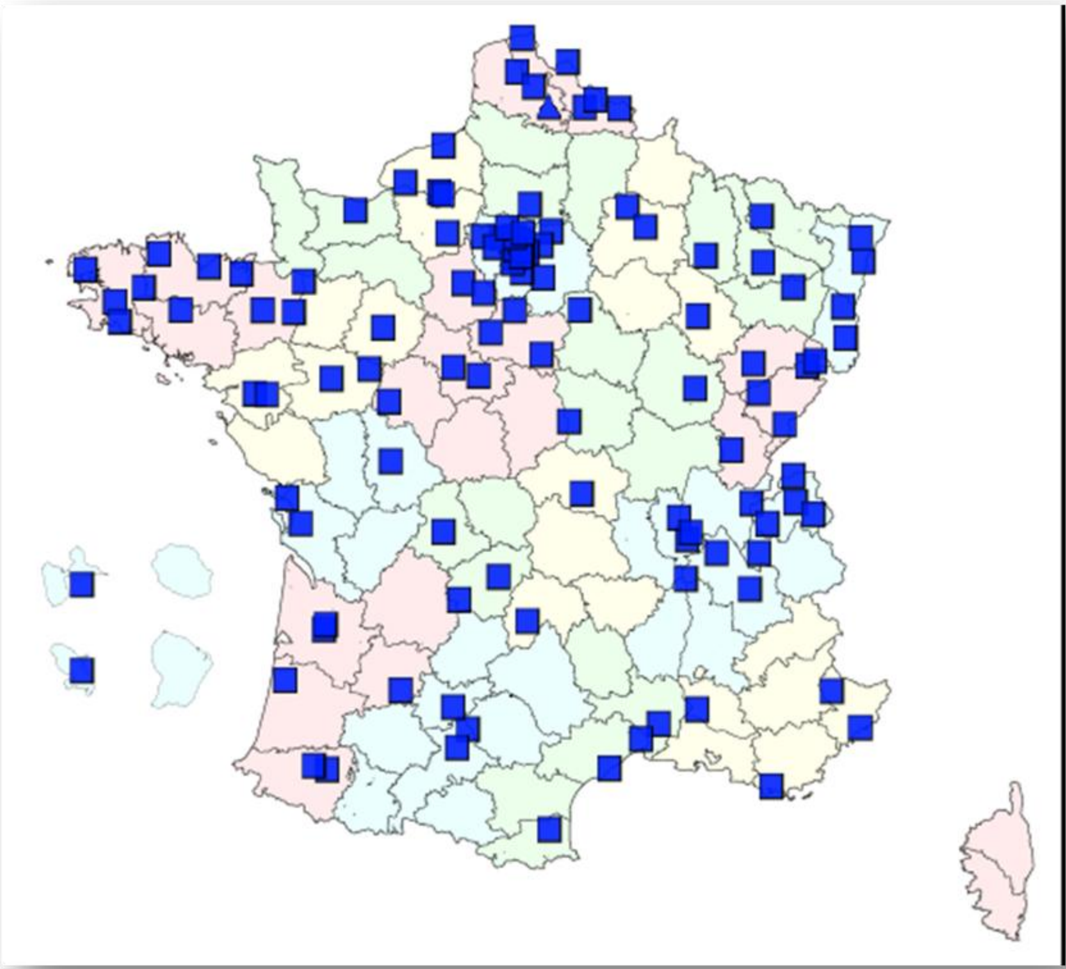
Dpt	Location	Opening date	Units	Capacity Mg/a	Treated quantity
		(last authorisation)			**2007/*2006****
1	BELLEGARDE SUR VALSERINE	1998 (2003)	2x8	128,000	113,944
3	BAYET	1982 (2005)	1x4+1x5	72,000	50,056
6	NICE	1977 (2005)	3x12+1x18	432,000	309,091
14	CAEN	1972	2x8	128,000	98,768
15	AURILLAC	1990 (2004)	<1	5,100	4,666
16	ANGOULEME/ La Couronne	1986 (2004)	1x5	40,000	*36,640*
17	LA ROCHELLE	1988 (2004)	2x4	64,000	57,573
17	ROCHEFORT/Echillais	1990 (2004)	2x2.5	32,000	33,953
19	BRIVE LA GAILLARDE	1973 (2005)	3x3.5	84,500	62,000
19	ROZIERS D'EGLETON	1997 (2005)	1x5.3	42,000	*40,000*
21	DIJON	1974 (2004)	2x11.6	140,000	*124,274*
22	DINAN/Taden	1998 (2006)	2 x7	96,000	*95,147*
22	LAMBALLE	1993 (2007)	1x5.9	47,200	40,665
22	PLUZUNET	1997 (2006)	1x7	56,000	22,424
25	BESANCON	1971 (2005)	1x3+1x4	56,000	50,000
25	MONTBELIARD	1987 (2005)	2x4	64,000	43,849
25	PONTARLIER	1989 (2004)	1x5	40,000	34,408
27	EVREUX/Guichainville	2003	2x5.6	90,000	90,101
28	CHARTRES	1999 (2004)	2x7.5	120,000	118,390
28	RAMBOUILLET/Ouarville	2000 (2004)	2x8	128,000	114,161
29	BREST	1988 (2006)	2x9	144,000	124,699
29	CARHAIX-PLOUGUER	1995 (2006)	1x4	32,000	29,153
29	CONCARNEAU	1989 (2006)	2x3.9	62,400	45,773
29	QUIMPER/Briec	1996 (2006)	2x4	64,000	*30,408*
30	NIMES	2004	1x14	112,000	101,026
31	BESSIERE	2000 (2007)	2x11.4	182,000	158,497
31	TOULOUSE	1969 (2006)	3x8+1x14	304,000	250,995
33	BORDEAUX/Bègle	1998 (2007)	3x11	264,000	245,181
33	BORDEAUX/Cenon	1985(2006)	2x8	128,000	123,063
34	LUNEL-VIEL	1999 (2007)	2x8	128,000	127,434
34	SETE	1992 (2005)	1x5.6	44,800	40,435
35	RENNES	1968 (2005)	2x5+1x8	144,000	124,914
35	VITRE	1998 (2005)	1x4	32,000	24,594
37	CHINON/St Benoit la foret	1984 (2004)	1x2.8	22,400	19,000
38	BOURGOIN JALLIEU	1986 (2007)	1x5 +1x6	88,000	80,256
38	GRENOBLE/La Tronche	1972	3x8.25	198,000	168,972
38	SALAISE SUR SANNE	1985		100,000	*92,400*
39	LONS LE SAUNIER	1994 (2004)	1x5	40,000	36,563
40	PONTENX Les Forges	1997 (2007)	1x5.3	40,600	40,148
41	BLOIS	1971 (2007)	2x5.5	88,000	91,157
41	VERNOU EN SOLOGNE	1987 (2004)	1x2.3	18,400	*7,154*
44	NANTES Arc en Ciel	1994 (2004)	2x7	112,000	89,284

44	NANTES Valorena	1987 (2003)	2x9.5	152,000	129,374
45	GIEN	1999 (2005)	2x5	80,000	26,443
45	ORLEANS	1995 (2004)	2x7	112,000	98,470
45	PITHIVIERS	1985 (2004)	1x3.25	26,000	23,800
47	AGEN	1983 (2001)	1x4.2	33,600	30,882
49	ANGERS	1974 (2004)	3x5	120,000	77,738
49	LASSE	2004	1x12.5	100,000	100,496
51	CHALONS-EN-CHAMPAGNE	1996 (2004)	1x12.5	100,000	149,062
51	REIMS	1989 (2004)	2x6.5	104,000	67,069
52	CHAUMONT	1984 (2006)	2x5	80,000	76,599
53	LAVAL/Pontivy	1984	1x4.5	36,000	*26,234*
53	PONTMAIN	1984(2004)	1x3.2+1x4	57,600	61,000
54	NANCY/Ludres	1995 (2006)	2x7	112,000	97,810
55	TRONVILLE EN BAROIS	1983 (2005)	1x3.5	30,000	23,488
56	PONTIVY LE SOURN	1989 (1997)	1x4	32,000	30,503
57	METZ - BORNY	2001 (2006)	2x8	128,000	*92,160*
58	DUNKERQUE	2007		86,000	
58	NEVERS	2002	1x6	48,000	38,106
59	DOUCHY-LES-MINES	1977 (2005)	2x5	80,000	90,526
59	LILLE /Halluin	2000 (2006)	3x14.5	348,000	344,993
59	MAUBEUGE	1981(2003)	2x5.5	88,000	83,092
59	VALENCIENNE/St Saulve	1977 (2003)	3x5	140,000	116,353
60	COMPIEGNE/Villers St Paul	2004 (2006)	2x10.8	172,500	*172,500*
62	ARRAS (pyrolysis)	2004	2x3.3	52,800	*35,000*
62	BETHUNE/Labeuvrière	1979 (2006)	2x5+1x10	160,000	*58,716*
64	MOURENX	1990	1x2	16,000	*9,362*
64	PAU	1975 (2005)	1x5+1X6	88,000	79,440
64	VALBERG	2005	1x0.5	4,000	*470*
66	PERPIGNAN/Calce	2000 (2007)	2 X11	176,000	180,644
67	HAGUENEAU	1990 (2006)	2x5	80,000	76,483
67	STRASBOURG	1974 (2006)	4 X 11	352,000	267,718
68	COLMAR	1988 (2005)	2x6.2	99,200	*81,102*
68	MULHOUSE	1999 (2006)	2x10.5	168,000	149,862
69	LYON NORD/Rilleux le pape	1989 (2004)	2x12	192,000	141,519
69	LYON SUD/Gerlan	1990 (2004)	3x12	288,000	*227,025*
69	VILLEFRANCHE	1984 (2005)	1x4.5+1x6.5	88,000	79,751
70	NOIDANS-LE-FERROUX	2007	1x5.2	41,000	
72	LE MANS	1975 (2008)	1x9+1x12	168,000	120,954
73	CHAMBERY	1977 (2005)	2x4+1x6	112,000	*80,649*
74	CRAN GEVRIER/Annecy	1984 (1993)	2x6+1x4.2	129,600	*135,298*
74	MARIGNER	1991	1x5	40,000	44,557
74	PASSY	1995 (1997)	1x7.5	60,000	44,129
74	THONON LES BAINS	1988 (2004)	1x5	40,000	39,000
76	DIEPPE	1971 (2002)	2x2.5	40,000	20,000
76	LE HAVRE/St Jean de Folleville	2003	2x12	192,000	172,760
76	ROUEN	2000 (2008)	3x14.5	348,000	296,922
77	LAGNY SUR MARNE	1985 (2005)	1x8+1x12	160,000	150,086
77	MONTHYON	1998 (2004)	2x7+1x4	144,000	117,760
77	VAUX-LE-PENIL	2003 (2005)	2x8	140,000	141,667
78	CARRIERE SOUS POISSY	1998 (2003)	2x7.5	120,000	115,258
78	CARRIERES SUR SEINE	1977 (2003)	2x10	160,000	117,683
78	MANTES:guerville	1997 (2004)	3x4	96,000	59,881

78	THIVERVAL GRIGNON/Behoust	1974 (2006)	2x10.1+ 1x14.7	280,000	188,113
82	MONTAUBAN	1986 (1992)	5	40,000	29,119
83	TOULON	1984 (2005)	2x12+1x14	304,000	250,931
84	AVIGNON/Vedenne	1995 (2005)	3x6	144,000	136,733
86	POITIERS	1984 (2004)	2x4	64,000	44,962
87	LIMOGES	1989 (1997)	3x5	120,000	90,680
88	EPINAL/ Rambervillers	1983 (2005)	2x3.5+1x6	104,000	90,493
89	SENS	1988 (2005)	1x3	24,000	16,927
90	BELFORT/Bourogne	2002 (2004)	2x6.2	99,000	72,269
91	MASSY	1987 (2004)	2x5.5	88,000	*67,255*
91	ULIS/villejust	1984 (2005)	1x6+1x8	112,000	*73,549*
91	VERT-LE-GRAND	1999	2x14	224,000	*152,652*
92	PARIS/ Issy les Moulineaux	2008	2x30.5	460,000	12,872
93	PARIS/ St Ouen	1990	3x28	672,000	607,819
94	CRETEIL	1978 (2003)	2x15	240,000	227,337
94	PARIS/Ivry sur Seine	1969 (2004)	2x50	800,000	669,339
94	RUNGIS	1985 (2004)	2x8.5	130,000	121,476
95	ARGENTEUIL	1975 (2004)	2x7.5+1x9	192,000	189,068
95	CERGY/St Ouen L'Aumone	1996 (2005)	2x10.5	168,000	*145,961*
95	SARCELLES	1978 (2005)	2x10	160,000	121,062
97	FORT-DE-FRANCE	2002	2x7	112,000	113,026
971	SAINT-BARTHELEMY	2001	1x1.5	12,000	9,501
		Total capacity		**14,782,700**	**12,022,754**

*Source 2007: SVDU, 2006: ITOM

Figure 1.7: Location of French waste incineration plants (ADEME, ITOM 2006)



Recent developments in energy recovery

Due to the difficulty faced in building new plants in urban areas, most of the plants are built outside these areas, making it almost impossible to recover the heat. For this reason electricity generation is increasing and heat valorisation is decreasing. By proposing that buildings using a significant amount of heat from an incinerator are exempt from tax, the state is trying to change this trend.

Table 1.10: Evolution of type of energy from waste

	2000	**2002**	**2004**	**2006**
Waste reated quantity t/y	11 782	12 598	13 630	12 950
Electricity, GWh	2 041	2 900	3 242	3 206
Heat, GWh	7 601	9 057	8 231	6 700*
Number of waste to energy plants	109	116	112	110
% units with energy recovery	51	69	84	93
% quantity of waste incinerated with energy valorisation	88	90	95	99
% MSW incinerated	27.3	29	28.2	27.1

* This decrease is due to the closure of one unit in Paris. A new unit has been in operation since June 2008

Waste as a renewable energy

Energy from MSW is the second highest renewable energy, after hydropower for electricity and wood for heat. Consequently one can say that energy from waste plays a significant role in renewable energy. In addition, estimates indicate that energy from waste plants avoids the emission of 2 Mt of CO_2.

Table 1.11: Place of energy from waste in 2004

2004	Electricity GWhe	Heat ktep
Hydropower	61 369	
Waste biogenic fraction of waste = 50%	1621 (total 3242)	358 (716)
wood	1 332	8 780
wind	629	
Geothermic near surface		316
Biogaz	446	55
Crop residue	366	190
Geothermic	29	130
Photovoltaic	26	
Solar heat		32
Total renewable energy	65 817	10 281
Total renewable energy in ktep	15 964	

Future of EfW

Today in France incineration still plays a key role in the waste strategy. However, the few new projects have to fight against a lack of public acceptance. Each time a plant is proposed it is strongly opposed and often the municipality propose another solution (e.g. MBT, anaerobic digestion). A symbolic fight for the 'association against incineration' is the Marseille incinerator. The construction was stopped following a court appeal by the opposition. An agreement was reached by building an MBT plant with anaerobic digestion on the spot to divert waste from the incineration unit.

The waste strategy has to follow the Grenelle objectives that limit incineration and landfill. The new revised department plans will have to justify each new waste to energy plan and to limit its capacity. The tax will add a small burden, but for incineration the level of tax will stay low compared to the treatment cost. Also few new incineration plants will be commissioned in the next ten years. As landfill and incineration are considered to be on the same level in France (no landfill ban, no obligation to recover combustible waste), the future of incineration is uncertain.

New grants will be allowed to promote waste recycling and recovery. Anaerobic digestion also has the advantage of being popular. Six units are in operation today, two to three new units should be built per year until 2012.

Many mechanical biological treatments have been built. Some will produce a solid recovered fuel that could be processed in a boiler or furnace. But few industrial plants are able to process this kind of product without too much change. The cement industry is currently undertaking a survey to look at the possibility to use it by feeding the fuel into main burner. Of course the utilisation of such fuel will depend on its quality and on the energy market price.

Germany

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Legislative regulations on waste management

The German Government started activities to develop an integrated waste management strategy in the early 1990s. The principles are the same as those of the EU Waste Framework Directive on Waste Disposal 75/442/EEC.

In this section the most important acts, ordinances, guidelines and memoranda will be described briefly. In this context only regulations affecting the management of non-hazardous waste will be considered.

Waste Disposal Act and Waste Avoidance and Management Act

The first **Waste Disposal Act** [**Bundesminister des Inneren 1972**] was enacted in 1972, three years before the EU Waste Framework Directive. It replaced approximately 50,000 landfill sites with 300 controlled landfills. This was accomplished within a few years; however, issues with logistics and shortages in capacity caused local crises and public opposition. To cope with the permanently increasing waste generation the **Waste Avoidance and Management Act** [**Bundesminister des Inneren 1986a**] was adopted in 1986. It set the principle of giving avoidance and recycling preference over disposal.

Air Emission Regulations

Along with the reorganisation of landfills, the number and capacity of waste incineration plants was extended. This technology was soon blamed for unacceptable air emissions, particularly after dioxins had been detected in the fly ashes of Dutch waste incinerators [Olie 1977]. Declining public acceptance in the early 1980s was the driver for the release of the **Technical Guideline Clean Air** (**TA Luft 86**) in 1986 [Bundesminister des Inneren 1986b]. Its limits were strengthened five years later by the **17. Federal Emmission Control Ordinance (17. BImSchV) [Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit 1990**]. This ordinance is one of the sources of the later EU Waste Incineration Directive 2000/76/EC (WID) and is (with a number of minor changes) still in power today.

The 17. BImSchV regulates the entire waste incineration process. For the combustion process a minimum temperature of 850°C is required, but if the concentration of organic chlorine (Cl) exceeds 1 wt% in the fuel this temperature has to be increased to 1,100 °C. The combustion temperature has to be measured after a flue gas residence time of >2 s downstream of the last air injection.

The grate ashes have to reach a Total Organic Carbon (TOC) < 3 wt% and detailed provisions are provided for co-incineration. Safety measures for different operation modes are also included.

The limits set for air emissions are of especial importance. Gaseous components, including fly ash, have to be monitored continuously. Heavy metals, Benzo(a)pyrene, and PCDD/F have to be sampled and analysed every two months during the first year of operation and later once per year. The sampling has to be performed over three days. The sampling time for heavy metals and Benzo(a)pyrene is restricted to 0.5 – 2 h, for PCDD/F the sampling

time is 6 - 8 h. Details for monitoring methods, measuring time intervals, and analytical methods are also included.
The actual daily and half-hourly emission standards of gas carried components for Germany are compiled in Table 1.12.

Table 1.12: Emission limits in the 17. BImSchV in mg/m^3 (273 K, 101.3 kPa, 11 vol% O_2, dry)

Parameter	*Daily limit*	*Half-hourly limit*
Dust	10	30
CO	50	100
TOC	10	20
HCl	10	60
HF	1	4
SO_2	50	200
NO_x (as NO_2)	200	400
Hg	0.03	0.05

The limits for the annual surveillance measurements are shown in Table 1.13.

Table 1.13: Emission limits for heavy metals and Benzo(a)pyrene in mg/m^3, for PCDD/F in ng(I-TE)/m^3 (273 K, 101.3 kPa, 11 vol.-% O_2, dry)

Parameter	*Limit*
Cd+Tl	0.05
Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V+Sn	0.5
As+Benzo(a)pyrene+Cd+Co(water sol.)+Cr[1]	0.05
PCDD/F	0,1

(1) alternatively Cr^{6+} compounds with the exception of $BaCr_2O_7$ and $PbCr_2O_7$

These stringent safety standards helped to reduce the public opposition against thermal **waste treatment to a great extent.**

Packaging Ordinance

Approximately 50 % of the volume of waste from households is packaging material. For this reason, regulations on the disposal of this waste stream were introduced in the **Packaging Ordinance [Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit 1991**], by shifting the responsibility for its adequate management to the manufacturers and retailers. As a consequence of this ordinance the **Dual System Germany (DSD**) was established. This collects packaging material free of charge for the householder and organises the recycling of fractions such as glass, paper, or plastics. The system is financed by the 'Green Dot' licence fee which the manufacturer - but in fact the customer - pays. Meanwhile the DSD lost its exclusivity and a number of dual systems are in operation.

Technical Ordinance on Waste from Human Settlements (TASi)

For mixed residential waste the government issued the **Technical Ordinance on Waste from Human Settlements (TASi**) in 1993 [**Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit 1993**]. The core target of the ordinance was the prevention of direct disposal of reactive waste. Its main objectives are:

- restriction of direct disposal of biodegradable waste on landfills;
- instructions for design, operation and allocation of future landfills;
- priority for material recovery including composting and anaerobic digestion; and finally

- thermal treatment of residual waste with energy recovery and - as far as possible - residue utilisation prior to final disposal.

The waste management hierarchy outlined above did not have to be followed strictly if technical or economic aspects were in favour of other strategies.

Two types of landfills were foreseen for the disposal of mixed municipal solid waste; their acceptance criteria are compiled in 0. The most important parameter is the residual content of organic matter, analysed as TOC, which is 1 wt% in the case of landfill class 1 or at the highest 3 wt% for landfill class 2.

Table 1.14: Acceptance criteria for German landfills as laid down in the TASi (landfill class 1 and 2) and in the Ordinance on Environmentally Compatible Storage of Waste from Human Settlements and on Biological Waste-Treatment Facilities (landfill class 3)

Parameter	*Unit*	*Landfill class 1*	*Landfill class 2*	*Landfill class 3*
vane shear strength	kN/m^2	≥25	≥25	≥25
axial deformation	%	≤20	≤20	≤20
uniaxial compressive strength	kN/m^2	≥50	≥50	≥50
LOI	wt%	≤3	≤7	-
TOC	wt%	≤1	≤3	≤18
extractable lithophilic substances	wt%	≤0.4	≤0.8	≤0.8
pH		5.5 - 13	5.5 - 13	5.5 - 13
el. conductivity	µS/cm	≤10,000	≤ 50,000	≤ 50,000
TOC	mg/l	≤20	≤100	≤250
phenols	mg/l	≤0.2	≤50	≤50
As	mg/l	≤0.2	≤0.5	≤0.5
Pb	mg/l	≤0.2	≤1	≤1
Cd	mg/l	≤0.05	≤0.1	≤0.1
Cr-VI	mg/l	≤0.05	≤0.1	≤0.1
Cu	mg/l	≤1	≤5	≤5
Ni	mg/l	≤0.2	≤1	≤1
Hg	mg/l	≤0.005	≤0.02	≤0.02
Zn	mg/l	≤2	≤5	≤5
F	mg/l	≤5	≤25	≤25
ammonium-N	mg/l	≤4	≤200	≤200
cyanide	mg/l	≤0.1	≤0.5	≤0.5
AOX	mg/l	≤0.3	≤1.5	≤1.5
soluble fraction	wt%	≤3	≤6	≤6
as breathing activity (AT_4)	mg/g			≤5[1]
or as gas formation rate in fermentation test (GB_{21})	l/kg			≤20[2]
upper thermal value (H_0)	kJ/kg			≤6,000

(1) mg O_2 with respect to dry weight, (2) standard litre of gas with respect to dry weight

The TASi - its full enaction was stipulated for 1 June, 2005 - could have been a strong instrument to promote waste incineration with energy recovery. However, it had no legally binding power, since it was solely requesting the establishment of an integrated waste management system from the relevant administrative bodies. Hence the federal government could not enforce its immediate application and the strong opposition to waste incineration made it difficult to site new plants. As a consequence almost all federal states and all local bodies made excessive use of permits which allowed the continuation of the status quo.

The principles and requirements laid down already in the TASi have later been used as the basis of the EU Landfill Directive. In that way this ordinance - although not really effective in Germany - resembled at least an important input for the waste management strategies in the EU.

Closed Substance Cycle Act (KrW-/AbfG)

In the early 1990s the German government chose to fight the ever increasing waste generation by introducing a landfill tax. This attempt failed due to heavy resistance, especially from various industry sectors that had to deal with high amounts of production residues. Another reason was the unclear constitutional situation, since a high fraction of the tax was not used to serve common interests in the waste disposal area but was allocated for other purposes.

At the same time Germany was sued at the European Court of Justice for not having fully adopted the Waste Framework Directive. Whereas the German legislative label 'waste' addressed only materials for disposal, in the EU Directive, materials diverted for recycling were also regarded as waste. A further promotion to enact new regulations originated from the World Summit in Rio de Janeiro which brought the term 'sustainability' on stage.

Hence in 1994 the **Act for Promoting Closed Substance Cycle Waste Management and Ensuring Environmentally Compatible Waste Disposal (KrW-/AbfG) [Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit 1994**] was issued to adopt the waste classification of the EU Waste Framework Directive; the KrW-/AbfG reinforced the fundamentals of the former TASi and set a series of new rules including:

- the establishment of a waste management hierarchy based on avoidance, utilisation, treatment, and disposal;
- the request for low-waste design of products and closed-cycle management of substances within plants;
- the introduction of the 'polluter pays' principle (producer and holder of waste is responsible for its disposal according to the principles laid down);
- the definition of environmental compatibility as the basic principle to decide upon priority between recycling and energy recovery.

For waste incinerators the KrW-/AbfG set criteria to distinguish between disposal and energy recovery. The latter operation mode is accepted if:

- the lower heating value of the material exceeds 11 MJ/kg;
- the combustion efficiency of the combustion plant exceeds 75%;
- the energy released by the process has to be used as heat or power; and
- the residues meet the landfill acceptance criteria of the TASi without further treatment.

The KrW-/AbfG also stated clearly that energy recovery will not be accepted for municipal waste, regardless of the compliance with the above cited acceptance parameters.

Regulation of Biological Treatment Processes for Waste

To open an alternative treatment route other than waste incineration, the 30. Federal Emmission Control Ordinance [Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit 2001a] was issued in 2001. This ordinance regulates the operation and environmental requirements for mechanical-biological waste treatment plants. Such plants have to meet air emission standards which are similar to those for waste incineration plants with the consequence that these plants have to control their emissions and have to be equipped with air pollution control systems.

Since mechanical and/or biological processes are not able to meet the landfill class 1 or class 2 criteria, the Ordinance on Environmentally Compatible Storage of Waste from Human Settlements and on Biological Waste-Treatment Facilities (AbfAblV)

[Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit 2001b] opened an outlet for the residues of such facilities by defining acceptance criteria for another landfill category, the landfill class 3. The standards are included in 0. Instead of 1 or 3 wt% the TOC has been set to 18 wt%. This standard is accomplished by the limitation of the upper heating value of the material to 6 MJ/kg and a restriction of the amount of extractable organic matter to 0.8 wt%.

Ordinance on Landfills and Long-Term Storage (DepV)
The EU Landfill Directive was adopted by German law in July 2001 with the **Ordinance on Landfills and Long-Term Storage Facilities and Amending the Ordinance on Environmentally Compatible Storage of Waste from Human Settlements and Biological Waste-Treatment Facilities (DepV)** [Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit 2002b]. This ordinance finally converted the principles of the TASi into a legally binding regulation. The direct disposal of untreated reactive waste in landfills was now definitely prohibited after 1 June 2005. After this date all standards for design, operation and aftercare of all landfill classes for municipal waste, commercial waste and waste requiring special surveillance (hazardous waste) came in force as they had been laid down already in the TASi. Any exemptions that had been granted expired.

Act on Commercial, Construction and Demolition Wastes
In 2002 the German government released new rules for the disposal of commercial as well as construction and demolition waste with the **Ordinance on the Management of Municipal Wastes of Commercial Origin and Certain Construction and Demolition Wastes** [Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit 2002a]. The disposal of these waste streams must be taken care of by their producers. The new ordinance defines pre-treatment and recovery requirements.

Energy consumption

Primary energy
Primary energy consumption in Germany in 2006 was 14,565 PJ and in 2007 it was 13,842 PJ. A breakdown into the different energy sources is shown in Table 1.15 [Bundesministerium für Wirtschaft und Technologie 2008].

Table 1.15: Primary energy consumption in Germany and the contribution of the different energy sources (absolute data in PJ, share in %)

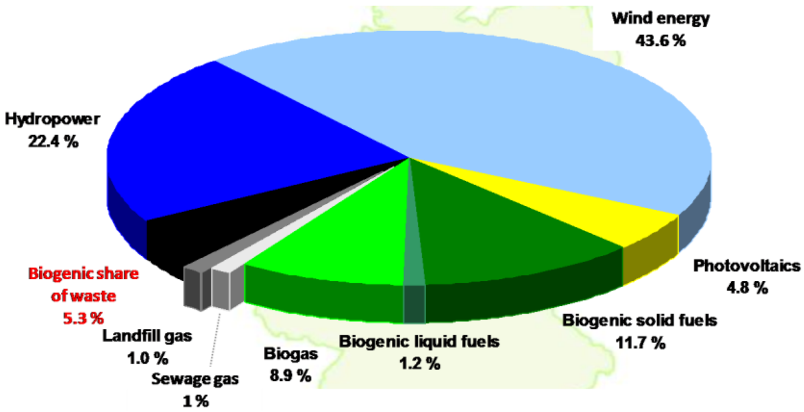
	2006 [PJ]	***2007 [PJ]***	***2006 [%]***	***2007 [%]***
mineral oil	5 179	4 678	35.6	33.8
natural gas	3 286	3 136	22.6	22.7
hard coal	1 923	1 952	13.2	14.1
lignite	1 574	1 618	10.8	11.7
nuclear	1 826	1 533	12.5	11.1
hydro	71	72	0.5	0.5
wind	111	146	0.8	1.1
other renewables	603	691	401	5.0
others	-7	16	0.0	0.1
total	14 565	13 842	100	100
renewables	785	909	5.4	6.6

The table shows that the primary energy consumption decreased from 2006 to 2007 by almost 10%. This is in line with a long term trend, which added up to a total reduction of almost 30% since 1990. The major energy sources are still oil, gas, and coal, but the contribution of renewable sources is permanently and rapidly growing, reaching 5.4% in 2006 and even 6.6% in 2007.

Power market

The total power supply in Germany in 2008 was approx. 616 TWh, which is equivalent to approximately 2217 PJ. The share of electricity from renewable sources was 15.1% or 93 TWh respectively 335 PJ [Working Group on Renewable Energies 2009]. The contribution of the different renewable sources is shown in Figure 1.8.

Figure 1.8: Renewable sources in the German power market in 2008

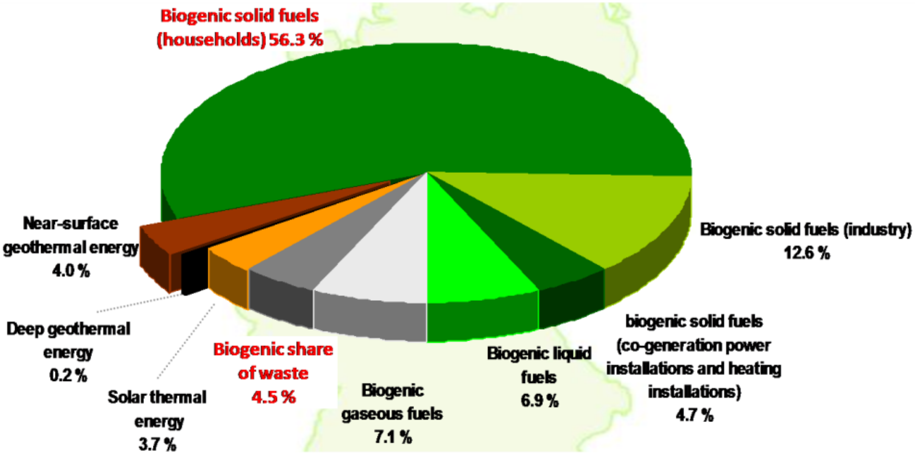


The pie chart shows that the main sources were wind and hydro power. However, the various types of biomass had a share of approx. 29% and this figure has rapidly increased over the past 15 years. The biogenic waste fraction accounted for 4.9 TWh or 17.7 PJ which represents approximately 5.3% of all renewable sources.

Heat market

The total heat demand in Germany in 2008 was approximately 5,170 PJ; renewable sources supplied 7.7% or 400 PJ to this figure [Working Group on Renewable Energies 2009]. The contribution of the single renewable sources is depicted in Figure 1.9. The main heat source is solid biomass for house heating. Biogenic waste has with 4.9%, a slightly lower share in the power market.

Figure 1.9: Renewable sources in the German heat market in 2008



Waste generation

Municipal solid waste

In Germany municipal solid waste (MSW) is managed by the public waste management system, which is partly operated by public bodies, partly by private companies owned by private bodies, or in private-public partnership. This is why there are good statistics for this waste category. The situation is different for waste from commerce and light industry. The statistics do only present that fraction which is taken care of by the public waste management system. Reliable data on the share which is disposed of by the private sector - in any case following the legislative regulations of waste treatment - are hard to find.

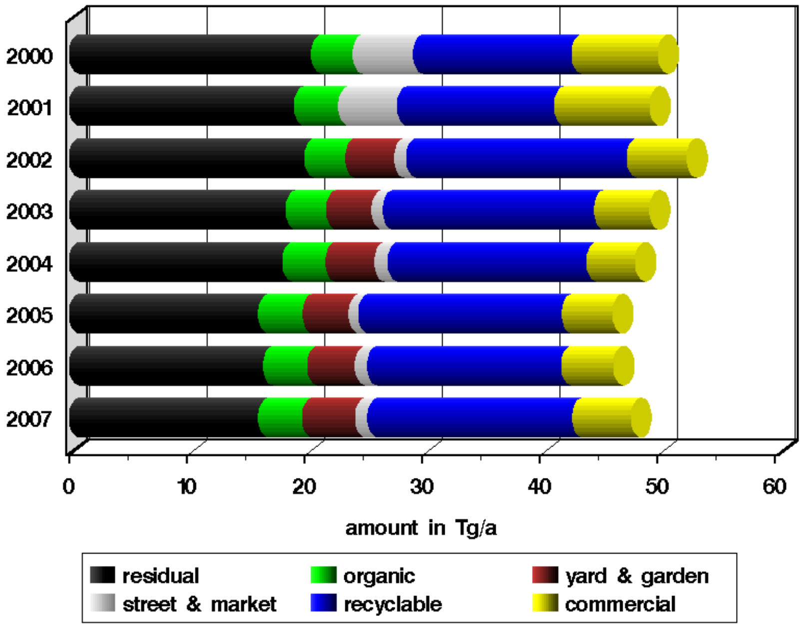
According to data published by the German Federal Office of Statistics (Statistisches Bundesamt) the total annual amount of residential waste was during the years 2000 to 2007 slightly reduced from 50 mill. Mg to 47.7 mill. Mg. The respective figure for commercial waste decreased from 7.3 mill. Mg in 2000 to 5 mill. Mg in 2007. This tendency, however, might not reflect a real decrease but rather a change to cheaper disposal routes in the private sector.

A breakdown into residual mixed MSW and separately collected organic or bio-waste and waste for recycling is compiled in Table 1.16 and visualised in Figure 1.10.

Table 1.16: Total residential waste, separately collected organic, recyclable, and residual household waste, and commercial waste between 2000 and 2007 in mill. Mg [Statistisches Bundesamt 2009]

Year	*Total residential waste*	*Residual & bulky waste*	*Organic waste*	*Yard & garden waste*	*Street & market waste*	*Recyclable waste*	*Commercial waste*
2000	50.015	20.598	3.531	0	5.060	13.491	7.335
2001	49.301	19.142	3.753	0	4.933	13.364	8.109
2002	52.455	20.023	3.465	4.163	943	18.769	5.092
2003	49.265	18.432	3.447	3.845	879	17.944	4.718
2004	48.048	18.147	3.661	4.172	1026	16.899	4.143
2005	46.130	16.079	3.776	3.924	728	17.313	4.310
2006	46.019	16.507	3.757	4.044	967	16.520	4.224
2007	47.704	16.088	3.743	4.509	973	17.410	4.981

Figure 1.10: Separately collected household waste fractions and commercial waste in Germany between 2000 and 2007 (Tg=mill. Mg)



Solid recovered fuel

There are two reasons to produce fuel from waste or waste fractions, so-called solid recovered fuel (SRF) which is in Germany called EBS (Ersatzbrennstoff, alternative fuel) or SBS (Sekundärbrennstoff, secondary fuel). Originally it was a product of mechanical-biological treatment (MBT) of waste, which became popular in Germany in the 1980s and 1990s as an alternative to waste incineration. An actual driver is the need of industry for cheap fuel, especially in times of exploding oil prices.

SRF is typically a mix of paper, wood, and plastics. Its heating value varies between 11 and >20 MJ/kg. The lower limit is set to comply with the German legislative regulation for energy recovery from waste derived fuels.

The utilisation of this SRF depends on one hand on its market price, on the other hand on its quality. The latter is mainly determined by its inventory of unwanted ingredients like halogens, heavy metals, and alkali metal compounds. The most critical component in that respect is chlorine (Cl). Municipal solid waste has a Cl concentration of 0.5 - 1 wt-%, whereas the respective figure for SRF is typically in the order of 1 or even >2 wt-%. Standards have been developed for the production of SRF, however, the quality assurance is still the major problem with SRF from MBT plants treating residual MSW. A number of such plants have been shut down for this reason since their product found no market. Good quality is more or less solely to be derived from well defined waste fractions, mainly from the commercial and industrial sector.

According to 2006 data from the Federal Statistical Office there were 64 MBT or similar plants for MSW in existence in Germany out of which only 52 were in operation. The theoretical capacity was 6.1 Mt of waste and the amount of produced SRF was approximately 2.4 Mt. There is an additional SRF stream of 4.2 Mt, produced from commercial and light industrial waste. The potential for SRF production from industrial waste is expected to exceed 9 Mt.

Energy from waste

Drivers and barriers

There are different types of drivers for energy from waste in Germany:

- The main legal driver is the above mentioned Ordinance on Landfills and Long-Term Storage (DepV), which resulted in a landfill ban for reactive waste and requires waste to be rendered inert prior to final disposal. For the time being only waste incineration can meet the standards set for access to German landfill sites class 1 or class 2. The second important legal driver is the 17. Federal Emission Control Ordinance, the 17. BImSchV, which calls for recovery of the released energy.
- An economic driver is the demand of cheap energy for industry. Since treatment and disposal of MSW are taken care of by the public waste management system (the costs of which are paid by the citizen) this energy, especially in the case of SRF utilisation, is subsidised and is offered at low cost.
- Finally, policy is, to a certain extent, promoting energy from waste since the biogenic fraction of waste is in the statistics categorised as renewable energy and the calculated saved CO_2 emissions can contribute to the reduction targets endorsed for the Kyoto Protocol.

There are also some barriers to energy from waste:

- Although the situation is by far more relaxed than during the 1980s and 1990s, waste incineration is still looked upon critically by part of the population. Perhaps surprisingly, in areas where waste incineration does not yet exist, interest groups have support in their fight against the siting of new plants; whereas in areas where there is experience with this technology the opposition is much lower.
- The energy efficiency for power generation in a waste incinerator is low compared to utility boilers and the need for gas cleaning makes the generation of power expensive.
- A factor which is at least not in favour of waste incineration is the non-application of the Renewable Energy Act on waste incineration. Its partly biogenic character is acknowledged for the statistics but the respective subsidies for the energy are not paid.
- The potential risk of contaminants in waste based fuels is limiting an extensive utilisation of SRF in high efficiency processes.

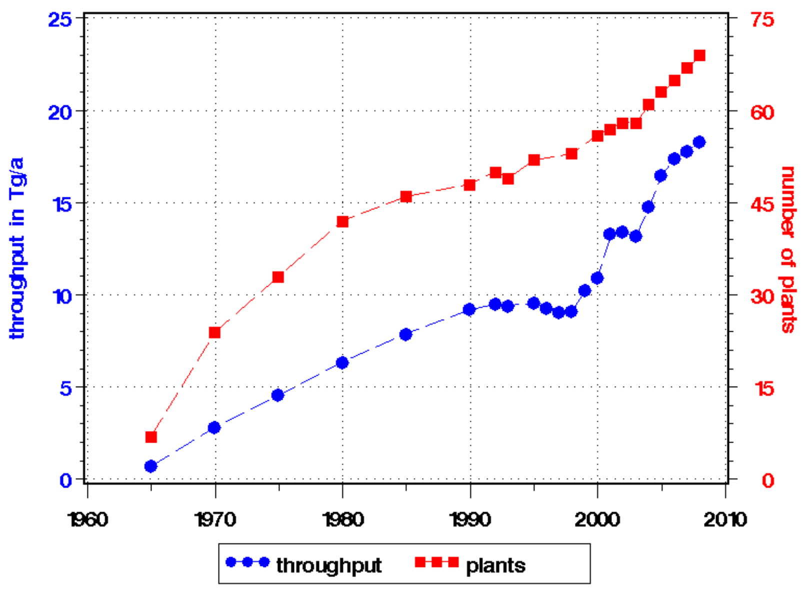
- Another limitation of extending the number of dedicated SRF power plants is the lack of a long term stable market for such fuel.

Waste incineration

Germany has extended its waste incineration capacity significantly over the past years. Figure 1.11 visualises the development of waste incineration in Germany, starting in 1965. The figure documents the steady increase in the number of plants as well as in their throughput. The growing public opposition against this technology caused a kind of moratorium after 1990. Although there was a slight further increase in the number of plants the throughput stayed almost constant.

This changed after the EU Landfill Directive was issued and it became evident that its adoption into German law would indeed bring the targets of the TASi into reality in a short space of time. As can be seen, the throughput of the German waste incineration plants was almost doubled between 1998 and 2008.

Figure 1.11: development of waste incineration in Germany between 1985 and 2008



In 2008 there were 68 waste incineration plants in operation with a total capacity of approx. 18 Mt. The map in Figure 1.12 shows the location of all plants for thermal treatment of MSW. The name of the location and theoretical capacity of the single plants can be looked up under the respective green numbers in Table 1.17 [Umweltbundesamt 2008]. The plants are ordered according to the federal state they are located in. It has to be mentioned that the total number given in Table 1.17 is not in line with the 69 operating plants published by ITAD, the association of German waste incineration plants [ITAD 2009]. The plants in Landshut, Rostock and Weißenhorn were obviously not in operation.

From 1986 on the municipality of Burgau in Bavaria operates a small pyrolysis plant for MSW with a capacity of 25,000 t. New technologies have been tested in Germany but did not enter the market. For the Siemens Thermal Recycling Process a plant was erected in Fürth but never got a permanent license and the Thermoselect plant in Karlsruhe was shut down due to economic problems after few years of operation.

Figure 1.12: Location of German waste incineration plants (green numbers) [Umweltbundesamt 2008]

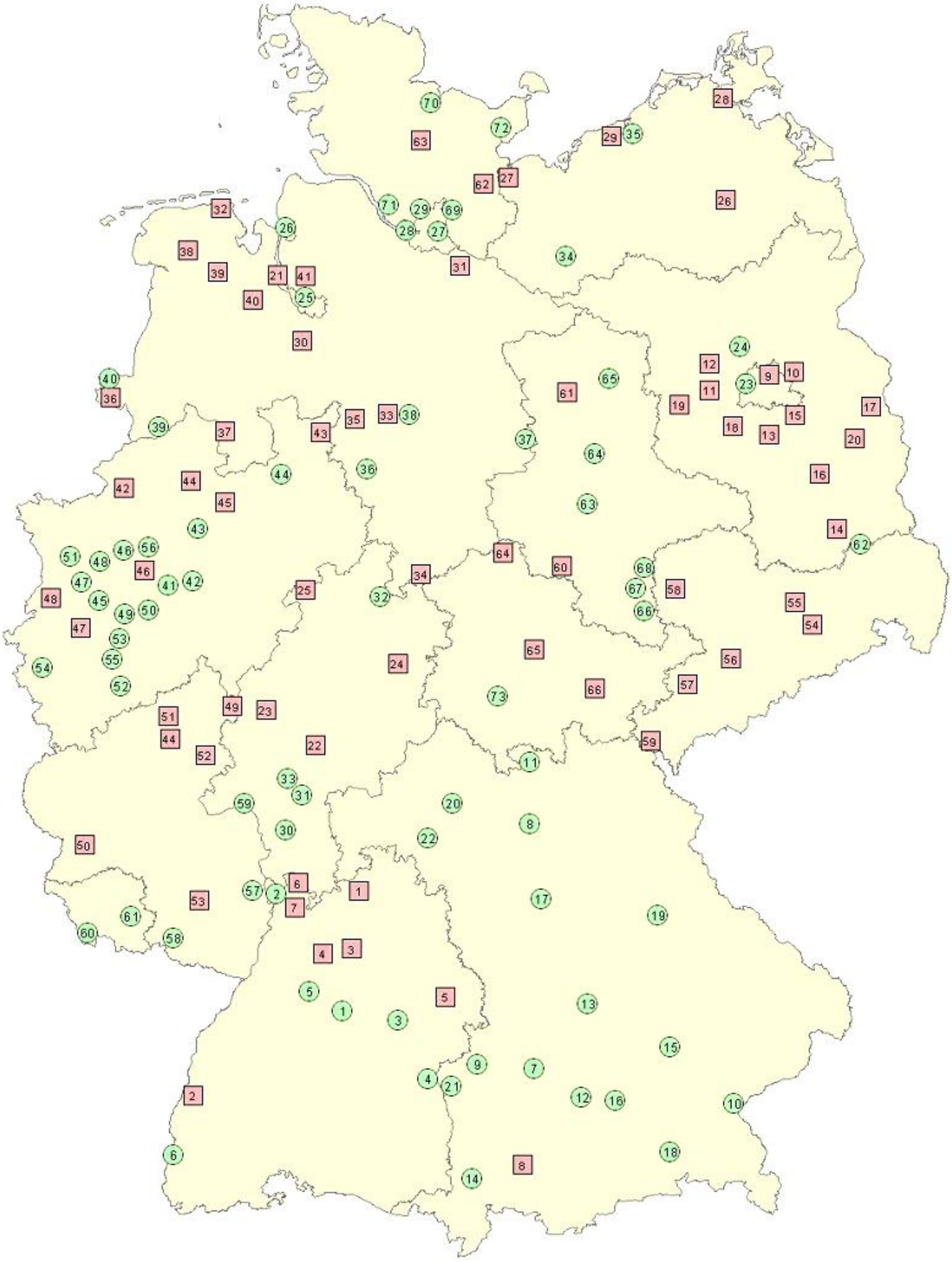


Table 1.17: Thermal waste treatment plants in Germany: state, location, and capacity

no	state	location	capacity [Mg/a]	no.	state	location	capacity [Mg/a]
1	BW	Stuttgart	420,000	39	NI	Salzbergen	120,000
2	BW	Mannheim	380,000	40	NI	Emlichheim	200,000
3	BW	Göppingen	140,000	41	NW	Hagen	120,000
4	BW	Ulm	120,000	42	NW	Iserlohn	230,000
5	BW	Böblingen	140,000	43	NW	Hamm	245,000
6	BW	Eschbach	150,000	44	NW	Bielefeld-Herford	330,000
7	BY	Augsburg	200,000	45	NW	Düsseldorf	450,000
8	BY	Bamberg	125,000	46	NW	Essen-Karnap	622,000
9	BY	Burgau (pyrolysis)	25,000	47	NW	Krefeld	350,000
10	BY	Burgkirchen	200,000	48	NW	Oberhausen	510,000
11	BY	Coburg	115,000	49	NW	Solingen	100,000
12	BY	Geiselbullach	85,000	50	NW	Wuppertal	385,000
13	BY	Ingolstadt	197,000	51	NW	Asdonkshof	234,000
14	BY	Kempten	70,000	52	NW	Bonn	240,000
15	BY	Landshut	45,000	53	NW	Leverkusen	210,000
16	BY	München	700,000	54	NW	Weisweiler	360,000
17	BY	Nürnberg	200,000	55	NW	Köln	569,000
18	BY	Rosenheim	60,000	56	NW	Herten	260,000
19	BY	Schwandorf	450,000	57	RP	Ludwigshafen	180,000
20	BY	Schweinfurt	145,000	58	RP	Pirmasens	189,000
21	BY	Weißenhorn	89,000	59	RP	Mainz	237,000
22	BY	Würzburg	170,000	60	SL	Velsen	210,000
23	BE	Ruhleben	520,000	61	SL	Neunkirchen	150,000
24	BB	Germendorf	80,000	62	SN	Lauta	225,000
25	HB	Bremen	468,000	63	ST	Staßfurt	300,000
26	HB	Bremerhaven	315,000	64	ST	Magdeburg	300,000
27	HH	Borsigstraße	320,000	65	ST	Stendal	300,000
28	HH	Rugenberger Damm	320,000	66	ST	Zorbau	300,000
29	HH	Stellinger Moor	160,000	67	ST	Leuna	195,000
30	HE	Darmstadt	212,000	68	ST	Lochau	80,000
31	HE	Offenbach	225,000	69	SH	Stapelfeld	350,000
32	HE	Kassel	150,000	70	SH	Kiel	140,000
33	HE	Frankfurt	525,000	71	SH	Tornesch-Ahrenlohe	80,000
34	MV	Ludwigslust	50,000	72	SH	Neustadt	56,000
35	MV	Rostock	166,000	73	TH	Zella-Mehlis	160,000
36	NI	Hameln	300,000				
37	NI	Buschhaus	525,000	**Total capacity**			**17,779,000**
38	NI	Lahe	230,000				

All waste incineration plants recover energy and utilise it by exporting power, process steam, heat or a combination of these energy forms. The energy efficiency of the single plants varies to a great extent. Some plants built during the 1980s and 1990s were located outside residential and industrial areas for public acceptance reasons and only convert their recovered energy to power. Although the Air Pollution Control (APC) systems of all plants were regularly upgraded, this was not the case for the energy recovery system. On the other hand, even some older plants are characterised by optimum energy use. The Schwandorf waste incinerator, for example, delivers high temperature steam to an aluminium smelter, serves a small district heating grid, and operates a turbine. Other plants like those in Mannheim have their steam cycle coupled with a close-by power plant and are equipped with an external oil fired super heater. The Mainz plant has its boiler coupled with a combined cycle natural gas turbine and achieves in this coupled state an energy efficiency exceeding 40%.

The efficient utilisation of energy only recently became a major objective in thermal waste treatment. Hence the calculation of a mean efficiency for heat or power of all German incineration plants is misleading. It can be estimated that new plants have primary or boiler efficiencies in the order of 80 - 85%. Conventional plants, which are mainly operated for power export, achieve an efficiency of 23 - 24% with an internal consumption which reduces this number by few per cent. For CHP plants the respective efficiencies depend on the operation mode and the respective demand.

Instead of calculating mean efficiencies it is more convincing to use the actual global data on generated heat and power and the respective exported quantities.

According to the German Federal Statistical Office [Statistisches Bundesamt 2008] the amount of residual household waste in 2006 was approximately. 16.7 Tg. CEWEP published in its Annual Report on Germany 2006 a total throughput in German waste incineration plants of

$$M_{waste} = 16.5\ Tg$$

Estimating a mean lower heating value of

$$H_u \approx 10\ MJ/kg$$

which is close to the value published by Umweltbundesamt during the last years [Johnke 2007] the total energy input into the incineration plants was approximately

$$E_{in} \approx 165\ PJ$$

For the recovered energy CEWEP published estimates of approx. 16.37 TWh including a self-demand of 3.3 TWh or

$$H_{out,\ total} \approx 59\ PJ$$
$$H_{out,\ self} \approx 12\ PJ$$
$$H_{out,\ net} \approx 47\ PJ.$$

This indicates a recovery of energy in terms of heat which is equivalent to

$$R_{heat} \approx 35.8\ \%$$

of the energy fed into all incinerators. The exported heat represents

$$U_{heat} \approx 28.5\ \%$$

of the initial energy inventory of the waste.

The same publication indicates a power generation of approximately 6.8 TWh and an internal demand of 2.13 TWh. These data are equivalent to

$$P_{out,\ total} \approx 24.5\ PJ$$
$$P_{out,\ self} \approx 7.7\ PJ$$
$$P_{out,\ net} \approx 16.8\ PJ.$$

The recovery of energy in terms of power can be calculated to

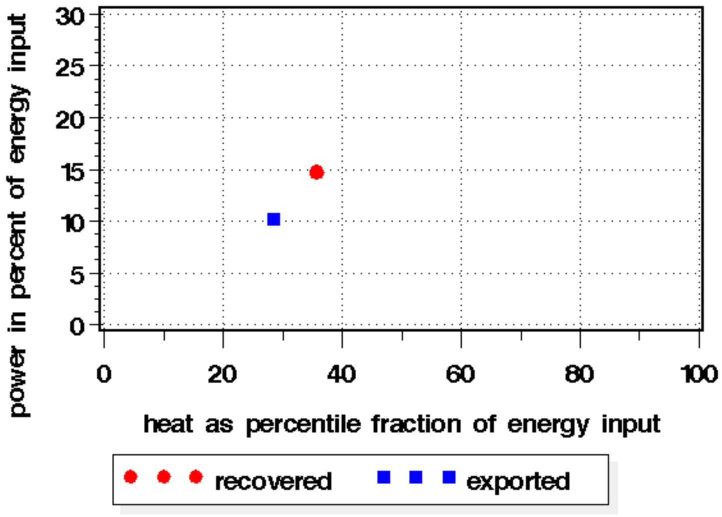
$$R_{power} \approx 14.84\ \%$$

and the respective export to

$$U_{power} \approx 10.2\ \%.$$

The graph shown in Figure 1.13 visualises the 2006 average power and heat numbers reported above, on one hand as generated energy, on the other hand as exported energy, given as a fraction of the overall energy input into all German incineration plants.

Figure 1.13: Average figures of recovered respectively exported power and heat of all German waste incineration plants in 2006



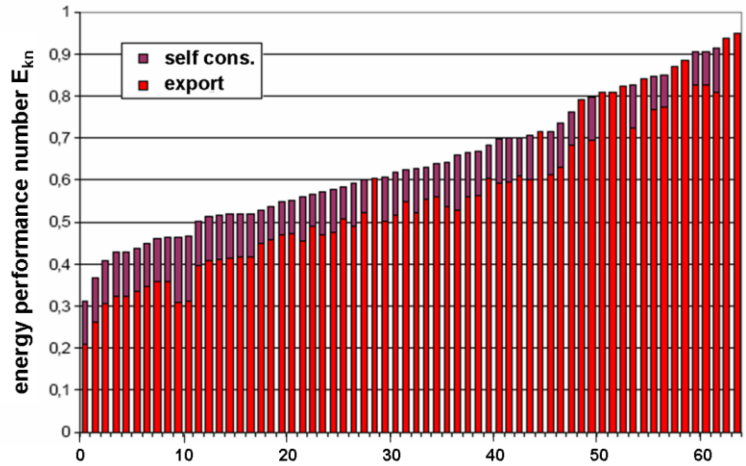
The revised EU Waste Framework Directive contains a formula to calculate a so-called 'energy efficiency' which will here be referred to as energy performance figure E_{kn} since it is not efficiency in a physical sense [Beckmann et al. 2007]. Using this formula which multiplies the power generation by a factor of 2.6 and the exported heat by a factor of 1.1 and divides the sum of both by the energy fed into the system results in

$$E_{kn} \approx 0.7$$

which means that the accumulated energy recovery of all German waste incineration plants complies well with the energy performance figure thresholds set in the revised Waste Framework Directive for the acceptance of an energy recovery status of 0.6 for old and 0.65 for new waste incineration plants.

In a report for the Umweltbundesamt this formula has been applied to 64 German waste incineration plants [Fehrenbach et al. 2007]. The bar plot shown in Figure 1.14 indicates the wide spread of the energy performance figure for individual plants between 0.31 and 0.95. 28 out of the 64 plants exceed 0.65, the threshold for new plants and 36 the limit of 0.6 for old plants.

Figure 1.14: Energy performance figure of 64 German waste incineration plants calculated using the R1 formula of the new EU Waste Framework Directive [Fehrenbach 2007]



Energy from SRF

SRF is in most cases used together with other fuels. Main users of SRF for co-combustion are power plants, cement and lime kilns, paper and steel industry. An overview of the co-combustion practice in 2006 is compiled in Table 1.18.

Table 1.18: Co-combustion in various industry furnaces in 2006

	SRT throughput in mill. Mg
Power plants	0.5
Cement kilns	2.0
Paper industry	1.4
Steel industry	0.1
Lime kilns	0.2
Total	4.2

The future of co-combustion is not clear due to the difficulties in quality control and the (for that reason) unstable market of SRF. An example illustrating this situation is the co-combustion in power plants. The high chlorine (Cl) content limits the utilisation of SRF due to the risk of Cl induced boiler corrosion. In 2006 co-combustion was practised in 8 hard coal and also in 8 lignite fired power plants. In 2007 only 6 hard coal and 2 lignite boilers continued co-combustion [Thiel 2007].

Cement kilns, too, cannot cope with high halogen levels in their fuel. They have a typical acceptance standard of <1 wt-% Cl which may also limit the utilisation of SRF in this industry sector. The total capacity for co-combustion in the cement industry in Germany is assumed to be in the order of 2 Mt, which means this potential sink for SRF is already more or less exhausted (Schu 2007).

Table 1.19: Dedicated SRF plants in Germany (CFB: circulating fluidised bed)

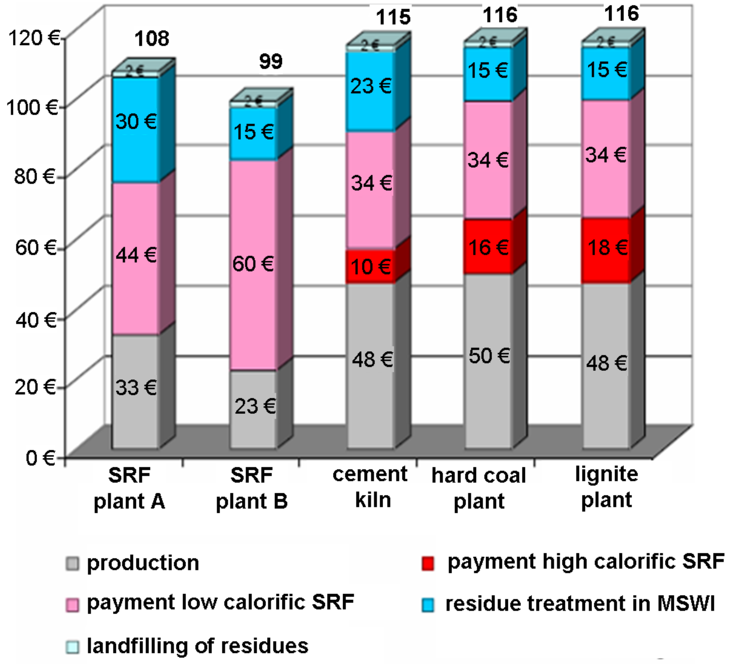
Location	Technology	Capacity in Mg/a	
		in operation	planned
Amsdorf	grate	60,000	
Andernach/Rasselstein			100,000
Aßlar	grate	15,000	
Bremen-Blumenthal	grate	60,000	
Degussa			
Erfurt-Ost	grate		64,000
Frankfurt			500,000
Großräschen/Freienhufen	grate		200,000
Hagenow			80,000
Heringen	grate		270,000
Hürth	grate		240,000
Meuselwitz-Licka	grate	50,000	
Minden Industriehafen	grate	35,000	
Neumünster	CFB	150,000	
Premnitz (former Polyamid 2000 AG)	CFB	100,000	
Premnitz	grate / CFB		130,000
Rheinberg	grate		300,000
Rostock	grate		136,000
Rüdersdorf	grate		200,000
Rudolstadt-Schwarza	grate		14,000
Schwedt	CFB		200,000
Sottrum			150,000
Stavenhagen	grate		90,000
Witzenhausen			250,000
Sum		**470,000**	**2,924,000**

As an alternative there are a number of dedicated combustion plants for heat and/or power in operation and a much higher number of such plants is in planning. An overview of the situation in 2006 is shown in Table 1.19. These plants are either using grate or circulating fluidised bed technology and are equipped with a flue-gas cleaning system which allows the compliance with the 17. BImSchV, the German regulation for air emissions from waste incineration plants.

The table shows that approximately 2.9 Mt of capacity were in the design or construction phase, but only 7 plants, with a total throughput of 0.47 MT, were in operation in 2006. How many of these projects will be realised is hard to predict at present. It can be assumed that some projects are rather theoretical ones and are only published by companies to give them a better standing in the negotiations with the respective power supplier. For example, a large project was announced by a copper refinery in Hamburg to take (initially) 750,000 t/y of SRF, but was cancelled after the copper refinery was given a good contract for power from the local energy supplier.

The main actual barrier for a full exploitation of waste for SRF production is the cost situation. Full SRF costs have to include a significant extra payment to the customer depending on the type of thermal process. A survey published by Prognos lists total costs for production, extra payments for utilisation and additional costs for residue treatment or disposal for the year 2006 [Alwast 2007]. The study compared the utilisation of SRF especially produced for utilisation in different plants. The results of the study are shown in Figure 1.15.

Figure 1.15: Costs of production and utilisation of 1 Mg of SRF in 2006 (adapted from [Alwast 2007])



According to these figures the total cost of SRF utilisation covers a range between 100 and 120 €/Mg, depending on the utilisation scenario.

Conclusions and outlook

Evaluating the actual situation in the waste-to-energy area in Germany, it can be concluded that the legal framework is in principle in line with the regulations on the EU level. In terms of landfilling Germany took stronger action than laid down in the EU Landfill Directive. This measure was a strong driver for waste incineration and at the moment the amount of residual MSW can be easily taken care of in existing waste incineration plants. Approximately 50% of these plants already comply with the energy performance threshold set in the revised EU Waste Framework Directive.

Further efforts for waste minimisation and improved recovery of special waste fractions will reduce the MSW that has to be incinerated in future. Extension of anaerobic digestion for separately collected organic household waste could play a major role here. This may not necessarily mean a surplus in waste incineration capacity since old plants can be taken out of operation.

Furthermore this free capacity may be used for commercial and light industrial waste treatment. In this sector there is a lack of reliable data describing the current situation and even less for future expectations.

The actual oversupply of SRF is assumed to range between 1 and 2 Mt and if co-combustion capacity is not increased and/or extension of dedicated plants does not progress, there may be increasing problems with the disposal of SRF over the next few years.

SRF will have a brighter future if the quality control of production can be improved. An extension of the number of dedicated SRF plants, preferentially for CHP, needs both successful planning applications and a long-term calculable and stable market.

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Italy

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The waste resource in Italy

Current national policy and regulations on waste in Italy

In 2006 the Italian Parliament replaced the previous regulation on waste - **based on the D.lgs. 22/1997** [2] which took in the Directives 91/156/CE_[3] , 91/689/CE [4] and 94/62/CE_[5] - by adopting the **D.Lgs. n.152/2006** [6], which was integrated in **D.Lgs. n. 4/ 2008** [7] two years later. The general regulations were based on criteria of caution, prevention, responsibility and co-operation between all subjects at national and local level (i.e.: private and public producers; private and public administrations involved in waste management and treatment) and with the aim of ensuring that waste management (recovery, recycling, discharge) can offer an adequate protection of people and environment and meet with criteria of effectiveness, efficiency, transparency other than economical. With regard to these aims, priority criteria are considered to be:

- development of clean technologies;
- use of commercial products with no or minimum impact on waste production;
- improvement of technologies able to eliminate/reduce pollutants in waste;
- prevention of waste production;
- stimulation, on a national and local level, of a more active role of public administrations for waste control, recycling and recovering of both material and thermal and electrical energy.

The current national legislation on waste seems to be heading in the direction now proposed by the revised EU Waste Framework Directive.

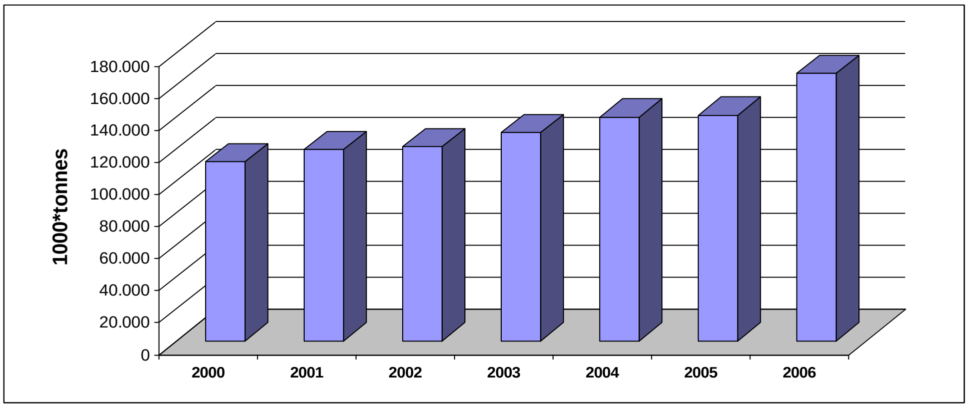
Regarding separately collected Municipal Solid Waste (MSW), the **D.Lgs. n.152/2006** [6] fixed targets (percentage of the total waste produced) to be reached in Italy by the end of December 2006 (almost 35%), December 2008 (almost 45%) and December 2012 (65%). A national regulation on the general structure and activity of local systems for a separate collection of MSW was then introduced in Italy in 2008 through the specific **DM 8 April 2008** [8] of the Italian Ministry of the Environment. Due to a lack of legislation for some aspects (mainly methodological aspects related to the quantitative assessment of system performance), the separate collection of MSW is currently regulated in Italy by local regulations set out on a regional basis. Industrial wastes generated by healthcare activities are currently classified and regulated through a specific legislative rule, the **DPR n. 254/2003** [9] not amended by the_**D.Lgs. n.152/2006_**[6]. The European Directives 2006/66/CE [10] and 2006/21/CE [11] have been incorporated in the Italian regulation in 2008 by the **Dlgs. n.188/2008** [12] and the **D.Lgs. n. 117/2008** [13] respectively. While the European Directives 2000/76/CE [14] (on waste incineration) and 1999/31/CE [15] (on waste landfilling) have been adopted as national rules through the **D.Lgs. n. 133/2005** [16] and the_**D.Lgs. n.36/2003** [17], respectively. The above mentioned **D.Lgs. n.152/2006** [6] also define regulations on waste planning, monitoring and reporting actions, which local and national authorities have to adhere to. Any company (private or not) involved in the activities of collection, transport, recovery, discharge of waste as hazardous waste producers, or public administration involved in the municipal waste management, are requested to qualify (CER code) and quantify, annually, the waste produced/managed according to the MUD (*Modello Unico di Dichiarazione ambientale*) reporting system as introduced by the **D.Lgs. n. 70/1994** [18]. On this matter, the **D.Lgs. n. 4/ 2008** [7] amended the **D.Lgs. n.152/2006,** [6] which allow all producers of non-hazardous industrial waste to qualify and quantify annually their waste through the MUD reporting system. A national *Waste Report* is published annually by the Italian Agency for the protection of the Environment (APAT, now named ISPRA), which offers an overview of the whole waste production and management in Italy; details of local waste production and management is also given by the reporting activity of regional authorities.

The latter reported figures of waste production and management in Italy were based only on the certified data published by ISPRA, mainly from the **2008 *Waste Report*** [19] which makes available up-to-date data 2007 and 2006 for municipal and industrial waste respectively. To derive some of the waste trends these data were integrated with data coming from the previous *Waste Reports* [20,21,22].

Waste production and management in Italy

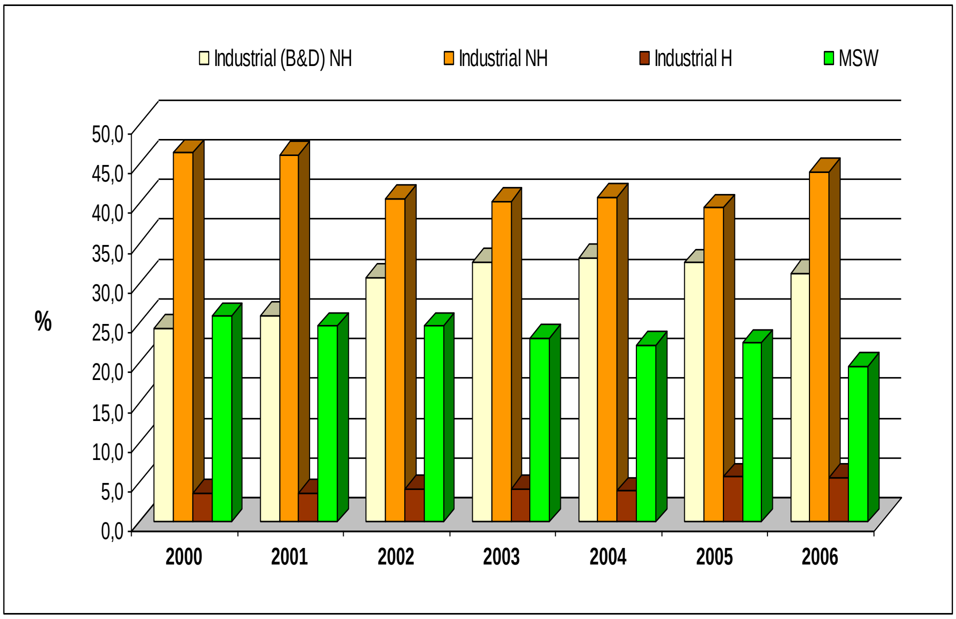
In the year 2006 a total production of waste of about 167 Mt was reached in Italy, corresponding to an increment of about 49% with respect to the year 2000 (Figure 1.16). Data were used to 2006 only, due to a current unavailability of data on industrial waste production for the year 2007.

Figure 1.16: Waste production in Italy (trend 2000-2006): total annual amount (1,000*tonnes) produced on a national basis (data source: ISPRA)



An increasing contribution of the industrial non-hazardous waste from building & demolition activities and the whole hazardous waste to total waste production is shown in Figure 1.17. The production of municipal solid waste seems to follow a decreasing trend from 2000 to 2006.

Figure 1.17: Waste production in Italy (trend 2000-2006): percentage contribution (%) of MSW waste, industrial hazardous (H) and non-hazardous (NH) waste, non-hazardous (NH) from building & demolition activities to the total production of waste on a national basis (data source: ISPRA)

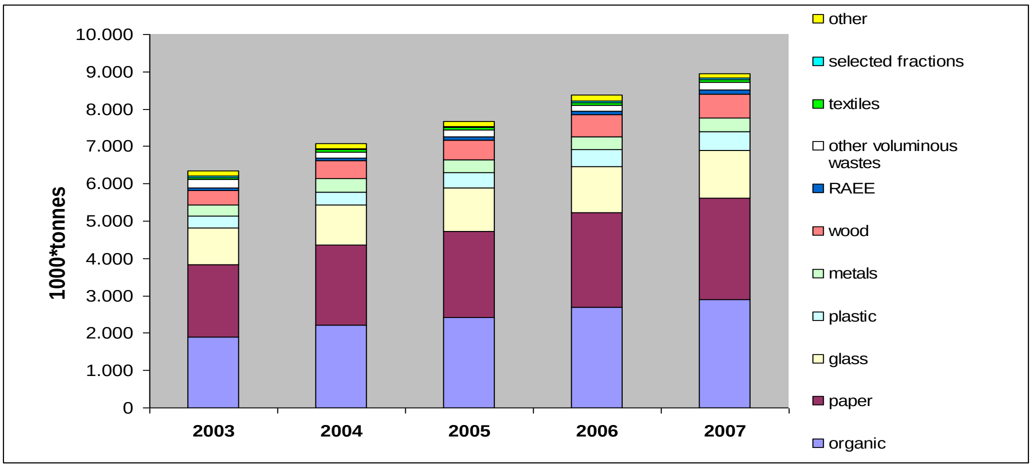


The total production of ***Municipal Solid Waste (MSW)*** in Italy increased during the period 1999-2007 from about 23.8 Mt in 1999 to about 32.5 Mt in 2007, with the main contribution of Northern regions (more industrialised area), even if an increase in production in Southern regions from 2001 can be observed. The highest values of per inhabitant production occurred in Central Italy (reaching 650 kg/cap/y in 2007) with respect to a national average value of 546 kg/cap/y.

The ***separately collected MSW*** accounted for a total of about 8.9 Mt in 2007 (3.6 Mt in 2003), about 27.5 % of the total MSW produced. This value was lower than that expected by the national regulation (35%). By analysing data per macro area, a differential and quite consistent degree of implementation in Italy of separately collected MSW can be observed: only in Northern Italy has the Government target been achieved (since 2004). Central and Southern Italy are still under target: of the total 8.9 Mt of separately collected MSW in 2007, only 1.2 and 1.5 Mt came from Southern and Central Italy, respectively, the main contribution (6.2 Mt) came from the northern regions.

From a qualitative point of view (Figure 1.18), the share of biodegradable fraction (organic+ paper+wood+textiles) of the total separately collected MSW in 2007 was about 71%, followed by glass (14.5%), plastic (5.6%), metals (4%), voluminous wastes (2.2%), RAEE (1.3%) and other fractions (1.7%).

Figure 1.18: Separately collected MSW in Italy (trend 2003-2007): total amount (1000*tonnes) of waste collected per merceological fraction (data source: ISPRA)



The amount of ***industrial (hazardous, non-hazardous) waste*** increased by about 63% from 2000 to 2006 (Figure 1.19), reaching a total amount of 134.7 Mts in 2006, of which 43.4 is non-hazardous wastes, 52.1 is non-hazardous wastes from building and demolition activities and 9.2 is hazardous wastes. Hazardous wastes were mainly produced in Northern (about 5.1 Million tonnes) and Central (about 3.3 Mt) Italy. With regard to 2006 data, note that the legislative regulations introduced in Italy by the **D.Lgs. n.152/2006** [6] allowed all producers of non-hazardous industrial waste to qualify and quantify annually their waste production through the MUD reporting system (a rule now amended by the **D.Lgs. n. 4/ 2008** [7]). This temporary change in regulation may have affected the real 2006 figure of industrial waste production. The percentage contribution of different economical sectors on the hazardous and non-hazardous waste production (year 2006) is shown in Figure 1.20.

Figure 1.19: Trend 2000-2006 of industrial waste production in Italy (1,000*tonnes) (Data source: ISPRA)

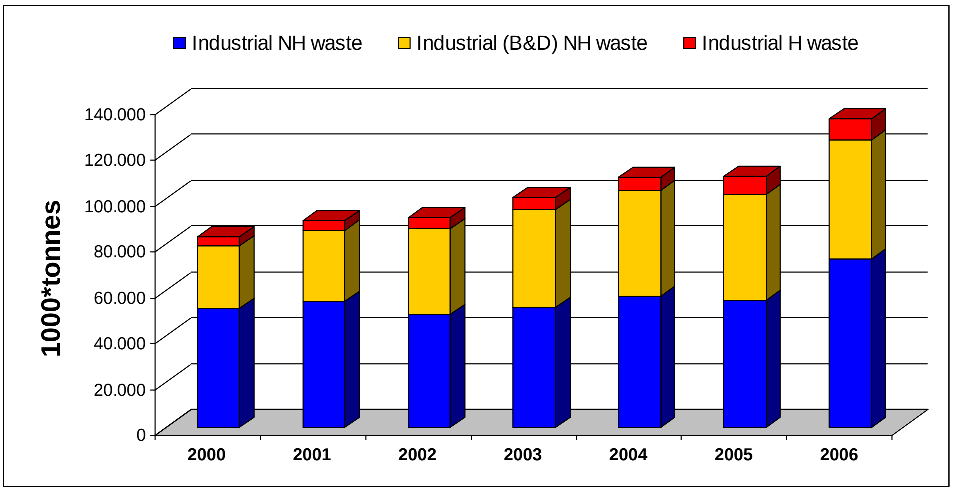
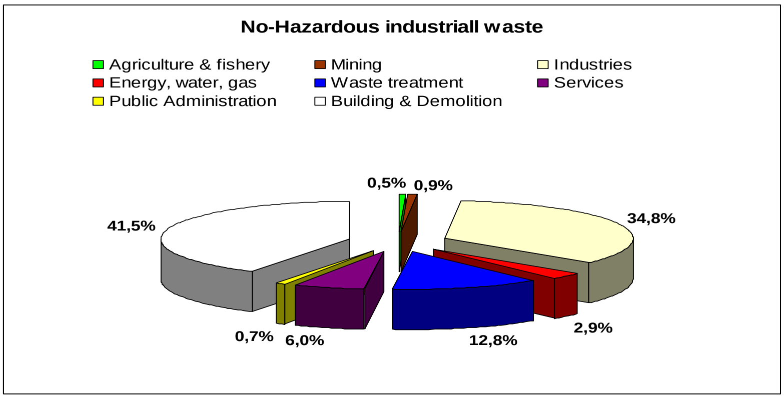
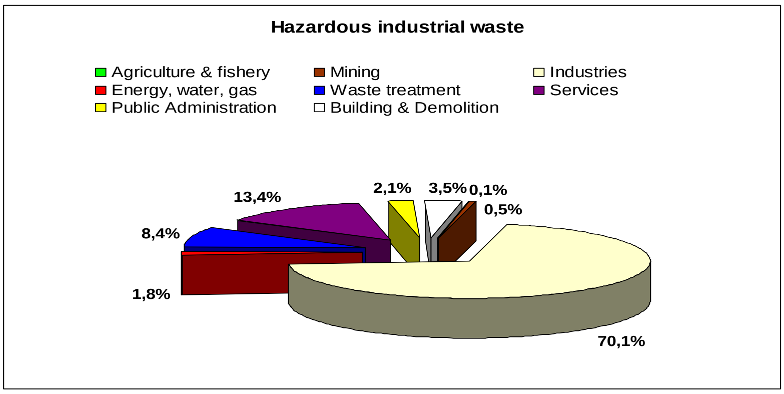


Figure 1.20: Percentage contribution of Italian economic sectors to the non-hazardous and hazardous industrial waste production (year 2006) (data source: ISPRA)



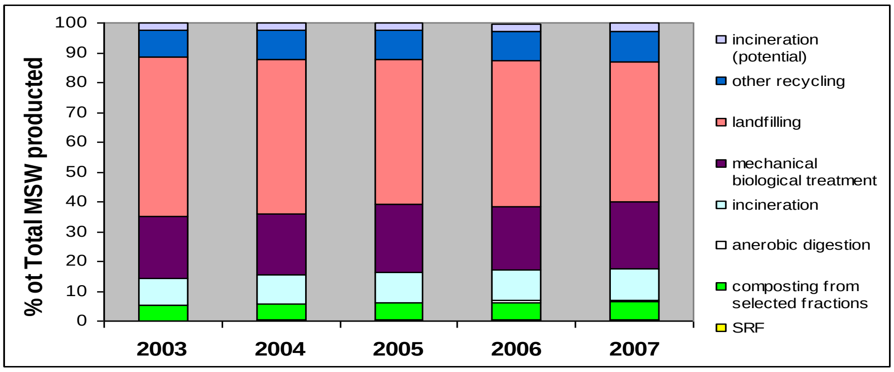


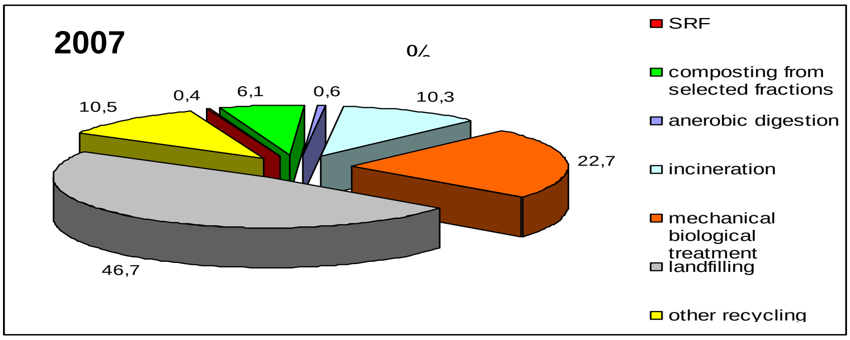
As shown in Figure 1.21, landfilling of waste and mechanical-biological treatments are the main ways for the management of MSW, their share of total MSW produced ranging from 74.6% (2003) to 69.4% (2007).

About 10% MSW annually produced goes to incineration (excluding the potential incineration of 2.4-2.6% of waste stored annually, most of which comes from the well-publicised issues with the waste collection the Naples area). Composting increased from 5.1% in 2003 to 6.1% in 2006) whereas 9 -10% of total MSW is submitted to recovery/recycling.

The amount of SRF (Solid Recovered Fuel) produced from MSW is low, ranging from 0.1% (2003) to 0.4% (2007).

Figure 1.21: MSW management in Italy: percentage contribution of different modalities of management. Trend 2003-2007 and situation in the year 2007 (data source: ISPRA)





A total amount of about 8.8 Mt of MSW (2007 data) was managed in the 133 *mechanical & biological treatment plants* (117 working in 2007) operating in Italy (9.6 Mt including waste of other origin).

The 276 *composting*, plants, (237 working in 2007) treated about 3.2 Mt of which MSW comprised 74.5% of the total input, followed by sewage sludge (15.7%) and material of different origin (9.9%). The total plant output production was 1.3 Mt/year, of which 15.3% was classed as green compost and 60.8% as mixed compost.

SFR production from waste in 2007 (41 working plants with a total authorized capacity of 6.5 Million tonnes/year) was 4.3 Mt.

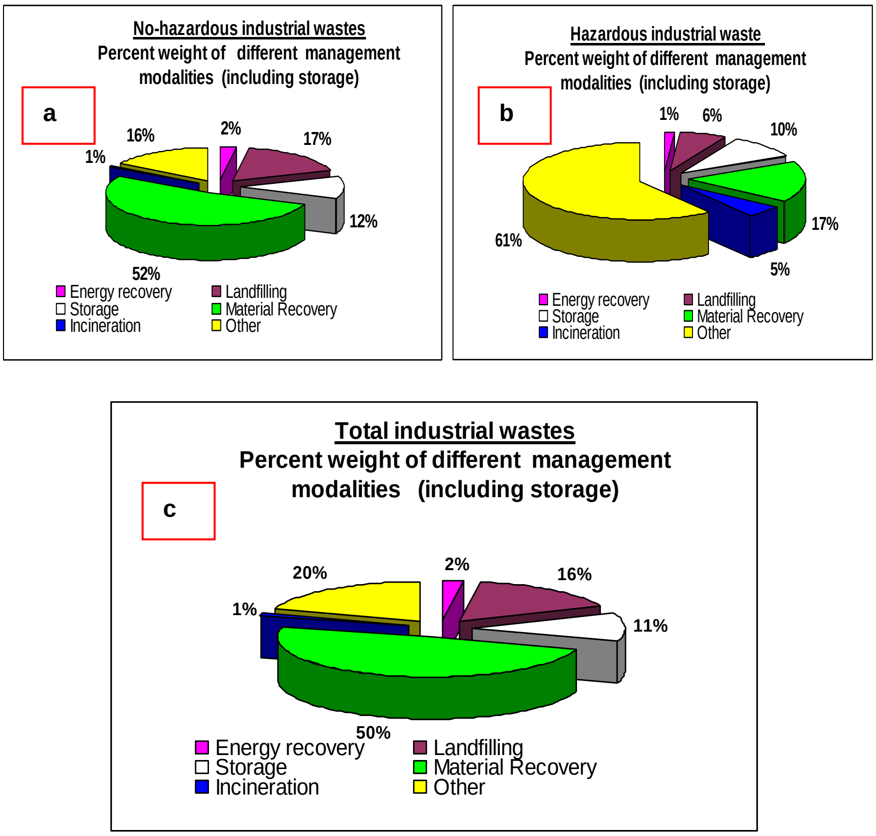
Incineration 2007 - 47 plants, with a total capacity of 4.48 Mt of waste (MSW: 2.98 Mt; dry fraction of CER 191212: 0.32 Mt; SRF: 0.66 Mt; industrial waste: 0.53 Mt, of which 0.07 Mt hazardous waste).

Landfill of waste 2007 - 269 plants, for about the 51.9% (16.9 Mt) of the total yearly production of MSW. Furthermore 0.41 Mt of sewage sludge and 1.8 Mt of industrial waste, for a total of 20.1 Mts were disposed in the same facilities.

The total amount of **industrial waste** produced in 2006 was 134 Mt. 117 Mt (91.6% non-hazardous and 8,4 % hazardous waste) were managed in the Northern regions of Italy (69.4 Mt, against 22.5 and 25.1 Mt treated in Central and Southern Italy, respectively).

Figures 1.22 a and b show that the material recovery was the main activity in the management of industrial waste (about half of the 117 Mt of industrial waste treated in 2006 (Figure 1.22 c).

Figure 1.22: Industrial waste management in Italy (year 2006): percentage incidence of different treatment modalities on the individual management of non-hazardous and hazardous industrial waste and on the whole management of industrial waste (data source: ISPRA)



Landfilling, storage (including temporary storage) and other treatments such as physical-chemical and biological treatment, were the main mode for the treatment of the residual fraction of industrial wastes (Figure 1.22 c), more significant than incineration and energy recovery. Industrial waste incinerated in dedicated or MSW plants or burned in co-combustion industrial plants amounted to some 3% of the total treated in 2006 (3.9 Mt). In detail, a total amount of 0.5 Mt of industrial wastes were treated in the 66 dedicated plants in operation in 2006, 0.6 Mt in plants also treating MSW, and about 2.8 Mt were co-combusted, the latter being composed of over the 95% of non-hazardous waste. Co-combustion was mainly used for electricity generation (32%), wood & paper industry (27%), treatment plants (14%), cement kilns (7%) and pottery industry (6%). A total number of 650 plants were in operation in 2006 of which 109 supported under the Green Certificate System, the 'support scheme' activated in Italy for the promotion of renewable energy.

Based on data published by ISPRA in the *2008 Waste Report*, a preliminary and rough assessment (complete information is not available for all plants) of a total energy recovery of abut 0,42 MkWe (2.696 MkWh) can be estimated for waste treated in co-incineration/co-combustion in the industrial plants in operation in 2006.

Renewable energy in Italy

Renewable energy production

The following figures showing renewable energy production in Italy were based on certified data produced by GSE, the Public Manager for the Electricity Services, as presented in a statistical report published in 2009 [28] and in the last periodical reporting on the Green Certificate System in Italy [29]. Furthermore we referred to data published on the web site of the National Authority for Electric Energy and Gas [30].

Gross electricity production (GWh/year) during the period 1997-2007 is reported in Figure 1.23.

The share of renewable gross energy is under 20% of the total (Figure 1.24). Renewable gross energy production was about 46,450 GWh in 1997, increased to about 55,000 GWh in 2001 and 2004, while the last available data (2007) was characterized by a lower result (49,411 GWh), corresponding to a 15.7% of the total gross energy production in the same year (about 314,000 GWh).

Figure 1.23: Total thermal, renewable (all sources) and hydro (pumping only) gross energy production (GWh) in Italy. Trend 1997-2007 (data source:GSE)

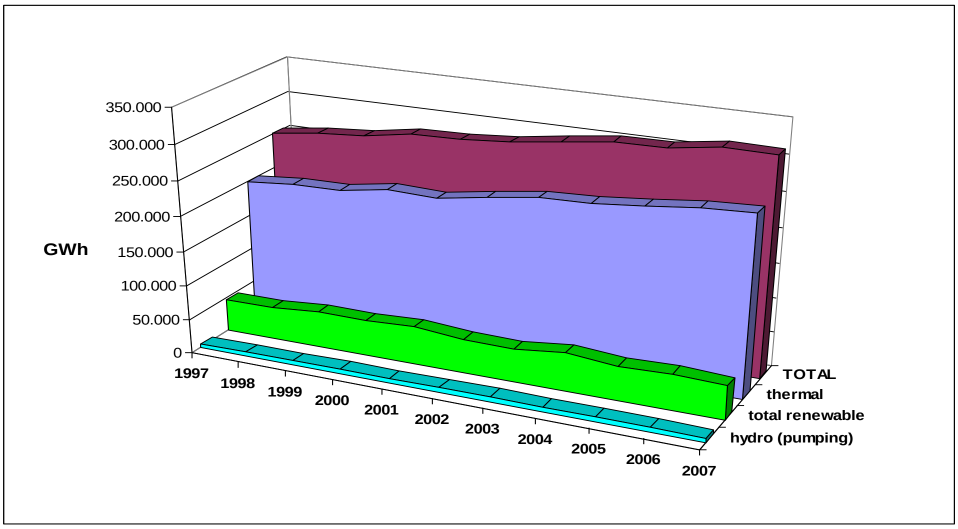
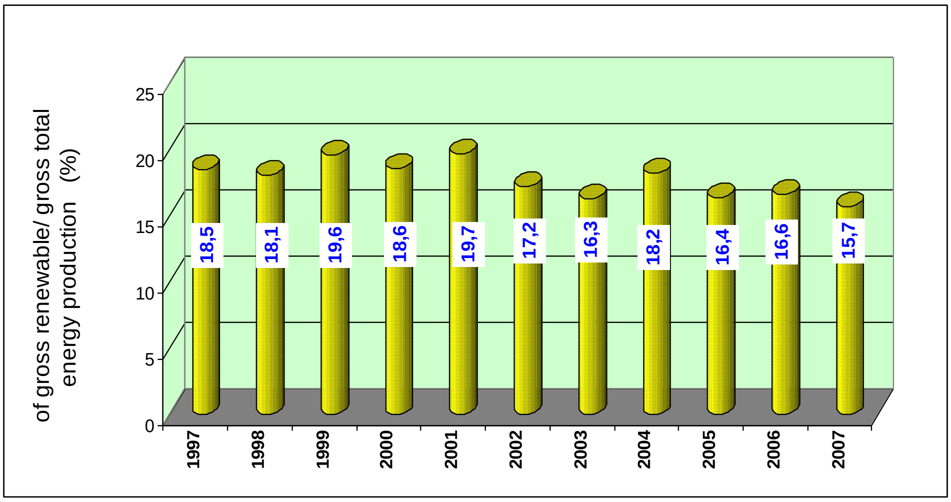


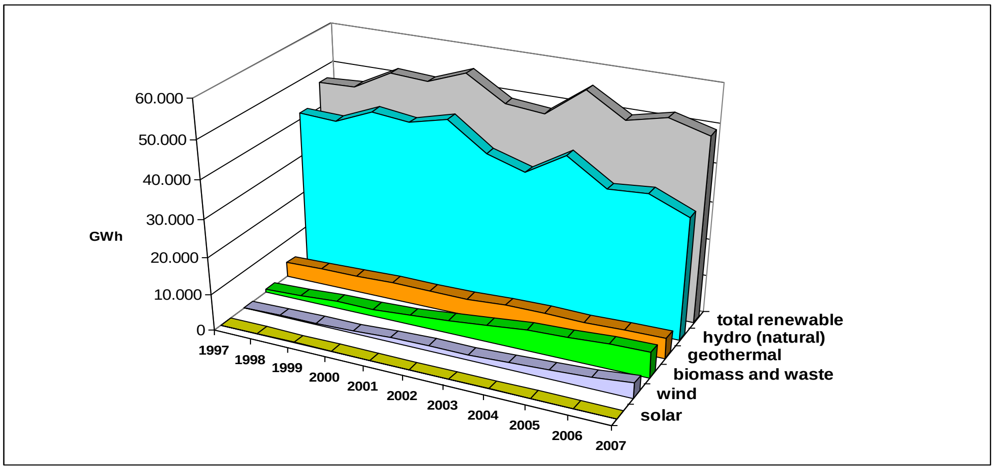
Figure 1.24: Percentage share of gross renewable production on gross total energy production in Italy. Trend 1997-2007 (data source: GSE)



Considering the Italian renewable gross production in the period (997-2007 (Figure 1.25), the following remarks can be drawn:

- The dominant role of the natural hydro sector, accounting for from 89% (1997) to 66% of the total renewable production.
- Asteady contribution of the geothermal source, which shows an increase from about 3,900 GWh (1997) to about 5,570 GWh (2007).
- Alow incidence of solar renewable energy: the related gross production increased from 13.7 GWh (1997) to 39.0 GWh (2007).
- Asignificant level, increasing with time, of the electricity generated by wind and biomass and waste sources. The wind gross energy accounted for about 118 GWh in 1997 and reached about 4,034 GWh in 2007. The gross energy production obtained from the whole biomass and waste source increased from about 820 GWh (1997) to about 6,950 GWh (2007).

Figure 1.25: Total and per source (all gross) renewable energy production (GWh) in Italy. Trend 1997-2007 (data source: GSE)



Details about of the gross production per renewable source (2003-2007), are reported in Figure 1.26.

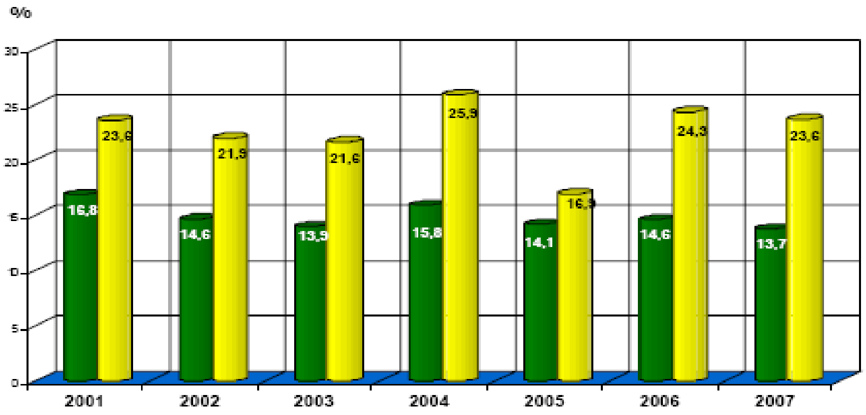
Figure 1.26: Total and per source gross renewable energy production (GWh) in Italy: detailed trend 2003-2007 (data source GSE)

Gross production of energy from renewable plants in Italy Trend 2003- 2007 (GWh)					
	2003	**2004**	**2005**	**2006**	**2007**
Hydro (total)	36.670	42.338	36.067	36.994	32.815
0-1 MW plants	*1.455*	*1.731*	*1.526*	*1.521*	*1.416*
1-10 MW plants	*5.732*	*7.218*	*6.091*	*6.354*	*5.684*
>10 MW plants	*29.483*	*33.479*	*28.451*	*29.119*	*25.715*
Wind (total)	1.458	1.847	2.343	2.971	4.034
Solar (total)	23	27	31	35	39
Gethermal (total)	5.341	5.437	5.325	5.527	5.569
Biomass & Waste (total)	**4.493**	**5.637**	**6.155**	**6.745**	**6.954**
Total Solid	**3.460**	**4.467**	**4.957**	**5.408**	**5.506**
MSW	*1.812*	*2.277*	*2.620*	*2.917*	*3.025*
crops & other agro-industrial wastes	*1.648*	*2.190*	*2.337*	*2.492*	*2.482*
Total Biogas	**1.033**	**1.170**	**1.198**	**1.336**	**1.447**
waste landfilling	*911*	*1.038*	*1.052*	*1.177*	*1.247*
sewage sludge	*3*	*1*	*3*	*3*	*9*
animal manure	*13*	*19*	*26*	*45*	*53*
crops & other agro-industrial wastes	*107*	*112*	*117*	*112*	*138*
Renewable (total)	**47984**	**55286**	**49920**	**52272**	**49411**

With regard to the profile of gross renewable energy production for the last reference year (2007) data reported in Figure 1.26 indicate that about 14% is from the biomass and waste renewable sources with contributions of about 43.5% coming from MSW incineration. About 35.7% can be ascribed to solid biomass from agriculture and other agro-industrial activities, while biogas from waste landfill contributes for about 17.9%.

Figure 1.27 shows data referred to the internal gross consumption of electricity. The reported data refer to the internal gross production of renewable energy only (green bar) or the whole gross production including renewable imported from abroad.

Figure 1.27: Trend 2001-2007 of the renewable gross energy production with respect (%) to the internal gross consumption of electric energy (figure extracted and modified from ref. 28)



Green bar:
internal gross renewable production / internal gross energy consumption
Yellow bar:
internal gross renewable production + foreign gross renewable production / internal gross energy consumption

Current national policy on renewable energy, supporting systems and perspectives

The strategies and criteria to reduce greenhouse gas emissions and comply with the Kyoto Protocol mentioned above - control of energy consumption, promotion and support for the use of energy from renewable sources, promotion of energy savings and energy efficiency - were substantially adopted in Italy by the so-called **CIP-6 Resolution** [31] adopted in 1992 by the Italian Inter ministerial Committee on Prices (CIP). Within this, a conventional mechanism aimed to promote and support electricity and co-generation plants fed with renewable sources (solar, wind, hydro, geothermal, waves & tides, biomass) was introduced. Under this mechanism (still in force) GSE - the publicly-owned company promoting and supporting renewable energy sources (RES) in Italy - purchases the electricity generated by these plants at an assured rate and trades it into the energy market. For plants qualified under the CIP 6 mechanism, the trend (from 2008 to all the residual years of validity of the CIP 6 support) regarding the total and per source number of plant/year are reported in Figure 1.28; and the expected per year production of renewable energy (total and per source) are reported in Figure 1.29.

Figure 1.28: Total and per source number of plant/year supported under the CIP 6 mechanism. Trend from 2008 to all the residual years of validity of the CIP 6 support (data source: GSE)

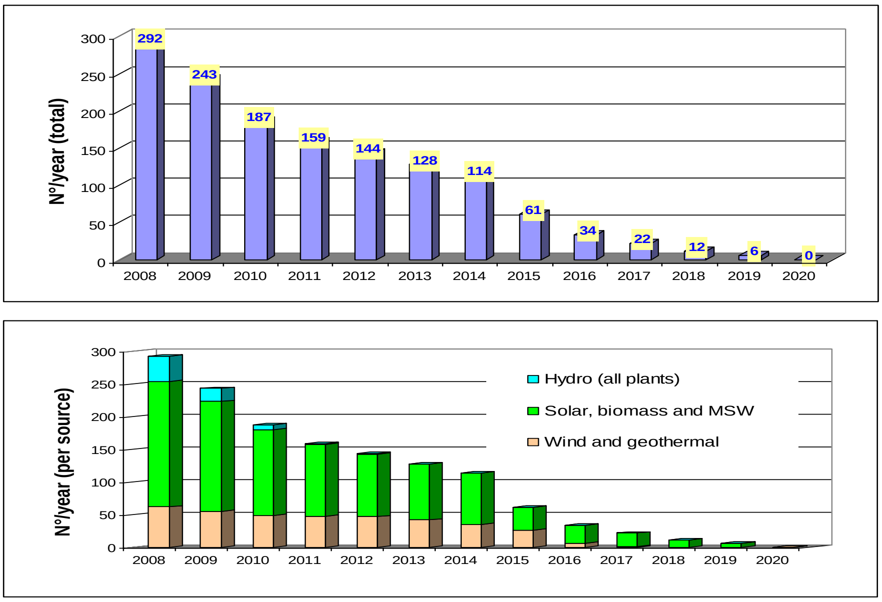
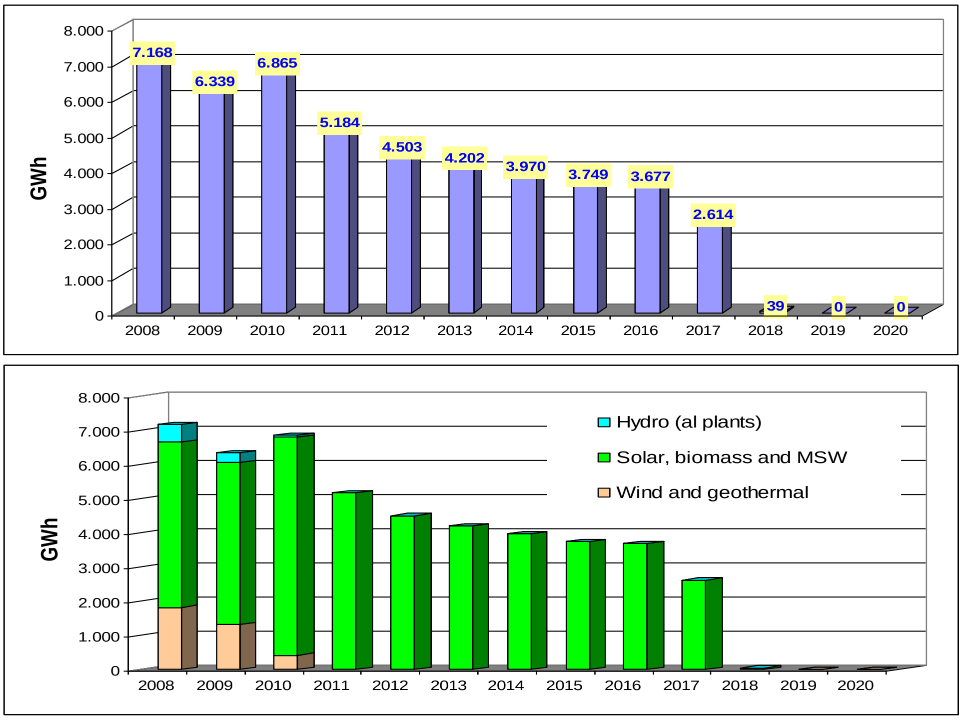
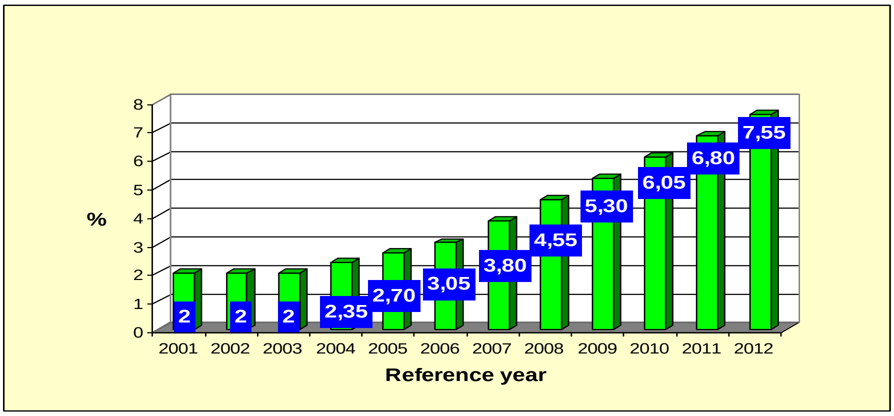


Figure 1.29: Total and per source expected per year production of renewable energy (GWh) of plants supported under the CIP 6 mechanism. Trend from 2008 to all the residual years of validity of the CIP 6 support (data source: GSE)



According to the European Directive 96/92/CE [33,] the **D.Lgs 79/99** [32] forced producers and importers of non renewable electricity energy to enter, from 2001 on, a minimum share of energy generated by renewable plants in the national energy network, introducing economical supporting mechanisms to promote such a requirement. The current shares of renewable energy to enter the national energy network are reported in Figure 1.30, for the time period 2007-2012.

Figure 1.30: Minimum share per year (2001-2012) of energy generated by renewable plants to enter on the national energy system according to D.Lgs 79/99 (data source: GSE)



The target share of energy generated by renewable plants can be reached through a direct production of renewable energy or by buying the corresponding amount of obligations (Green Certificate) from other qualified producers of renewable energy. This supporting mechanism was confirmed and detailed by later regulations, the **D.Lgs n. 387/2003** [34], taking in the national legislation the European Directive 2001/77/EC [23], the **DM 24/10/2005_** [35] of the Italian Ministry of Economic Development, the **Law n. 244/2007_** [36] for assessing the national economic budget for the years 2008 and the **DM 18/12/2008_** [37] of the Italian Ministry of Economic Development.

Another supporting mechanism - the all-inclusive feed-in tariff - was also made available by the **DM 18 dic 2008_** [37] for plants meeting specific requirements, as later discussed.

To benefit from the *all-inclusive feed-in tariff* or the Green Certificate Supporting Systems, plants should obtain the qualification of RES-E ('IAFR') released by GSE, according to specific procedures (**DM 21/12/ 2007** [38] of the Italian Ministry of Economic Development) which allow calculation of the amount of electricity energy generated that meets the renewable criteria. Note that regulations introduced by the above mentioned D.Lgs n. 387/2003 [34] changed the previous definition of renewable energy sources, considering as renewable the energy from non-fossil sources (wind, solar, geothermal, wave and tidal, hydro, biomass, landfill gas, biogas and gas from waste water treatment), including the biodegradable fraction of products, wastes and residues (both from plants and animals) from agricultural activities, forestry management and related industrial activities, as the biodegradable fraction of municipal and industrial wastes.

Hybrid plants (fed with both renewable and non–renewable fuels, including waste) can be supported for renewable source only, after qualification by GSE.

The on demand all-inclusive feed-in tariff scheme is applicable to plant upgraded/repowered, total or partial renovation, reactivation or new plants (IAFR qualified), only if it meets the following requirements:

a) use of RES (excluding the solar source);
b) nominal power not exceeding 1 MW (200 kW for on-shore wind plants);
c) commissioned after 31 December 2007.

This scheme represents an alternative to the Green Certificate; the flat rates (Eurocent/kWh) fixed by the **Law n. 244/2007** [35] depend on the source of renewable energy.

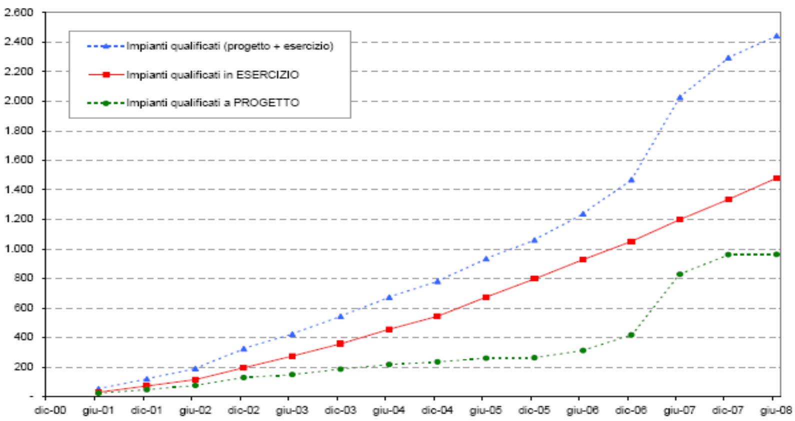
The Green Certificate scheme applies to larger plants (>1 MW). Based on regulations introduced by the Law n. 244/2007 [36] a Green Certificate size of 1 MWh from January 01, 2008 is currently in force. The period of time covered by the Green Certificate System is 15 years for plants, including hybrid, operating after 12/31/2007. It becomes 12 years for plants operating before 12/31/2007 and 8 years for the non renewable energy from co-generation plants and for the non renewable energy from plants (even hybrid) treating not-biodegradable wastes which comply with the CV requisition.

For plants starting after 12/31/2007 with an annual average nominal power >1 MW (>0.2 MW for wind plants), GSE releases Green Certificates calculated by multiplying the net energy production of the plant for a specific coefficient. The economic value of the supporting scheme (Green Certificate) is basically defined by the energy market according to the offer/bid low. Before the Law n. 244/2007 [36] came into force, the reference bid price was calculated by GSE as the difference between the purchase price of energy from CIP 6 plants and the revenue obtained by selling the electricity on the energy market.

According to the new method introduced by n. 244/2007, [6] the 2008 bid reference price was set at 112.88 €/MWh, which results from the difference between the reference value of 180.00 €/MWh; and the 2007 annual average market price of electricity (67.12 €/MWh), as fixed by the National Authority for Electric Energy and Gas at the end of each year.

Figure 1.31 shows the trend of plants admitted to the Green Certificate support system in the period 2000-1008.

Figure 1.31: Number of plants qualified by GSE as IAFR energy plant and admitted to the Green Certificate Supporting System from 2000 to 2008: total number of IAFR plants, number of certificated operating plants or certificated but not operating (planned) plants per year (Figure extracted and modified from ref 29)



Blue line: all plants (expected)
Red line: operating plants (actual)
Green line: planned plants

An overview of the current status of the Green Certificate mechanism in Italy is presented in the following figures. In particular Figure 1.32 reports the amount (GWh) and percentage of the renewable energy supported by the Green Certificate System on the total renewable energy produced in Italy in the year 2007.

Figure 1.33 reports the amount (GWh) the relative contribution of the specific source of renewable energy supported by the Green Certificate expected from IAFR qualified plants in operation at the end of June 2008.

Figure 1.32: Amount (GWh) and percentage share of renewable energy supported by the Green Certificate System on the total renewable energy produced in Italy in the year 2007 (data source: GSE)

	Energy gross production from all renewable plants in 2007 (GWh)	Renewable Energy supported by the Green Certificate System	
		GWh	% of Energy gross production
hydro	32.815	2.876	8,8
wind	5.569	866	15,5
biomass and waste	5.506	553	10,0
biogas	4.034	2.645	65,6
geothermal	1.447	716	4,9
solar	39	2	5,4
Total renewable sources	**49.411**	**7.658**	**15,5**

Figure 1.33: GWh of renewable energy in Italy supported by the Green Certificate expected from IAFR qualified operating plants at the end of June 2008 (data source: GSE)

Working renewable plants - Status at June 30, 2008			
	N° of plants	Nominal Power (MW)	Theorical productivity from qualified plants supported by Green Certificates (GWh)
hydro	873	5.032	5.058
wind	182	2.094	4.980
biomass	76	1.456	2.416
biogas	255	267	1.618
geothermal	13	440	972
solar	47	5	6
waste	35	909	824
Total renewable sources	**1.481**	**10.024**	**15.873**

The Guarantee of Origin (GO) certificate for electricity generated by RES-E or high-efficiency co-generation plants (released by GSE), is an on-demand certificate which does not give economic support to producers but allows them to prove that all or a share of their energy is produced from renewable sources, according to Italian national regulation (**D.Lgs n. 387/2003** [34]).

In the case of hybrid plants, the Guarantee of Origin refers only to the electricity generated by the renewable source, including the biodegradable fraction of the waste.

In 2007, GSE released the Guarantee of Origin for 3,062 GWh or renewable energy. The number of plants complying with GO rules are shown in Figure 1.34.

Figure 1.34: Renewable energy plants identified by GSE as meeting requirements for the Guarantee of Origin at the end of June 2008 (data source: GSE)

Source	GO qualified plants (n°)	Nominal Power (MW)	Expected energy production (GWh)
Hydro	78	1.476	4.177
Biomass	3	30	187
Winf	2	40	85
Biogas	5	7	39
Total	**88**	**1.552**	**4.488**

A preliminary assessment of the maximum theoretical potential level of renewable energy production in Italy to 2020, expressed in terms of primary energy replaced, can be derived by the Position Paper [39] of the Italian Government. This Paper takes into account many aspects, such as the potential, availability and possible alternative use of each renewable source as well as the environmental constrains related to landscape impact, the socio-economic sustainability of these policies, including incentives, and the effects of the promotion of renewable energy on the electricity market prices for consumers and industry. It also takes into account the need for investments in the transmission grid, to accommodate for small scale distributed power generation resources that need to be interconnected like an internet network and in the form of two-way interacting infrastructures.

Compared with 6.71 MTOE (Million Tons of Oil Equivalent) in 2005, the total maximum theoretical potential for renewable energy at 2020 could increase to 20.97 MTOE, of which 8.96 would be electricity, 11.40 heating and cooling and 0.61 biofuels.

As regards the 'biomass', a total potential at 2020 of 14.50 TWh for electricity (Figure 1.35) was estimated. In particular it was assumed that the potential energy coming from the exploitation of industrial waste could be 5 TWh/year, with an expected efficiency of 25%. For MSW, the biodegradable part is assumed to be the 40% of total, with a potential of 4TWh. For landfills, the expected 3.2 TWh includes the annual potential of 1.7 TWh from the exploitation of gas generated by anaerobic digestion, and 1.5 TWh from landfill gas, subject to an improvement in gas capture technologies and to a reduction of the waste treatment system. For dedicated energy crops, it is necessary to assume high levels of incentives. Total potential at 2020 would be 14.50 TWh, compared with 6.16 TWh of 2005.

Figure 1.35: Theoretical national potentials for the production of renewable energy at 2020. Details for Electricity (data source: ref 39)

	State of implementation 31 december 2005		Total potential energy available by 2020	
	Power (MW)	Energy (TWh)	Power (MW)	Energy (TWh)
Hydro power plants > 10MW	14.920	28,50	16.000	30,72
Hydro power plants < 10MW	2.405	7,50	4.200	12,43
TOTAL HYDRO SOURCE	**17.325**	**36,00**	**20.200**	**43,15**
Wind plants on-shore	1.718	2,35	10.000	18,40
Wind plants off-shore	0	0,00	2.000	4,20
TOTAL WIND SOURCE	**1.718**	**2,35**	**12.000**	**22,60**
Building integrated PV plants	27	0,03	7.500	9,00
Power PV plants	7	0,01	1.000	1,20
Solar thermodynamic	0	0,00	1.000	3,00
TOTAL SOLAR SOURCE	**34**	**0,04**	**9.500**	**13,20**
Traditional geothermic	711	5,32	1.000	7,48
New generation geothermic	0	0,00	300	2,24
TOTAL GEOTHERMIC SOURCE	**711**	**5,32**	**1.300**	**9,73**
Plants using biomass coming from crops and other agro-industry waste	389	2,34	769	5,00
Plants using biodegradable part RSU	527	2,62	800	4,00
Plants using landfill gas, sewage treatment plant gas and biogas	285	1,20	492	3,20
Plants using dedicated energy crops	0	0,00	354	2,30
TOTAL BIOMASS, LANDFILL GAS AND BIOLOGICAL PURIFICATION	**1.201**	**6,16**	**2.415**	**14,50**
Wave and tidal energy	0	0,00	800	1,00
TOTAL WAVE AND TIDAL ENERGY	**0,00**	**0,00**	**800**	**1,00**
TOTAL	**20.989**	**49,87**	**46.215**	**104,18**
TOTAL PRIMARY ENERGY REPLACED	**4,29 MTOE**		**8,96 MTOE**	

For heating/cooling (Figure 1.36) a total of 389,933 TJ, or 9.32 MTOE was assessed as potential from the biomass source, assuming that a 5% will be used in civil heating with an average efficiency of 50% and that 50% of the new power capacity is co-generative with an average yield of 70%.

Figure 1.36: Theoretical national potentials for the production of renewable energy at 2020. Details for heating & cooling and biofuels (data source ref 39)

	State of implementation 31 december 2005		Total potential energy available by 2020	
	Power (TJ)	Energy (MTOE)	Power (TJ)	Energy (MTOE)
Geothermal	8.916	0,21	40.193	0,96
TOTAL GEOTHERMAL SOURCE	**8.916**	**0,21**	**40.193**	**0,96**
Solar heating	1.300	0,03	47.000	1,12
TOTAL SOLAR SOURCE	**1.300**	**0,03**	**47.000**	**1,12**
Biomass for civil sector	57.820	1,38	233.333	5,57
Cogeneration (+district heating)	21.000	0,50	156.600	3,74
TOTAL BIOMASS	**78.820**	**1,88**	**389.933**	**9,32**
Biofuels	12.600	0,30	25.600	0,61
Biofuels for import			150.400	3,59
TOTAL BIOFUELS	**12.600**	**0,30**	**176.000**	**4,20**
TOTAL	101.636	2,4	653.127	15,6

With regard to biofuels (Figure 1.36), the Position Paper [39] accounted for a total internal potential of 25,600 TJ, or 0.61 MTOE, assuming a consumption of 40 Mt by 2020 (based on the present growth rate of gas oil consumption for transportation) and that, in order to produce the 5.5 Mt necessary to cover the 10% of energy from biofuels (assuming 2nd generation biofuels are introduced), it would be necessary to cover an agricultural area of 5 Mha, equal to 16.7% of the area of the country and about 60% of the cropped arable land.

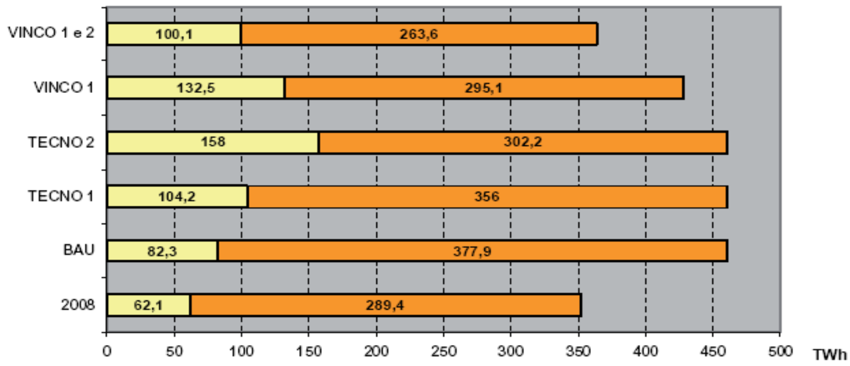
Considering that Italy could produce at most 800,000 - 1,000,000 tons a year, using an agricultural area of approximately 600,000 hectares, instead of the current 260,000 (equivalent to 25,600 Tj or 0.61 MTOE), resorting to import is considered unavoidable to reach the above mentioned target of 10% of fuel consumption.

As pointed out in a report recently presented by GSE to the Italian Parliament,[40] the energy market seems to be currently interested in the electrical energy generation from renewable sources. This trend is expected to continue in the near term, even if influenced by the future national and European choices on energy and environmental policy. This is because of the capability of the Italian government and the Italian energy industrial sector to plan, support and promote technological development and innovation in the field of renewable energy and to cover the need for annual investment to develop new renewable plants. It was estimated[40] that the sustainable European climate and energy policy (the so called 'Environment-Energy 20-20') could result in a business and occupational opportunity for Italy by 2020, more or less consistent with the capacity to stimulate and economically support internal development and implementation of renewable technologies in Italy, rather than importing renewable energy.

The report mentioned above[40] points out that Italy, within the Law n. 244/2007[36] enhances, for the time period 2007-2012, the minimum share of the electrical energy derived from renewable sources that each year has to be generated within the national energy system, from the value of 0.35% fixed by the D.Lgs 387/2003[34] to 0.75%. Furthermore, Italy has declared annual national targets for the period to 2015 to achieve a minimum level of 25% of internal gross consumption of electrical energy from renewable energy. The EU Renewable Energy Directive, (RED) assigns a share of 17% of the gross total internal consumption of energy (electricity, heat, fuels for transport) used in 2020 should be from renewable sources (including 10% of transport fuels as biofuels) and a reduction in greenhouse gas emission of 14% (with respect to 2005) in Italy.

This means that a share of 25-30% of renewable energy on internal electrical energy consumption has to be achieved in Italy by 2020, depending on the target of GHG reduction (25% or 30%). An additional amount of renewable energy can be added to its actual level depending on the medium-term potential of renewable production in Italy. Estimates of the renewable energy production (TWh) for 2020, for various final gross energy consumption estimates calculated from different models, were taken into account and compared in the GSE report [40] (Figure 1.37): the provisional potential declared in the 2007 National Position Paper[39] previously described (labelled Tecno 1); the national scenario assessed by European Commission and IEA (labelled Tecno 2); a Business As Usual scenario (labelled BAU); two scenarios (labelled Vinco 1 and Vinco 2) based on national targets for renewable energy and GHG reduction as defined in the Energy and Climate Change Package of the European Commission (approved on 23 /01/2008), where the Vinco 2 scenario referred to a situation of both the renewable energy and the GHG target are included, while in the Vinco 1 the target of GHG reduction is excluded.

Figure 1.37: Scenarios at 2020. Renewable energy production to cover the final gross energy consumption. Renewable energy (yellow bar) and residual gross energy consumption (red bar) (Figure extracted from ref 40)



The renewable energies potential (104.2 TWh) to cover the final gross consumption at 2020 assessed by the Italian Government (Tecno 1 scenario) seems to be lower (-54 TWh) than that predicted by the European Commission and the IEA (Tecno 2 scenario). The Vinco 1 +2 scenario shows that if the national renewable target is set with respect to the GHG targets at the same time, the renewable potential is lower. While, under the business-as-usual model, a much lower renewable production relative to the gross final consumption at 2020 would be obtained.

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Netherlands

The municipal solid waste resource in the Netherlands

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This report:

- summarises national policy/strategy on waste management and the recovery of energy from waste;
- provides data on the historical arisings and management of MSW;
- briefly discusses the factors affecting waste growth, and estimates the MSW arisings in 2020;
- assesses the potential for increasing the amount of energy which is recovered from MSW in NL.

National policy/strategy

Waste policy

The second waste management plan of the Netherlands was published on 14 December 2009 and came into force one month later. The plan was sub-titled: towards a material chain policy, which clearly states the focus on material recycling within current waste policy. The plan contains the next objectives for waste policy:

- Limitation of the production of waste. This means that the growth in total waste production must be decoupled from economic growth.
- Limitation of the environmental impact of the activity 'waste management'. This means in principle that as much waste as possible must be recovered, that only waste which cannot be recovered may be disposed of, and that only incombustible waste may go to landfill.
- The limitation from a chain-oriented waste policy viewpoint of the environmental impact of production chains (raw material extraction, production, usage and waste management, including reuse). This means, among other things, that for the reduction of the environmental impact in the waste phase, the whole chain must be taken into account, and that the efforts to reduce the environmental impact in the waste phase may not result in shifting the environmental impact to other phases in the chain.

Quantitative objectives relevant for waste-to-energy

The general waste objectives in the previous section result in the following quantitative and measurable objectives. A selection of objectives relevant for waste-to-energy is made.

1. Promotion of prevention of waste, such that the decoupling between the Gross Domestic Product (GDP) achieved in the period 1985-2006, and the development in total waste production is strengthened. This means that the total waste production in 2015 may not be greater than 68 Mton, and in 2021 may not be greater than 73 Mton.
2. Increase in recovery from 83% of all waste in 2006 to 85% in 2015. This can mainly be achieved by promotion of waste separation at source, and post-separation of waste streams. By this means, it becomes easier to achieve product reuse, material use and reuse.
3. Increase in recovery from 51% of all household waste in 2006 to 60% in 2015. Objectives are included in various Directives for the percentages of recovery to be achieved for different waste substances, such as packaging, batteries and electrical

and electronic equipment. No other objectives for separate waste substances are stipulated in addition to these legislatively stipulated objectives. This means that municipalities have a limited degree of freedom in implementing the achievement of the objective of 60%.

4. Reduce the deposition of combustible residual waste from 1.7 Mton in 2007 to 0 Mton in 2012.

Qualitative objectives

5. Optimal usage of the energy content of waste that cannot be reused. To this end, more usage of waste as fuel in plants with a high energy efficiency, and improvement of the energy efficiency of the existing waste incineration plants (WIPs), are aimed at.
6. Better usage of residual heat from waste incineration. Within the context of the Ministry of Economic Affairs' 'Plan of Approach for Heat' (Aanvalsplan warmte), it will be investigated together with the Ministry of Economic Affairs and Commerce how the potential for the usage of waste heat can be better realised in local situations.
7. Contribute to the following specific ambitions of the Balkenende IV cabinet, in the context of the integral chain approach to waste materials policy:
    - by 2020, in comparison to 1990 levels, a reduction of CO_2 emissions by 30%. (theme 'climate change');
    - by 2020, - no risk to man or environment due to the distribution of hazardous substances (theme 'distribution');
    - in 2010, the loss of biodiversity to be stopped (theme 'land usage').

Capacity planning and D10/R1-status

The new plan, although still not in force, is already under debate and as a result a proposal for change is in progress. The proposal is a result of the emerging overcapacity for incineration in the Netherlands, leading to a political consensus that capacity should be stabilised and a willingness to ensure waste incinerators already in operation achieve good energy performance (R1-status), before the rest of the Waste Framework Directive is implemented in the Netherlands. This led to a gentlemen's agreement which was signed on 2 December 2009. (in Dutch http://www.lap2.nl/nieuwsbericht.asp?i=33).

The companies involved in waste incineration agreed on a cap on new capacity up to 2020. The minister of the environment will investigate the possibility of changing the status of waste incinerators with high energy efficiency to recovery (R1) in advance of the implementation of the new European waste framework directive. A list of incinerators and their proposed future status is given in Table 1.20 (http://www.lap2.nl/uitvoering.asp?i=55).

The status is based on calculation made by SenterNovem. The interpretation of the D10/R1-formula is made by SenterNovem since no European guidance exists so far. The EU is expecting to formulate guidance in 2010. In case this diverges from the Dutch method it will be seen if and how the Dutch method will be changed.

Table 1. 20: Incinerators, capacity and energy efficiency according to the new WFD

Waste Incinerator	Existing or new.	capacity (kton)	Energy Eff. (1)	Status	capacity R1 per 1-1-2010 (kton)	capacity R1 per 2011 / 2012 (2) (kton)
AEC Amsterdam	Existing	800	0,63	R1	800	800
HRC Amsterdam	Existing	500	0,78	R1	500	500
ARN	Existing	310	0,67	R1	310	310
AVR Duiven	Existing	400	0,39	D10		
AVR Rozenburg	Existing	1.300	0,59	R1 (3)	1300	1300
AVR Rotterdam, will close 1-1-2010						
AZN lijnen 1-3	Existing	715	0,90	R1	715	715
AZN lijn 4	Existing	275	1,15	R1	275	275
E.ON Delfzijl	New	275	0,96	R1	275	275
GAVI Wijster	Existing	630	0,49	D10		
HCV Alkmaar	Existing	675	0,55	D10		
HCV Dordrecht lijnen 1-4	Excisting	240	0,21	D10		
HVC Dordrecht lijnen 1,4,5	Excisting/ New	396	0,61	R1		396
Omrin Harlingen	New	228	0,95	R1		228
Sita bestaand, geen aanvraag ingediend						
Sita BAVIRO (4)	New	224	0,63	R1		224
Twence lijnen 1, 2	Existing	300	0,41	D10		
Twence lijn 3	Existing	216	0,67	R1	216	216
Totaal (kton)		**7.311**			**4.391**	**5.239**

Overcapacity

The overcapacity on the waste incineration market leads to:

- Decrease in waste treatment prices. Recently the municipalities of the Utrecht Province signed a contract with AVR for 40 EURO/ton residual MSW. This is less than half the price a couple of years ago.
- Some plans were stopped. Essent decided not to increase their capacity in Wijster.
- First closure of a waste incinerator in years. The AVR Rotterdam waste incinerator will close next month.

Renewable energy policy

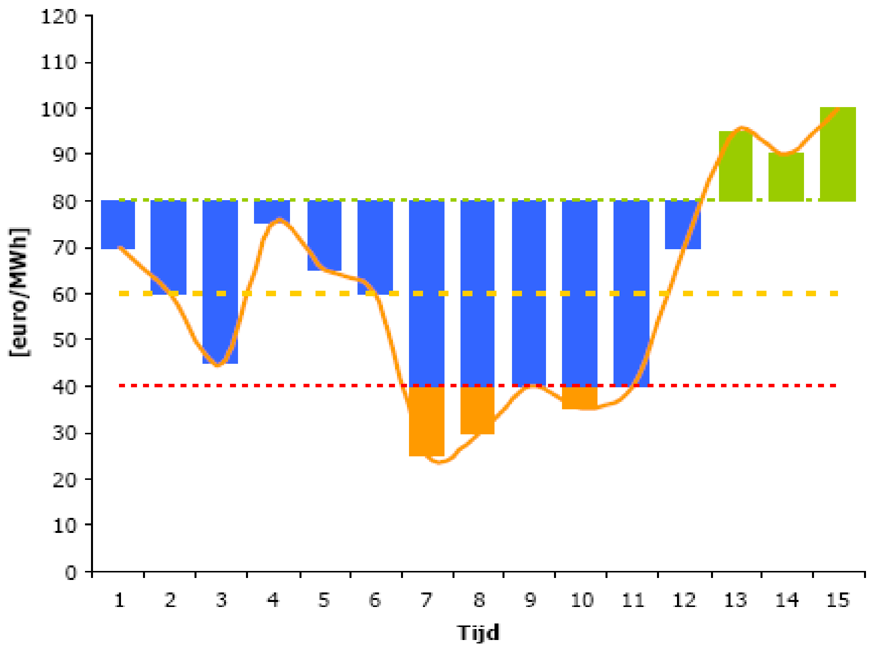
A new strategy was introduced by the Government in 2007 entitled '*clean and efficient'.* The main targets set out in this strategy are the reduction of the greenhouse gases by 30%, 20% renewable energy in 2020 and an annual efficiency improvement of 2%.

SDE (subsidy renewable electricity)

The main instrument in stimulating renewable energy is the SDE. This subsidy scheme is designed to stimulate investment in the production of renewable energy. The SDE is not an investment grant; it is a utilisation subsidy, for renewable energy generated. The SDE subsidizes the lack of profit of a production unit of renewable energy.

For this purpose for each technology a basic price is determined. This is the average production costs of renewable energy per production system. These prices are calculated for e.g. offshore wind, co-combustion of biomass, and also for (the biomass fraction of) waste incineration. Based on a basic market price the subsidy level is defined as the difference between the basic price and the market price. Every year the market price is estimated and after a subsidy year the subsidy paid is corrected for the actual electricity prices. This means that in case of high electricity prices the subsidy might be zero. (Green bars in Figure 1.38 indicate profit, not negative subsidy).

Figure 1.38: Example of how SDE-subsidy is calculated.
Green line: basis price; red line: basic electricity price; orange line: developing price through time. Blue bars are the subsidy required, green bars, not subsidy but profit.



SDE for waste incineration

For waste incineration the cost calculation is difficult because the cost structure is dominated by income from waste. Furthermore, a minimum energy recovery is obliged for all waste incineration due to environmental legislation (e.g. BBT). Therefore only electricity generation above 22% efficiency is granted within the SDE. The basic prices are 5.5 €ct/kWh for 23% efficiency up to 6.6€ct/kWh for efficiencies over 30%.[1] According to the market this is too low for a profitable benefit.

[1] The efficiency is electricity + 2/3 of the heat produced. However the subsidy is only granted for the electricity part.

Heat

The ambitious targets for efficiency improvement and renewable energy require the use of all energy systems, including heat. Therefore this year a plan for heat (aanvalsplan warmte) has been introduced by the ministry. The plan is not official, so the details are not available however the most important points are:

- subsidising CHP by the SDE;
- mapping heat demand and supply in industrial regions, in this way to decrease the discharge of heat;
- support to the agreements with different sectors (e.g. agro sector).

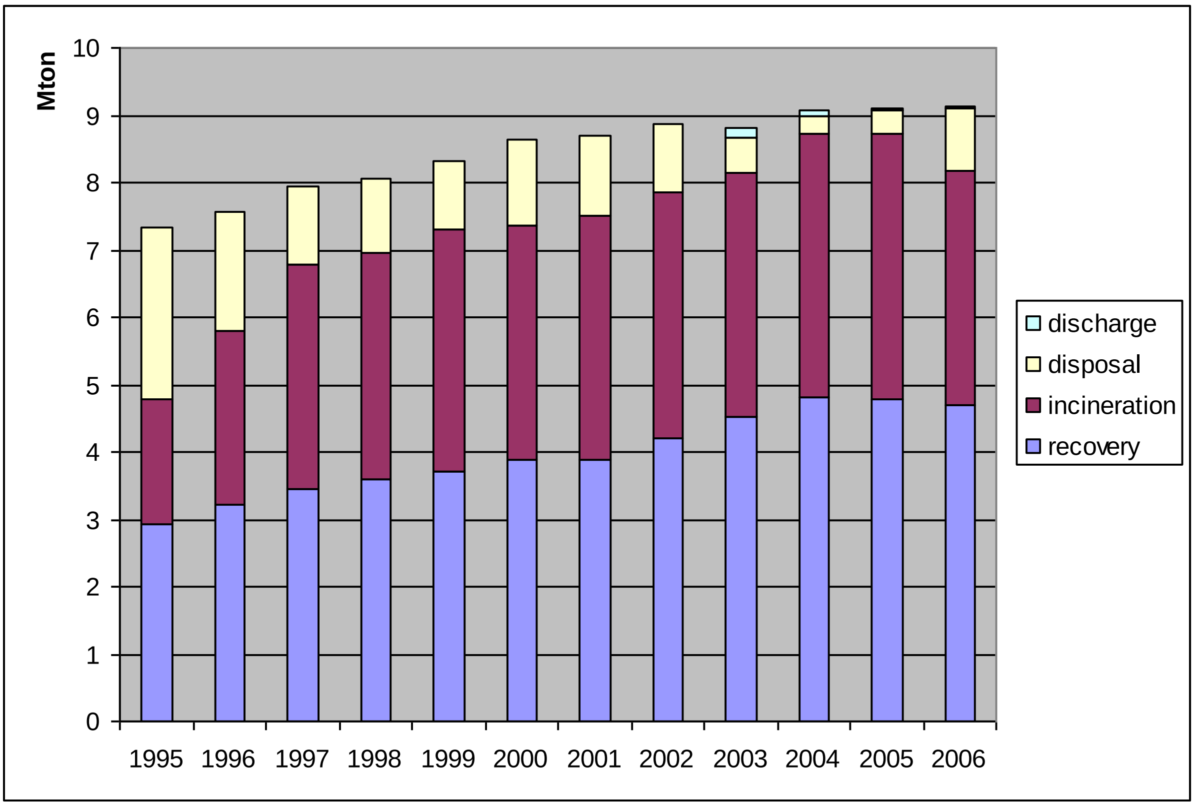
Current situation

Household waste

Dutch statistics use a distinction between different sectors for waste. For household waste the total production of waste increased over the last 13 years from 7.3 Mt in 1995 to over 9 Mt in 2006. In this period recovery increased from 40% in 1995 to 53% in 2006, mainly due to increasing separate collection of paper and a better recovery of bulky waste.

From the non-recyclable waste a clear shift from landfilling to incineration is seen in the period 1995-2005. However, in the period 2003-2005 part of the recovery and incineration took place in Germany. After the landfill ban in Germany on 1 June 2005 this export decreased dramatically leading to a capacity shortage in the Netherlands. The surplus of waste of approximately 1 Mt is landfilled.

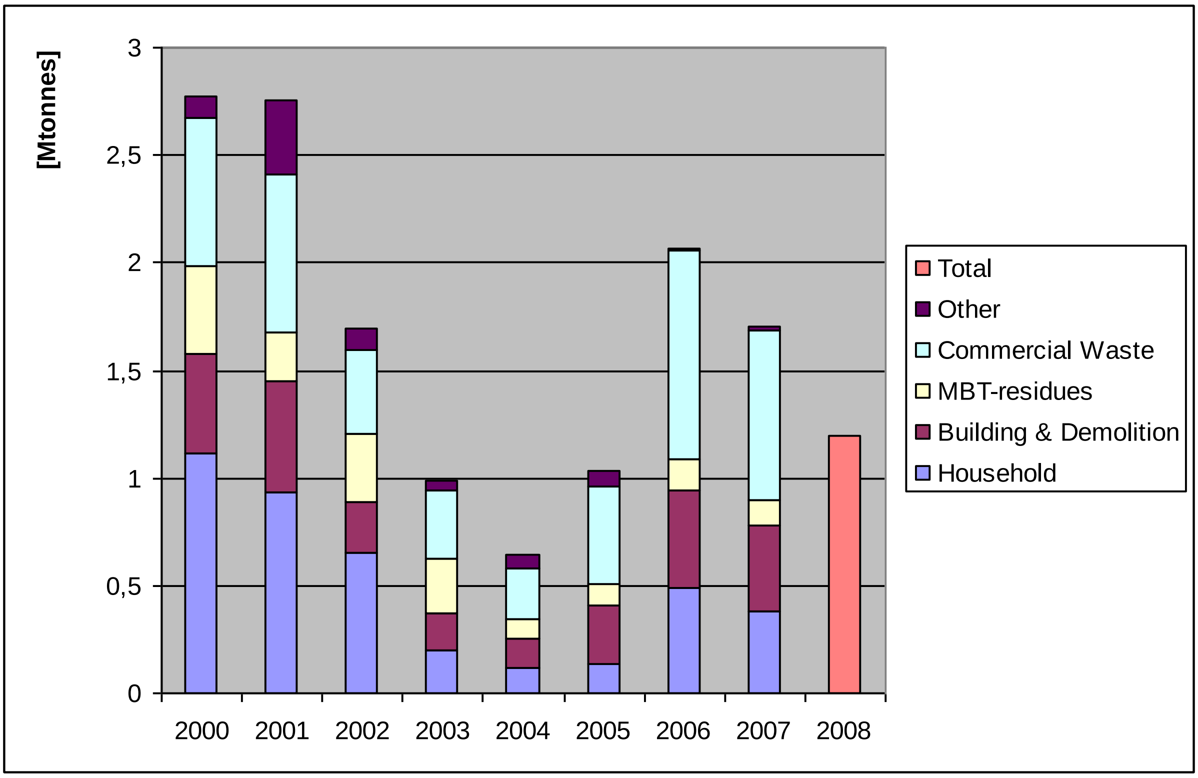
Figure 1.39: Treatment of household waste in the Netherlands (1995-2006)



As earlier, an important aspect of the capacity planning is to enable the incineration of all non-recyclable combustible waste. For this purpose, this waste is monitored for the period of the first waste management plan.

The amount is stable for the last eight years around 10 Mt, which contains 4.7 Mt waste from household, 2.2 Mt waste from commercial premises, 1.8 Mt combustible mixed demolition waste and approximately 2 Mt other waste (mainly sludge). Here we see the same development as for household waste - an increase in the landfill of combustible waste due to a lack of incineration capacity. In recent years the landfill decreased again, now leading to an overcapacity and a stop to landfilling of combustible waste.

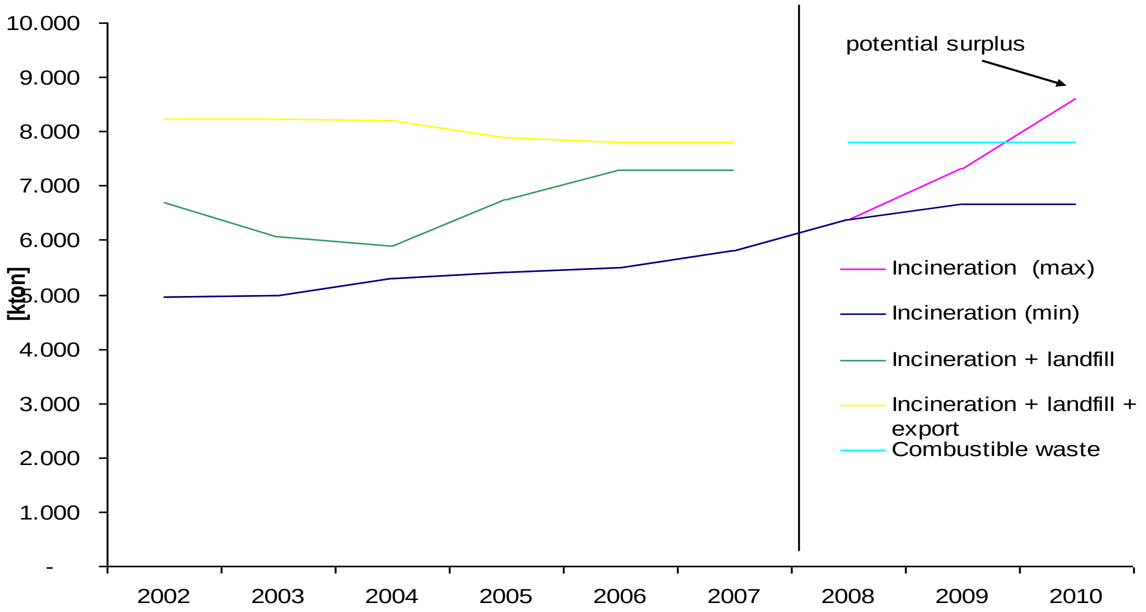
Figure 1.40: Landfilling of combustible waste in the Netherlands (SenterNovem 2009)



Incineration capacity

The 10 Mt combustible, non-recyclable waste contains approx 2 Mt of waste not suitable for waste incineration. This is the high calorific part of building and demolition waste and the sludge. Thus, around 8 Mt of incineration capacity is needed for the amount of waste produced over the last few years (see yellow line in Figure 1.41). The plans for increase of incineration capacity show enough development to treat all combustible waste produced today. There was a surplus of capacity in 2009 due to a decrease in waste due to the economic crisis and the availability of new waste incineration capacity. As a result, the Waste Incinerator of AVR in Rotterdam will close in January 2010.

Figure 1.41: Incineration capacity and planned (status October 2008)



Future energy recovery potential

The current focus on energy production, especially on heat production, has led to the consideration of heat production in all new initiatives. At three locations the integration of waste incineration with industrial heat demand leads to an efficient coupling of systems. On most sites where the capacity is increased new capacity leads to more heat delivery. Development of electricity production is relatively straightforward, and, due to the subsidies available for the renewable part, it is proposed for all new non-industrial coupled installations.

The electricity power capacity increased in 2007 to 506 MW producing 2900 GWh of electricity in 2008. The net production was 2204 GWh and the total heat production 10.5 PJ. With a waste input of 6.1 Mton (61 PJ), the average efficiency was 13% and heat efficiency 17%. The total capacity will be 7.3 Mton within a couple of years. It is assumed that there will be an increase in particular in the heat production since the new waste incinerators all use heat delivery.

Norway

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Waste policy

Overall waste policy

The regulation on recovery and treatment of waste (Avfallsforskriften)

The Avfallsforskriften (the Norwegian version of the Waste Incineration Directive) is a document covering the collection and treatment of electrical and electronic products, batteries, vehicles and tyres and the regulation for waste landfilling and incineration of waste. This regulation forbids the landfilling of wet organic waste (sludge, food waste), although there are exemptions where consent has been granted.

Hazardous wastes and export/import of waste are also covered by this regulation. About 300,000 t of waste are exported every year, mostly to Sweden. The current trans-boundary transport regulations concerning waste do not allow any ban/restriction (market-regulated). However the Norwegian authorities stress that their ultimate goal is that Norwegian produced waste should be treated in Norway, mostly to assure proper treatments and because waste is seen as a resource for material and energy recovery. The authorities are committed to closely watch export/import of waste.

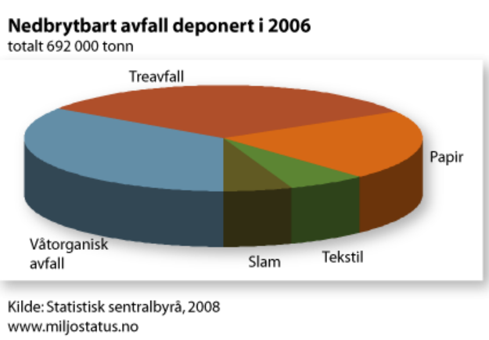
The 'final treatment' fee (Sluttbehandlingsavgift)

This tax system was established in order to reflect the environmental impacts imposed by the waste 'final treatment' techniques. Landfilling and combustion without energy recovery are considered as 'final treatments' and are subject to this fee, which is meant to stimulate the use of 'non-final' treatments such as recovery or combustion with energy recovery. The cost for landfilling varies with the quality of the landfill and was between 434 and 566 NOK/t in 2008.

Ban on the landfilling of biologically degradable waste from 01.07.2009

About 4.8 Mt of biologically degradable waste (wood, wet organics, sludge, textiles and paper) were generated in Norway in 2006. About 0.7 Mt were landfilled (see Figure 1.42). The main basis for this ban is the reduction of GHG emissions and the expected improvement in the material and energy recovery rates. In 2008, emissions from landfills represented about 2.2% of the total Norwegian GHG emissions.

Figure 1.42: Landfilled biologically degradable waste 2006



The total amount of waste which will be diverted from landfills to other treatments is estimated to be approximately 1 Mt a year. This is because biologically degradable waste is often mixed with other fractions (plastic, etc). SFT (Norwegian Pollution Control Authority) evaluated that 75% of this stream will go to waste combustion.

More specific EfW

Factors that are relevant to EfW in Norway are:

- There is a district heating network development support scheme (by local authorities).
- Landfilling ban (see previous section).
- Energy recovery rate requirement (50%).
- Subsidy/contribution from Enova. The state-controlled company Enova (created in 2001) manages economic subsidies (‘the energy fund’) for new or improved energy systems using renewable energy sources.
- Emissions fees (CO_2, SO_2, NOx, dust, HF, HCl, Hg, Cd). Waste incineration installations are subject to fees based on their measured emissions except for CO_2 (fixed fee of 59 NOK/t waste i.e. about 200 NOK/t CO_2).
- Long-term public policies:
    - Research programmes (the CenBio research centre, etc).
    - Bio-energy strategy plan 2008 with the overall goal of 14 new TWh bio-energy by 2020 (which includes the bio-fraction of waste).
    - Energy policy.
    - Climate policy.
    - Waste prevention.
    - National (material and energy) recovery rate target (75%).

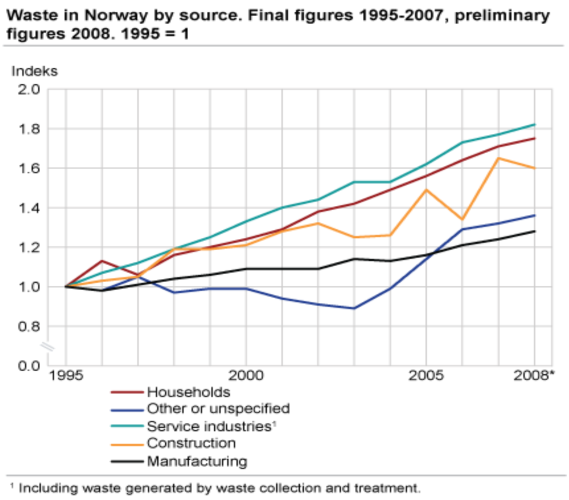
Current situation

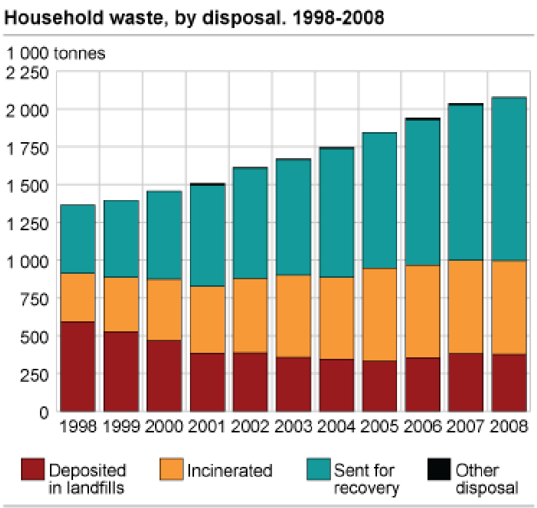
Definition of waste (Statistics Norway, SSB):
Waste/refuse: Discarded objects or materials.
Household waste: Waste from normal household activity, as well as large objects such as furniture.
Hazardous waste: Waste that cannot be treated together with normal waste because it can lead to serious contamination or risk injury to people or animals.

Historical MSW arisings

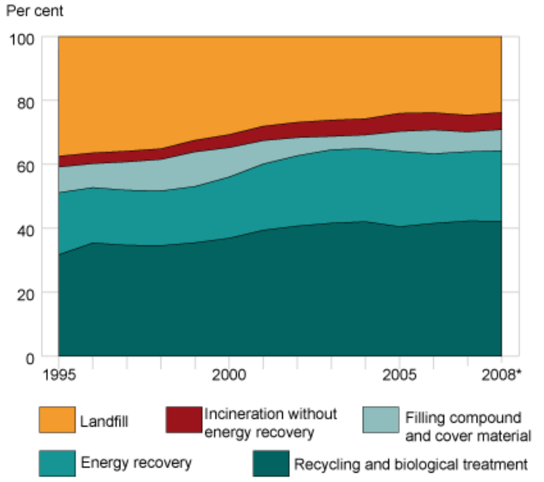
The three following figures (1.43-1.45) summarise the situation.

Figures 1.43-1.45: Waste arisings in Norway





Waste in Norway, by method of treatment[1]. Final figures 1995-2007, preliminary figures 2008. Per cent



[1] Exported waste is categorised according to the treatment or disposal it undergoes in the destination country, insofar this treatment or disposal method is known. Exported waste for which the treatment or disposal method is unknown, is categorised under unknown or specified handling. Imported waste is not covered by the statistics..

(Text adapted from SSB website, www.ssb.no)

During the period 1995-2008, the total amount of waste increased by 48% to 10.9 Mt. In comparison, the GDP increased by 44% in the same period.

Sharp growth in household waste

The amount of household waste has risen by 75%, exceeding the growth in total waste amounts. One possible explanation for the disproportionate growth in household waste could be a substantial increase in imports of consumption goods, which means that the waste from production is generated abroad. Private households account for 22% of the total waste (including scrapped cars). In comparison, manufacturing industries account for 37% of the total waste, of which 75% is from production processes.

Getting closer to national target

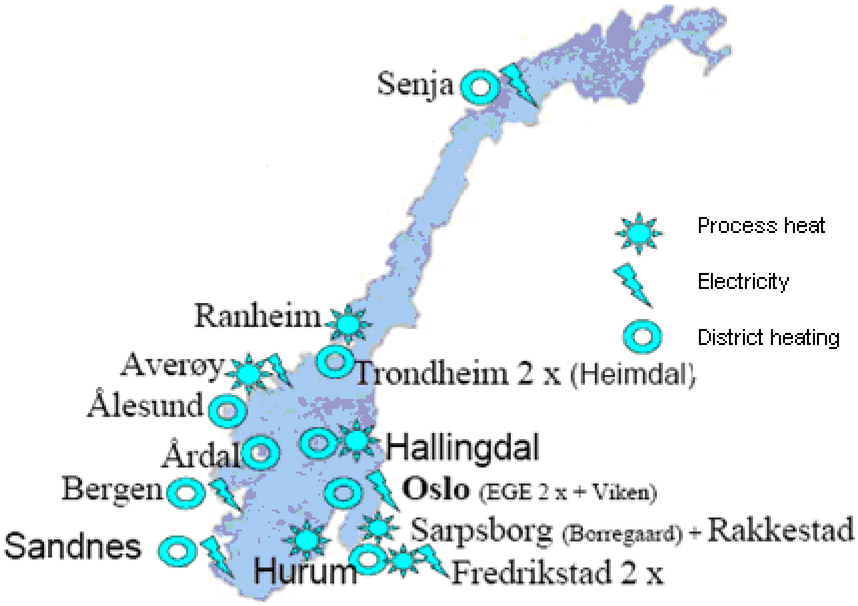
About 71% of the waste where the waste treatment was known was recovered in 2008 (excluding hazardous waste): about 37% went to recycling (material recovery), 22% to energy recovery and 11% to composting or as filling/cover in landfills. The national target is to increase this figure to 75% by 2010 and to 80% if this is economically and environmentally justifiable.

Recovery has increased by about 70% since 1995, while the amount going to landfill has decreased by 31%. In 2006, about one quarter of the waste going to landfill was biodegradable, compared to one third in 1995.

We throw more plastic and paper

In 2006, 1.3 Mt of paper and 0.5 Mt of plastic were discarded, an increase of 7 and 6% respectively from the previous year and 41 and 47% from 1995. The plastic and paper go into recovery, leaving the amount for disposal almost constant during the period.

Figure 1.46: Plants generating energy from waste in Norway, 2009. Source: Rune Dirdal, Avfall Norge



Waste incineration situation in Norway (2009, Avfall Norge):

- Ca 1.1 Mt waste is combusted (60% household waste).
- Current incineration capacity: about 1.1 Mt/y in 19 installations (see Figure 1.46).
- New (upcoming) capacity: 800,000 t/y in 10 new installations by 2011 (520,000 under construction or contracted and 300,000 planned).

Energy production from waste (2009, Avfall Norge, see also Figure 1.46):

- 1.26 TWh heat to district heating (about 50% of the total heat production).
- 0.50 TWh steam to industry.
- 0.11 TWh electricity to the grid.

Future MSW arisings

Preliminary figures for 2008 show an increase in waste of 2% from 2007, compared to 6% the year before. There is no indication that waste generation could be levelling out.

Future energy recovery potential

It is expected that 0.7-1 Mt (SFT, SSB and Avfall Norge) of waste per year are to be diverted from landfilling after the ban in July 2009. 75% is expected to be combusted (SFT).

The 692,000 tons (Figure 1.42) represents the amount of biologically degradable waste previously landfilled. However this waste fraction is most often mixed with other fractions, which is why the real amount of diverted waste can therefore be estimated to 1,000,000 tons (Avfall Norge). The required combustion capacity can therefore be estimated to about 750,000 t.

New capacity: 800,000 t/y in 10 'new' installations by 2011 (520,000 under construction or contracted and 300,000 planned).

Sweden

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The municipal solid waste resource in Sweden

Waste management in Sweden has greatly improved over the last 15 years in terms of its resource efficiency and environmental impact. This is the result of a number of powerful policy instruments, including producer responsibility, restrictions on landfilling, and landfill taxes. Sweden's entry into the EU has also had an impact. The volume of waste, however, has continued to grow.

Waste resources in Sweden

Some 121 Mt, 4.7 as municipal solid waste and 116 Mt as industrial and commercial, non-hazardous waste was generated in Sweden in 2006. Around half of the total amount, or 70 Mt, consists of mining waste and 22 Mt represents wood waste. Approximately 2.8 Mt of hazardous waste were produced in Sweden during 2006. The largest fraction was mineral contaminated waste such as asphalt etc.

Definition of municipal solid waste (MSW)

Municipal solid waste in Sweden is defined as household waste and other equivalent waste produced from other activities. The two categories are defined as:

- Household waste: Waste produced in the household. Waste produced due to business activities is not included within the fraction household waste.
- Waste from other equivalent activities: Waste with a similar complexity and content as waste produced in the household. The waste is produced by the citizens at restaurants, schools etc.

Other waste not included in the MSW definition is commercial, industrial waste and waste covered by the producer responsibility.

National policy/strategy

The Swedish Environmental Protection Agency has produced a national waste management plan '*A Strategy for Sustainable Waste Management*' based on the environmental quality objectives. This plan explains the significance of the objectives and it clarifies the connection between objective and measures taken. It also analyses the effects of various policy instruments and measures, and it points the way to the future by defining five areas given priority within waste management.

The overall aim of the national waste management plan are formulated in the national environmental objectives: "*The total quantity of waste should not increase, and the maximum possible use should be made of the resource that waste represents, while at the same time minimising the impact on, and risk to, health and environmen*t."

Since 1991, each municipality is obligated to have a waste plan. This plan must cover all types of waste found in the municipal area and identify the actions necessary for their appropriate environmental management and their management as resources. Waste planning has brought about improvements in management by encouraging the establishment of extensive systems for source separation and recycling.

Waste policy

The overall aim of the Swedish environmental policy and protection is to ensure that we can hand on to the next generation a society in which the major environmental problems have been solved. Sixteen national environmental objectives have been adopted by the Swedish Riksdag.

Waste management falls under three environmental objectives viz: 'A Good Built Environment', 'Reduced Climate Impact' and 'A Non-Toxic Environment'.

Incineration, landfilling, and hazardous waste management are all governed by EU regulations, while for biological treatment Sweden has national guidance for minimizing impacts on the environment. The EU waste hierarchy is implemented as a guide to the proper management of waste in Sweden. Waste prevention is the highest priority, followed by reuse, recycling, and safe disposal.

MSW management has improved and thus the environmental impact has been reduced greatly over the last 15 years in Sweden. The improvements are the results of implementation of a number of powerful instruments and policies such as:

- 1991 introduction of carbon dioxide tax has given biofuels a favoured position.
- 1994 producer responsibility was used for packaging material to reduce the amount of packaging in the waste stream. Producer responsibility has increased since 1994 and other materials such as cars, tyres, electronic waste etc are now covered as well. The recycling level has constantly increased with time.
- 2000 a landfill tax of 250 SEK[2]/t was launched.
- 2001 implementation of EU's landfill directive (1999/31/EG) in Swedish legislation (SFS 2001:512). A control program was implemented for all active landfills.
- 2002 a ban on the disposal of sorted combustible waste materials to landfill.
- 2002 implementation of EU's waste incineration directive (2000/76/EG) in Swedish legislation (SFS 2002:1060 and NFS 2002:28).
- 2003 an increase in landfill tax to 370 SEK/t.
- 2005 a ban on the disposal of organic waste materials to landfill.
- 2005 the new national waste plan was launched.
- 2006 a third increase of the landfill tax to 435 SEK/t.
- 2006 Incineration tax. The use of waste as a fuel is taxed on the organic fossil carbon (12.5% fossil carbon) content. Per tonne of fossil carbon the tax rates for the two elements are 150 SEK/t as energy tax and 3 374 SEK/t as carbon dioxide tax. CHP plants are excluded from the two new tax elements. The main purpose of the incineration tax is to favour material recycling and biological treatment of waste and if a thermal method is used electricity production is promoted.
- 2008 All active landfills need to fulfil the control program.

Of the listed policies above, the incineration tax, landfill tax and landfill ban are the most powerful tools to make changes to the waste management system.

[2] 10 SEK equal to approximately 1 €

MSW management in Sweden

Landfilling has decreased and material recovery, biological treatment and incineration for energy recovery have increased as a result of more sorting of waste at source and changes in waste treatment. The quantity of energy and materials recovered has risen dramatically. These measures have also reduced the environmental impact of waste management. Greenhouse gas emissions have fallen and there has also been a general decrease in emissions of hazardous substances such as heavy metals and organic pollutants. But the environmental impact of the waste generated in Sweden could be further reduced by properly applying and reviewing existing rules and policy instruments. Further focus must be put on reducing the hazardous nature and the volume of the waste generated, learning more about toxic pollutants, helping households and enterprises to recycle and separate more of their waste, and increasing our participation in work on waste management within the EU.

MSW treatment methods in Sweden

The most important methods of waste treatment in Sweden are:

1. Material recycling of packages, waste paper, tires, scrap metal and electronic waste etc.
2. Biological treatment of organic waste fractions.
3. Waste-to-energy by incineration
4. Landfilling.

Moreover, it is important that hazardous waste is collected and dealt with in a manner that is environmentally sound. Sweden is working in the long term towards reducing the amounts of hazardous substances that are used in all products that, eventually, become waste.

1. Recycling

A number of specific fractions are collected to be further used in the production of new products. In addition to the traditional material recycling large quantities of waste can be recycled at construction sites. Possible applications include structures at landfill sites, infilling works and road construction. The Swedish EPA is currently working on the development of criteria valid for waste recycling in construction.

2. Biological treatment

Biological treatment refers to the digestion or composting of readily decomposed organic waste, such as food waste, by the action of micro-organisms. Digestion takes place under anaerobic conditions and produces biogas and digestion residues. Composting, in contrast, requires the presence of oxygen and its products are carbon dioxide, water and compost. Compost and digestion residues can be used as fertilisers, soil products, and soil improvers, thus returning plant nutrients and humus to the soil. Biogas can be combusted to produce energy or upgraded for use as vehicle fuel. An increasing amount of waste is processed by digestion and composting, and environmental objectives call for further increases in the recycling of food waste.

The biological treatment of waste can release methane and nitrous oxide, which are greenhouse gases, and ammonia, which contributes to eutrophication and acidification. Leachate, mainly from composting, contains organics and nutrients and its release can cause eutrophication and offensive odours. The Swedish EPA has issued guidance on safety measures to be used in biological treatment to minimise impacts on the environment. Compost and bio-fertiliser plants can gain certification for the quality assurance of their products. Certification rules for compost and digestion residues have been issued by SP Swedish Technical Research Institute, setting standards for the entire waste management chain from waste feed to final use. As of the beginning of 2008, seven biogas plants (of 18) and two composting plants (of 24) had gained certification.

3. Waste-to-energy incineration
Even though growing quantities of waste are incinerated, emissions of dioxins and metals from incineration plants have been greatly reduced due to better cleaning of the flue gases and better incineration conditions. Another factor is the decreasing concentration of metals, including mercury, in the incinerated waste stream. The Swedish EPA is following a number of lines of research to further reduce the environmental impact of incineration.

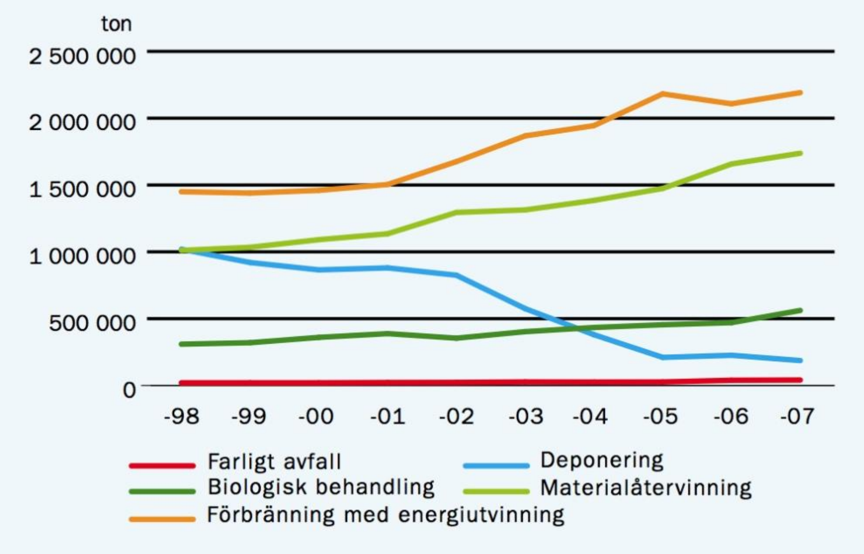
Incineration, with energy recovery, using modern technology is a good way to recycle (by energy recovery) the combustible, non-recyclable waste. In 2006 the Swedish Riksdag imposed a tax on the incineration of household waste in order to encourage an increase in material recycling.

4. Landfilling
Landfills are required for waste fractions that cannot or should not be recycled or disposed by biological treatment or incineration. Moreover, there are several thousands of landfills in Sweden that are no longer in use. They may contain anything from mining waste to old domestic waste, including many pollutants that are a threat to human health and the environment. New legislation enacted in 2001 has tightened requirements on the landfilling of waste in Sweden.

Waste management today
Waste management today is far more resource-efficient and has less effect on the environment than it did ten years ago. The measures taken since the 1990s to achieve more resource-efficient use of waste have yielded results. More source separation and changes in waste treatment have reduced the amount of waste going to landfill. Of the 121 Mt of non-hazardous waste material produced in Sweden during 2006, 23% was material recycled (53% if mining waste is excluded), 15% incinerated with energy recovery (35% if mining waste is excluded), 59% was sent to landfill (8% if mining waste is excluded). The majority of the waste material produced within the mining industry was sent to landfill, 62 of 70 Mt.

Figure 1.47 presents the annual MSW volumes treated by biological methods, incineration with energy recovery, material recycling and landfill between 1998 and 2007. Moreover the amount of collected hazardous waste is also presented in the figure, however the volumes are too low to be presented clearly in Figure 1.47.

Figure 1.47: Amount of MSW treated by incineration with energy recovery, material recycling, biological processes, landfill or collected as hazardous waste. Data is reported as annual tons treated between 1998 and to 2007. (Source: Swedish Waste Management Association, 2008)



A distinct increase in waste treated by incineration with energy recovery and material recycling is noticeable since 1998; meanwhile a drastic decrease of waste to landfill is observed at the same time. An increase in waste material recovered by biological methods is also noticeable since 1998, just not in the same quantities as incineration and material recycling.

Some examples of key-figures presenting improvements in MSW management:

- The volume of MSW going to landfill decreased from 1,380,000 t in 1994 to 186,000 t in 2007.
- Landfilling of waste other than MSW has also decreased. Compared with 1994 the amount landfilled has reduced by 60% by 2006. This waste is now recovered by either material or energy recycling.
- By 2008 Swedish landfills must be converted for long-term safe disposal under EU requirements.
- Incineration with energy recovery produced heat equal to the annual consumption of 810,000 normal homes and electricity equal to 250,000 normal homes in Sweden.
- Emissions from waste incineration have been reduced by more than 90% despite a significant increase in the amount of waste incinerated.
- More than 1.7 Mt of materials were recycled from household waste in 2007, equal to more than double when compared with1996 figures.
- Recycling rates have been increasing continuously since 1994, when the materials recovery rate was around 40%. Recycling of packaging increased from 40% in 1994 to more than 70% in 2006.
- Recycling of paper remains unchanged at a high level of 91% - a level well above the target 0f 70%.
- No tyres are sent to landfill today.
- 85% of used cars are recycled.
- 16 kg/cap of electrical and electronic waste was collected in 2007.

On the other hand, the target of avoiding any increase in the amount of waste is not being met, with the volume of household waste growing by 28% from 1994 to 2006. A reduction in the amount of waste will require measures targeted at the production and consumption of products.

In 2007 totally 4,717,380 t, equal to 514 kg/person, of MSW was treated in Sweden. Table 1.21 below presents the treated amounts divided in treatment categories as well as the amount of energy recovered (when it is applicable).

Table 1.21: Treated MSW volumes in Sweden 2007. (Source Swedish Waste Management Association 2008)

Method/Class	Amount totally (tons)	Per person (kg/person)	Energy recovered (MWh)
Hazardous waste	40,880	4.5	-
Material recycling	1,737,720	189	-
Biological treatment	561,300	61.1	Vehicle gas: 112,860 Electricity: 1,230 Heating: 67,960 To natural gas[1]: 36,370
Incineration energy recovery	2,190,980	239	Heat[2]: 12,151,270 Electricity[2]: 1,482,750
Landfill	186,490	20.3	Heat: 267,000 Electricity: 23,000
Total	**4,171,380**	**514**	**14,142,440**

(1) Biogas from biological treatment is delivered on the natural gas net.
(2) Approximately 50% of the energy originates from incineration of waste material other than MSW such as industrial and imported waste material. This means that the energy from MSW could be estimated to be 5,955,052 MWh heat and 726,661 MWh electricity

In 2007, 30 waste incinerators with energy recovery were in use as well as 18 biogas plants and 24 composts facilities. In addition, 170 landfill sites were in operation in 2007, however 40 of these were closed by the end of the year.

Environmental impacts of MSW management

Waste management today is far more resource-efficient and has less effect on the environment than it did fifteen years ago. The impact of waste management on the environment has been mitigated, with lower emissions of climate-change gases and of generally hazardous substances such as heavy metals and toxic organic pollutants.

The environmental impacts of waste management are directly or indirectly relevant to a number of Sweden’s 16 national environmental objectives. Table 1.22 presents the impact of waste management on the environmental objectives.

Table 1.22: Environmental impact of waste management on national environmental objectives, in % of Sweden's total emissions (2002). (Source Swedish EPA 2008)

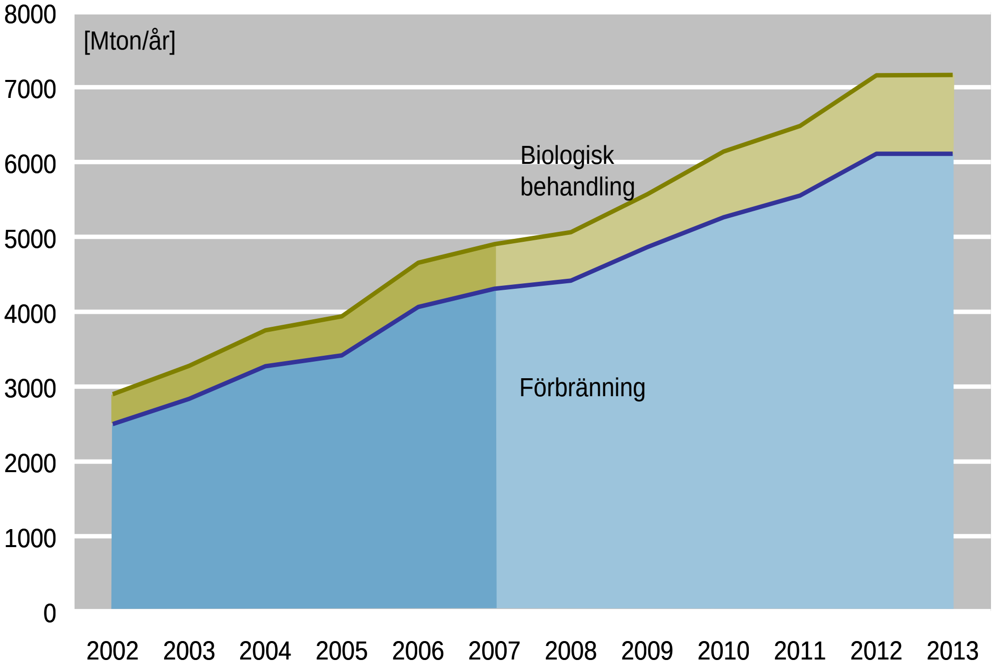
Environmental objective	Gross contribution from waste management	Net contribution from waste management
Reduced climate impact	3%	No information available
A Non-Toxic Environment (Pb, Cd, Hg, dioxins released to air)	2 – 3%	No information available
Good built environment a. Consumption of energy sources	0.6%	-2.0%
Good built environment b. Consumption of non-renewable energy resources (coal, oil, gas, uranium)	0.8%	-0.1%
Zero Eutrophication (water and soil)	1.7%	0.7%
Natural Acidification Only (including nitrogen oxides and ammonia)	2.4%	0.8%
Clean air a. Nitrogen oxides	1.7%	-0.4%
Clean air b. Volatile organic compounds	1.3%	0.8%

Future MSW management in Sweden

The amount of waste that needs to be recovered in Sweden is unfortunately still increasing. Thus many Swedish communities are considering future investments in biogas plants and/or waste incinerators.

Figure 1.48 below presents the treatment capacity, of today as well as a predicted capacity by 2013, of the two methods biological and thermal treatment.

Figure 1.48: Total treatment capacity of MSW within the two methods incineration and biological treatment. An estimation of the expansion from today until 2013 is also presented. (Source: Profu 2008)



The National Environmental Objectives state that by 2010, 35 % of food waste should be treated by a biological process. Today the treated amount is equal to only 17 %, thus rather important changes need to take place very soon if the objective is to be achieved. If we reach the goal of 35% biological treatment, and if it is treated in a biogas plant the estimated annual energy recovery is 470,000 MWh, and if 100% of the food waste is recovered in a biogas plant 1,350,000 MWh could be produced annually. These numbers should be compared with the annual production of 220 000 MWh today.

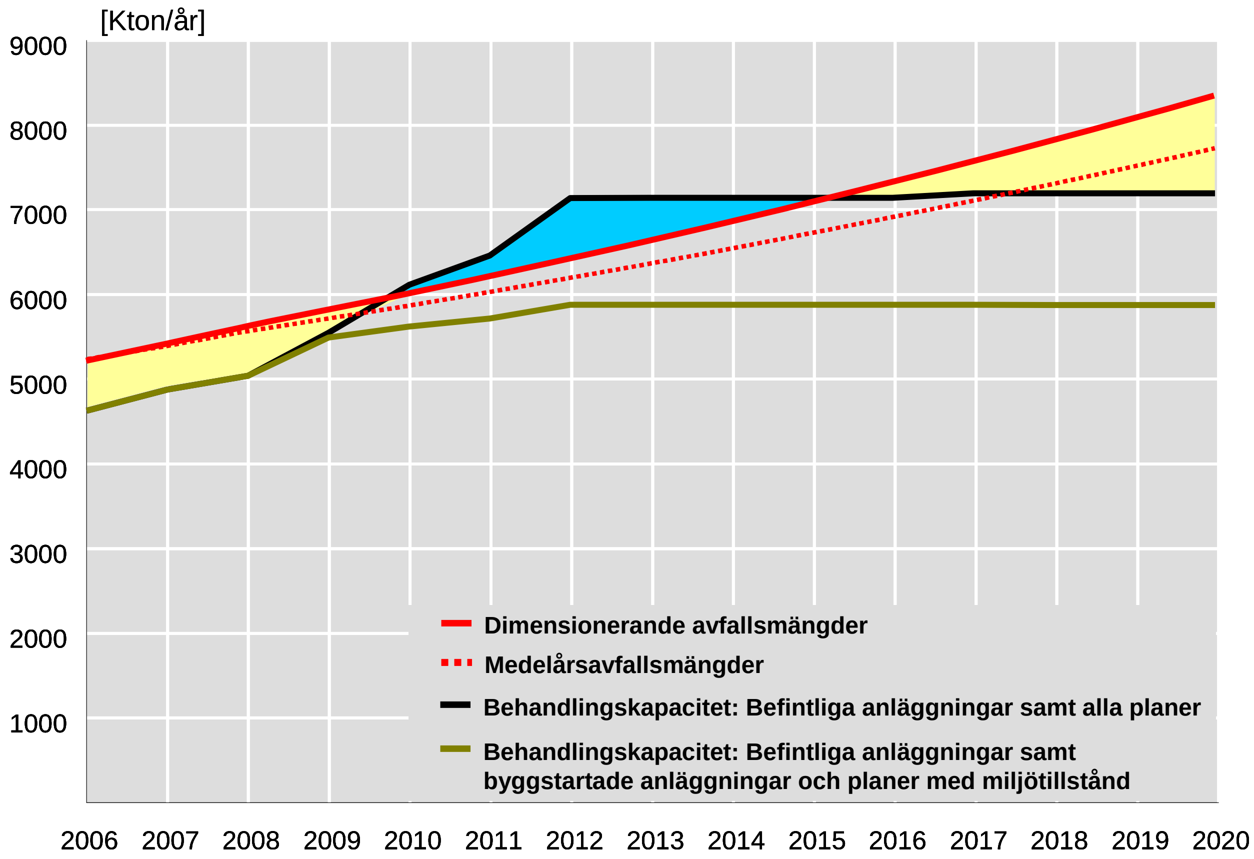
Table 1.23 presents the planned expansion in MSW incineration plants in Sweden. In total an expansion of the treatment capacity of more than 2 Mt is planned, equal to approximately an expansion of approximately 50% compared to the treated amount (4.5 Mt) today. If all the planned plants are built, the estimated amount of annual energy production will be approximately 20,000,000 MWh.

Table 1.23: Existing MSW incineration capacity in Sweden the year of 2007 and the planned for year 2013. The communities marked with yellow have achieved the environmental approval meanwhile the blue is still in the planning process. The total capacity of treated waste is presented in annual tons. (Source: Profu 2008)

	2007	2013
Befintliga		
Avesta	50 000	50 000
Boden	50 000	80 000
Bollnäs	40 000	80 000
Borlänge	40 000	80 000
Borås	90 000	90 000
Eksjö	55 000	55 000
Finspång	30 000	30 000
Göteborg	430 000	520 000
Halmstad	162 000	162 000
Hässleholm	36 000	36 000
Jönköping	165 000	165 000
Karlskoga	43 000	43 000
Karlstad	50 000	50 000
Kiruna	60 000	60 000
Kumla	170 000	170 000
Köping	25 000	25 000
Lidköping	100 000	100 000
Linköping	366 000	380 000
Ljungby	55 000	55 000
Malmö	390 000	535 000
Mora	17 000	17 000
Norrköping	200 000	400 000
Skövde	50 000	50 000
Stockholm	520 000	760 000
Sundsvall	260 000	260 000
Umeå	160 000	160 000
Uppsala	375 000	375 000
Västervik	46 000	46 000
Nya		
Enköping	0	72 000
Helsingborg	0	120 000
Täby/Sörab	0	190 000
Uddevalla	0	98 000
Uddevalla	0	32 000
Åmotfors	0	51 000
Befintliga PTP		
Stockholm, PTP	170 000	170 000
Södertälje, PTP	100 000	175 000
Örebro, PTP	35 000	35 000
Nya PTP		
Västerås, PTP	0	400 000
Landskrona, PTP	0	50 000
Ängelholm, PTP	0	35 000
Örebro, PTP	0	50 000
Tidaholm, PTP	0	40 000
Totalt		
Planerad ny kapacitet med tillstånd		960 000
Planerad ny kapacitet utan tillstånd		1 152 000
Summa alla planer samt befintlig kapacitet		6 352 000

The effect of the expansion of the treatment capacity by incineration is presented in Figure 1.49. Currently there is a shortage of capacity within the Swedish market (marked with yellow in the figure) and this will continue, even if all the plants with environmental approval (green line in the figure) are built. However, if all plants in planning are built a surplus (marked with blue in the figure) of capacity will be available for some years.

Figure 1.49: Amount of waste (kt) available for incineration on the Swedish market from today and predicted capacity the year of 2020 (two red lines)



The black line shows the treatment capacity if all existing plants and all planned are built. The dark green line shows the capacity if all existing plants and the one with environmental approval will be built. (Source: Profu 2008).

UK

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The municipal solid waste resource in England

This report:

- provides a summary of the national policy/strategy on waste management and energy from waste;
- summarises the data on the historical arisings and management of MSW;
- briefly discusses the factors affecting waste growth, and estimates the MSW arisings in 2020;
- assesses the potential for increasing the amount of energy which is recovered from MSW in England.

National policy/strategy

The European Union has been the major source of environmental legislation and guidance in relation to the management of waste in the UK, but, following the publication of a report[3] on climate change in 2006, current policy initiatives for both waste management and supply of energy are placing more emphasis on reducing greenhouse gas emissions.

Waste policy

The main area of European legislation that UK waste policy has to meet is the Landfill Directive. This aims to prevent, or minimise, the negative effects on both the environment and human health caused by landfilling of wastes. It will require the amount of biodegradable municipal solid waste sent to landfill in the UK to be reduced:

- to 75% of 1995 levels by 2010 (the UK has a four year derogation);
- to 50% of 1995 levels by 2013; and
- to 35% of 1995 levels by 2020.

Table 1.24 shows the Landfill Directive targets (tonnes of biodegradable waste) for the UK.

Table 1.24: Maximum tonnages of biological municipal waste (BMW) that can be landfilled

	2010	2013	2020
UK	13,700,000	9,130,000	6,390,000
England	11,200,000	7,460,000	5,220,000
Scotland	1,320,000	880,000	620,000
Wales	710,000	470,000	330,000
Northern Ireland	470,000	320,000	220,000

England landfilled 9.3 Mt of BMW in 2008/09. This is 40% less than was land filled in 2001/2. England has also increased its MSW recycling rate from 12% in 2000 to 37.6% in 2008/09, and further increases in recycling rates should enable it to meet the 2010 target. Investment is also being made in the additional treatment facilities required to meet the 2013 target, but delays (current economic situation affecting financial approval and obtaining planning approval) may impact on delivery of the 2013 target.

[3] Stern report - The Economics of Climate Change. October 2006

The UK Government has implemented the requirements for landfilling of biodegradable waste through the Waste and Emissions Trading Act 2003. This sets Waste Disposal Authorities annual allowances limiting how much biodegradable municipal waste (BMW) can be landfilled in any particular year, with effect from April 2005. The Government will fine Authorities that do not achieve their annual targets, but this legislation will allow Authorities to buy allowances from other Waste Disposal Authorities if they expect to landfill more than their allocations and sell their surplus if they expect to landfill less than their allowance.

The main area of national legislation is the Landfill Tax Regulations. Landfill Tax is a tax payable for each tonne of waste sent to landfill and was introduced by the Government in 1996 as a way of encouraging more sustainable means of waste management through recognising the hidden financial effects of the environmental impact of landfill. The landfill tax, which is currently £40/t, is increasing at a rate of £8/t each year, and will continue to increase at this rate until 21013/14 when the tax will be £72/tonne. This increase in landfill tax will cause a significant increase in waste disposal costs and will provide a further incentive to move to more sustainable means of waste treatment in the near future.

Although most waste legislation in the UK has been introduced to meet the requirements set by European Directives, the UK Government has also introduced additional legislation, some of which is specifically aimed at encouraging recycling.

Waste strategy

The Government first published a national waste strategy in 2000. The Prime Minister's Strategy Unit reviewed the progress towards the targets set within Waste Strategy 2000 in 2002. The report suggested that 'Waste Strategy 2000' may not be sufficient to move waste onto a more sustainable footing and the Government established the Waste Implementation Programme to address the recommendations made by the Strategy Unit.

An updated waste strategy[4] was published (following consultation during 2006) in May 2007. The aim of the Waste Strategy for England 2007, which sets the Government's vision for sustainable waste management, is to reduce waste by making products with fewer natural resources, breaking the link between economic growth and waste growth. Products should be re-used, their materials recycled, energy from waste recovered, and landfilling of residual waste should occur only where necessary. The 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;
- maximise the environmental benefit from that investment through increased recycling of resources and recovery of energy from residual waste using a mix of technologies.

The main points of the waste strategy are:

- A strong emphasis on waste prevention with householders reducing their waste (for example, through home composting and reducing food waste) and business helping consumers, for example, with less packaging. There will also be a new national target to help measure this.

[4] Waste Strategy for England 2007. Defra, May 2007

- More effective incentives for individuals and businesses to recycle waste, leading to at least 40% of household waste recycled or composted by 2010, rising to 45% by 2015 and 50% by 2020. This is a significant increase on the targets (30% by 2010 and 33% by 2015) in the previous waste strategy (which was published in 2000).
- Plastics and aluminium - proposals for higher packaging recycling requirements beyond the 2008 European targets to increase recycling (because of savings in carbon dioxide emissions).
- Increasing the amount of energy produced by a variety of energy from waste schemes, using waste that can't be reused or recycled. It is expected that from 2020 a quarter of municipal waste - waste collected by local authorities, mainly from households - will produce energy, compared to 10% in 2006.
- The Government continues to examine ways in which the diversion of degradable and recyclable materials from landfill can be achieved. It has announced a consultation on the potential ban of certain materials (including combustible materials) from landfill. In addition it is looking at the potential for greater convergence in policy between commercial and industrial waste and MSW and the potential to change the landfill tax to increase the level of tax for some ash materials.

Other measures include:

- Removing the ban on local authorities introducing household financial incentives for waste prevention and recycling, through early legislative change so local authorities would have the option to introduce revenue-neutral schemes (potentially reducing annual residual waste landfilled by up to 15% - equivalent to 1.5 Mt or 130 kg/household).
- Government will work with the Direct Marketing Association to develop a service so that people will be able to opt-out of receiving unaddressed as well as addressed direct mail. The Government is also considering moving towards an approach where people would only get direct mail if they opted in by placing their name on the direct mail register.
- Government will work with retailers to reduce the use of free single use bags. This could involve retailers only selling long-life bags, or retailers charging for disposable bags and using the proceeds to sell long-life bags at a discount.
- Recycling extended from the home and office to public areas by providing recycling facilities in shopping malls, train stations and cinema multiplexes, so that recycling becomes a natural part of everyday life.

The Government has also stated that it intends to consult on the possible introduction of further reductions in the amount of biodegradable waste that is landfilled (this could result in similar legislation to that already existing in a number of European countries, such as Germany and Sweden). It announced in October 2009 that there will be a consultation during 2010 on banning the landfilling of food waste, cans, paper, glass and wood waste.

Renewable energy policy

The UK Government published an updated energy strategy[5] in May 2007. The use of renewables is a key part of this strategy to tackle climate change and deploy cleaner sources of energy. There is currently a target that aims to see renewables grow as a proportion of UK electricity supplies to 10% by 2010, with an aspiration for this level to double by 2020. The Renewables Obligation (RO) is the main mechanism for incentivising this growth, and government subsidies (known as renewable obligation certificates (ROCs)) are paid to power generators for every unit of renewable energy produced.

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[5] Meeting the Energy Challenge. A White Paper on Energy. May 2007

The UK Government recognises that generating energy from that portion of waste that cannot be prevented, reused or recycled has both energy and waste policy benefits. It also recognises that the biodegradable fraction of waste is a renewable resource, and that energy generated either directly from waste or through the use of a refuse-derived fuel has benefits for security of supply.

The white paper proposes making energy-from-waste incineration plants eligible for ROC subsidies if they produce combined heat and power (CHP), rather than electricity only. The biomass element of waste fuel will qualify for one ROC for every unit of energy (MWh) that CHP plants produce. However, established technologies like landfill gas power generation and the co-firing of non-energy crop biomass will see a drop in their ROC subsidies to just 0.25 ROCs per MWh.

The UK Government is supporting emerging technologies for renewable power generation by offering them two ROCs per MWh. This includes 'advanced conversion technologies' such as anaerobic digestion, gasification and pyrolysis plants. The energy white paper highlights the Government's intention to support anaerobic digestion, stating that: "Anaerobic digestion is an emerging technology which is currently under-developed in the UK. It offers the potential to generate renewable energy - not only electricity, but also heat and fuel - from manures and slurries and certain organic wastes such as food waste, whilst at the same time mitigating methane emissions from agriculture and landfill." The Government will also be investing £10 million to support the anaerobic digestion sector.

Other relevant policy initiatives

The aim of the Waste Implementation Programme (WIP) is to drive waste management solutions up the waste hierarchy, and thus improve the sustainability of waste management. Two of the activities in this programme are:

- The new technologies work stream - this focuses on the biodegradable element of municipal waste. It aims to overcome the barriers to the successful development and take-up of proven and near market waste technologies by providing a comprehensive package of support to local authorities and their stakeholders.
- The demonstrator programme - this will provide up to £30 million of assistance to set up new waste treatment technology demonstration projects. The programme is intended to overcome the possible risks of introducing alternative technologies in England through the provision of accurate and impartial technical, environmental and economic information to key decision-makers in local authorities and the waste industry in general.

The Government also provides a financial incentive to energy recovery from waste through the Enhanced Capital Allowances (ECA) scheme. This specifically supports both advanced thermal conversion technologies and technologies for use of secondary recovered fuels (RDF).

Current situation

This section initially discusses the definition of MSW in the UK. It then presents historical data on the arisings and management of MSW in England, and lists (not exhaustively) residual waste facilities (primarily EfW) that are either in operation, under construction or proposed.

Definition of municipal waste in the UK[6]

The principal waste streams are:

- Household waste - includes waste from household collection rounds, dry recyclables collected through banks or kerbside collections, bulky waste collections, hazardous household waste collection, garden waste collections, and waste from services such as street sweeping, litter and civic amenity sites. The definition also covers waste from schools.
- Commercial waste - waste arising from wholesalers, catering establishments, shops and offices.
- Industrial waste - waste arising from factories and industrial plants. The UK definition of industrial waste does not include construction and demolition waste.
- Construction and demolition waste - waste arising from the construction, repair, maintenance and demolition of buildings and structures.

Municipal waste arisings in the UK include all wastes under the control of local authorities or agents acting on their behalf, which means all household waste, municipal parks and garden wastes, and council office waste. It also includes any waste collected by local authorities from businesses.

The Government issued a consultation paper on the definition of municipal waste in 2007, and a further consultation was issued in 2009. Changes to the definition of MSW are likely to be introduced by April 2010, and the main change will be the exclusion of separately collected construction waste

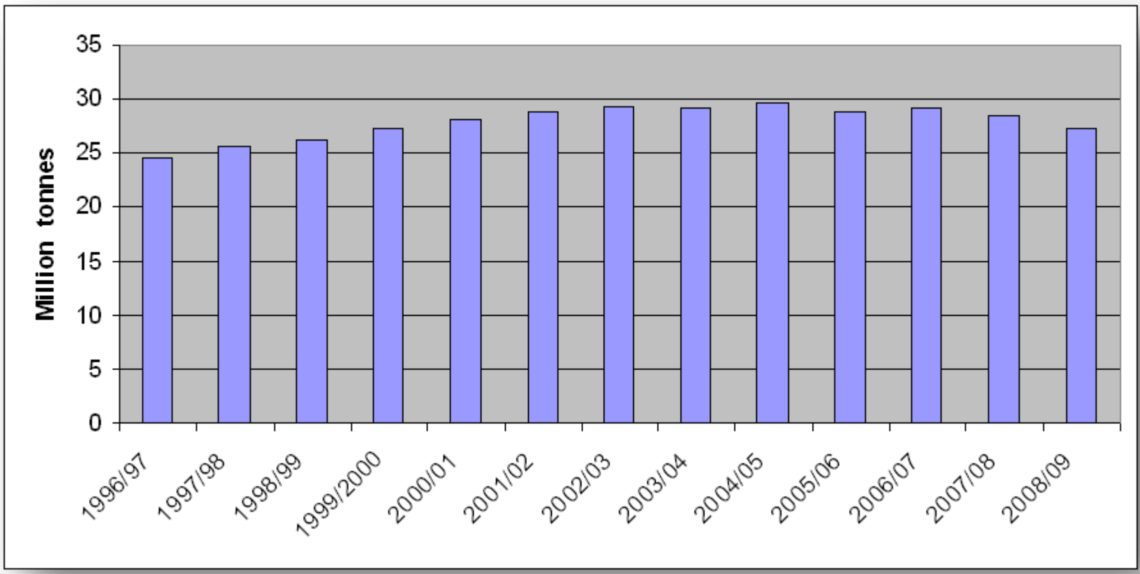
The main difference between the arisings of MSW in the UK and the arisings of MSW in other countries is that the amount of business waste collected as part of the MSW stream is much lower in the UK. In many other countries, the definition of MSW includes commercial and industrial waste of a similar composition to household waste. However, in the UK, businesses are expected to make their own arrangements with private sector waste management companies for the collection, treatment and disposal of their waste. Local authorities in the UK can compete in this sector, but only collect a small fraction of this waste, mainly from smaller shops and trading estates. Some local authorities in the UK are reducing the amount of business waste that they collect because this additional waste can make it more difficult to meet targets for landfilling of biodegradable waste. However, in the light of proposed changes in the definition of MSW mentioned above, this situation may change.

Historical MSW arisings in England

Figure 1.50 shows that the arisings of MSW in England increased from 24.6 Mt in 1996/97 to 29.4 Mt in 2002/03. This represents an average growth rate of about 3% per year, which is similar to growth in GDP. However, there has been little growth in arisings since then, and the overall arisings of 27.3 Mt in 2008/09 were lower than the arisings of 28.1 Mt in 2000/01.

[6] As mentioned above, following discussion with the EU the UK is revising its interpretation of the definition of municipal waste. The definition will include all biodegradable waste from commercial, industrial and institutional waste that is similar to municipal waste (see: http://www.defra.gov.uk/environment/waste/strategy/legislation/landfill/targets.htm). In practice this will mean that the amount of waste classed as MSW will increase significantly.

Figure 1.50: MSW arisings (Million t) in England 1996/97 to 2008/09

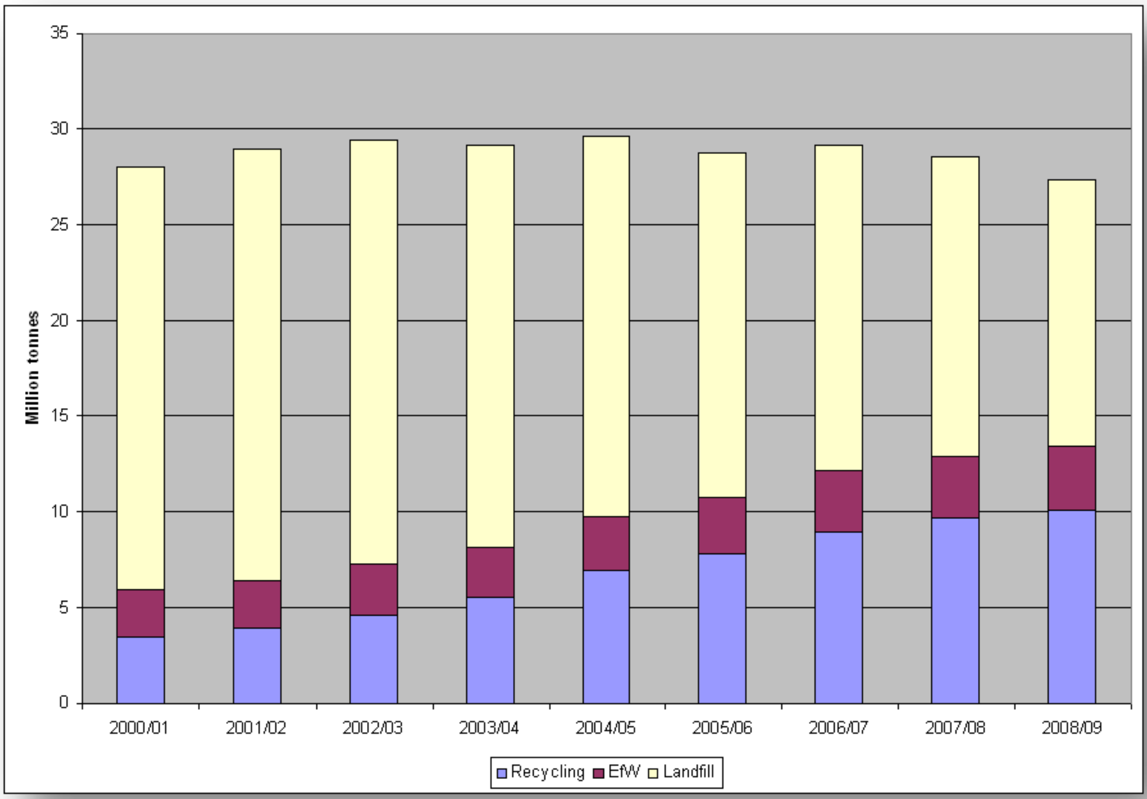


Although MSW arisings grew at an average of 3% per year from 1997/98 to 2000/2001, the average rate of growth since then is now averaging less than 1% per year. There are a number of possible reasons for the lower growth rate since 2002/03:

- Waste minimisation campaigns, but these usually take at least five years to show any noticeable effect.
- Lower arisings of garden waste collected due to a combination of drier summers and an increase in the amount of material that is home composted.
- Restrictions placed on the types of waste taken to the household waste recycling centres.

Figure 1.51 shows how MSW has been managed in England since 2000/01. The recycling (including composting) rate has increased from 12% in 2000/01 to 37% in 2008/09, and the amount of MSW sent to EfW facilities increased from 2.4 Mt in 2000/01 to 3.32 Mt in 2008/09.

Figure 1.51: Management of MSW in England



The household waste recycling rate, rather than the MSW recycling rate, is usually reported for the UK. The household waste recycling rate is based on arisings of household waste, and the materials which can be included in the tonnage of household waste which can be recycled exclude both source separated construction and demolition waste arisings at a civic amenity (public recycling and disposal) site, and any bottom ash from EfW facilities which is recycled. A compost product can only be classified as being recycled if it has a beneficial use (a low quality compost used as a soil improver is classified as recovery, but not recycling). The household waste recycling rate achieved in England in 2008/09 was 38%.

Table 1.25 shows that the MSW arisings of 27.3 Mt in 2008/09 represented an average arising of 532 kg/person/y.

Table 1.25: MSW arisings in England in 2008/09

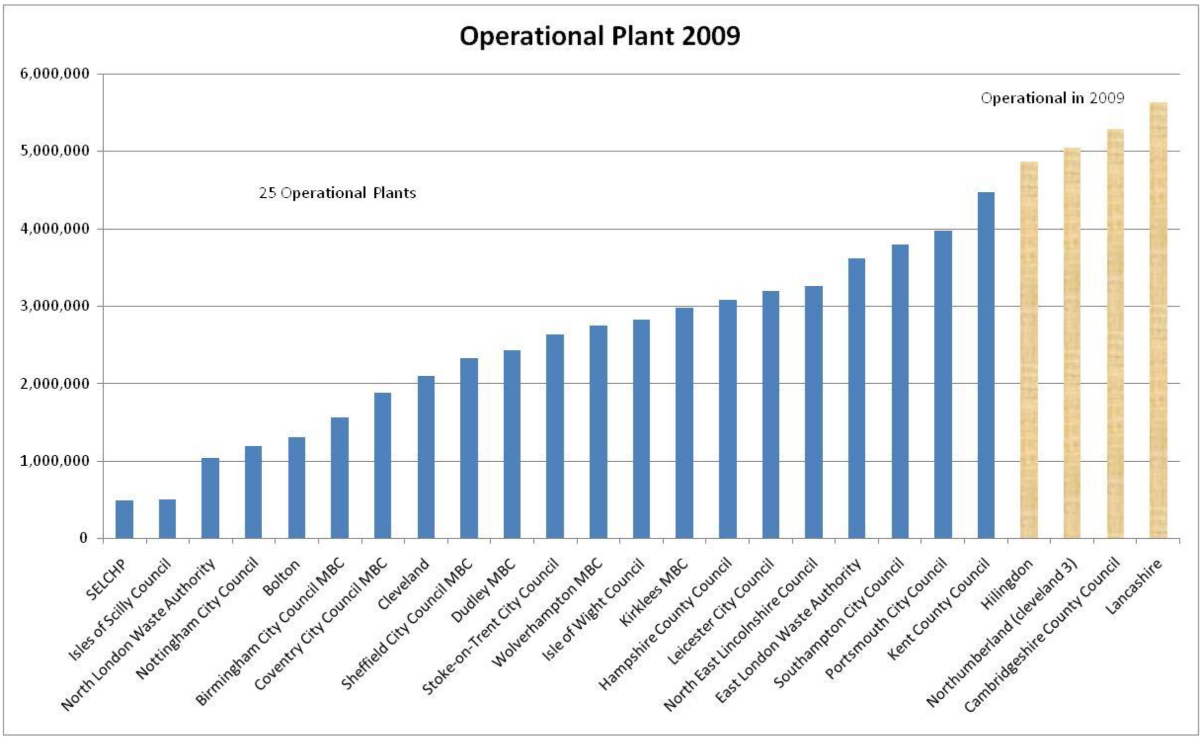
	MSW arisings
Tonnage (‘000 tonnes)	27,333
kg/person/year	532
kg/household/year	1,205

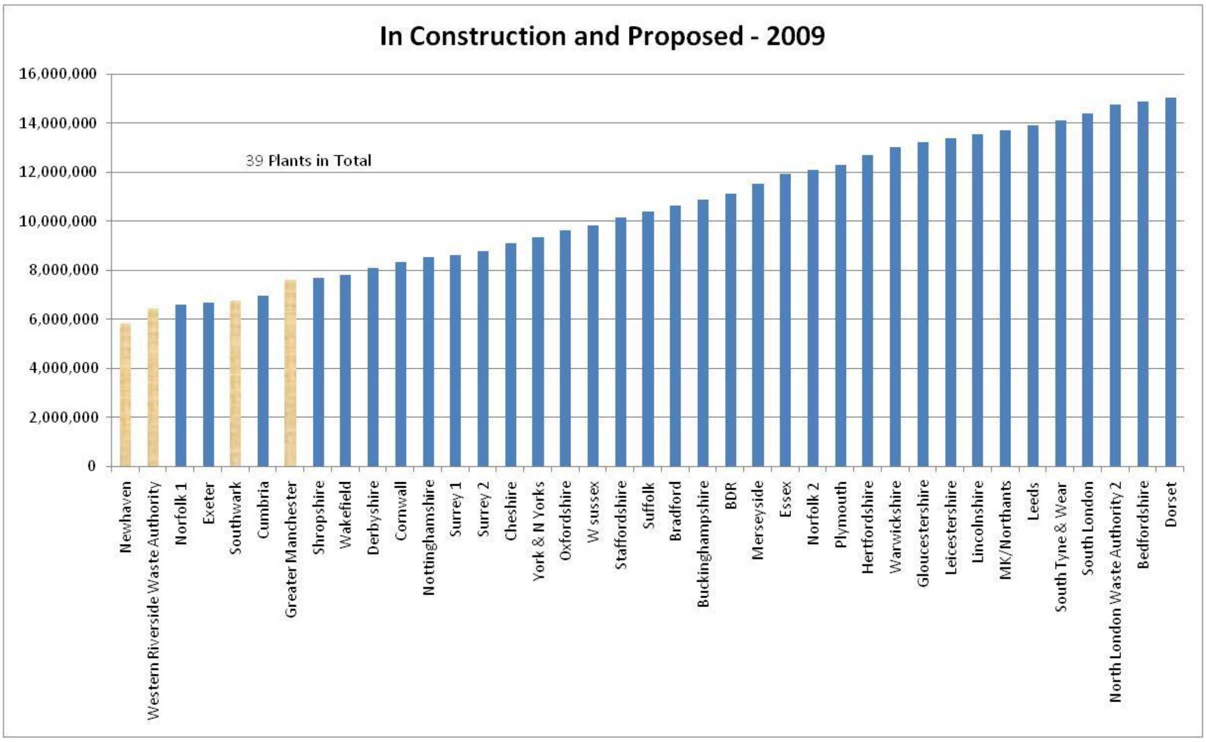
The total MSW recovery (recycling/composting and waste sent to an EfW facility) rate increased from 21% in 2000/01 to 49% in 2008/09. This was mainly due to the increase in the amount of waste which was either recycled or composted.

Figure 1.52a shows the operational residual waste treatment plants (primarily direct EfW) operational as at 2009; 25 operational facilities with a combined throughput capacity of about 5.5 million tonnes. As Figure 1.52b shows there are a further 39 facilities at various stages of development - four in construction and the others either progressing planning, in procurement, or in pre-procurement development. Given the difficulties in development (particularly in securing planning) it is unlikely that all of the listed facilities will actually progress to the operational phase but it does demonstrate the total additional capacity that might be developed (in excess of 8 million tonnes) if all of the facilities were delivered.

In terms of energy generating capacity the operational plant equates to about 400 MWe (or assuming 50% renewable component then 200 MWe of renewable energy). There is therefore the potential to increase this to over 1,000 MWe (500 MWe renewable) in the period up to 2020.

Figure 1.52a and 1.52b: Energy from waste capacity





A survey[7] of commercial and industrial waste arisings conducted in England in 2002/03 identified that the total arisings were 68 million tonnes (30 million tonnes of commercial waste and 38 million tonnes of industrial waste). 45% was recycled, 44% was landfilled, and less than 5% was sent to an energy recovery facility.

Future MSW arisings

Historically, waste arisings have been shown to grow in line with, or even above, the level of economic growth. Consequently, if this trend continues, a 3% p.a. growth in waste would result a doubling of waste arisings in 20 years. However, the continuation of this trend is now considered to be unsustainable, and thus the sixth Environment Action Programme set an objective to achieve a decoupling of resource use from economic growth through significantly improved resource efficiency, dematerialisation of the economy and waste prevention.

A European study[8] has assessed the factors affecting household consumption, and the effects on the environment (resource use, energy use and waste). Another European study[9] developed a model which assesses the effects of food, recreation, ‘infotainment’, care, clothing, and housing on waste growth and used this to model four scenarios which all assumed continued economic growth but had different future lifestyles. The results showed that waste continued to grow, with some lifestyles resulting in waste growth rates which could be considerably higher than the GDP growth rate, and other lifestyles resulting in waste growth rates which were lower than GDP growth rates.

[7] Strategic waste management information 2003. Environment Agency, 2006.
[8] European Environment agency 2005. Household consumption and the environment. European Environment Agency Report 11/2005.
[9] European Commission 2003. Scenarios of household waste generation in 2020. Report by Joint Research Centre for the European Commission, June 2003.

Data[10] on MSW arisings from a number of European countries from 1997 to 2003 indicate that in some countries (e.g. Belgium and the Netherlands) waste arisings are growing more slowly than GDP growth. The data also suggest that countries that have higher MSW recycling rates are also seeing lower growth rates in MSW arisings; this may be because the impacts due to many years of publicity/education information on waste awareness and recycling are now becoming noticeable. However, this trend does not appear to be evident in either France or Germany.

There are a number of predictions for future MSW arisings in England:

- A model[11] which assesses the impact of lifestyle changes on household waste arisings in the UK. This model has a base case scenario in which waste quantities grow at an average of over 2% per year from 2005 to 2020.
- A model[12] which predicts future waste arisings based on national waste strategies and the need to meet various legislative targets. This model has a base case growth rate of over 2% per year from 2005 to 2020.

These models predict average growth rates of between 1% and 2% per year, and Waste Strategy 2007 developed four growth scenarios for MSW in order to assess a range of possible future outcomes to 2020:

1. 2.25% per annum reflecting recent trends in growth in consumer spending;
2. 1.5% per annum in line with national waste growth in the five years to 2004/05;
3. 0.75% per annum, in line with current projections of household growth and reflecting more closely national waste growth in the five years to 2005/06; and
4. 0% growth, representing the possibility that waste growth will be decoupled from household and economic growth.

It is unlikely that scenario 4 (0% growth) will occur due to Government policy regarding future house building, and it is also unlikely that scenario 1 (2.25% growth) will occur due to the emphasis on future waste minimisation in the new national waste strategy. Consequently, an average growth rate of 1% per year is frequently used to predict future waste arisings (this reflects the growth rates used in scenarios 2 and 3).

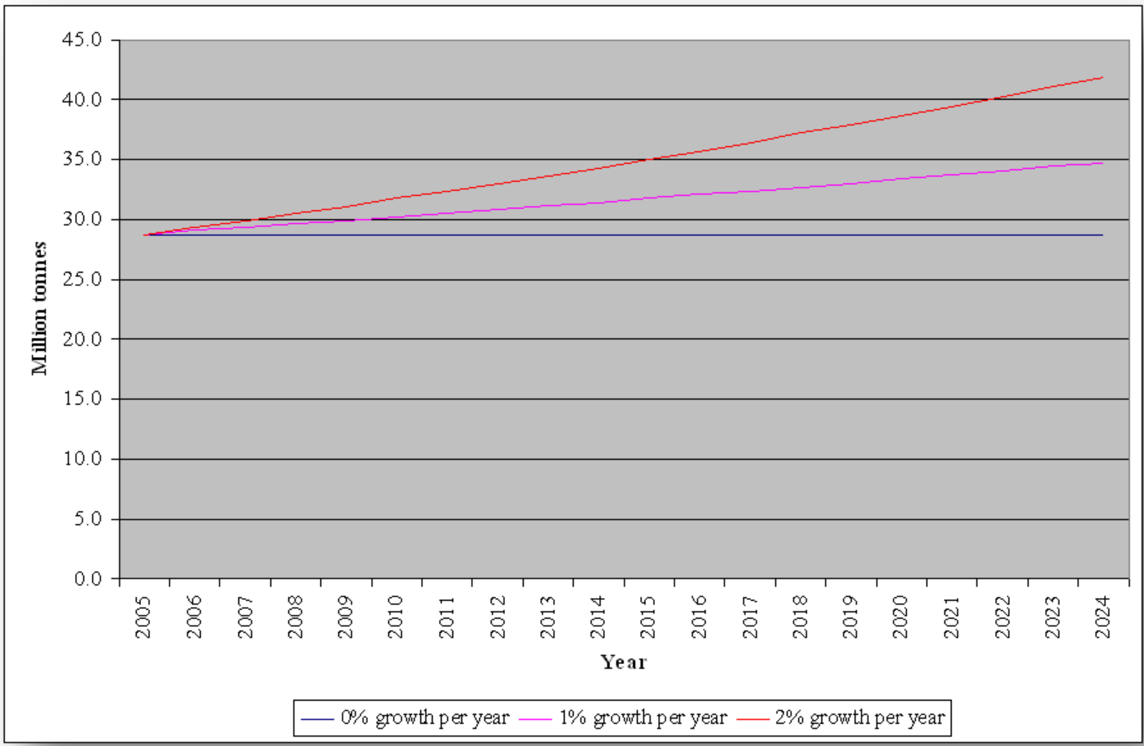
Figure 1.53 shows that an average growth rate of 1% per year would increase the arisings of MSW to 33.3 Mt per year by 2020 (an average growth rate of 2% per year would result in MSW arisings of 38.7 Mt by 2020).

[10] Eurostat - ec.europa.eu/eurostat

[11] Future Foundation 2006. Modelling the impact of lifestyle changes on household waste arisings in the UK. Report by the Future Foundation and Social Marketing Practice for Defra 2006.

[12] Oakdene Hollins 2005. Quantification of the Potential Energy from Residuals (EfR) in the UK. Report by Oakdene Hollins for The Institution of Civil Engineers and The Renewable Power Association, March 2005.

Figure 1.53: Projected MSW arisings in England



Future energy recovery potential

The Landfill Directive will require England to landfill a maximum of 5.2 Mt of biodegradable waste in 2019/20 (this is equivalent to about 8 Mt of landfilled MSW).

The Waste Strategy sets a target of recycling 50% of household waste by 2020. As household waste represents a high proportion of MSW, it is likely that this will equate to a 50% recycling rate for MSW. The projected arisings of MSW in 2020 are 33 Mt, and if the 50% recycling rate is achieved, the arisings of residual waste in 2020 will be about 17 Mt/y.

The amount of waste that will need to be recycled in order to meet this target will include waste which is composted. The collection of a significant tonnage of food/kitchen waste will be required in order to achieve the 50% recycling target, and whilst the Animal By-Products Regulations (ABPR) require these to be treated using either in-vessel composting or anaerobic digestion (AD), the Government has, through the waste strategy, indicated its preference for AD because of its potential for energy generation. This could result in a minimum of 1 Mt of MSW sourced food/kitchen waste being treated in AD plants.

If 17 Mt are recycled (the 50% recycling rate is achieved), and the maximum permitted tonnage of 8 Mt of MSW is landfilled (this figure includes reject streams from MBT plants), then a further 8 Mt will need to be diverted from landfill. Although this waste could be composted in order to reduce its biodegradable content to a very low value, and thus stabilise it, Government policy initiatives are much more likely to result in energy being recovered from it. This figure of 8 Mt is likely to be a minimum as the amount of waste will continue to grow during the typical 25-year lifetime of a treatment plant, and this suggests that the potential amount of waste in England from which energy would be recovered in 2020 is likely to be between 9 Mt and 10 Mt/y (see Figure 1.52b).

CHAPTER 2: ENERGY RECOVERY FROM MSW (ONE STEP FURTHER)

Edward Pfeiffer (KEMA) and Timo Gerlagh (NL Agency, formerly SenterNovem)

Introduction

Over the last few decades, the solid waste management systems in many OECD countries have changed significantly. In the past, landfill was the standard disposal route for waste. However, in recent times, waste management has been all about utilising the value of waste in terms of material and energy in the best way possible. The various components of the solid waste management system have been arranged into what has become known as the waste hierarchy. The waste hierarchy is what the waste management policy in most countries is based on. In the first place, it promotes prevention and material recycling. When recycling is not feasible energy recovery is the main option. Landfill is the least preferred option in the chain.

Waste hierarchy, the integrated solid waste management approach:	
Prevention	Life-cycle design, cradle-to-cradle approach
➥ Recycling	Product and material recycling as long as practically reasonable
➥ Energy recovery	Utilisation of combustible non-recyclable waste as an energy source
➥Final disposal	Environmentally safe storage of inert, non-recyclable waste in landfill sites

This hierarchy is implemented in all countries that were present at the workshop. However, differences in implementation are enormous. In particular, the role of EfW shows a variety of policy interpretations, making it impossible to draft one clear picture for the optimal energy recovery system. Therefore, the title of this chapter refers to bringing the energy recovery 'one step further' since an attempt to define just one optimal solution would not be appropriate. The main question is:

Which policy measures are the most effective in a country to improve the energy production from non-recyclable waste?

This chapter will further:

- describe the most important differences between countries;
- investigate the potential of the different technologies employed;
- give the overall lessons learned from the workshop;
- specify the lessons for four different stages in EfW development.

The following abbreviations and definitions are used throughout this chapter:

BAT best available technology
CHP combined heat and power
EfW energy from waste, the technologies aiming to recover energy from waste
LFG landfill gas
MBT mechanical biological treatment, non-thermal treatment technology of MSW
NGO non-governmental organisation
SRF solid recovered fuel, fuel made from waste, to be used in industrial boilers or co-firing

WtE waste to energy, power plants using MSW as fuel, often based on grate technology

The current waste management situation and differences between countries

By using waste as an energy source, the environmental performance of a waste management system improves considerably. Quite simply, the use of fossil fuels is replaced and bio-energy can be produced. Looking at the waste used in WtE plants, roughly 50% (energy based) is biomass and this proportion of the energy recovered can, therefore, be counted as renewable energy.

Three types of energy recovery have been identified: to produce electricity only, to produce heat only and to produce a combination of electricity and heat (CHP). For many years in the Netherlands, energy production has focused on electricity[13], whereas for the last few decades in Scandinavian countries the focus has been on heat production (currently, there is a shift in interest towards CHP).

Table 2.1: Key figures market penetration of WtE and its energy efficiency (most data 2006)

Country	Combustible, non-recyclable MSW		Energy recovery	
	Mt/year	Incineration	Electricity	Heat
Germany	15.1	98%	11%	33%
France	20.3	55%	6%	16%
Netherlands	5.9	93%	14%	13%
Sweden	4.3	95%	10%	86%
United Kingdom	20[14]	17%	13%	4%
Norway	1.7	35%	7%	92%
Canada	9.2	6%	7%	28%

Table 2.1 gives an indication of the incineration and energy recovery rates in the different countries. The totals in the second column are the sum of MSW incinerated and landfilled. The amount of waste incinerated is well known in most countries, but the amount of combustible, non-recyclable waste that is landfilled is more difficult to extract from available statistics. Most countries know the amount of household waste incinerated; because these data are available and comparable between the countries, these were used for Table 2.1. However, this ignores commercial and industrial waste that is non recyclable and combustible[15]. This means that the incineration percentages are high estimates. Despite this limitation, Table 2.1 clearly shows the differences in current waste management systems. This strongly influences the best approach for policies to optimise energy recovery. In some cases, most waste is already incinerated and efficiency improvements should be found within the current system. In countries such as the UK and Canada, new

[13] This figure still underestimates the focus on electricity. Most heat is, in fact, used to raise steam for the production of electricity by integrating the steam cycles of incineration with a nearby gas-fired CHP-plant (at Moerdijk, NL). In case this plant is counted as an electricity producer, the energy recovery rates for electricity and heat are 18% and 4%.

[14] Due to an increase in recycling, it is not to be expected that all the MSW is available for energy production, only 8-9 Mt/year should be considered combustible, non-recyclable waste.

[15] For France, we know that this is about 13 Mt/year, for the Netherlands 1 Mt/year. The incineration percentages are, therefore, high estimates. For France, the percentage would be 35% and for the Netherlands 80%, if these streams were included.

plants will be built in the near future and, therefore, more opportunities for the introduction of heat and electricity will be possible.

This chapter briefly describes the current status in the development of EfW and attempts to identify the best route for energy optimisation for a number of given (national or regional) situations. It is clear that for a country where incineration plays a minor role and is not a well-accepted technology, an alternative strategy is required compared with a country where WtE is well established and accepted.

During the workshop, the situations of the countries mentioned in Table 2.1 were used as examples for strategies on energy recovery from MSW. Furthermore, a discussion was initiated on how to bring the WtE infrastructure one step further in those countries. This chapter discusses the results in a comprehensive way, paying attention to drivers and barriers for energy recovery from MSW and how national policies can influence these in a positive way. Drivers and barriers are divided into certain policy areas, briefly described here.

Policy areas influencing EfW

Besides the waste policy where EfW is preferred to landfilling and incineration without energy recovery, a number of other policy areas influence the potential for energy recovery. Energy and climate policy has a significant impact in cases where energy efficiency and emissions reduction due to LFG emissions reduction are important topics. An underestimated policy area is spatial planning, which has a major impact on the siting of waste incinerators in the first place and to the subsequent ability to utilise waste heat from the combustion process.

Policy areas interacting with EfW:	
- Waste policy	Defines the framework for waste management systems.
- (Renewable) energy policy	Defines the role of EfW positioning the energy infrastructure, recognises renewable energy component.
- Climate change prevention policy	Interacting with the waste management hierarchy.
- Environmental policy	Defines environmental preconditions for EfW.
- Spatial planning policy	Describes where EfW facilities may be built.
- Industrial and innovation policies	Promote the development of industry and/or technologies.

Although this looks relatively straightforward, in practice, overlap occurs between policies - policies strengthen each other or can be counterproductive. The influence on the development of EfW can be positive or negative. There can be a significant difference between policies, implementation and the market response. Also, differences occur when it comes to how waste management should be implemented between national policies and policies on a regional level. Besides the impact of policies, other factors also play an important role in the way EfW is managed. The major external factors are:

- Energy market: When energy prices are high due to local market conditions, the world energy market or high tax rate on fossil fuels, the energy market becomes a driver.
- Geographic location: The higher the latitude the better the opportunities for district heating in cities; at lower latitudes district cooling may be an additional driver.
- Cultural aspects: Centralised and social versus decentralised and individual cultures. In the former, culture is a driver. In the latter, culture is a barrier for more EfW.
- NGO position: NGOs are very important in relation to the public acceptance of EfW. Therefore, their position is discussed in more detail.

NGOs and public acceptance

In relation to EfW, NGOs are important stakeholders (in addition to authorities and the market). Due to their impact on public opinion, it often appears that they can make or break a project. The different positions taken by NGOs in different countries reflect the complexity of the public-relations topic and, as a consequence, virtually every EfW case has to be treated separately and on its own merits. Some general comments are made in the box below.

Comments on NGOs and energy from waste:

- All NGOs agree that waste management systems have to be improved to move away from landfilling!
- The NGO position towards EfW can differ considerably from country to country.
- Even within a country, the NGO position can differ.
- In countries where NGOs are mostly against it, EfW has a bad reputation.
- When EfW has a good reputation, NGOs accept it if it is performing above a minimum standard.
- In local situations, the 'not in my back yard' (NIMBY) phenomenon plays an important role, whatever the waste management solutions are.
- Small-scale solutions are often preferred to large-scale solutions.
- CHP or heat only is preferred to electricity only.
- Often, biological treatment solutions are preferred to thermal treatment.
- The ultimate goal is the 'zero waste society' - better to be realised today than tomorrow.
- The NGO concern is that investments made in EfW hamper the development towards a zero waste society.

In the zero waste society, waste management is all about prevention and product/material (reuse) recycling. The ideal consequence is that no waste is available for EfW applications or final disposal. Another approach based on these values is 'cradle-to-cradle', meaning everything is designed for reuse making effective recycling or even up-cycling (increasing quality of use) possible. Developing the waste management system, including its EfW applications, must not obstruct the way towards the ultimate goal: a sustainable society.

The best approach for constructive interaction with NGOs and public acceptance:
- Prepare the interaction by means of stakeholder analysis, know their arguments and background.
- Early stage interaction with NGOs is recommended, discover common criteria before making choices.
- The improvement of the waste management system has to be the leading objective.
- Don't look at the single solution only, but place the initiative in the waste hierarchy.
- Locations for processing facilities have to be selected with care using rational arguments.
- Make an environmental impact assessment at an early stage, look seriously at the alternatives.
- Apply BAT as long as it is reasonable and well proven.
- Show the risks of applying innovative technologies on full scale.
- Show the impact of doing nothing, prove that it is time to act and losing time harms the environment.
- Visit similar projects and plants to that intended in the new project, organise stakeholder-to-stakeholder contact.

Energy potential from technologies

Based on the introduction of the EfW topic and the lessons learned, effective policy approaches can be derived leading towards EfW technologies being more extensively applied. To put these approaches in perspective, it is important to know how different methods of waste treatment are related to each other when it comes to energy recovery. The box on the next page presents the key figures.

Lessons learned from Europe on delivering a sound waste management infrastructure[16] and thus creating a sound environment for taking EfW one step further include:
- a regime of certainty making it possible to invest;
- partnership in waste management between different governmental layers;
- transparency creating a basis for public trust;
- an integrated approach across waste streams and their treatment methods.

These aspects can be analysed for the stages in the development of EfW. In the EfW policy approaches, four stages can be identified:
- Stage 1 Utilisation potential of biogas from landfill.
- Stage 2 Production of electricity by means of combustion or digestion.
- Stage 3 Integrated CHP.
- Stage 4 Innovations (towards higher energy utilisation rates).

These stages are described in section 3 and a level of waste utilisation and energy recovery typical for each stage of development is given. Definitions of the terms used in these descriptions are given below. This chapter will not investigate the potentials of the different technologies used, albeit they play a major role in many discussions on energy from waste. Therefore, a short overview of the different technologies is also given in this section.

The development of energy utilisation can be defined in two ways

Starting at stage 1, each stage takes EfW one step further by:

[16] Delivering key waste management infrastructure: lessons learned from Europe, SLR Consulting/The Chartered Institution of Wastes Management, November 2005.

- Increasing the utilisation rate of non-recyclable, combustible **waste** streams W-rate.
- Increasing the **energy** recovery rate per MJ of waste being used as a fuel E-rate.

Definitions of different ratios indicating the extent to which waste is utilised as an energy source:
W-rate: Waste utilisation rate, ratio in % between the waste used as an energy source and the amount of the combustible, non-recyclable waste in a certain country in PJ/year (mass x heating value).
E-rate: Energy recovery rate, ratio in % between the useful energy produced and the energy content in PJ of the waste used in EfW systems.

In reality, a mixture of several stages can occur in a country. The status is determined by the mainstream technologies (including their performance) used in the waste management system. How EfW can be taken one step further and how interaction with policies take place is explained below for each stage.

Potential of different technologies:
This chapter does not analyse the relationship between energy recovery and the technology chosen. However, because of the importance of technology for energy recovery, some comments should be made here. Within Task 36, a lifecycle analysis (LCA) comparison is made of different treatment routes for MSW. The WRATE-model is used, which as one of the results calculates the energy recovery of the waste management system analysed. This is the energy produced in electricity and heat as a percentage of the energy content of the input waste. In the case of fuel production from waste, the energy produced in an external power plant is included. The final energy recovery is from 6% (for a high-quality modern landfill with LFG recovery and heat production) to around 95% (for a waste incinerator with high-efficiency CHP, as currently available in Sweden). For MBT, a wide range of outcomes is presented due to the different possibilities for the use of the high-calorific fractions produced. This means that in the case of bio-drying/separation (especially with a high percentage of fuel production and energy recovery with high efficiency (95%, as in CHP incineration)), the overall efficiency can end up around 60%. With lower percentages of fuel recovery and only electricity production, the overall energy recovery is around 15%. In cases where the biological treatment is only meant as a pre-treatment for landfill, the energy production is much lower. For landfill, the LFG production is limited even in the case of a well-managed landfill site. With optimal recovery of the gas and maximum energy recovery, the energy production as a percentage of the energy content of the waste landfilled is only 6%.

Technology	**Potential energy recovery**
Incineration (electricity)	25%
Incineration (CHP)	40%-95%
MBT bio-drying/separation	15%-60%
MBT anaerobic digestion/separation	15%-30%
MBT stabilisation for landfill (limited SRF-production)	8%-15%
Landfill	6%

Stages in development

The four stages mentioned in section 2 above are described in this section. Section 4 will show the situation in the specific countries of the IEA Bioenergy Task 36.

Stage 1: Proper landfilling and material recycling

Stage 1 is applicable to countries where landfilling is the most common practice and where WtE is not well accepted due to reasons such as:

- too expensive compared with landfill due to high investments and low energy prices;
- no limitation in the availability of landfill sites close to sources of waste;
- the belief that the environmental impact is worse compared with landfill;
- the belief that WtE impedes the growth of material recycling;
- no stringent policy on energy recovery of combustible, non-recyclable waste.

In stage 1, the public acceptance for EfW technologies in general, and WtE in particular, is low and often confirmed by poorly performing, non state-of-the-art EfW facilities in a country. In general, the waste management policy will focus in the first place on proper landfilling, minimising the environmental impact and the escape of harmful greenhouse gases (particularly methane (CH_4) and nitrous oxide (N_2O)), and maximising the recovery of LFG. LFG is used in gas engines or upgraded to 'green' gas (bio-methane) and injected into the natural-gas grid or used locally for transportation purposes. Stage 1 also deals with material recycling, including composting. Attention is paid to the promotion of schemes for separate collection and the build-up of a proper recycling infrastructure. The extent of recycling has to be carefully considered since:

- recycling leads to degradation of the material being recycled, demanding more and more energy and other resources;
- high-end utilisation of recycled materials and/or products need to be guaranteed.

In waste management planning, the capacity for EfW facilities is the result of, on one hand, optimistic estimation of the impact of prevention measures and the recycling capacity and, on the other hand, a conservative approach of the waste supply. Thus, preventing the build-up of excessive EfW capacity is of importance. When there is not enough EfW capacity, export or landfilling take care of the excess waste volumes.

In stage 1, strategic planning is essential to indicate how much EfW capacity is needed in the mid term (say e.g. the next ten years) to improve the performance of the waste management system. Also, indications have to be given of locations, sizes and criteria applicable to the selection of new EfW projects. In relation to energy, these criteria can either be modest or stringent, aiming at high energy efficiency by means of CHP. In the latter case, policies have to be in place promoting CHP and bringing heat supply and heat demand together in such a way that doesn't lead to unreasonable extra waste-treatment costs.

Special interest is often focused on innovative technologies, as an alternative to traditional mass burn systems (e.g. gasification, pyrolysis, plasma treatment and MSW digestion technologies), because the societal and political acceptance for these technologies is often high. However, experience over time has shown that, in many cases, only pilot plants have been demonstrated, with varying results and no subsequent scale-up to mainstream market application. The search for the ultimate technology doesn't mean that it is not allowed to apply traditional tried-and-tested technologies. A transition, supported on a national scale, is often the best way to introduce new technologies in the waste management system.

Table 2.2: Policy impact matrix stage 1, proper land filling and material recycling

Policy category	Driver	Neutral	Barrier
Waste policy	++		
Energy policy		√	
Renewable energy policy	+	√	
Climate policy	+		
Environmental policy	+		
Spatial planning policy		√	+
Industrial, trading policy	+	√	
Innovation policy	+	√	
Waste policy is the main driver towards proper landfilling and recycling. The climate, environmental and renewable energy policy are drivers, too. Innovation, industrial and trading policies can be a driver mainly in relation to material recycling.			
W-rate: from below 0% (dumping, no LFG extraction) to 100% (state-of-the-art landfill sites everywhere) E-rate: around 10%, LFG is converted to electricity by means of gas engines			

Stage 2: Electricity production in waste-to-energy plants

Stage 2 is applicable to countries moving away from landfilling of combustible waste and having a well-established material recycling system.

Once proper landfilling and material recycling is in place, the emphasis can change towards EfW systems that are fuelled by non-recyclable, combustible waste. Whatever the local situation is, electricity can be produced in all cases and is thus the most common way of utilising the energy content in the waste. The main technologies are:

- biological treatment: digestion of biodegradable waste and the resulting biogas is used in gas engines;
- thermal treatment: waste combustion by means of grate firing or fluidised bed systems.

The main policy leading to the growth of EfW facilities is a ban on combustible wastes going to landfills, often part of an integrated waste management policy. The ban is sometimes enforced by a taxation system, making landfilling so expensive that WtE makes economical sense. In practice, a landfill gate fee of around 100 euro/tonne will be sufficient to enforce a change in the waste management system towards energy recovery. Energy policy can be of help in making energy recovery more feasible, especially when existing energy prices are low. In promoting EfW facilities, careful attention has to be paid to site selection (leading to optimal locations) and, from the point of view of energy, sizing to prevent overcapacity. The impact of energy, renewable energy and climate policy is still relatively low since the energy income is small compared with the gate fee, typically in the order of 20%.

Table 2.3: Policy impact matrix stage 2, electricity production in WtE plants

Policy category	Driver	Neutral	Barrier
Waste policy	++		
Energy policy	+		
Renewable energy policy	+	√	
Climate policy	+	√	
Environmental policy		√	
Spatial planning policy			+
Industrial, trading policy		√	
Innovation policy		√	
Waste policy is the main driver towards electricity from waste. The energy, climate and renewable-energy policy are drivers too. Spatial planning is often a barrier leading to a lack of suitable locations.			
W-rate: between 80% (some landfill with no LFG extraction) and 100% E-rate: between 15% and 25%, energy conversion is a mixture of LFG, digestion and mass burn			

Stage 3: Integrated CHP approach

Stage 3 is applicable to countries focusing on combined heating (cooling) and power applications instead of electricity-only production. Site selection is crucial for energy supply and energy demand. Supply and demand, especially when they are of the same order of magnitude, have to be brought together to make heat (cooling) delivery economically feasible. To site heat demand (district heating and cooling, heat demand in industry, heating greenhouses, etc) and heat supply by means of EfW technologies close together, the public acceptance and the trust in the technology and reliability of heat supply has to be great. In each new project, CHP has to be the starting point in the development, being as high on the agenda as the waste supply itself. Support of local authorities and stakeholders is a pre-condition for the development of successful CHP projects. Since the infrastructure needed to create CHP is, in most cases, expensive, circumstances have to be created making investments possible under normal market conditions. For example, this can often be ‘soft loans’ or the government investing in infrastructure and owning it for the first five years or so.

Table 2.4: Policy impact matrix stage 3, integrated CHP approach

Policy category	Driver	Neutral	Barrier
Waste policy		√ (?)	+
Energy policy	++		
Renewable energy policy	+		
Climate policy	+		
Environmental policy		√	
Spatial planning policy	++		
Industrial, trading policy		√	
Innovation policy		√	
Energy policy is the main driver towards more CHP. The spatial planning policy is crucial for CHP success, bringing heat demand and supply together. Waste policy is sometimes a barrier since facilities promoted by waste policies are often located in remote areas.			
W-rate: almost 100%, all combustible waste is used as an energy source, effective landfill ban (some countries directly implement CHP and, therefore, could have a lower W-rate) E-rate: between 25% and 55%, energy conversion mainly by means of CHP, almost no LFG			

Stage 4: Innovation and increased energy utilisation rates

Stage 4 is applicable to countries were CHP applications are common and a next step is to, possibly, increase utilisation of recovered energy. Stage 4 innovations can also occur in former stages as a demonstration project. In stage 4, innovation and high utilisation of recovered energy are mainstream. Stage 4 countries are international trendsetters.

Increasing the utilisation of recovered energy is possible by:
- lowering internal energy consumption (electricity and heat);
- higher gross electricity conversion efficiencies, by means of high steam parameters, ORC (Organic Rankine Cycle), etc;
- higher CHP efficiencies by means of flue-gas condensation, heat-pump applications, etc;
- energy storage facilities;
- improved re-use of by-products, an indirect energy effect;
- highly energy efficient SRF applications.

Table 2.5: Policy impact matrix stage 4, innovation and increased energy utilisation rates

Policy category	Driver	Neutral	Barrier
Waste policy		√	
Energy policy	++		
Renewable energy policy	++		
Climate policy	+		
Environmental policy		√	
Spatial planning policy		√	
Industrial, trading policy	+		
Innovation policy	++		
(Renewable) energy policy in combination with innovation policy are the main drivers towards high performance EfW systems. Climate and industrial policies can support this development.			
W-rate: 100%, all combustible waste is used as an energy source, effective landfill ban E-rate: between 45% and 85%, high CHP rates, integration with industry, high electrical efficiencies On a national level, it is almost impossible to go beyond 35% due to asynchronous supply and demand.			

Energy from waste development stage IEA Task 36 countries

The EfW development stage differs from country to country. Even in the EU, where a common waste management policy exists, the development stages differ. In Figure 2.1, an overview is given of the development stage in the IEA Bioenergy Task 36 countries. Countries with high energy utilisation rates (X-axis) are Germany, Sweden and the Netherlands. Lower utilisation rates occur in Canada, France and the United Kingdom. Norway is a special case. The number of EfW systems in Norway is limited, but the utilisation rate is good because waste is exported to high performing WtE plants in Sweden. The energy recovery (Y-axis) shows a marked difference between the Scandinavian countries, with an almost 100% recovery of available energy, and the other countries. The difference is due mainly to the emphasis on heat production in the Scandinavian countries (see Figure 2.2). This figure also shows that, for high energy-recovery rates, heat is the key factor.

Figure 2.1: The amount of combustible waste incinerated (X-axis) and energy (Y-axis)

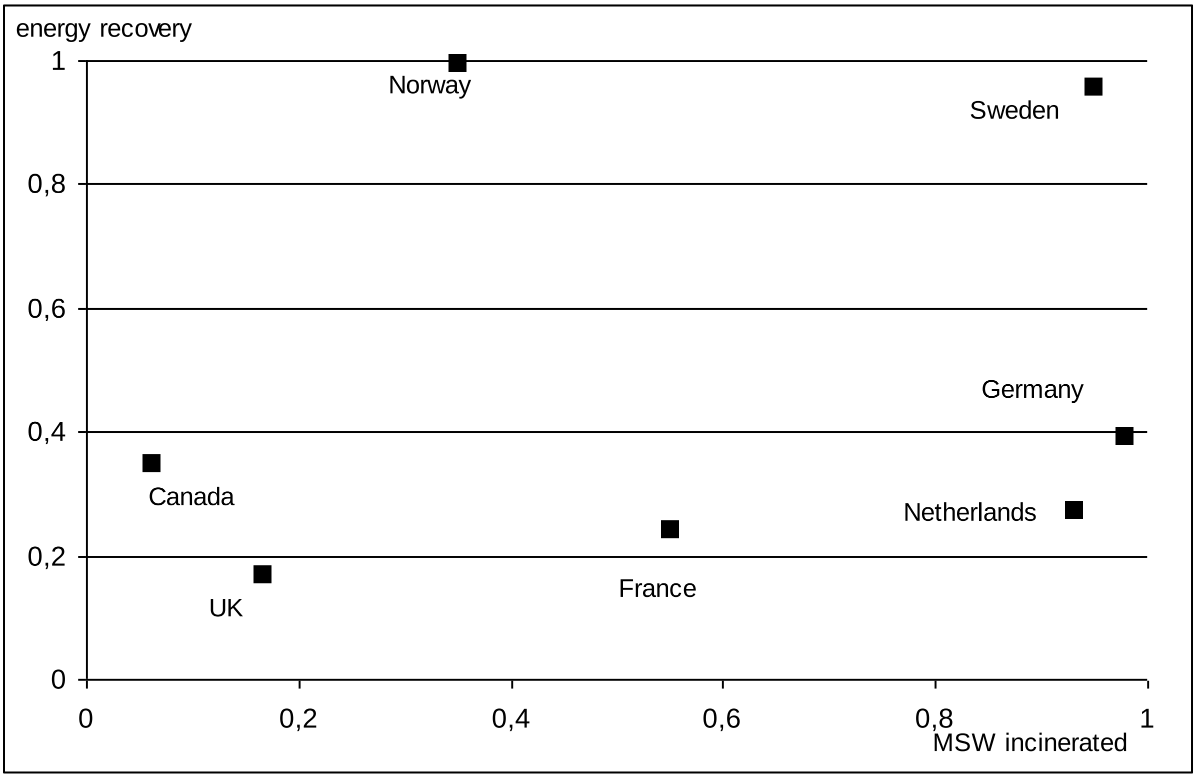
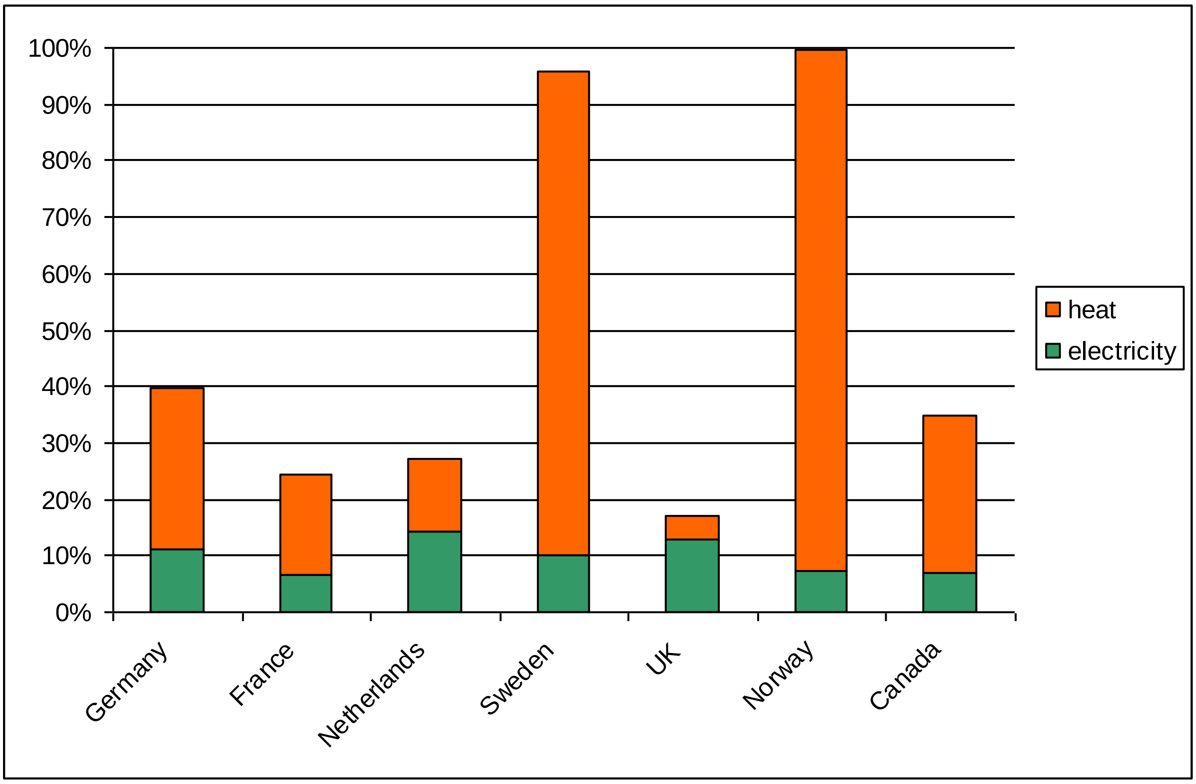


Figure 2.2: Energy recovery from waste incineration as percentage of the heat content of the input



Country-specific situation

The main drivers and barriers for the development of EfW in the Task member countries are presented below. In combination with the data presented above, this leads to the four-stage development as described in this chapter. It is difficult to describe all countries in terms of the stages mentioned above. However, the points mentioned give a good indication of the position of the country within the framework described.

The Netherlands

- Waste incineration is the common treatment method for MSW. Electricity production is well developed thanks to subsidies for (renewable) EfW, but the heat potential is not extensively exploited.
- The high investment costs of heat networks, combined with low energy prices, presents a high barrier for heat use from incineration. It is difficult to find someone who will take the responsibility for the heat network.
- Spatial planning is vital. What is needed is more insight into heat demand in the vicinity of incinerators and an active policy to cover the long-term risks of building heating capacity.

Germany

- The introduction of a ban on landfilling untreated organic waste in 2005 was a strong driver for waste incineration with energy recovery.
- The incineration capacity has been increased by 50% in subsequent years.
- Siting of waste incineration plants with only electricity export has been revised after the decision of the European Court on 'disposal' versus 'recovery' of waste in an incinerator (February 13, 2003). Progress is slow since the total capacity has almost been reached.
- Energy policy became a driver during recent years and improved energy efficiency is high on the agenda - although no promotion activities in terms of extra tariffs are in place.
- Public perception promoted MBT for a long time. Technical and economical problems as well as over-estimated markets have subdued development.
- Energy policy is a particularly strong driver for SRF from clean sources of waste. The cement industry is a frequent customer, so also is the lime industry, whereas the future of co-combustion in power plants seems unclear.
- Technology development might improve the situation in the SRF market if economics are favourable.

Norway

- The landfill ban in 2009 will finally increase the use of waste as a fuel.
- Due to the cold climate and the dominant role of hydropower, there is a high interest for heat production.
- Differentiated fees for landfill and incineration resulting in a shift away from landfill.

France

- During the last ten years, the incineration capacity stayed quite stable, but the number of units declined from 330 to 116 sites by the closure of small units (fewer than 10,000 t/year).
- Policy for waste treatment led to a reduction in landfill and incineration, and a focus on waste minimisation, organic valorisation and recycling. Incineration is not really considered an option in this discussion
- A tax similar to the one existing for landfill will be introduced in 2010 for incineration

- The energy recovery will stimulate anaerobic digestion and LFG recovery. Public acceptance is the key factor in the further development of waste incineration. Integration with a waste reduction strategy is vital in getting more incineration accepted.

Sweden

- Energy recovery levels are very high as a result of past decisions to integrate waste incineration into the heat infrastructure.
- Reduction of landfilling by recycling and incineration of the residual waste.
- Waste incineration is integrated in heat production infrastructure.
- Carbon emission tax is differentiated for incineration, with and without energy production.
- Changes in heat demand, due to less cold winters, lead to a renewed demand for balancing heat supply and demand.

Canada

- No active policy so far on the reduction of landfilling; the main interest is on the reduction of LFG emissions at a provincial level.
- Increasing interest in alternative fuels and technologies.
- Public acceptance is essential in the approval of new waste treatment infrastructure and the endorsement of novel technologies.
- Renewable energy incentive programmes in some provinces have led to more energy generation from LFG.

United Kingdom

- The Landfill Allowance Trading scheme (LATs) has been introduced to encourage the diversion of biodegradable waste from landfill and to ensure the UK meets its targets for reducing biodegradable waste in landfill.
- Reference: http://www.defra.gov.uk/environment/waste/localauth/lats/index.htm
  At a national level, a number of alternative technologies to landfill are being supported. The market lead is EfW, but there are market mechanisms in place to support new alternative technologies, such as anaerobic digestion. For example, the Renewable Obligation, which places an obligation on all power suppliers to supply a certain percentage of renewable power, has been updated so that novel technologies receive more reward per MWh generated. These technologies include advanced combustion technologies (including those using waste feedstock) and a part of the power generated by waste CHP plants.
- Public acceptance is vital in developing a new waste-treatment infrastructure. In the UK, the public is wary of EfW. This has the effect of encouraging local authorities to select new technologies, which may be less efficient in energy recovery, because the public do not have such a strong aversion to these technologies. The Government's Waste Infrastructure development programme has been developed to encourage the right infrastructure at the right time.
- Overall, waste incineration, including energy recovery, will increase during the years leading up to 2020 (see section 1).

Further reading/more data

- Delivering key waste management infrastructure: lessons learned from Europe, SLR Consulting/The Chartered Institution of Wastes Management, November 2005.
- CEWEP-country-information. Regulatory updated on website http://www.cewep.eu/
- ISWA, Energy from Waste, State-of-the-Art- Report, Statistics 5th Edition, Copenhagen Denmark, August 2006.
- For France www.sinoe.org

All country presentations of the workshop can be found at:
http://library.ieabioenergytask36.org/vbulletin/showthread.php?p=5#post5

CHAPTER 3: ENVIRONMENTAL IMPACTS OF MANAGING RESIDUAL MUNICIPAL SOLID WASTE

Judith Bates, AEA

Introduction

This chapter compares the environmental impacts of a range of options for managing residual municipal solid waste (MSW), i.e. the waste that remains after source separation of recyclable fractions. The options are compared to see whether particular types of waste management treatments offer any particular environmental benefits and whether it is possible to discern a hierarchy of environmentally preferred options.

Waste management options modelled

A wide range of options are available for treating the residual component of MSW, ranging from combustion based techniques to biological processes such as anaerobic digestion and composting. There are also systems which combine elements of both, using sorting techniques to recover recyclable materials such as metals, and splitting the waste into an organically based component which can be biologically treated and another fraction - a refuse derived fuel (RDF) which can be combusted. Six examples spanning this range of options were examined.

1. Energy from Waste (EfW) plant exporting electricity.
2. EfW plant exporting heat and power (combined heat and power - CHP).
3. Mechanical Biological Treatment (MBT) plant where recyclable materials such as metals are first separated out and the remaining waste is:
    a. biodried to produce a refuse derived fuel which is burnt in an EfW plant;
    b. sorted into an organic component which is anaerobically digested and a fraction which is burnt in an EfW plant;
    c. sorted into an organic component which is composted and a fraction which is burnt in an EfW plant.

For comparison, the option at the bottom of the waste hierarchy, landfill, was also examined. The characteristics of the plant were chosen to be typical of what can be achieved today with modern plant. A description of the plant and key characteristics are given in Table 3.1. While the list of examples examined is not exhaustive, it covers the main types of treatment options in use across IEA countries.

Table 3.1: Characteristics of waste treatment options

Scenario	Abbreviation	Details
Energy from Waste - electricity production	EfW	Facility has an inclined reverse-acting grate capable of burning a broad range of waste calorific values without the need for any auxiliary fuel. Dry urea is injected into the furnace for NOx abatement. Bottom ash is sent for recycling. *Energy recovery: electrical generating efficiency (based on electricity exported and NCV of waste) 23.4%.* *Metal recovery: 80% of ferrous metals and 30% of non-ferrous metals in waste.* *Landfill: for every 1,000 t of waste treated, 26 t of fly ash and flue gas treatment residues are landfilled.*
Energy from Waste - CHP	EfW - CHP	As EfW plant except for energy recovery *Energy recovery: electrical generating efficiency (based on electricity exported and NCV of waste) 21%* *heat efficiency (based on heat exported and NCV of waste) 22%.*
MBT – bio-drying	MBT – bio-drying	Initially, materials are screened and separated. Metals are recovered for recycling, rejects are disposed of to landfill and the remainder of the material is dried to produce RDF. The RDF is then combusted in an EfW plant. *Metals recovery: 82% of ferrous metals and 86% of non-ferrous metals in waste.* *Landfill: for every 1,000 t of waste treated, 164 t of waste are rejected by the MBT process and landfilled and 15 t of fly ash and flue gas treatment residues are landfilled.*
MBT - anaerobic digestion	MBT - AD	Incoming waste is divided into separate substance flows by a number of screening and separating procedures. Subsequent separation of light-density material and medium solids produces a substance suitable for anaerobic digestion. After the AD and oxidation process, the suspension is separated into solid and liquid matter. The liquid is forwarded to the mixer; the solids will first be dried, then landfilled. The initial separation process also produces an RDF, which is combusted in an EfW plant. *Metals recovery: 82% of ferrous metals and 86% of non-ferrous metals in waste.*
MBT - in vessel composting	MBT - IVC	Incoming waste is shredded and then sieved into three fractions. The 'fines' fraction is composted in a closed hall for six weeks, and the stabilite produced is then landfilled. The intermediate fraction produced is separated into materials for recycling and RDF. The oversize fraction is fed back into stabilite for disposal to landfill and some into the bunker for re-shredding. The RDF is combusted in an EfW plant. *Metals recovery: 82% of ferrous metals and 86% of non-ferrous metals in waste.* *Landfill: for every 1000 t of waste treated, 13 t of waste are rejected by the MBT process and landfilled, 662 t of stabilite from the AD process are landfilled, and 1 t of fly ash and flue gas treatment residues are landfilled.*
Landfill	-	The landfill has a clay/HDPE composite liner and landfill gas is recovered and used in a gas engine to generate electricity wherever possible; when this is not possible it is flared. Biological oxidation of methane in the cap is assumed to be 10%. Landfill gas emissions are considered over a 150-year period. Over the lifetime of the landfill, about 50% of the methane is recovered and combusted.

Assessing environmental impacts

The environmental impacts of the different waste management options were assessed using the WRATE software tool. WRATE (Waste and Resources Assessment Tool for the Environment) is an integrated waste management life cycle analysis tool developed for the Environment Agency in the UK[17]. It was developed in conjunction with ISO standards (ISO 14041) on Life Cycle Assessment, and both the data on waste management processes contained in the tool and the tool itself have been peer reviewed. It calculates the potential impacts of all stages in the collection, management and processing of municipal waste. The calculation takes account of the infrastructure and its operation, as well as any benefits associated with materials recycling and energy recovery. The calculation produces an inventory of emissions to air, soil and water and of the use of abiotic (non-renewable) resources, which can be analysed within the tool using a variety of impact assessment methodologies. These methodologies characterise the scenario studied in terms of impact categories, such as global warming, acidification potential, eutrophication, abiotic resource use etc. The tool does not evaluate some of the very local, site-specific impacts which can be associated with waste management options, such as noise and odour.

As the aim is to compare treatment options rather than estimate the impacts associated with managing waste, elements which are common to each treatment route - the collection of waste, management of recyclables collected at the kerbside and transport of the waste to a transfer station - were not included in the modelling. Onward transport of the waste, transport of all recyclables and other products from the waste management process, such as RDF and compost, was included as was transport and final disposal of all rejects and waste products. Assumptions about transport distances are shown in Table 3.2.

The waste composition which was assumed for the modelling (shown in Table 3.3) was derived by looking at waste compositions reported for a number of IEA countries, and is intended to be representative of the residual waste which would be left after separate, kerbside collection of recyclables. Table 3.4 shows assumptions made about the electricity mix. Two aspects to the electricity mix are defined, the generating technologies which make up the average electricity mix - this is used to calculate the environmental impacts associated with electricity used, e.g. to operate equipment at MBT plant, and the ‘marginal mix’ - the type of generation which is displaced or avoided when electricity is produced by the waste management option. As discussed below, the benefits of avoiding conventional electricity generation are quite significant in determining the overall environmental benefits of the waste management options, and the modelling thus also considered the environmental impacts of the options under a variety of marginal mixes.

[17] http://www.environment-agency.gov.uk/research/commercial/102922.aspx

Table 3.2: Transport distances assumed for modelling

Material	Transport stage	km
MSW	Transfer station to first treatment point (EfW plant, MBT plant, landfill)	80
RDF	MBT to EFW	100
Stabilite	MBT to landfill	100
Recylables (metal and plastic)	EfW or MBT to recyclables processor	100
'Rejects'	MBT to landfill	100
Bottom ash	EfW to landfill	100
APC residues	EfW to hazardous landfill	200

Table 3.3: Waste composition assumed for modelling (NCV = 8.8 MJ/kg)

Waste fraction	%
Paper/card	18%
Plastic film	8%
Dense plastics	7%
Textiles	3%
Absorbent hygiene products	5%
Wood	2%
Combustibles	5%
Non-combustibles	3%
Glass	3%
Organic -food waste	25%
Organic -garden waste	8%
Ferrous metals	3%
Non-ferrous metals	1%
Fines (<10mm)	8%
WEEE	1%

Table 3.4: Energy mix assumed for modelling

Energy source	'Average' generation mix	'Marginal' generation mix			
		'Typical' (coal/gas)	Coal based	Gas based	'Low carbon'
Coal	25.4%	50%	100%		
Oil	2.9%				
GAS CCGT	23.9%	50%		100%	15%
Nuclear	22.5%				
Waste	3.6%				
Hydro	14.6%				85%
Other renewables	7%				

Climate change impacts

Greenhouse gas emissions

Landfilling of solid waste produces just over 2% of the total greenhouse gas (GHG) emissions in Europe and in the US[18], and reducing these emissions is an important contribution that waste management can make to tackling climate change. Figure 3.1 compares the greenhouse gas emissions associated with treating 100,000 tonnes of waste in each of the treatment options described earlier. As shown in Figure 3.2, the net overall greenhouse gas balance represents the balance between GHG emissions from the waste management process itself, and emissions savings (shown as negative in the graph) due to the materials which are recycled or energy which is produced. These give emissions savings as they avoid the production of energy and materials elsewhere. A net negative emission indicates that overall the treatment option has led to a net reduction in GHG emissions. This does not necessarily mean that managing waste via this treatment option would lead to a reduction in GHG emissions as, described earlier, common elements of the waste management process, such as collection of the waste, have been excluded,

The main sources of GHG emissions are methane (CH_4) contained in fugitive landfill gas emissions, i.e. landfill gas which is not recovered from the landfill and therefore seeps out into the atmosphere, and carbon dioxide (CO_2) released when materials containing carbon from fossil fuel sources (e.g. plastics) are combusted. CO_2 which is of biogenic origin, e.g. from combustion of food and garden waste and of the paper and card in the waste, is not considered to contribute towards global warming, as it is 'short cycle' carbon, i.e. it has been sequestered from the atmosphere relatively recently[19].

The key emissions savings that the waste treatment options offer are from the energy produced, which avoids production of electricity from fossil fuels, and recovery of metals for recycling, which avoids production of metals, particularly for aluminium which is a very energy intensive process.

It is clear from Figure 3.1 that all of the options considered offer significant benefits over landfill in climate change terms, reducing GHG emissions from managing the waste by at least 35% compared to landfill (i.e. from 19 kt CO_2 eq for landfill to 12.5 kt CO_2 eq for the worst performing option, MBT with in-vessel composting and RDF going to EfW). The benefits are largest for routes where all the waste is combusted in an EfW plant, with the bio-drying route also offering significant benefits. In both of these cases there is an overall reduction in GHG emissions. This is due to the large amount of energy recovered in these cases which leads to a large 'credit' due to the CO_2 emissions from conventional electricity generation which are avoided. The amount of energy recovered in each waste management option, which is shown in Table 3.5, has a strong influence on the climate change impact.

[18] Based on data from national greenhouse inventories for 2007 for the US and European Community as submitted to the UNFCCC, available from http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/4771.php

[19] This assumption is also made e.g. in the preparation of national estimates of greenhouse gas emissions.

Table 3.5: Energy recovered from the waste

	Net electricity exported kWh/t*	% of energy content of waste
EfW	574	23%
MBT - bio-drying; RDF to EfW	462	19%
MBT - AD + RDF to EfW	349	14%
MBT - IVC + RDF to EfW	176	7%
Landfill	138	6%

* i.e. electricity generated minus any electricity used on plant

Recovering and using both heat and power from the EfW plant improves the environmental performance of all the waste management options which use EfW, emphasising the importance of considering the use of CHP where it is feasible.

Figure 3.1: Comparison of climate change impacts (for managing 100 kt of MSW)

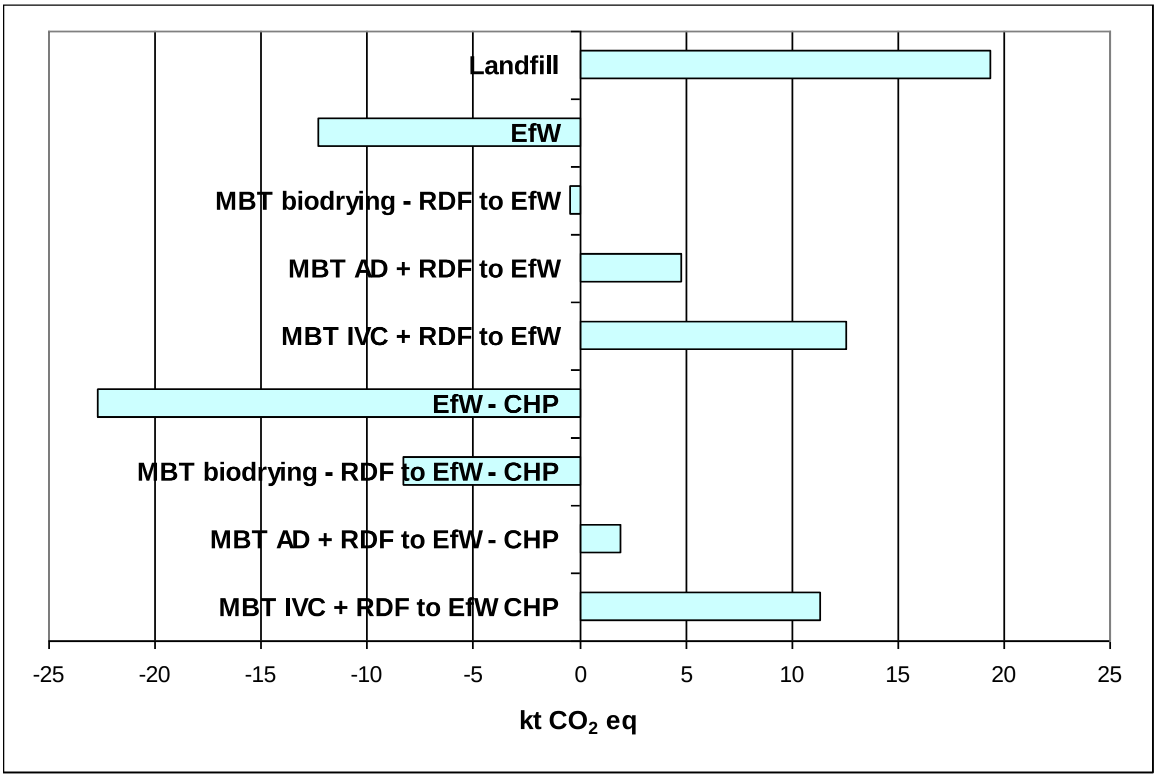
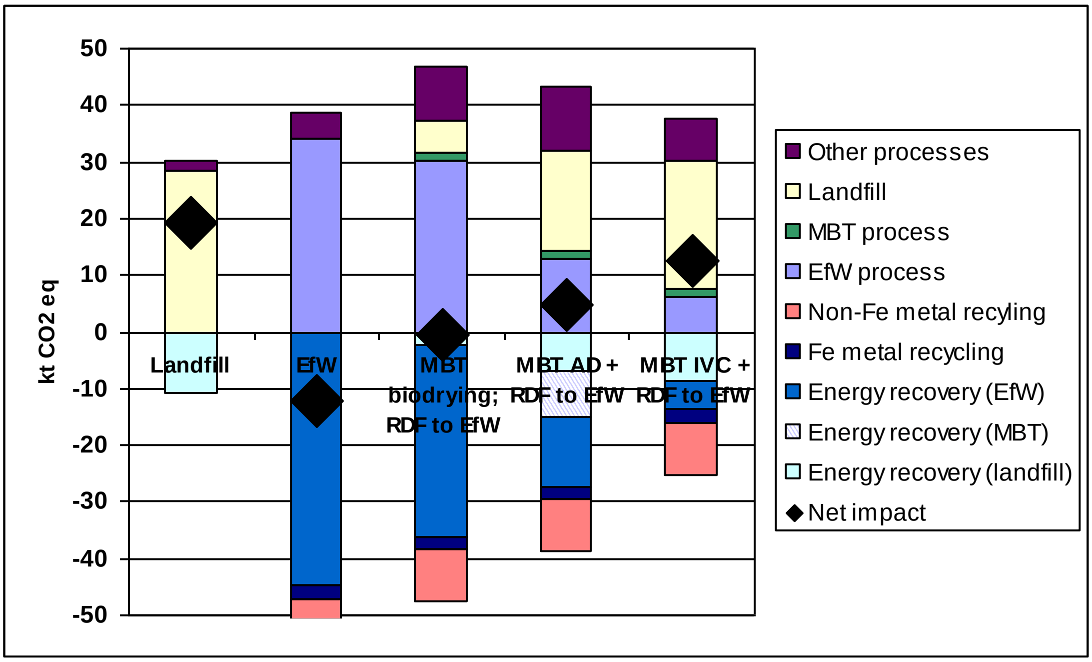


Figure 3.2: Contribution of processes and material and energy recovery to climate change impacts



Impact of increased material and energy recovery

Given the importance of both energy recovery and materials recovery, the sensitivity of environmental impacts to increased energy recovery and improved materials recovery were examined. The efficiency of the EfW plant was increased to 25%, and that of the EfW - CHP plant to 20% for electricity and 70% for heat. The materials recovery rate for non-ferrous meals in the EfW plant was increased to 50% and in the MBT options, recovery of dense plastics (by e.g. near infra-red (NIR) separation) was implemented (with 50% of dense plastics recovered). It is assumed that all of the materials recovered, go on to substitute for the use of virgin products. Figure 3.3 shows how increased energy and materials recovery improves the climate change impact of all the waste treatment options, although the relative performance of the options is unaffected, i.e. the EfW plant still offers the lowest climate change impact. In particular, there are substantial benefits from recovering and recycling plastics in the MBT options, and from fully utilising all of the heat which an EfW - CHP plant can produce.

Impact of different electricity mixes

As much of the GHG ‘savings’ for the waste treatment options, particularly for the EfW plant, comes from the energy they produce, the sensitivity of the climate change impact to the type of electricity generation which is replaced was examined. Figure 3.4 shows the performance of each of the options if coal fired electricity, gas CCGT, a coal/gas mix or a low carbon based electricity source (e.g. predominantly hydro backed up with gas) were the avoided electricity source.

Whenever the electricity generation which is avoided would have come from fossil fuel generation, then all of the waste treatment options have a lower climate change impact than landfill. The relative impacts of the different waste treatment options is unchanged, with the EfW based options having the lowest climate change impact whether generation from coal, gas or a mixture of the two is avoided.

Figure 3.3: Influence of improved energy and materials recovery on climate change impacts

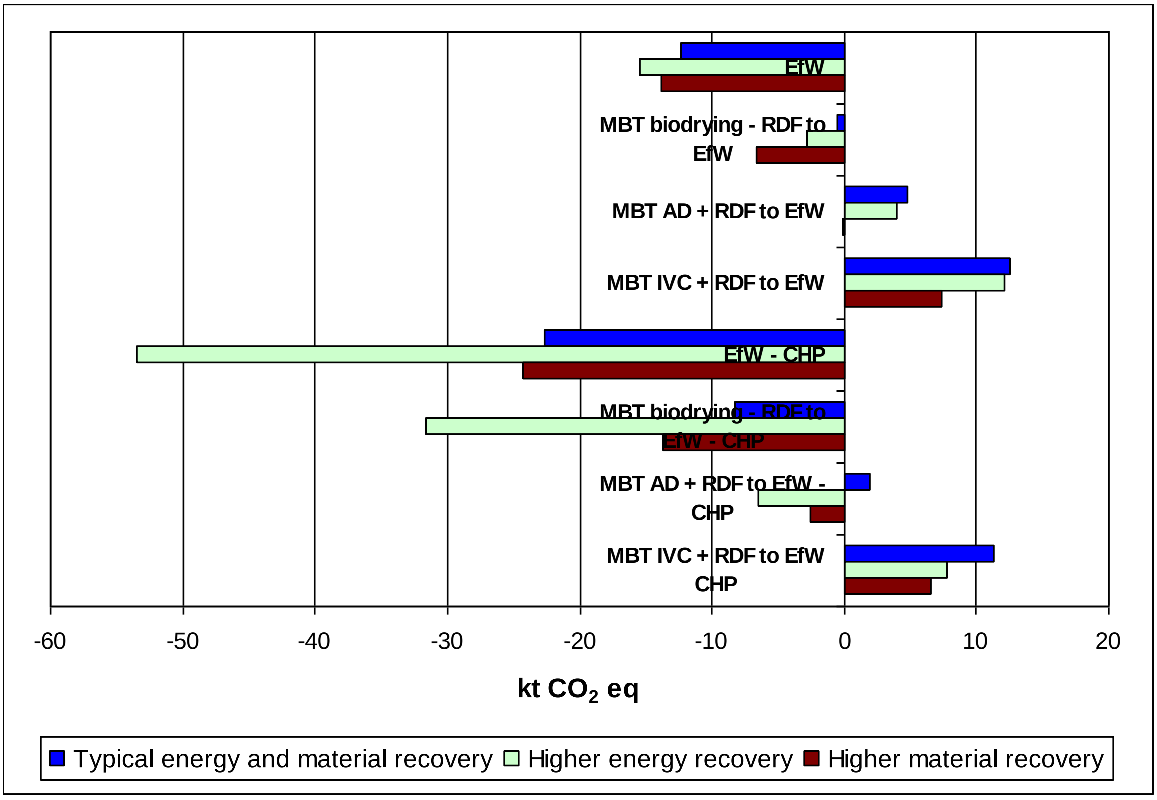
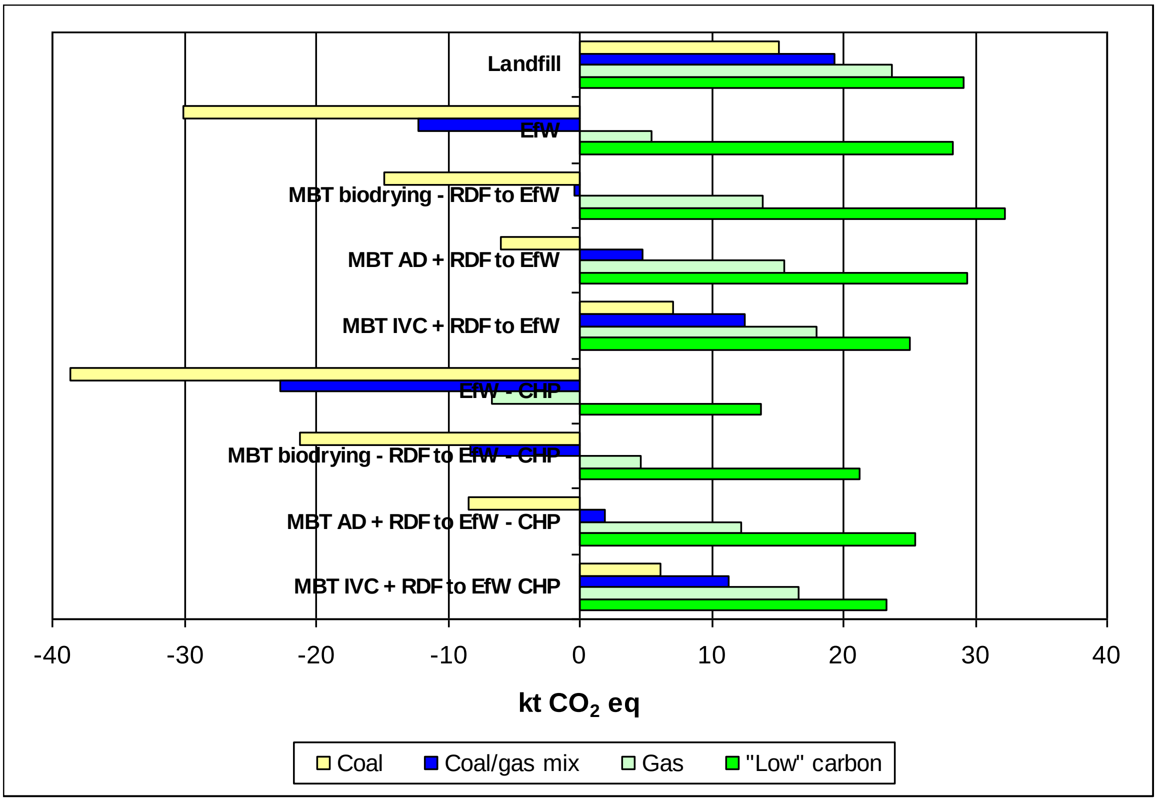


Figure 3.4: Influence of electricity generation type on climate change impacts



Climate change impacts are obviously lowest where coal fired generation is displaced and highest when a low carbon electricity generation source is displaced. Where a low carbon source is displaced, all the treatment options which recover heat as well as electricity (by burning the residual waste or RDF in an EfW - CHP plant) have a lower climate change impact than landfill. However, where only electricity is produced then not all options perform better than landfill. The EfW and MBT - AD options have a climate change impact broadly equivalent to landfill, the MBT - bio-drying process has a climate change impact about 10% worse, and the MBT - IVC process about 15% less. In countries, where low carbon sources such as hydro or nuclear form the majority of electricity generation, it is thus important to carefully consider the electricity source which may be displaced, if an accurate assessment of climate change and other impacts is to be made.

Other environmental impacts

Waste treatment processes have a number of other potential environmental impacts resulting from emissions of pollutants to air and water, and the use of non-renewable resources

Methodologies have been developed to allow the aggregation of emissions which cause a similar type impact by looking at the relative impact of different emissions and assigning an 'equivalency factor' to allow emissions to be summed on the basis of their 'potency' in terms of the environmental impact. So in the example above of climate change, the global warming potential of different GHG is used to convert all emissions into equivalent emissions of CO_2, allowing the emissions to be summed and the overall impact assessed. Relatively robust methodologies are available to look at the impact of abiotic (non-renewable) resource depletion, acidification and eutrophication in this way. Methodologies also exist for a number of other impacts (e.g. human toxicity and aquatic toxicity) but these are less robust, and so are not discussed here.

Abiotic resource depletion

In the case of abiotic depletion, i.e. depletion of non-renewable resources, all of the waste management methods examined showed overall savings of resources (Figure 3.5). This is mainly due to the savings in fossil fuels from the electricity which is produced when managing the waste[20], with smaller savings from use of metal ores and fossil fuels due to metal recycling. Those treatment options where the most energy is recovered, i.e. those based on EfW plant, therefore have the largest benefits in avoided use of resources.

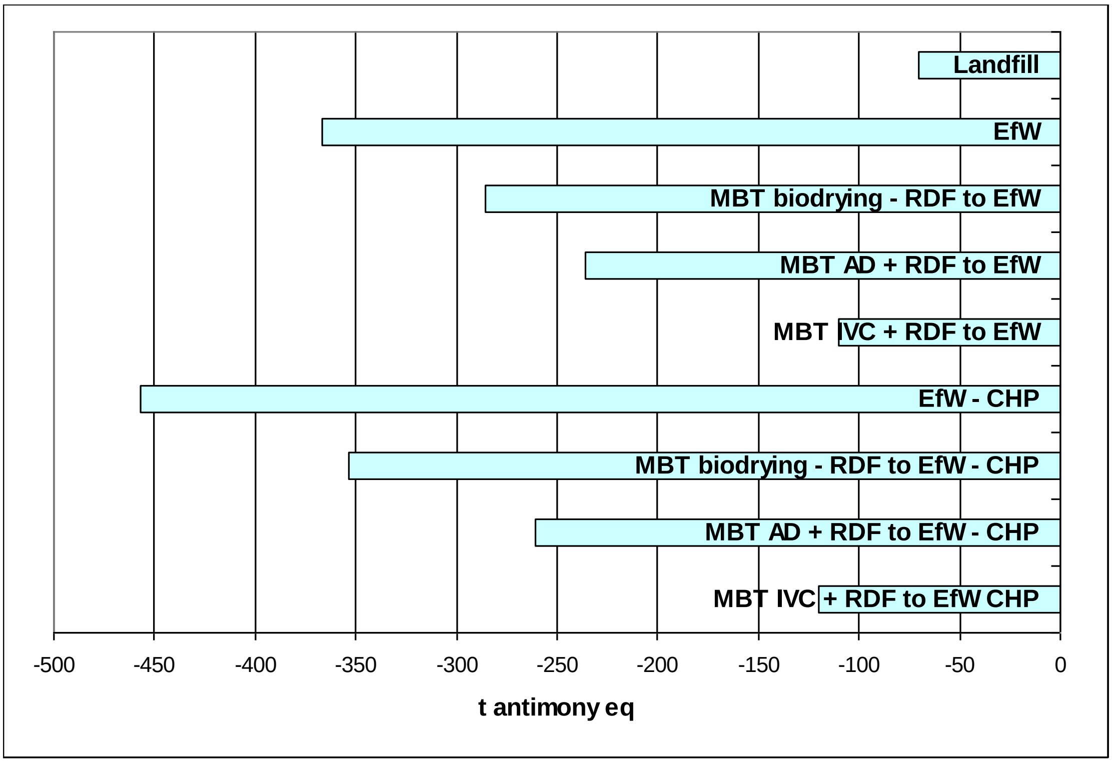
Where the electricity produced would otherwise have come from a 'low carbon' mix, which is less heavily based on fossil fuels, then there are less resource savings for all the waste management options, and while options based on EfW still deliver the largest saving, the differences are less pronounced, particularly as the metal recovery, which is achieved at a higher rate in other waste management options, starts to become a more dominant contribution to resource savings.

Improved material recovery rates in the facilities improves the resource savings further - typically by about 60 t antimony eq when plastics recycling is incorporated in the MBT processes and about 9 t antimony eq when recovery of metals is improved at the EfW plant.

[20] As the common element of collection was excluded from the comparison, this should not be taken to mean that waste management can always reduce the use of resources. Similarly, in a global sense, as the boundaries of the comparison excludes the resources which were consumed to produce the waste, it cannot be concluded that waste management avoids resource depletion.

The ranking of the options is unaffected however, with the EfW options still giving the greatest benefit.

Figure 3.5: Comparison of resource depletion (for managing 100 kt of MSW)

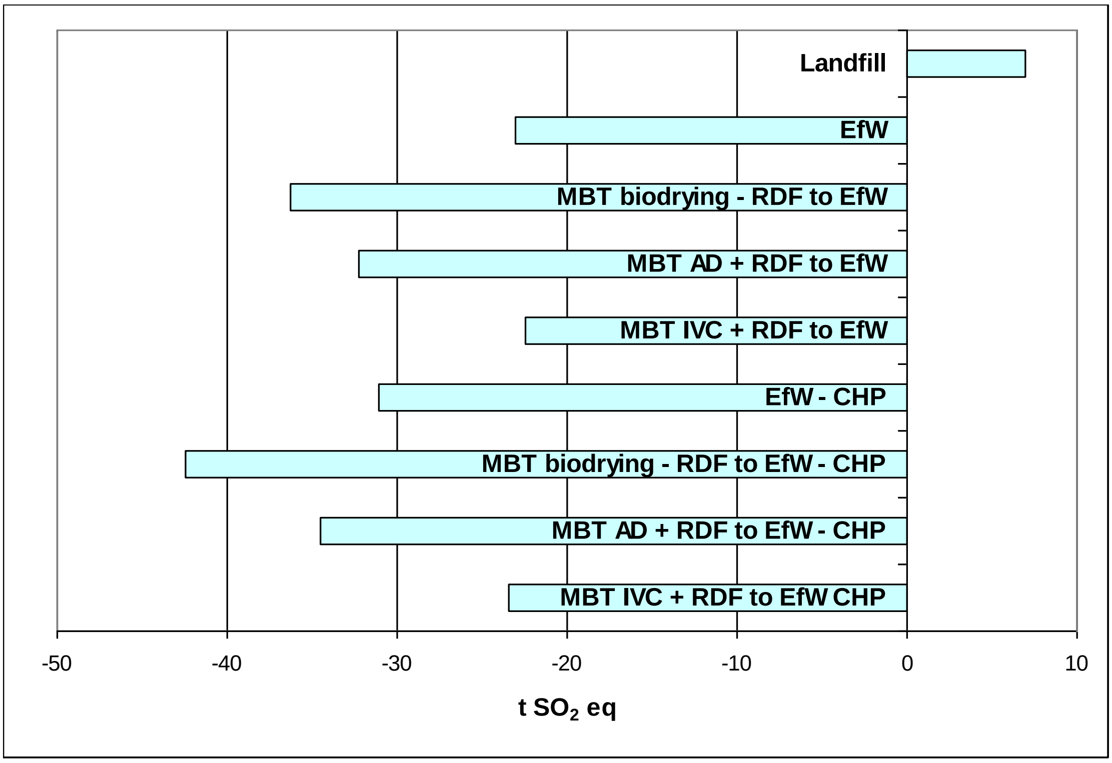


Acidification

In the case of acidification (Figure 3.6), the net impact is a balance between emissions of acidifying pollutants (such as SO_2 and NO_x) which are avoided due to energy recovered and metal recycling, and the emissions of these pollutants from the waste management plant and from vehicle emissions in transporting the wastes. The largest reduction in acidification options are offered by the MBT - bio-drying system and the MBT - AD based system (due to the large benefit offered by metal recycling); with the EfW plant being broadly equivalent to the MBT based IVC system. Including plastics recovery in the MBT processes more than doubles the reduction in acidifying pollutants as shown in Figure 3.6, so that even with improved metals recovery at the EfW plant, all the MBT based options have a lower acidifying impact than the EfW plant.

When the electricity offset is produced by gas or a low carbon fuel mix, which have low emissions of the acidifying pollutants, then the pattern becomes even more pronounced, with the EfW option having net overall emissions of acidifying pollutants and performing worse than all of the MBT based options.

Figure 3.6: Comparison of acidification impacts (for managing 100 kt of MSW)



Eutrophication

Eutrophication impacts (which are evaluated on the basis of emissions of phosphorus, ammonia and nitrogen compounds to air, water and soil) are highest for MBT processes (Figure 3.7) which landfill stabilite, due to release of these pollutants from the landfill. The EfW plant has the lowest impact, as emissions from the plant are largely offset by emissions avoided due to the recovery of energy, and to a lesser extent, the recovery of metals.

Improved material and energy recovery do reduce eutrophication impacts, but those for the MBT - AD and MBT - IVC options remain relatively high, as they are dominated by the contribution from landfilling of rejects and stabilite, and the ranking of the options is unaffected. Similarly, changes in the type of electricity mix displaced do not alter the ranking of the treatment options, and even when a low carbon energy mix is displaced, the EfW plant and the MBT - bio-drying options still have a significantly lower impact than the other MBT options and landfill.

Figure 3.7: Comparison of eutrophication impacts

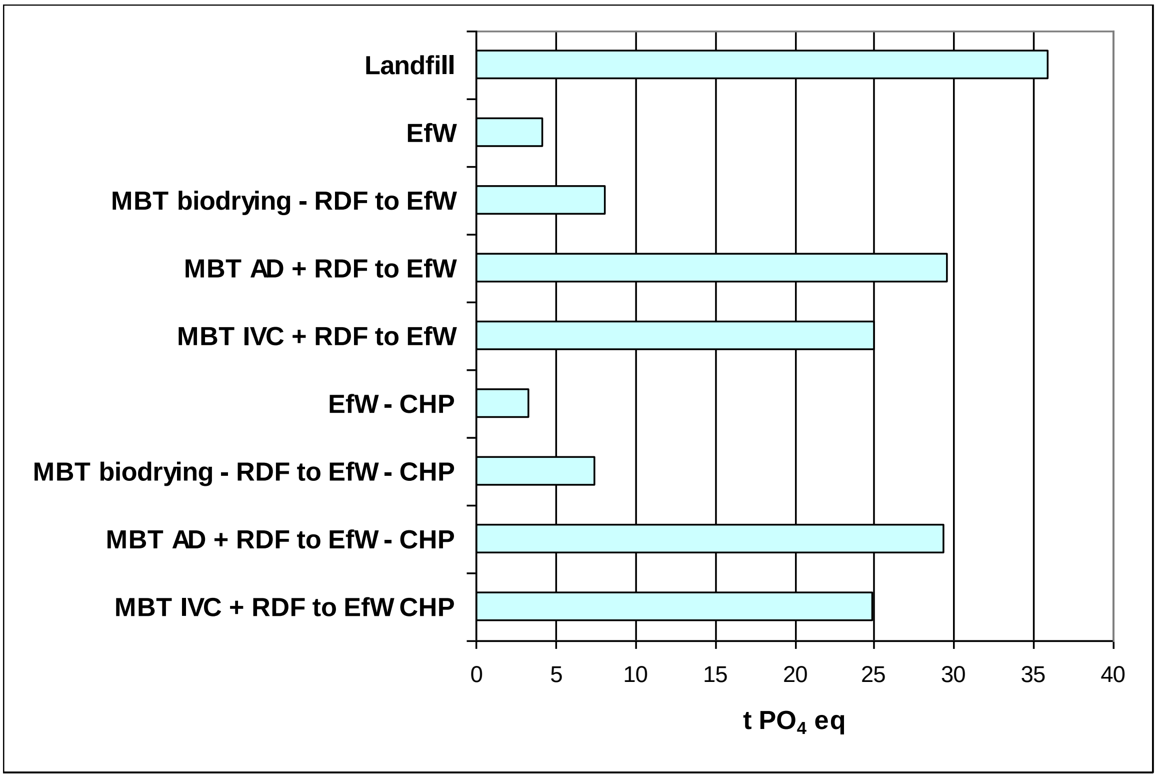
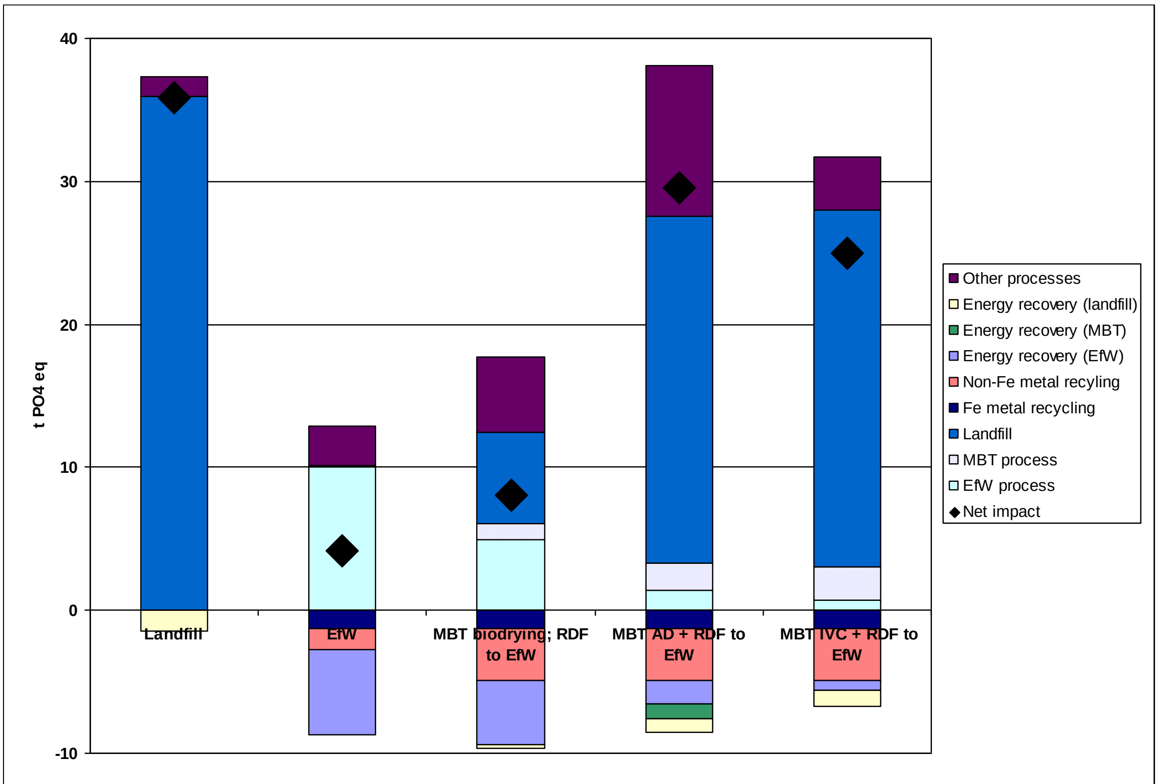


Figure 3.8: Contribution of processes and materials and energy recovery to eutrophication impacts



Uncertainties in modelling

The modelling aimed to take typical processes and waste compositions, to allow a generic comparison of treatment options. Each treatment option was based on an example of plant which is currently available that could be considered an example of good practice. A sensitivity analysis was used to look at the effect of assumptions, such as electricity mix, that are known to have a significant impact on results to try and ensure that any conclusions drawn are valid over a range of circumstances.

Two areas where there is thought to be a degree of uncertainty, are the modelling of landfill gas emissions from landfilling of stabilite, and the benefits of non-ferrous metal recovery. The former is because it is difficult to estimate the degree of stabilisation which has occurred during the MBT process and to relate this to the generation of landfill gas at a later date. The impact of non-ferrous metals recovery may be overestimated as the only option for modelling this recycling is of aluminium recycling. In reality, there may be a mixture of non-ferrous metals - e.g. in an EfW plant, the non-ferrous metals which are recovered by eddy current separation while predominantly comprised of aluminium, may also contain other metals such as copper and zinc. The benefits of recycling these metals, while still likely to be significant, are however (particularly in the case of climate change impacts) likely to be lower than for aluminium.

The sensitivity of the results to changes in the waste composition, have also not yet been evaluated.

Overall conclusions

All the treatment options considered had, for a typical coal/gas electricity mix, lower environmental impacts than landfill. The ranking of the non-landfill options depends on the environmental impact considered and, for some options, was also affected by the electricity mix that is displaced when energy is recovered from the waste. While no treatment option performed best under all the cases and impacts evaluated, overall, the EfW plant had the best environmental performance, where there is no opportunity to utilise heat, and the EfW - CHP plant where there is an opportunity to supply heat.

Energy recovery and materials recovery of energy intensive materials such as metals and plastics, have significant benefits for all the environmental impacts evaluated, and should be maximised in any waste management option that is implemented. If EfW is part of the option, whether burning MSW directly or RDF, then making the plant a CHP one reduces environmental impacts, particularly if heat utilisation is high.

Climate change impacts are often a key concern and for this impact, an EfW plant (or EfW - CHP plant if heat can be utilised) has the lowest impact, whenever the electricity displaced is based on coal or gas or a mixture of them. However, if the energy recovered is displacing very low carbon electricity, then there is much less differentiation between the options, and the MBT - IVC option performs best, having a slightly lower impact than the EfW plant. An EfW - CHP plant, however, has a lower impact than an MBT - IVC option. For countries with a low carbon electricity mix, it is thus important to consider when assessing options, the structure of electricity supply, and whether one of the low carbon sources, or a marginal, higher carbon source is likely to be displaced.

In the case of depletion of resources, the EfW and EfW - CHP plant have the lowest impact, although the difference between these and other options is less pronounced for a very low carbon electricity mix.

EfW also has the lowest impact when eutrophication is considered, and (together with the MBT - bio-drying option) performs significantly better in this impact area, even when the effects of improved material recovery at MBTs and a low carbon energy mix are evaluated.

The one impact evaluated where EfW does not perform as well is acidification, where emissions of acidifying pollutants from the process are higher than from the MBT treatment options, and the higher metal recovery rates in the MBT processes deliver substantial savings in emissions of acidifying pollutants. The MBT - bio-drying process generally has the lowest acidification impact, although if gas or a low carbon electricity mix is being displaced, then the MBT - IVC process, which involves the lowest amount of combustion of waste, has the lowest impact.

CHAPTER 4: OVERVIEW OF TECHNOLOGIES USED FOR ENERGY RECOVERY

This chapter presents a short overview of established technologies for integrating energy recovery into solid waste management systems. It includes a description of alternative and emerging technologies based on gasification or pyrolysis of waste.

The fundamentals of the technologies are briefly described including - where available - flow diagrams, mass and energy balances, eventual pre-treatment necessities, and residue qualities. For some technologies typical plant designs are presented.

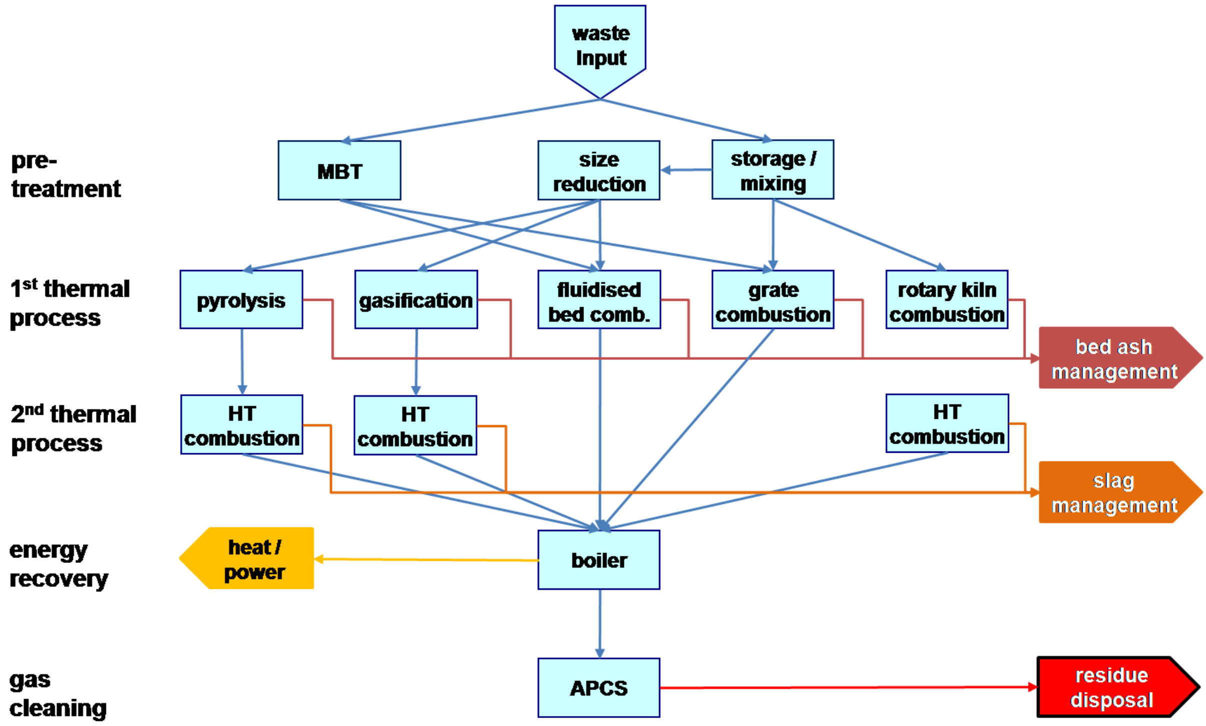
The technologies examined are:

- grate incineration;
- fluidised bed incineration;
- rotary and oscillating kilns;
- options for mechanical and biological treatment (MBT);
- gasification;
- pyrolysis.

Gasification and pyrolysis of waste and waste derived fuels are in principal designed as at least two-stage processes with a direct combustion of the process products.

Figure 4.1 illustrates the various options for energy recovery from waste. Some options (combustion in grate systems and rotary kilns) process waste without pre-treatment, whereas other options, especially fluidised bed combustion, and (in most cases) gasification and pyrolysis, require size reduction combined with removal of metallic species.

Figure 4.1: Various common configurations for energy from waste plants (HT: high temperature; APCS: air pollution control system)



Solid recovered fuel (SRF) from MBT plants is typically either used as co-combustion fuel in cement kilns or coal fired power plants or burnt in fluidised bed or grate furnaces. Residues from MBT and sorting plants end up in grate furnaces.

Figure 1 also shows that all of the listed processes contain a heat recovery boiler and, in many process chains, rather complex air pollution control (APC) systems. Since these stages do not depend on the front-end thermal process, they are more or less equal for all applications and are described in a separate section (below). The same applies to storage, mixing, size reduction and metal scrap separation facilities.

One important issue for energy from waste (EfW) systems is the quality and management of process residues. This is true for residues such as bed ashes and slags from high temperature combustion, but is a particular issue for APC residues. The first mentioned residues may have some utilisation potential, but APC residues are characterised by high levels of pollutants and require treatment and/or specialised disposal.

The figures and statistics provided here are based on operational processes and collated from data sets relating to 2006 or 2007 - unless otherwise stated.

In addition, the Task also attended a study tour of Japanese waste management plants in November 2009. A summary of this study tour and data on the plants visited is available in Appendix 2: Study tour of Japan.

Pre-treatment stages of EfW technologies

As mentioned above, many EfW plants use process stages which are independent of the thermal process. The first of these stages is the storage and pre-treatment of the feedstock. Pre-treatment systems are required to ensure that the waste is in an appropriate form for the combustion process.

There are a number of commonalities in pre-processing, including removal of bulky items; mixing of the waste to homogenise the composition and the calorific value of the material; and size reduction where necessary. These processes take place at the front end of the plant, often within a reception hall or waste bunker. Figure 4.2 shows a typical reception hall of a waste incinerator.

Figure 4.2: Waste reception hall of the Dutch Alkmaar incinerator

For combustion in grate furnaces, waste pre-treatment is (in principle) not needed. That is why grate incinerators are often referred to as 'mass burn' facilities. In reality, however, the bunker of such facilities is often equipped with a rotary shear for crushing bulky material. Furthermore, the crane operator mixes the waste in the bunker to achieve a more homogenised feedstock for the combustion chamber.

The waste reception area includes a bunker, which has the dual function of providing temporary storage and protecting the surroundings from odours. This area is kept under negative pressure (to ensure odours remain within the building). Cranes are used to mix the waste in the bunker and to fill it into the feeding chutes of the incinerator (see Figure 4.3).

Figure 4.3: Waste bunker with two cranes mixing the waste (left) and filling the feeding hopper with a crane load of waste (right)

In contrast, fluidised bed (FB) incinerators need fuel of limited particle size; for stationary or bubbling bed furnaces the preferred particle size is < 50 mm, for circulating ones < 25 mm; revolving FBs are more flexible and can cope with material of up to 200 mm.

Hence for these plants more effort has to be spent in the pre-treatment of the waste fuel. This starts with sorting and removal of bulky and metallic items. The latter is done by magnetic separation for ferrous and, to an increasing degree, also by eddy current systems for non-ferrous scrap removal. This procedure is mainly followed by crushing and/or shredding.

A more complex and also more expensive pre-treatment of waste for FB combustion comprises an MBT plant which produces SRF as a fluffy or pelletized material. This fuel is also used for combustion in dedicated power plants or as co-combustion fuel in coal fired power plants, cement kilns and other industrial furnaces. The methods applied involve sorting, sieving, crushing or shredding and eventually moulding.

Rotary kiln plants are mainly used for treatment of industrial and hazardous waste. These facilities are relatively flexible and can take solid, liquid, pasty, sludgy, and gaseous waste. A speciality is the combustion of hazardous waste ‘drummed’ in containers such as 200 l barrels. The type and variety of accepted waste often requires complex storage in different forms, ranging from bunkers to tank farms and sealed bunkers with the capability to make the waste inert. The actual fuel mixture has to be composed based on good knowledge of composition and calorific value of the various waste types.

Thermal processes

Overview

The thermal processes applied for energy recovery from waste are combustion, gasification and pyrolysis. Their principal distinguishing feature is the oxygen content in the process atmosphere; furthermore, the processes are operated in different temperature ranges.

Pyrolysis is an endothermic process, always performed under strictly inert atmosphere without access for any oxidising agent. The effect is thermal degradation and fragmentation of organic constituents. Gasification (also endothermic) is a sub-stoichiometric oxidation process, whilst combustion is the total oxidation of the fuel.

Table 4.1 summarises some of the typical process parameters for pyrolysis, gasification and combustion processes.

Table 4.1: Typical operation parameters and reaction products of thermal waste treatment processes

	Pyrolysis	Gasification	Combustion
Temperature / °C	250 - 700	800 - 1,400	850 - 1,400
Pressure / bar	1	1 - 50	1
Atmosphere	Inert / N2	O_2, H_2O, air	air, O_2
Stoichiometry	0	< 1	≥ 1
Gaseous products	H_2, CO, C_nH_m	H_2, CO, CH_4, CO_2	CO_2, H_2O
Solid products	Ash, coke	Slag	Ash/slag

Pyrolysis and gasification for energy recovery from waste are, in most cases, followed by immediate combustion of their gaseous – and in the case of pyrolysis, also solid - reaction products. Such processes (at full scale) have mainly entered the market in Japan. Their characteristics are described in more detail below.

Pyrolysis

Pyrolysis is the thermal decomposition or fragmentation of organic matter in a strictly inert atmosphere. The reaction starts at 200 - 250°C and is, in this region, often called degassing - at high temperature the terms carbonisation or coking are also common. The highest temperature in these processes is in the order of 700°C.

The main pyrolysis reactions in the various temperature ranges are listed in Table 4.2.

Table 4.2: Main pyrolysis reactions as a function of temperature [Lenz 1979]

T in °C	Reactions
100 - 120	Drying
250	Split off: H_2O, CO_2, H_2S, HCl
340	Destruction of aliphatic bonds, split off: CH_4, aliphatics
380	Formation of pyrolysis coke
400	Splitting of C-O and C-N bonds
400 - 600	Transformation of bitumen to pyrolysis oil and tar
600	Cracking of long-chain compounds, formation of aromatics
>600	Formation of butadien, cyclohexane, benzene, PAH

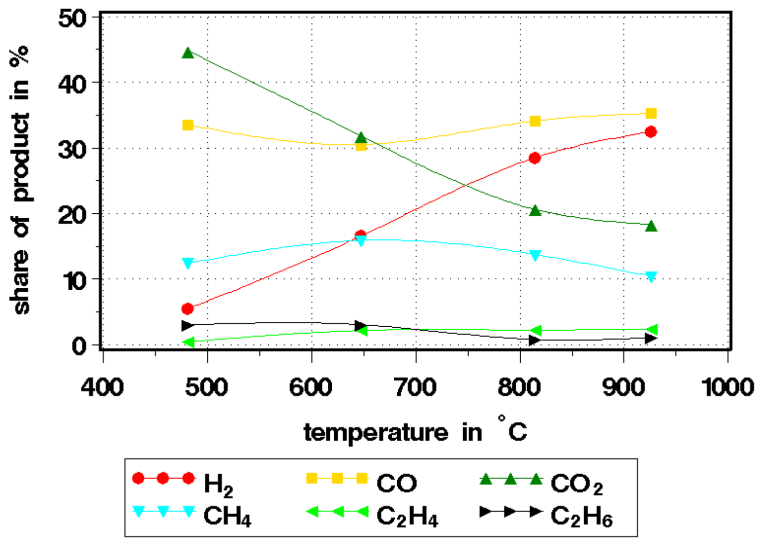
Products of pyrolysis of waste are:

- gases, predominantly CO, H_2 and short chain hydrocarbons;
- so-called pyrolysis oil comprising low volatile hydrocarbons up to tars;
- solids, which are a mixture of coke and inert ashes.

The proportion of gaseous, liquid and solid products will depend on the reaction temperature. The amount of gaseous products increases slightly with the temperature, whereas the share of solid residues decreases.

The gas phase composition is a function of the reaction temperature, too. Figure 4.4 shows the influence of temperature on the distribution of gaseous pyrolysis products as obtained in experiments with waste mixtures [Lenz 1979]. It is evident that with increasing temperature, the yield of H_2 increases and that of CO_2 goes down. Methane has its highest concentration at about 650°C.

Figure 4.4: Share of major gaseous pyrolysis products as a function of reaction temperature (adopted from [Lenz 1979])



Typical concentration ranges and mean mass flows in the gas from waste pyrolysis in the temperature regime of 600 - 650°C are compiled in Table 4.3. The dust content is missing; it depends on the type of pyrolysis process and the turbulence in the gas phase.

Table 4.3: Pyrolysis gas concentration ranges and mean mass flows per Mg of waste in the temperature range 600 - 650°C (adopted from [Bilitewski 1985, Fichtel 1987])

	Concentration [mg/m³]	Mass flow [kg/Mg]
CO_2	150,000 - 250,000	90
CO	70,000 - 120,000	45
H_2	4,000 - 6,000	2.5
SO_2	<100	<0.05
H_2S	1,000	>0.5
COS	Traces	

	Concentration [mg/m³]	Mass flow [kg/Mg]
NH_3	20 - 100	0.03
HCN	1 - 50	0.01
CH_4	30,000 - 40,000	18
C_2H_4	10,000 - 15,000	6
C_2H_6	14,000 - 18,000	8
C_nH_m	Traces	

The table indicates that pyrolysis gas has a rather complex composition and direct use requires extensive gas cleaning, which is especially difficult for the removal of sulphur compounds and sticky dust particles or tar. This is the reason why pyrolysis application in waste treatment is realised with direct combustion of the gas phase without major prior cleaning.

The advantage of such processes is the good quality of the metal scrap in the solid pyrolysis residues which have - due to the absence of oxygen - clean metallic surfaces.

Gasification

Gasification is the partial oxidation of organic substances using oxygen, air, or steam as oxidising agents. The reaction product, called synthesis gas (or syngas), consists mainly of H_2 and CO with small amounts of methane and other short chain hydrocarbons. The reaction is endothermic. It is called autothermic if the energy needed for the reaction is supplied by sub-stoichiometric combustion of the organic substance. If the reactor is externally heated, the gasification is called allothermic. The solid residues are inert ashes or slags and fly ashes.

As with pyrolysis, gasification of MSW is in most cases also followed by combustion of the gas in a combustion chamber. Only the Schwarze Pumpe and the Thermoselect processes have implemented gas cleaning for use of the gas in a gas engine. The first German Thermoselect plant (now shut down) however, burnt the cleaned gas in a combustion chamber. Table 4.4 shows analytical data measured in the synthesis gas of the Thermoselct process at a gasification temperature of approx. 1,200°C.

Table 4.4: Synthesis gas concentration ranges and mean mass flows per Mg of waste analysed in the Thermoselect process (*: ng(I-TEQ)/m³, **: mg(I-TEQ)/Mg, [Stahlberg 1995])

	Concentration [mg/m³]	Mass flow [kg/Mg]
O_2	<1,000	<1
CO_2	400,000 - 500,000	410
CO	400,000 - 450,000	420
H_2	22,000 - 30,000	27
HCl	100 - 300	0.3
H_2S	600 - 1,500	0.9

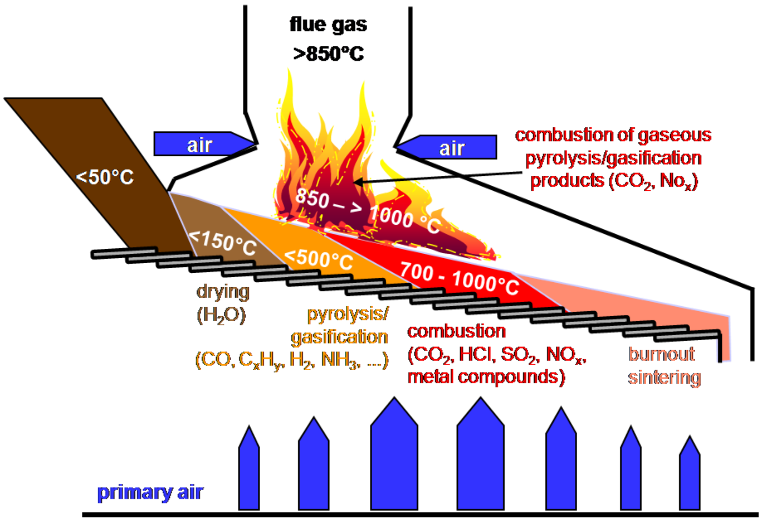
	Concentration [mg/m³]	Mass flow [kg/Mg]
SO_2	800 - 3,000	1.5
HCN	1 - 10	<0.01
N_2	20,000 - 25,000	25
CH_4	<0.5	<0.0005
C_nH_m	<0.1	<0.0001
PCDD/F	<0.05*	<0.05**

Combustion

Combustion is the total oxidation of a fuel, predominantly of its organic components, but also of some inorganic ingredients like elementary sulphur. The process is exothermic with the main energy releasing chemical reactions:

$$C + \frac{1}{2}O_2 \rightleftharpoons CO \qquad \Delta H = -110.5 \text{ kJ/mol}$$
$$C + O_2 \rightleftharpoons CO_2 \qquad \Delta H = -393.5 \text{ kJ/mol}$$

Figure 4.5: Principal processes inside the combustion chamber of a grate furnace



In reality, combustion is the final stage in the chain of chemical reactions which take place between the entry of the waste into the combustion chamber at ambient temperature and its final combustion temperature in the range of 800 to > 1,000°C.

The process can best be explained by examination of the combustion of waste in grate furnaces, where the fuel forms a bed on top of the grate and the combustion air is injected through the grate. The different local temperatures and oxygen concentrations cause a succession of reactions from drying through pyrolysis and gasification to final combustion. A schematic of this reaction chain is depicted in Figure 4.5.

The same processes take place in all combustion facilities, although the local distribution and the time scales differ. In fluidised beds, for example, the described processes are rather fast following each other around a single grain of the fuel in the continuum of the sand bed; the final gas burnout takes place in the freeboard.

Typical composition data for flue gas from waste incineration are listed in Table 4.5. The table has been compiled for grate furnace systems with an air consumption of 4,500 m^3. Fluidised bed systems may be operated at lower air supply which would increase the concentration of the gaseous species. The fly ash or dust concentration can be much higher, particularly in stationary or bubbling beds, since the bed material will to a certain extent also be transferred into the flue gas stream.

Table 4.5: Raw gas concentration ranges and mean mass flows per Mg of combusted waste (*: ng (I-TEQ)/m^3, **: mg(I-TEQ)/Mg, [IAWG 1997])

	Concentration (mg/m^3)	Mass flow (kg/Mg)		Concentration (mg/m^3)	Mass flow (kg/Mg)
O_2	60,000 - 120,000	500	NO	100 - 500	2
CO_2	150,000 - 200,000	900	NH_3	5 - 30	0.1
H_2O	110,000 - 150,000	600	CO	<10 - 30	0.1
dust	1,000 - 5,000	20	TOC	1 - 10	0.02
HCl	500 - 2,000	6.5	Hg	0.1 - 0.5	0.002
SO_2	150 - 400	2	PCDD/F	0.5 - 5*	<5**

The table indicates the necessity of thorough cleaning before the gas is emitted to the atmosphere.

The solid residues from waste incineration are bottom ashes and fly ashes.

Energy recovery

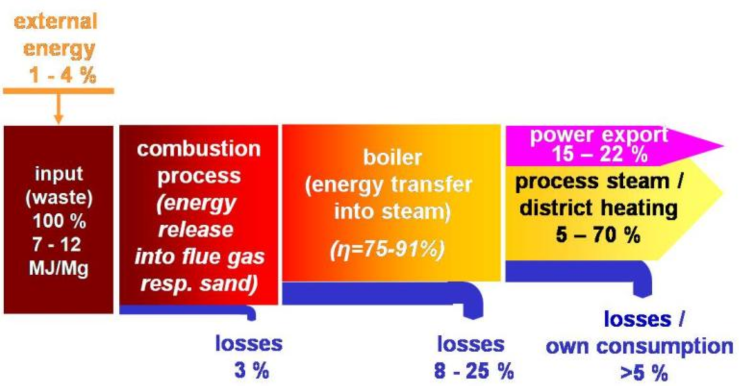
In all modern thermal processes, the chemical energy of the fuel which is finally released into the off-gas of a combustion process is recovered in a boiler. Three alternatives are available for utilisation of the heat:

- direct export as heat for district heating (usually through a so-called 'steam cycle') or as process steam to industry;
- conversion to electricity using turbines;
- both by using heat directly and generating electricity, called combined heat and power (CHP).

A varying part of the generated energy - depending on the process technology - is often used internally in the operation of the plant.

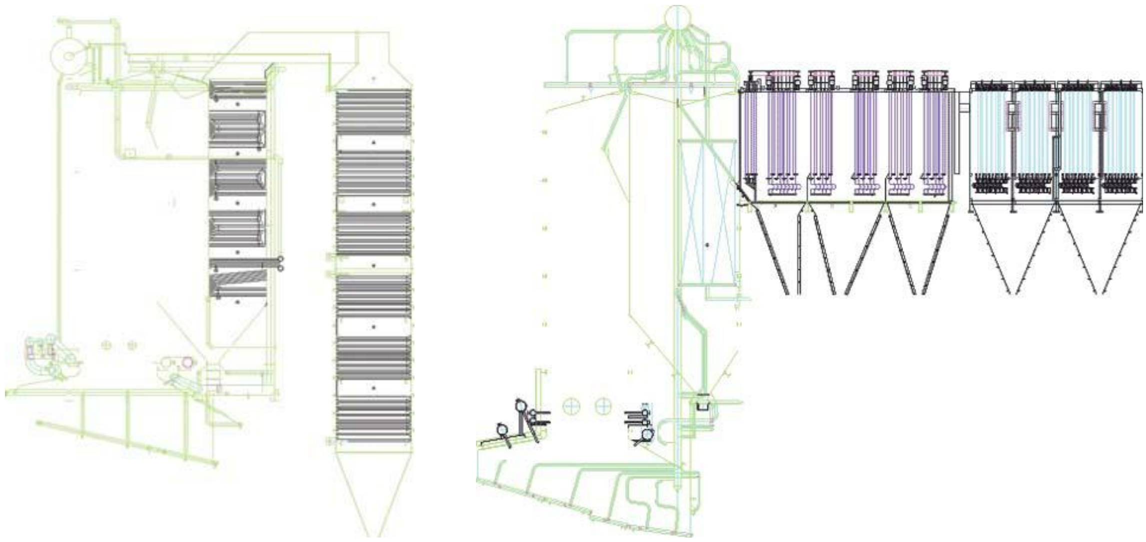
The principles of energy recovery in incineration plants are explained in Figure 4.6. The scheme is in principle valid for all kinds of combustion plants with heat recovery boiler; i.e. in the context of this report for grate incineration as well as for fluidised bed systems or combustion in combustion chambers.

Figure 4.6: Energy flow in a waste incineration plant



The design of boilers used in EfW plants is, in principle, the same as in power plants. Schematics of two commonly used configurations, a vertical and a horizontal boiler, are shown in Figure 4.7.

Figure 4.7: Vertical (left) and horizontal boiler (right) [Vølund 2006]



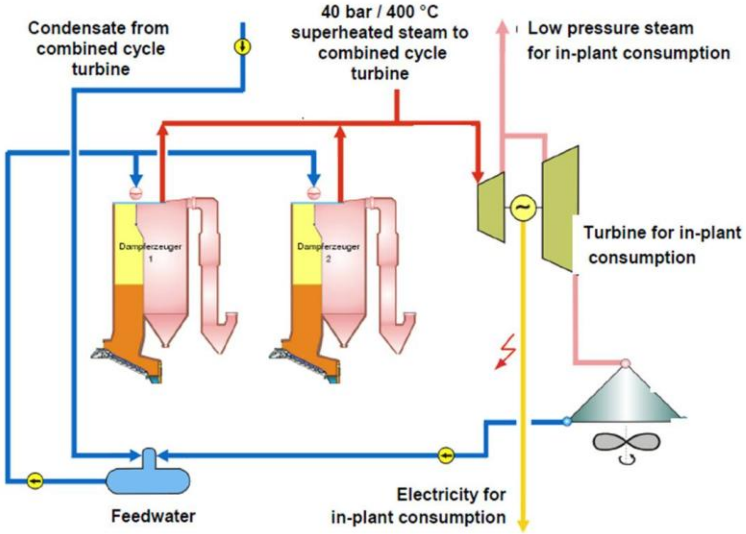
Boilers in modern waste incineration plants of any kind reach a primary efficiency of 85%, some even slightly higher. However, they are operated at lower steam conditions than those in power plants (typically 400°C and 40 bar to avoid corrosion caused by the high Cl inventory of most waste fuels and the resulting high chloride concentration in the ash layers on the boiler tubes). The consequence is a lower power efficiency of about 22 - 25%. Accounting for in-house consumption, the export of power rarely exceeds 21%.

In recent years there has been a growing interest in renewable energy around the world. The drivers for this include the awareness of limited fossil fuel resources and the more and more recognisable effects of global warming. This awareness has pushed energy recovery from thermal waste treatment high up on the agenda, the more so since the biogenic energy inventory in MSW is acknowledged in a number of countries and in some of these even supported by higher power prices.

The first approach for improved power efficiency in waste fired boilers was the application of higher corrosion resistant boiler wall materials, such as Ni-base alloys. This has been demonstrated at facilities at Brescia (Italy) and in the new Amsterdam waste incineration plant. Brescia operates the boiler at 450°C, 450 bar, and reaches an efficiency of 26%; Amsterdam (with 440°C and 130 bar) achieves 30% [Martin 2006; AEB 2006].

Another approach to improving efficiency is the concept of integration of a waste boiler and a combined cycle natural gas turbine, which has been realised in Mainz, Germany. The concept is shown schematically in Figure 4.8 [Martin 2006]. T he achieved power efficiency is ≥ 40%.

Figure 4.8: Combination of EfW and gas turbine (Mainz concept, [Martin 2006])



Air pollution control (APC)

Process stages

In waste incineration, the removal of pollutants from the flue gas is one of the most important and most expensive process stages. This process is a regulatory requirement since the air emission limits applicable for waste incineration are the most stringent of all the industrial combustion processes. In the EU the Waste Incineration Directive sets the standards in 2000 [European Parliament and Council 2000] and these have been adopted by legal regulations in the member countries. Only few member countries, e.g. The Netherlands and Germany, decided on minor deviations from the directive to even higher standards. Regulations outside the EU are of similar stringency as can be seen in the compilation of selected national air emission standards in Table 4.6.

Table 4.6: Air emission limits in the EU, Canada, Japan, and the USA in mg/m^3 (PCDD/F in ng(I-TEQ)/m^3), daily means of dry gases at 273 K, 101.3 kPa and standardised to the respective O_2 concentration (* : Cd+Tl)

	EU	The Netherlands	Germany	Canada	Japan	USA
O_2 (vol%)	11	11	11	11	12	7
Dust	10	5	10	17	10-50	24
HCl	10	10	10	18	15-50	25
HF	1	1	1			
SO_2	50	40	50	21	10-30	30
NO_x	200	70	200	110	30-125	150
CO	50	50	10		50	100
Hg	0.05	0.05	0.03	0.057	0.03-0.05	0.03-0.05
Cd	0.05	0.05	0.05*	0.014		0.02
Sb+As+Pb+Cr+Co+ Cu+Mn+Ni+V	0.5	0.5	0.5			
TOC	10	10	10			
PCDD/F	0.1	0.1	0.1	0.14	0.5	0.14-0.21

The ranges given in Table 4.6 for Japan demonstrate that most emission standards are not fixed values, but calculated from the throughput of the plant and its stack height. Such procedures make a lot of sense, since they not only take the concentration of pollutants into account, but also their dispersion.

Flue gas cleaning can be achieved in many ways and is in principle independent of the type of the combustion process. The design of the actual configuration in a specific full scale plant depends not that much on the desired quality of the cleaned gas - which in any case has to comply with about the same emission standards everywhere - but on investment, operation, and maintenance costs. The disposal or eventual utilization options of the APC residues has a high impact as does the (land) space available in case of any future upgrading. Other important factors are administrative regulations like the permit or ban for liquid effluents, and finally even personal preferences of the stakeholders.

This explains why today all technologies and all kinds of combinations of abatement options can be found in full scale installations.

It is common practice to organise the APC systems by installing subsequent process stages to remove the pollutants in the following order:

- fly ash;
- acid gases;
- specific contaminants like Hg or PCDD/F;
- nitrogen oxides.

Significant research activities during the last decade have led to the development of simplified processes which allow the combination of formerly separate gas cleaning processes and contribute to a great improvement of the eco-efficiency of modern waste incineration plants.

The following brief description of the most common gas cleaning options uses information taken mainly from three sources [IAWG 1997, Vehlow 2006, US EPA 2009].

Particle removal

The first step in most APC systems is the fly ash removal which can be done by:

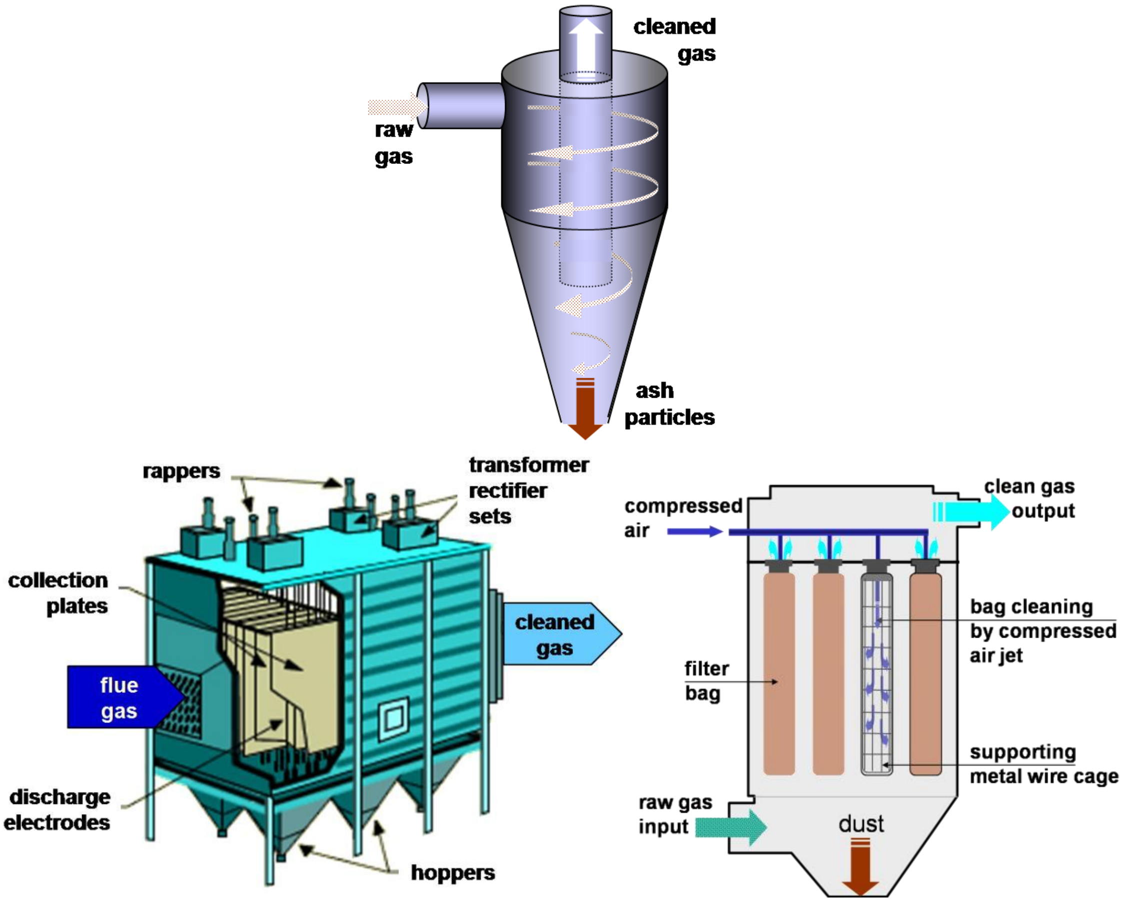
- cyclones;
- electrostatic precipitators (ESP);
- fabric filters or bag houses.

A cyclone uses inertial impaction for fly ash separation. The gas is entering a cylindrical chamber tangentially at high velocity and is forced into a cylindrical path. The centripetal force acting on the particles causes them to collide with the walls where they impinge and settle down into the discharge hopper. The gas is extracted through a central tube. A scheme of a cyclone is shown in the left part of Figure 9. Due to their limited removal efficiency for fine particles, cyclones are not often found in modern plants or they serve for pre-deposition of the coarse fly ash.

In an ESP, the flue gas passes an electric field with spray anodes charging the dust particles and cathodic collection plates where they are deposited. The simple design, low pressure loss and easy operation make ESP the most widely applied option for fly ash separation in waste incineration - as well as in other combustion facilities like coal fired power plants. A scheme of a technical design is shown in the top right part of Figure 4.9. A modern ESP, which comprises at least two and often three sections, guarantees, dust removal efficiencies of >99% for particle sizes between 0.01 and >100 µm. Three-field ESP reach clean gas dust levels in the order of 1 mg/m^3.

In a few installations, wet ESP are implemented at the back end for polishing purposes. In these ESP the collecting plates are cleaned with water instead of rapping. The residues from wet ESP are a sludge or suspension and their disposal may cause specific problems.

Figure 4.9: Scheme of a cyclone (top left), an ESP (top right), and a bag house filter (bottom)



Fabric filters can achieve even lower emission values than those of ESP. In a fabric filter the raw gas passes fabric bags which are supported by metal cages from the outside to the interior. The fly ash stays on the outer surface of the filter bags and is periodically removed by an air pulse blown into the bag from the interior. This cleaning releases the particles which fall into the discharge hopper. A schematic of a fabric filter is shown in the bottom part of Figure 4.9. Fabric filters guarantee clean gas dust concentrations in the order of 1 mg/m^3 and below.

Chemical gas cleaning

Primary fly ash deposition in the APC system is usually followed by chemical gas cleaning, which can be performed in two different ways:

- by wet-scrubbing;
- by dry scrubbing.

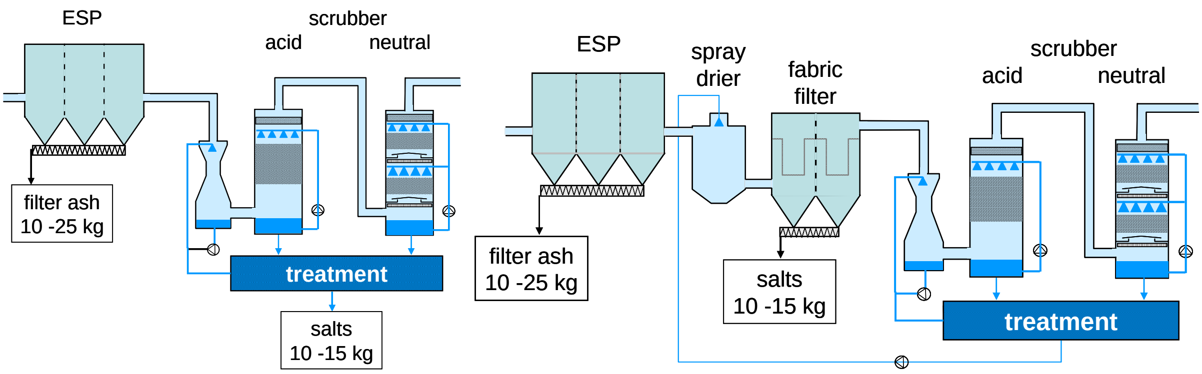
Wet scrubbing

Wet scrubbing is based on the principle of absorption of gaseous components in a liquid. The efficiency of such absorption processes depends on the available surface of the liquid, which controls the mass transfer out of the gas into the liquid phase. Different techniques are used to achieve this goal:

- venturi scrubbers;
- packed towers;
- plate and tray towers;
- film absorbers.

Wet scrubbers operate close to stoichiometry and are common in waste incineration in central Europe. Today's systems are two-stage installations with an initial acid scrubber, followed by a neutral or weakly alkaline one. The acid scrubber is often either a spray or venturi type and reduces the flue gas temperature from 180 - 200°C down to 63 - 65°C. In the second stage packed towers are mainly used. Wet systems are operated with or without discharge of liquid effluents. The latter configuration is currently the preferred approach.

Figure 4.10: Schemes of wet scrubbing systems with (left) and without (right) liquid effluents



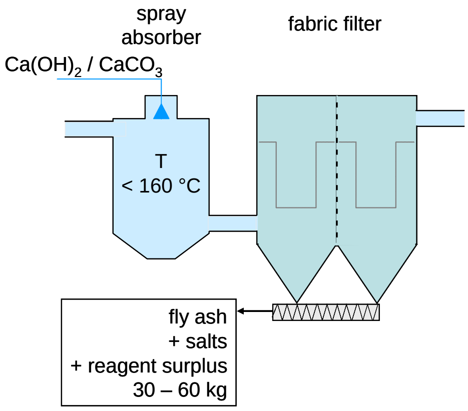
These two-stage systems have very high removal efficiencies for the halogen hydrides HF, HCl, and HBr, for mercury, and for SO_2. For these components, the raw gas concentrations are easily reduced well below the emission standards.

The solid scrubbing residues are removed from the gas flow in a subsequent - in most cases fabric - filter. An alternative way to evaporate the scrubbing solutions is by drying in steam heated devices.

Dry scrubbing

Dry and semi-dry scrubbing processes are simple and cheaper than wet methods, which explains their preferred installation in many plants across the world. In most cases the adsorbent - most common ones being limestone, $CaCO_3$, calcium oxide, CaO, of lime Ca(OH)2 - is either injected directly into the gas duct or into a spray dryer downstream of the boiler. This can be done in dry form (dry process) or as a slurry (semi-dry process). A typical configuration of dry scrubbing is shown in Figure 4.11.

Figure 4.11: Scheme of a dry scrubbing system



The scrubbing products are in most cases removed from the flue gas by a fabric filter. In some installations, a separation of the fly ashes prior to the spray dryer may be found. For such purpose, cyclones are commonly installed.

The main disadvantage of dry scrubbing systems is the high amount of APC residues produced. Even where these are recycled back into the feed, it is unavoidable that a high surplus of unspent additive remains. This surplus increases if lower emission limits have to be reached.

Another option for dry scrubbing is the NEUTREC® process which applies freshly ground $NaHCO_3$ for neutralisation of acid gases. The gas cleaning products can be treated for utilisation in other processes like metal melting or glass production [Korte 1994]. This process operates close to stoichiometry, like wet systems, so minimising solid APC residues.

NO_x abatement

For the abatement of NO_x two strategies are followed:
- the non-catalytic removal (NSCR) by injection of ammonia or another nitrogen containing compound into the hot flue gas (at about 950°C) in the first flue of the boiler; or
- the selective catalytic reduction (SCR) at a temperature level of 250 to 300°C, in most cases at the end of the gas cleaning system after reheating of the flue gas.

Both strategies allow compliance with the air emission limit of 200 mg/m^3 laid down in the Waste Incineration Directive. However, if even lower emission limits are enforced, the SCR may be advantageous.

Residue management

There are three categories of solid residues from EfW facilities:
- bottom or bed ash (largest contributor in terms of weight);
- fly ash (dust);
- APC residues.

Whereas the air emissions from EfW facilities are strongly (and at almost the same standard) regulated all over the world, a similarly common perspective in view of solid residues is missing. There is no uniform understanding of the principles of their disposal, treatment, or utilisation.

The least problematic of these residues are bottom or bed ashes from grate or FB combustion and slags from gasification or high temperature combustion processes. Countries like the Netherlands, Germany and Denmark utilise almost all of these ashes in the building sector, preferentially in road construction. These countries have issued respective regulations and quality standards. The Netherlands even utilise part of the filter ashes. Japan is starting utilisation of vitrified bottom ashes from waste incineration and of molten slags from gasification and high temperature systems. Most countries, however, dispose of the solid residues from EfW processes to landfill.

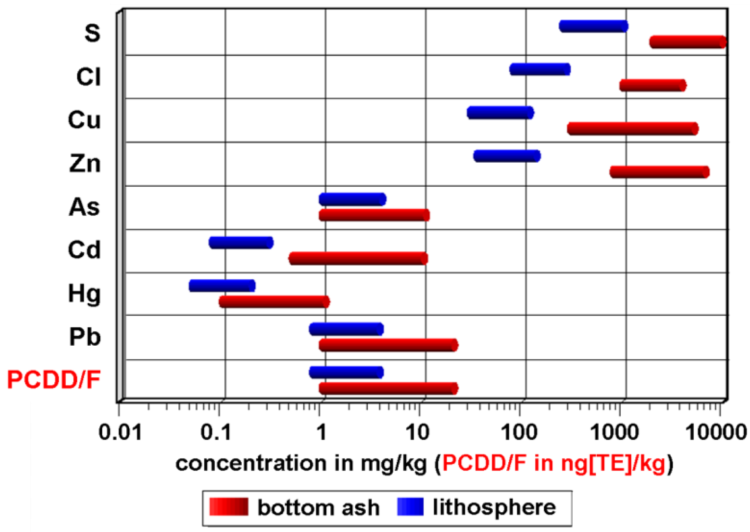
Quality standards have been developed for bottom ashes from waste combustion and are applied in a number of countries to control the access to utilisation options or to different types of landfills.

Fly ash is considered hazardous because of its high inventory of heavy metal compounds and of low volatile organic micro-pollutants such as dioxins. The typical disposal option for these residues is to landfill. This is also the case for APC residues due to their high level of water soluble alkali and alkali earth alkali.

Bottom ashes

Bottom ashes from grate or bed ashes from fluidised bed systems can be characterised as a mixture of silicatic and oxidic phases. The ashes from these plants are sintered, the respective residues from gasification or high temperature combustion are molten and those from pyrolysis contain a significant amount of carbon, the so-called pyrolysis coke.

Figure 4.12: Concentration ranges of selected elements in grate ash, boiler ash and fly ash (adopted from [IAWG 1997])



The mass and volume reduction of thermal waste treatment causes an enrichment of a number of heavy metals in the bottom ashes. Figure 4.12 shows concentration ranges of selected metals in MSW bottom ashes and in the earth's crust [IAWG 1997]. With the exception of As and Hg, all heavy metals, even those with a significant volatility in waste incineration like Cd, are highly enriched in the grate ashes compared to the lithosphere. That is why these materials have to be properly assessed when determining their utilisation or disposal option.

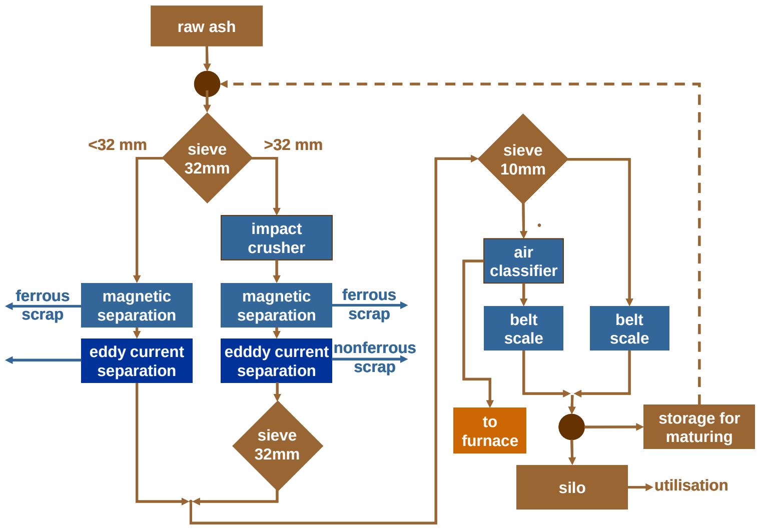
Another important component of the bottom ashes is the salt inventory in the bottom ashes. Since ashes from grates are typically discharged through a quench tank, the very soluble chlorides are generally washed out, especially if the quench tank is operated as a kind of washer with a slight water surplus [Reimann 1994]. In such cases, Cl concentrations in bottom ashes range from 1 - 5 g/kg. Sulphates are far less soluble due to the high Ca inventory in the ashes and hence there is only a limited wash-out to be expected in the quench tank. Ranges of sulphate concentrations in bottom ashes are reported to 3 - 50 g/kg [Belevi 2000].

A key parameter for the disposal and utilisation of bottom ashes is the TOC (total organic carbon) which characterises the quality of the burnout. In a number of EU countries, a TOC limit of 1 wt% is set for utilisation in road construction [LAGA 1994].

In modern well operated EfW plants, the TOC in bottom ashes is typically well below this number [Reimann 1994, Pfrang-Stotz 1999, Bergfeldt 2000, Vehlow 2002].

Raw bottom ashes from incineration of mixed MSW contain significant amounts of ferrous and non ferrous metal scrap. It is common practice that at least the ferrous, and increasingly also the non ferrous, metals are recovered. If it is intended to use the bottom ashes, the obligatory post-combustion treatment is much more extended. A typical flow sheet of advanced ash treatment as performed at the Hamburg, Germany, waste incinerator MVR is shown in Figure 4.13.

Figure 4.13: Bottom ash pre-treatment at the Hamburg waste incineration plant MVR (adopted from [Zwahr 2006])



After discharge from the furnace, the ashes are stored for a few days for de-watering before they undergo further treatment which consists of sieving to remove bulky fractions and magnetic separation of ferrous scrap and eddy-current separation of non-ferrous metals. The metal fractions, up to 10 wt% of ferrous and approximately 1 wt% of non-ferrous scrap, are sold to recycling companies.

The ashes are than stored for aging or maturing for typically three months. The aging causes a reduction of the alkalinity of the bottom ashes by the uptake of CO_2 from the air and a certain re-speciation of mineral phases. Both reactions have a stabilising effect on the ashes.

The access to a landfill or to a specific utilisation scenario depends not only on the residual carbon inventory but also on the leaching properties of the material in question. There are a number of standardised protocols for elution testing [IAWG1997]. Some EU member countries developed their own test protocols such as the NEN in The Netherlands and the DIN tests in Germany. In future, the CEN compliance tests will be the official test procedure in the EU. Legal tests in other parts of the world are the Japanese JLT-13 test or the US EPA TCLP test which is also used in other parts of the world. A comparison of various standards for disposal, as well as for utilisation, points out that the requirements for leaching stability are more or less of equal stringency around the world.

Filter ashes

Filter ashes are deposited at temperatures at or slightly below 200°C. Heavy metal compounds which are volatilised inside the combustion chamber are to some extent condensed on the surfaces of the chamber and the concentration of elements such as Cl, Zn, As, Cd or Pb can significantly exceed those found in the grate ashes. Furthermore, the inventory of low volatile halogenated organic micro-pollutants such as PCDD/F or PCB is also increased compared to that in bottom ashes since these compounds are synthesised inside the boiler. Due to their elevated pollutants inventory boiler and filter ashes have to be characterised as hazardous waste. They are typically disposed of on special - and expensive - disposal sites, including underground. In Germany they are sometimes used in old salt mines for the backfilling of caverns.

The high cost of sustainable final disposal of filter ashes is one reason for numerous attempts to detoxify these materials in order to get access to less expensive disposal routes or even to utilisation scenarios. A broad spectrum of different processes has been proposed and tested at different scales [IAWG 1997]:

- solidification and stabilisation;
- melting and vitrification;
- combined processes like the 3R Process.

For the time being, vitrification is only applied in Japan, often together with fusion of bottom ashes. The molten products have excellent elution stability. Care has to be taken to avoid air pollution by evaporation of metal compounds. The energy consumption of all these processes, however, is very high. That is why none of them - although developed and tested during the 1980s - have made it to the market in Europe. The favoured option in Europe is disposal in dedicated sites.

APC residues

The residues from wet gas cleaning without water discharge and those from dry or semi-dry APC systems carry high levels of soluble salts, especially of alkali and alkali-earth chlorides or sulphates. Due to their high solubility, a safe disposal route can only be guaranteed on special disposal sites. Attempts have been made to utilise parts of the ingredients of these residues in order to minimize the disposal problem. One challenge is the closing of the chlorine cycle. Different processes to recover NaCl [Karger 1990], HCl [Menke 1999], Cl_2 [Volkman 1991], or gypsum have been tested. All such processes can only be successful if they end up with high quality products and if there is a long-term market for the products. Currently, in Germany only a few EfW plants produce HCl and NaCl.

A different - and finally very cheap - way of disposal of filter ashes (and APC residues) is practiced in Germany where authorities enforce the backfilling of cavities in old mines. Salt caverns are already being filled by semi-dry flue gas cleaning residues from EfW in big bags. This strategy - which is even accepted as 'utilisation' - may be justified on the basis that the chemical and physical properties of the original salt and the disposed residues are similar. However, as for similar activities in old coal mines, this argument can hardly be justified.

Thermal treatment 1: grate incineration

Technology	Incineration in grate furnaces
General concept	Combustion of untreated waste in air or oxygen enriched atmosphere on a grate Capable of burning waste with a LHV (lower heating value) of 6 - 12 MJ/kg, for higher LHV the grate or part of it is water cooled
Status of commercialisation	Oldest (since 1874) and prevailing EfW technology world wide Commercially proven, used in >500 plants Many plants have been in operation for 15 - 30 years
Combustion temperature	>850^{0}C (>1,100^{0}C for hazardous or high-chlorine wastes)
Size (per line) Size (per installation)	3 - 40 t/h Very broad; the biggest installations treat about 1.2 - 1.4 million t/a
Energy recovery	Primary or boiler efficiency: 75 - >85% Power efficiency: up to 30%, in combination with power plants higher (40%+) Heat only and CHP can reach >70%

Types of grates

A grate furnace is capable of burning untreated waste. In a grate furnace, the waste is fed in via a feeding chute and then pushed into the combustion chamber by a hydraulic ram or a travelling grate. There are a number of different grate designs in operation but their prime function is the controlled transport of the waste through the combustion chamber. The design has to guarantee efficient mixing of the fuel bed and permanent coverage of the metal parts to protect them against over-heating. In all grates the primary air is injected from below, through the grate.

Out of the three general grate elements (rolls, bars and belts or plates), the latter are today only used as feeding grates. The other types are briefly described below.

- **Roller grates** (see left part in Figures 4.14 and 4.15) use slowly turning perforated rollers to transport the waste through the combustion chamber. An advantage of such grates is that only about 30% of the total grate surface is exposed to the hot combustion chamber, whereas the other part is cooled by the primary air; hence roller grates cope well with high calorific waste. They have also been preferred for high throughputs. The whole design and especially the wear of the sealing of the roller nips make this grate type more complex and expensive than some other types.

Figure 4.14: Four types of common grates: roller (left), forward-acting reciprocating (centre), horizontal (right top), reverse-acting grate (right bottom)

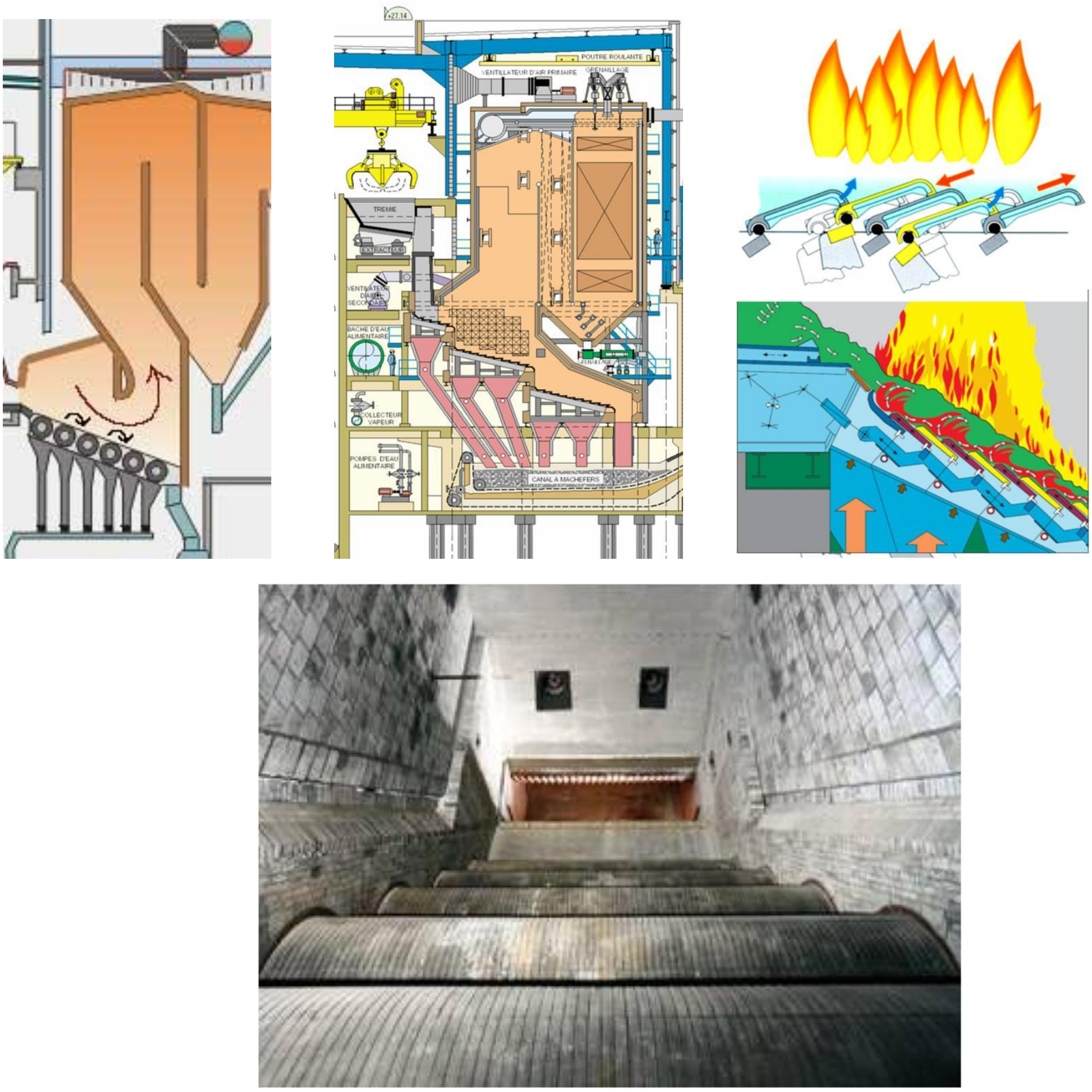


Figure 4.15: Combustion chamber with two lines of a horizontal grate (left) and five lines of a reverse-acting (right; adopted from [Martin 2009])

- **Reciprocating grates** are grates that use bars to transport waste. The most common designs are rows of bars, with one fixed and the next one partly stacked below the first one, moving. If the moving bars push the waste towards the end of the grate the type is called forward-acting grate or stoker. These grates are moderately inclined (see central picture in Figure 4.14). The figure indicates that the grate can be stepped for improved mixing.

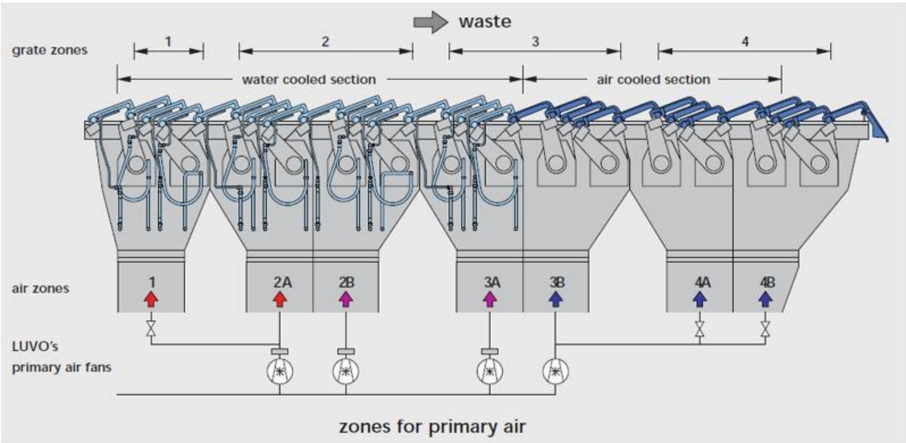
  Forward-acting grates can also be built horizontally (see top right of Figure 4.14 and left picture in Figure 4.15). The figure shows the movement of the bars.

  The bottom right drawing of Figure 4.14 and the right photo in Figure 4.15 show the reverse-acting or Martin grate. In this case the bars push the waste against the transport direction. This design requires a steeper angle and accomplishes a good vertical mixing of the waste.

For high throughputs, the combustion chamber can be equipped with two or more lines of bars as shown in Figure 4.15 for a horizontal and a reverse-acting grate.

To extend the combustion capability to LHVs exceeding 12 MJ/kg, forward-acting grates are often partly equipped with water cooled bars. The design shown in Figure 4.16 has been used in the new lines of the AEB Amsterdam waste incinerator [AEB 2010].

Figure 4.16: Water cooled horizontal grate in the AEB Amsterdam incinerator



Combustion chamber

The combustion chamber can be configured as counter-, middle-, or parallel-flow system, depending on the location of the flue gas exit. The different designs are seen in the schemes of full scale facilities shown in Figures 20 to 23.

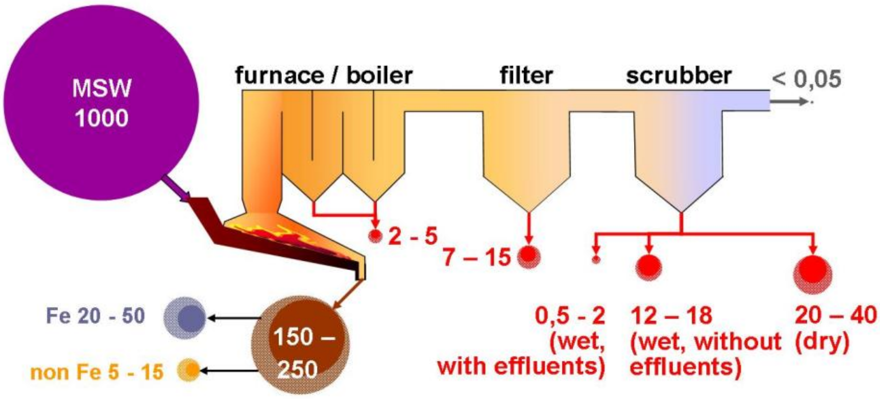
Mass flow

Figure 4.17 shows average ranges for the mass flow as found in modern waste incinerators [IAWG 1997]. The air consumption is approx. 4,500 m^3/t of waste.

In Western industrialised countries, between 15 and 25 wt% of the waste feed leaves the plant as bottom ashes. In Japan, this share is in the order of 10 - 15 wt%. Most published data include the grate siftings which are only recently, and only in some countries, kept separate from the bottom ash. The mass flow of siftings depends on the type of grate and its time of operation. The siftings may increase the amount of unburnt matter in the bottom ash. In view of utilisation, however, the inventory of metallic aluminium, which tends to drip through the grate voids, is of much higher concern.

The bottom ash contains significant amounts of ferrous and non-ferrous metal scrap which is now routinely recovered using magnetic and eddy current separation.

Figure 4.17: Schematic of typical mass flows in a MSW grate incinerator



The amount of boiler ash (the ash deposited in the boiler) depends on the type of boiler and on the dust load of the flue gas leaving the combustion chamber. Mean figures in modern plants are 2 - 5 kg per t of waste. Boiler ashes should not be combined with the grate ash, but be treated together with the filter ash; this requirement has been enforced by legislative regulations in some countries.

The fine particulate fly ashes are preferentially removed from the flue gas by ESP or fabric filters. The amount produced is dependent on the raw gas fly ash concentration - usually in the range 1.5 - 5 g/m^3. Dust loads in modern waste incinerators which use a so-called 'gentle' combustion in order to limit the PCDD/F formation inside the boiler [Vogg 1991] are found at the lower end of that range.

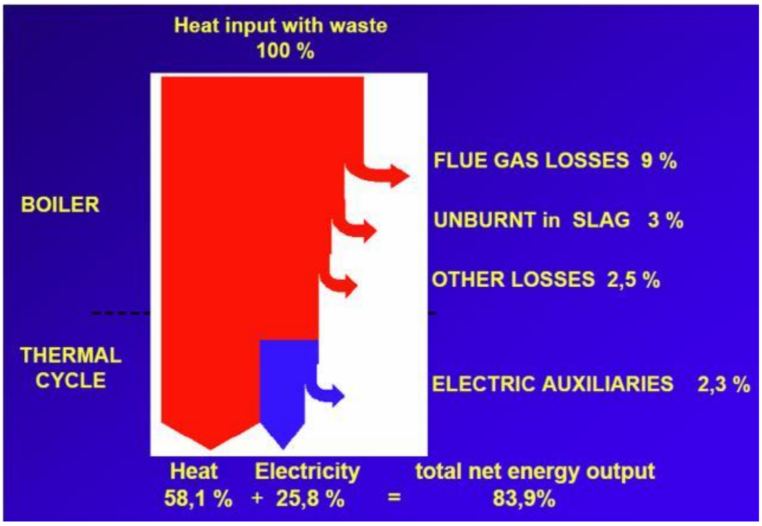
The mass flow of APC residues shows actually the highest variation of all residues. As described above, a wet scrubber is operated close to stoichiometry. If the discharge of scrubber effluents - after cleaning and neutralisation - into a sewer is permitted, the residue, a neutralisation sludge comprising mainly metal hydroxides, is only in the order of approx.0.5 - 2 kg. In case of wet scrubbing with effluent evaporation another 12 - 18 kg of dried soluble salts have to be added.

In semi-dry or dry systems the amount of residues is significantly increased because of un-reacted additives. The 20 - 40 kg per t of waste is a typical value found in modern waste incineration plants.

Energy flow

As an example of the energy flow in a modern waste incineration plant, Figure 4.18 shows the energy balance of the energy optimised waste incinerator in Brescia, Italy.

Figure 4.18: Energy balance for the Brescia, Italy, waste incineration plant



The flow scheme documents a primary or boiler efficiency of about 85%. For other plants, even slightly higher figures have been reported.

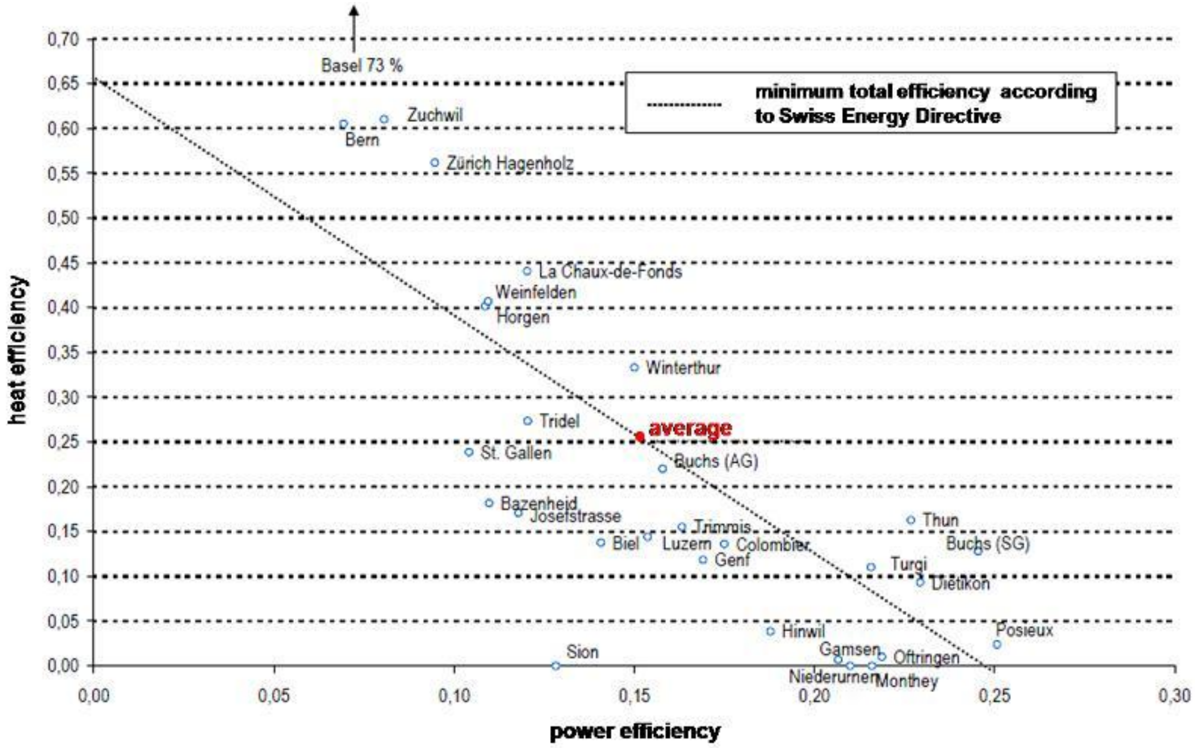
In the case of Brescia, a power efficiency of almost 26% is achieved, which allows a net power export 24.5% of the initial heat input. Most plants, however, reach only 15 - 20%.

CHP is practiced increasingly for better utilisation of the energy inventory of the waste. In Brescia, 58% of the waste input energy is used as heat. Other plants which are only designed for heat utilisation (as in Sweden), reach efficiencies in excess of 70%.

The variation in the energy efficiency of 29 existing (Swiss) waste incineration plants is shown in Figure 4.19 [Hügl 2008]. There are plants like Fribourg-Posieux with high power generation of 25%, but low heat utilisation of only 2.5%. Other plants like Basel utilise export heat (73%) but have a power efficiency of only 7%.

The tendency to optimise the energy recovery in Switzerland is indicated by the line which shows the minimum energy efficiency requirement of the Swiss Environmental Agency BAFU for new waste incinerators.

Figure 4.19: Distribution of heat and power efficiencies in all 29 Swiss waste incineration plants [Hügl 2008]

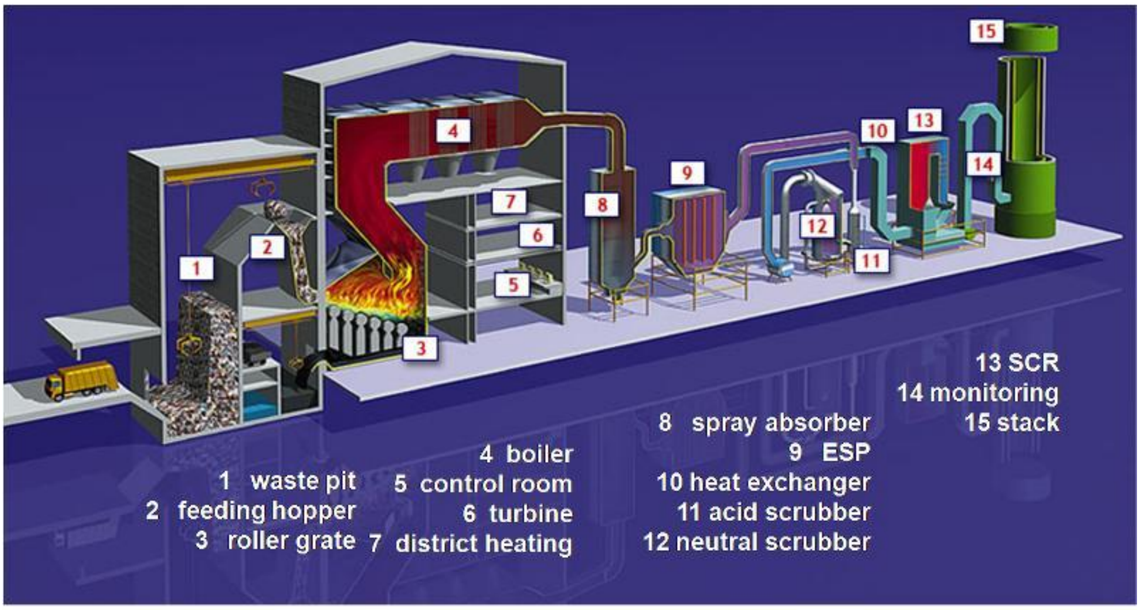


Schematics of waste incineration plants with grate furnaces

Figures 4.20 to 4.23 show schematics for four modern waste incineration plants. The flow diagrams show the design of different options that are not necessarily the most technically advanced, nor the most efficient, or the most economic. However, at the time they were developed the facilities were best adapted to the prevailing local circumstances.

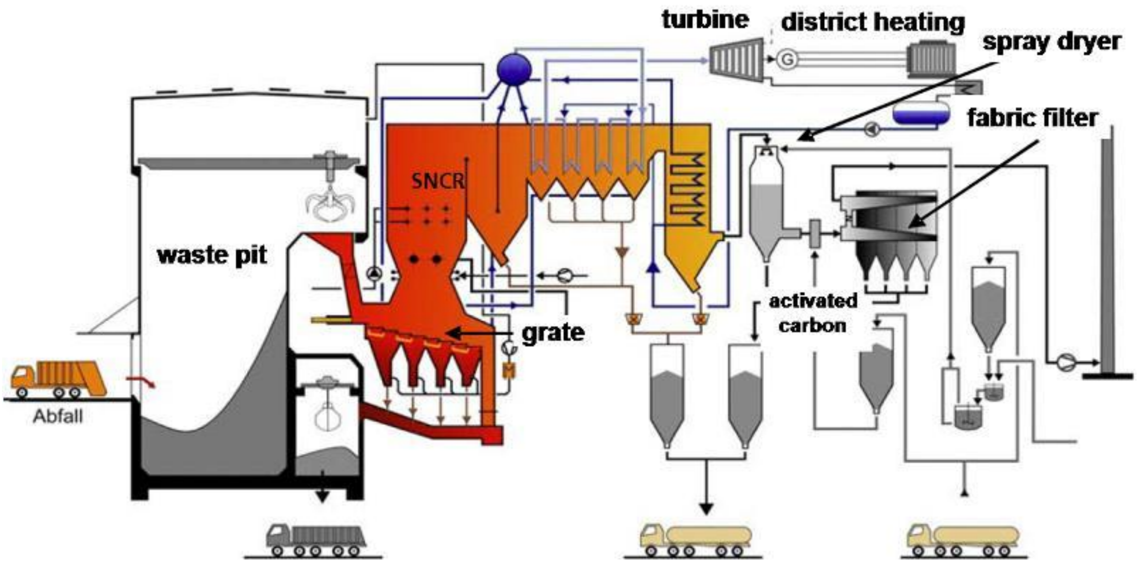
The Offenbach plant (Figure 4.20) was built in 1970 with (at that time) the preferred roller grate system. It was last upgraded in 1996. Its annual throughput is 250,000 t of MSW and it exports heat and power. The reported power efficiency is approximately 7% and about 31% of the energy input is used as heat. The plant has been built in a remote location and clients for heat consumption are limited. Furthermore, the boiler is of the conventional design with 400°C and 40 bar steam parameters.

Figure 4.20: Flow diagram of a MSW grate incinerator equipped with a roller grate, parallel-flow combustion chamber, horizontal boiler, wet scrubbing with spray dryer, SCR (Offenbach, Germany)



The plant is equipped with a wet scrubbing system with internal evaporation and a SCR for NO_x abatement.

Figure 4.21: Flow diagram of a MSW grate incinerator equipped with a forward-acting grate, middle-flow combustion chamber with SNCR, horizontal boiler, dry scrubbing (Leuna, Germany)

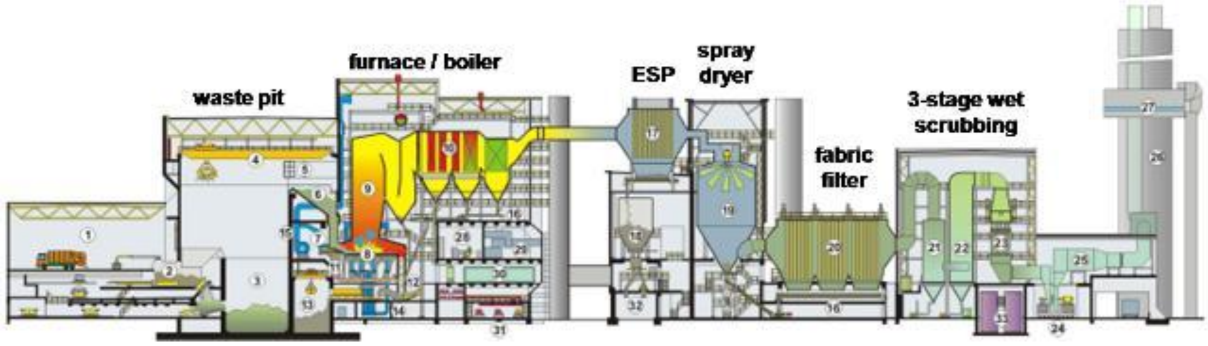


The Leuna facility (Figure 4.21) with a throughput of 390,000 t/a began operation in 2007. It generates power only with a net efficiency of 20%. The plant has a rather 'lean' APC system with SNCR and dry scrubbing.

The new extension of the Amsterdam waste incinerator (Figure 4.22) came into operation in 2007. It comprises two identical lines with a throughput of 265,000 t/a each, which makes the facility, with a total throughput of 1.4 million t, the biggest waste incinerator in the world.

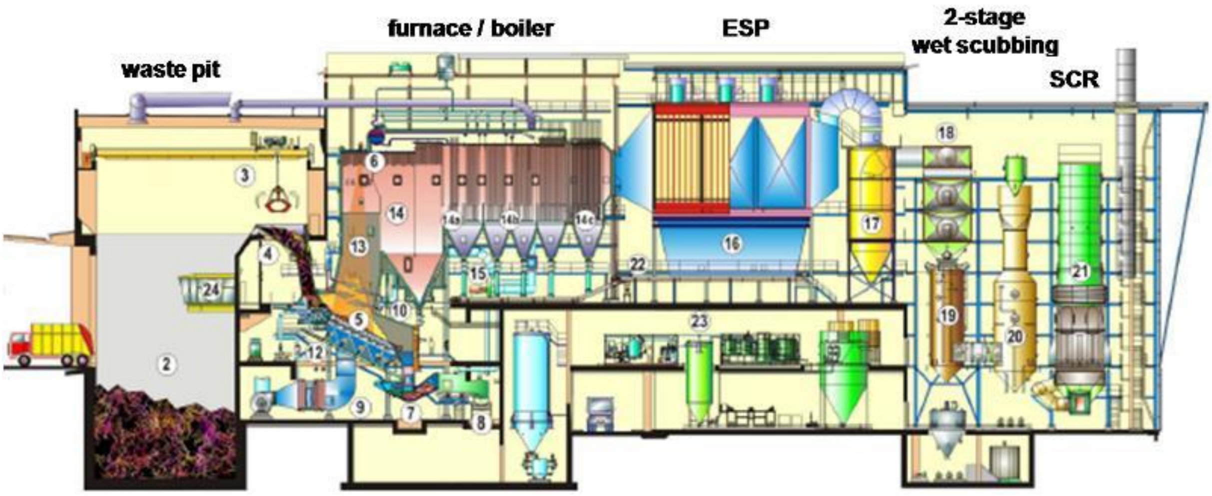
The new lines have a power efficiency of approximately 31%, which is not only due to the high steam parameters (440°C, 130 bar, but also to an additional economiser downstream of the ESP and another one in the third so-called fine scrubber. The plant produces $Ca(Cl_2)$ and gypsum from the scrubber effluents and has installed a highly-sophisticated bottom ash treatment for optimised metal recovery.

Figure 4.22: Flow diagram of a MSW grate incinerator equipped with a horizontal grate, middle-flow combustion chamber with SNCR, horizontal boiler, 3-stage wet scrubbing with spray dryer (Amsterdam new lines, The Netherlands)



The Swiss Fribourg-Posieux waste incinerator (Figure 4.23) started operation in 2001. It is a small plant with one line only and a design capacity of 88,000 t/a. In 2007 it treated 81,600 t and achieved an availability of 95%. The plant is optimised for power generation; the respective efficiency is 25% and the in-house demand is 5.7%.

Figure 4.23: Flow diagram of a MSW grate incinerator equipped with a reverse-acting grate, counter-flow combustion chamber, horizontal boiler, 2-stage wet scrubbing with liquid effluents, SCR (Fribourg-Posieux, Switzerland)



Architectural features

The architectural design of modern plants has become of increasing significance in most countries that utilise EfW technology. The principal driver for this is to achieve greater public acceptance. Figure 4.24 illustrates some of the design concepts that have been realised in different countries.

Figure 4.24: Pictures of selected waste incineration plants with special architectural features

NL - Amsterdam

NL - Rotterdam

F – Chartres

I - Brescia

D - Mainz

J – Maishima (Osaka)

J - Saitama

DK - Esbjerg

Thermal treatment 2: fluidised bed (FB) incineration

Technology	Incineration in fluidised bed furnaces
General concept	Combustion of pre-treated (shredded) waste in a bed of sand (partly with dolomite), fluidised by air injected through nozzles in the floor of the furnace Preferentially used for SRF Waste particle size <200 mm The sand facilitates an efficient heat transfer and is separated from the extracted bed ash and recycled LHV of the fuel can change in wide ranges from < 5 MJ/kg - >20 MJ/kg Only atmospheric facilities are used in waste incineration
Status of commercialisation	For waste incineration practiced since approx. 1970 Commercially proven, used in >50 plants for MSW incineration Mainly used in Japan for smaller throughputs
Combustion temperature	Bed temperature 800 - 850^{0}C Freeboard temperature >850 - 1,100°C
Size (per line) Size (per installation)	3 - 15 t/h <10,000 - 660,000 t/a
Energy recovery	Primary or boiler efficiency: 80 - >85% Power efficiency: up to 25% Heat only and CHP can reach >70%

Types of FB furnaces

FB furnaces consist of a rectangular or cylindrical combustion chamber where finely grained fuels are burned in a fluidised sand bed, sometimes with the addition of dolomite for the capture of acid gases. FB furnaces were initially developed for the combustion of sewage sludge and are today deployed mainly in Japan for the use of municipal waste. Currently, they are becoming more popular for the combustion of SRF and biomass.

The share of (waste) fuel in the sand bed is typically of the order of 2 - 10 % only, depending on the calorific value of the fuel.

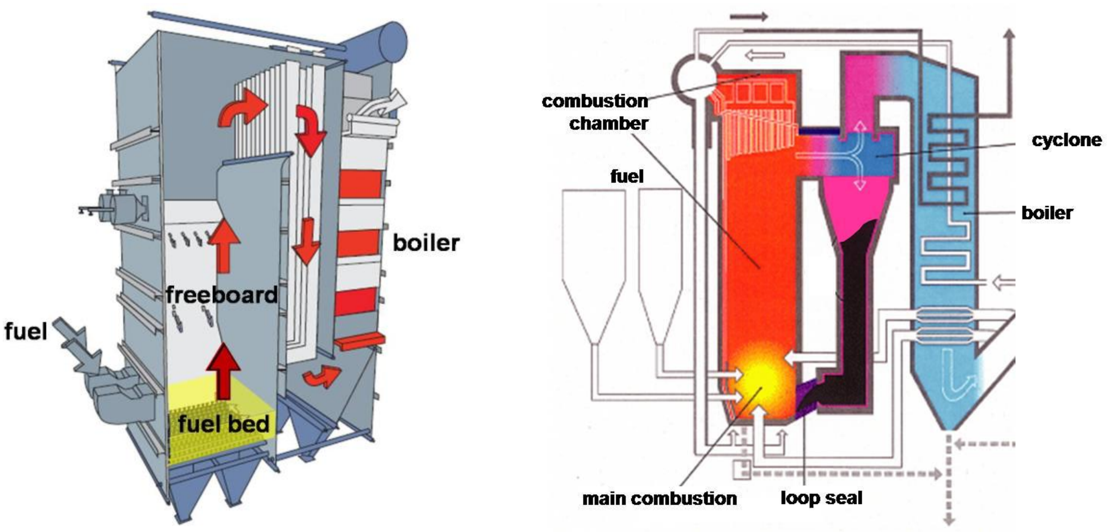
All FB furnaces have the advantage to establish a uniform distribution of the waste in the fluidised fuel bed, which enables a homogeneous and stable combustion. Another advantage is the wide range of heating value of the fuel that can be burnt in this type of furnace. The energy density in the fuel bed can be varied by controlling the share of fuel in the bed.

These advantages, however, have to be paid for by the need for pre-treatment of the fuel, as, for establishing fluidisation, the particle size of the fuel has to be limited. Another limitation is the fuel bed temperature, which is typically kept < 850°C to avoid melting of ash components and the collapse of the fluidised bed.

Three types, stationary, circulating, and revolving or internally circulating fluidised beds have been used for waste incineration.

- **Stationary** FB furnaces are the simplest designs (see Figure 4.25). The fluidisation forms a fuel bed which fills only a small fraction of the height of the furnace. Depending on the expansion and fluidisation this type is often also called bubbling fluidised bed.

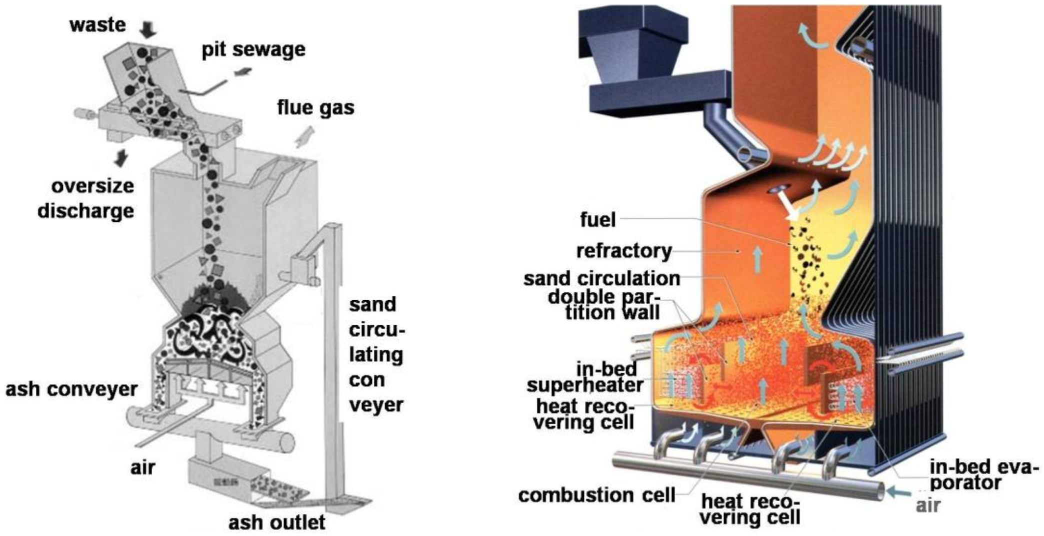
Figure 4.25: Stationary (left) and circulating (right) fluidised bed furnaces



- **Circulating** FB furnaces (see Figure 4.25) operate with higher suspension, which causes an entrainment of part of the bed material out of the combustion chamber. This material is precipitated in a cyclone and fed back into the furnace.

  For better fuel bed temperature control and more efficient energy extraction, part of the boiler is integrated in the combustion chamber walls. In some furnace designs the superheater is placed in the area where the sand is fed back into the furnace. In this area, almost no chlorides are present in the material, which reduces the corrosion risk. Experience shows that erosion on the boiler tube walls is not a problem.

Figure 4.26: Two schemes of revolving or internally circulating fluidised bed furnaces



- **Revolving** - also called internally **circulating** - FB furnaces (see Figure 4.26) have a design that establishes internal horizontal eddies and increases the residence time of the fuel in the lower part of the furnace. Such FBs cope with more coarse fuels. In most cases the feeding system is a twin-screw mechanism, which acts as a kind of shredder. The resulting particle size can exceed 20 cm - big hard lumps are discharged (see left furnace in Figure 4.26).

  The larger particles burn on the (in most furnaces) inclined floor until they can be discharged at outer ash discharge ports (left design in Figure 4.26) or in the centre opening (see right design in Figure 4.26).

  In new plants, evaporator and superheaters are often installed in cells in the outer parts of the fuel bed for the same reason as in the case of circulating FBs (see left furnace in Figure 4.26).

  More than 140 plants using the revolving FB furnace are in operation.

Mass and energy flows

Mass and energy flows are not fundamentally different from those for grate based incinerators. A typical mass balance cannot be established since the total amount of residues and especially the amount of bed ash, depends strongly on the degree of pre-treatment of the waste. A complete mass balance of a selected EfW process must of course include all process stages, which means the mass flow in the sorting and pre-treatment also has to be taken into account.

The total amount of solid residues is the same in all combustion processes, provided the burnout is of equal quality. The distribution, however, depends on the process applied and that means, as a common rule, that the amount of fly ash is typically much higher than in grate systems. The few published reports underline this assumption.

Due to the small particle size and the long residence time in the sand bed, the burnout of bed as well as of fly ash and the gas phase is always excellent.

The gas cleaning processes are common for all combustion processes and if the same fuel is burnt, the APC residues are also identical, again independent of the combustion process. However, since waste for FB plants is pre-treated, it should be assumed that the amount of pollutants in the fuel is lower than in mixed MSW and that hence the amount of APC residues is lower, too.

The energy balance is also in principle not different from that of a grate incineration plant. Considering the use of pre-treated and typically higher calorific waste, the energy input per ton of fuel is higher and so are the generated energies. The percentile energy flow, however, is fully in line with the overview energy balance shown in Figure 4.6.

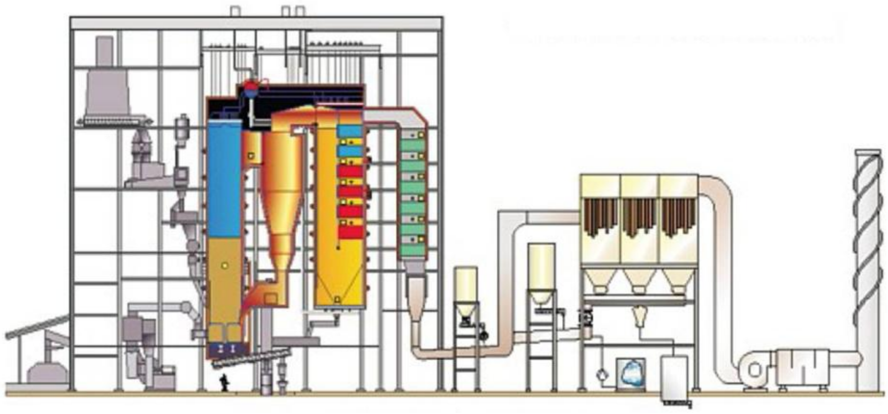
Schematics of waste incineration plants with FB furnaces

The layout of FB incineration plants is in principle identical with that of grate based plants, except for the furnace. That means the furnace is followed by a heat recovery boiler. In most cases, vertical boilers are installed. The cooled flue gas enters one of the gas cleaning systems as described above. The selection of FB systems depends on local conditions and sometimes political preference and not on the combustion technology.

FB incinerators are mainly found in Japan, but also for combustion of SRF and co-combustion in Sweden and the Iberia peninsula.

The Norrköping facility, equipped with a circulating FB furnace, started operation in 2003. The plant has a thermal capacity of 75 MW and is equipped with SNCR and dry gas cleaning. The flow diagram of the plant is shown in Figure 4.27 [Wilén 2004].

Figure 4.27: Flow diagram of the Norrköping FB waste incineration plant



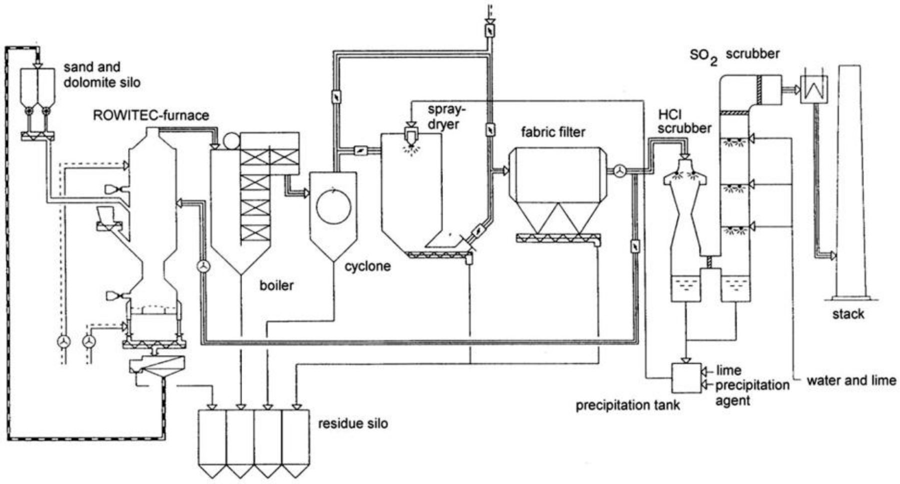
An almost identical configuration is found in Coruna, Spain, in the SOGAMA FB incinerator. This plant started operation in 2000. It is part of a complex with an SRF production facility. The incinerator has a capacity of 1,200 t/d, which adds up to approximately 400,000 t/a.

The revolving FB technology has been used in the waste management centre Tirmadrid in Madrid-Valdemingomez with a recycling, SRF, composting, and SRF combustion plant. The latter one has three identical lines with an SRF throughput of 80,000 t/a each.

The flow diagram is very similar to that of the ROWITEC plant, which was built during the 1990s in Berlin-Ruhleben, Germany, but had to be dismantled after a short operation time due to poor waste quality.

The scheme shown in Figure 4.28 of this Berlin plant visualises a cyclone for precipitation of primary fly ash and a spray dryer for evaporation of the effluents from the two-stage wet scrubbing system downstream of the fabric filter. In the Madrid plant, the wet scrubbers are missing and the gas cleaning is performed by injecting slaked lime and activated charcoal into the spray dryer.

Figure 4.28: Flow diagram of the Berlin-Ruhleben FB waste incineration plant (out of operation)



External appearance

The three plants shown below are of:

- The Madrid-Valdemingomez plant at the end of the construction phase. The three revolving FB furnaces are seen in the foreground.
- The second aerial view shows the circulating FB SRF plant in Coruna (in the background) with SRF production plant and composting facility.
- The third picture shows the SRF combustion plant in Omuta, Japan, a revolving FB plant with three lines, 105 t/d throughput each.

Figure 4.29: Aerial views of FB combustion plants


ES – Madrid-Valdemingomez


ES - Coruna


J - Omuta

Thermal treatment 3: gasification

TECHNOLOGY	GASIFICATION IN VARIOUS TYPES OF REACTORS
General concept	Mainly multi-stage processes with gasification of waste in shaft or fluidised bed furnaces, in gasification chambers, in entrained flow systems or on grates The synthesis gas can be used for chemical synthesis, fed into gas engines, directly burnt, or co-combusted in power plants All processes end up with molten solid residues
Status of commercialisation	In Japan, 95 plants with 195 lines and a total throughput of approx. 17,500 t/d
Temperature	Gasification: 300 - 1,400°C Post combustion chamber: up to 1,350°C
Size (per line) Size (per installation)	< 1 - 11 t/h <10,000 - 150,000 t/a
Energy recovery	Primary energy efficiency typically > 80% Power efficiency: Ebara claims 22 - 33% depending on waste type and plant size, however, this excludes in-house demand for operation and oxygen production

Type of gasification reactors and process schemes

There are a number of different reactor types that are in operation in waste or SRF gasification plants:

- shaft furnaces / fixed beds;
- moving beds / grates;
- fluidised beds with HT combustion of the synthesis gas or its co-combustion in a power plant;
- entrained flow systems;
- combined degassing in a channel followed by gasification in a chamber.

For the first category, Figure 4.30 shows the scheme of a Nippon Steel shaft furnace. These furnaces have been developed from steel furnaces and are almost always operated in co-treatment together with coal. The share of coal varies between 5 and 10%. The gasification temperature is in the order of 1,000°C, the energy for the process is supplied by partial combustion of coke and residual waste remaining in the lower part of the shaft furnace where the temperature may reach 1,800°C.

A flow scheme of a Nippon Steel shaft furnace gasification plant is shown in Figure 4.31. The synthesis gas is directly fed into a combustion chamber which is followed by a conventional APC system, in this case, a dry scrubbing system [Nippon Steel 2010].

Figure 4.30: Scheme of and reactions in a Nippon Steel shaft furnace

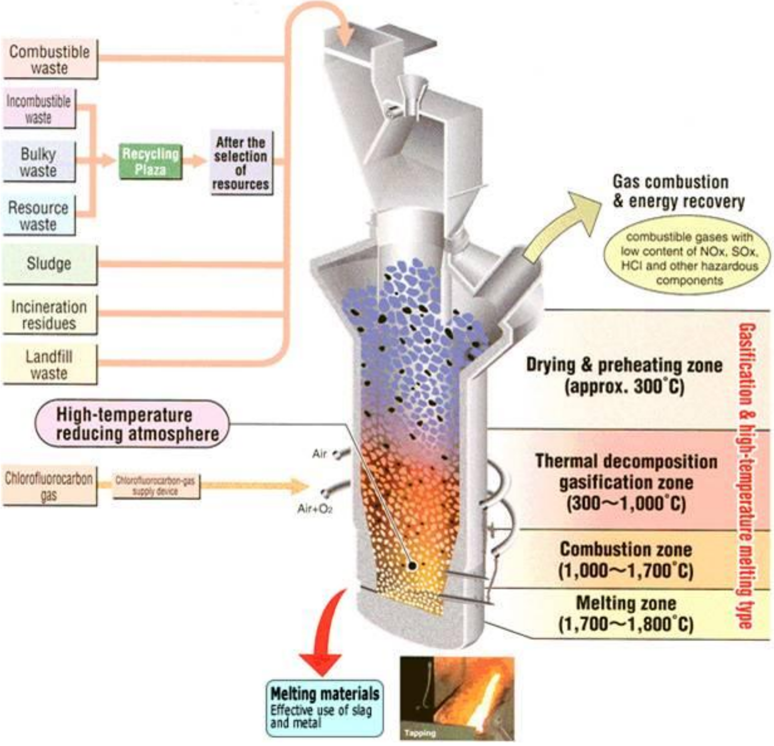
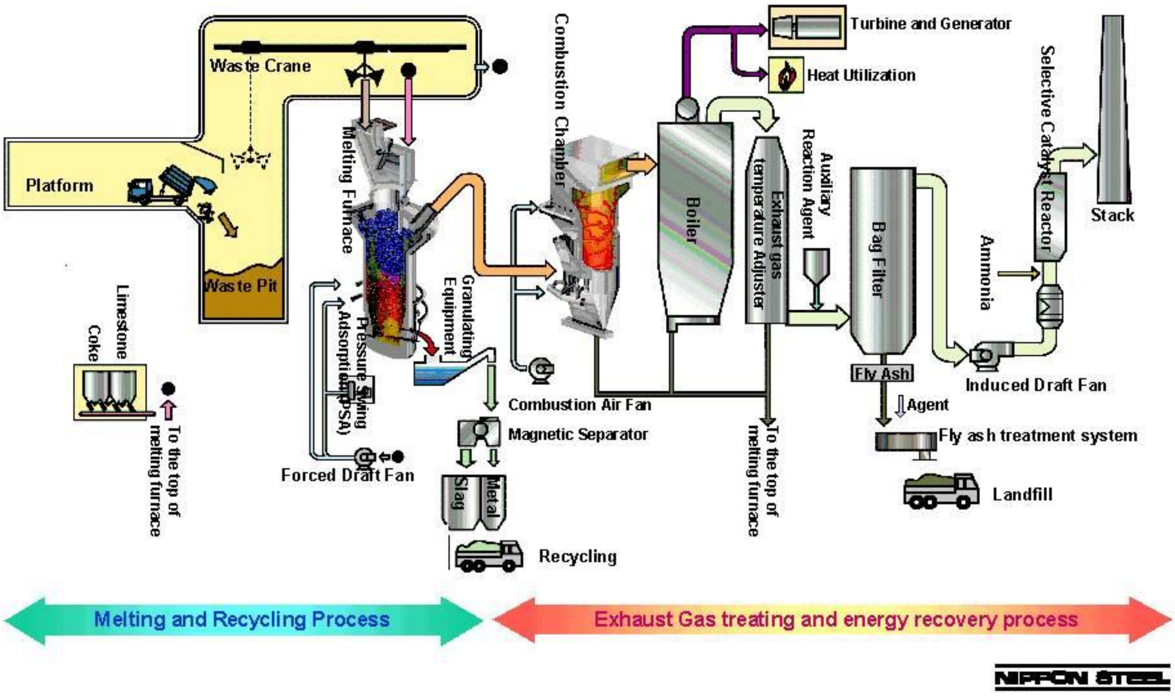


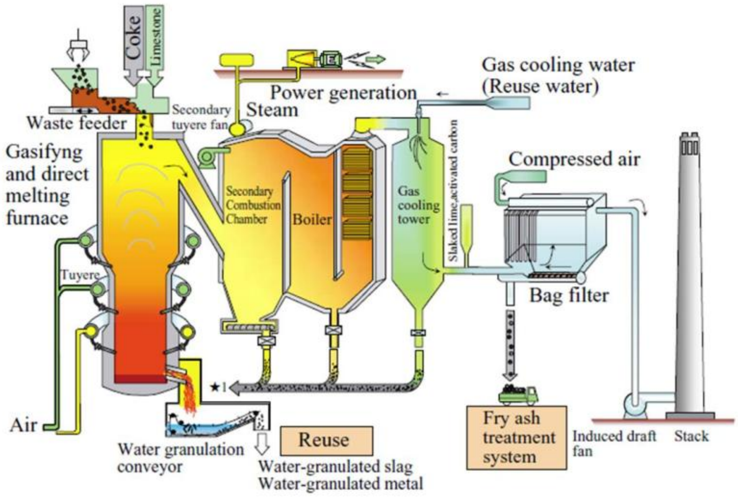
Figure 4.31: Flow diagram of a Nippon Steel MSW gasification and combustion plant



Nippon steel built 28 such plants with 57 lines and a capacity of 6,200 t/a in Japan.

A similar process is the JFE High-Temperature Gasifying and Direct Melting System. A flow diagram is depicted in Figure 4.32 [Nishino 2009]. The gasifier also treats waste with a small addition of coke; limestone is added for capture of sulphates. JFE has built ten plants with 20 lines and a total capacity of 1,500 t/d.

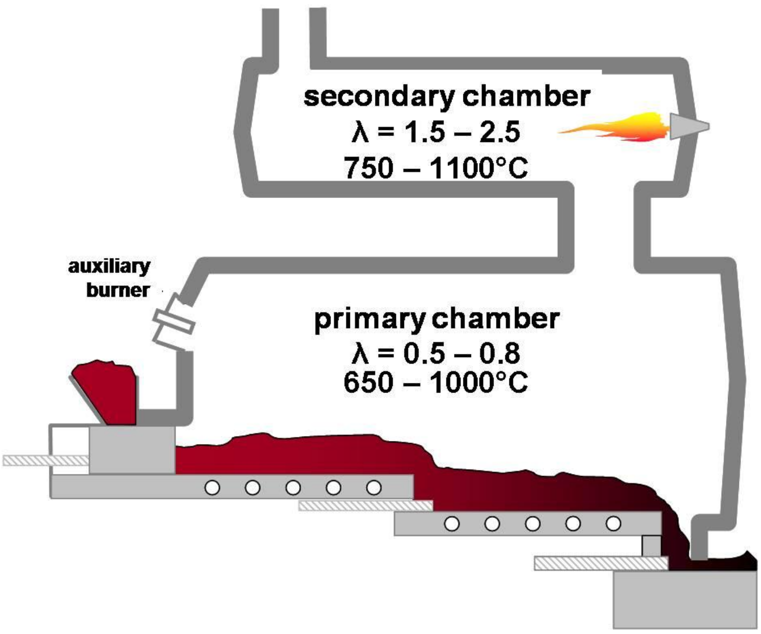
Figure 4.32: Flow diagram of the JFE High-Temperature Gasifying and Direct Melting System



There are four other minor companies building shaft furnace plants. The entire number of implemented facilities is 47 with 93 lines and a capacity of 8,500 t/d.

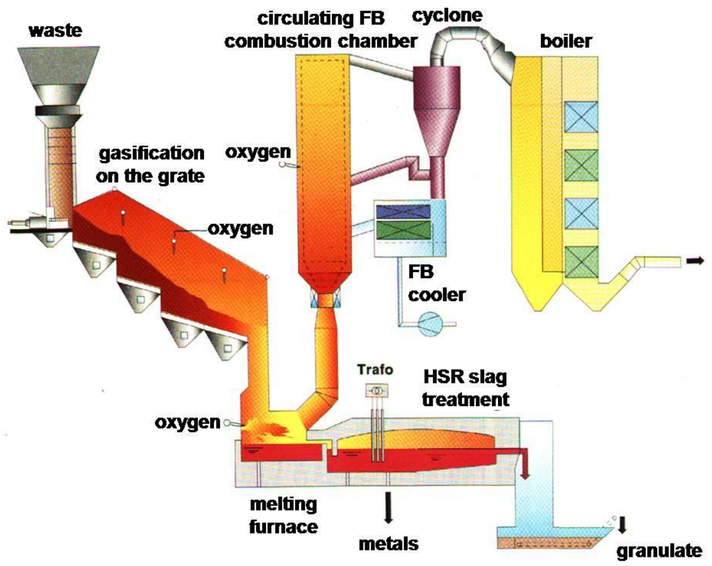
A quite different system is the Consumat Two-Stage Combustion that has had a limited market in the United States and Canada for small sizes (capacity few t/h). The scheme of the furnace in Figure 4.33 shows two combustion chambers on top of each other. The lower chamber is operated under sub-stoichiometric oxygen supply, which means it can in fact be called gasification. The plants were equipped with boiler and APC system.

Figure 4.33: Furnace of a Consumat Two-Stage Combustion plant



A complex process combining gasification in a grate furnace with combustion in a FB and ash melting in a melting furnace is the RCP Process, developed in the mid 1990s by vonRoll. A first plant with a throughput of 6 t/h was built in Bremerhaven, Germany, on the premises of the existing waste incinerator. The plant was closed after a few years of operation (1997 - 2003) due to financial problems. However, the process is currently offered in Japan by Hitachi. Figure 4.34 shows the thermal part of a RCP plant.

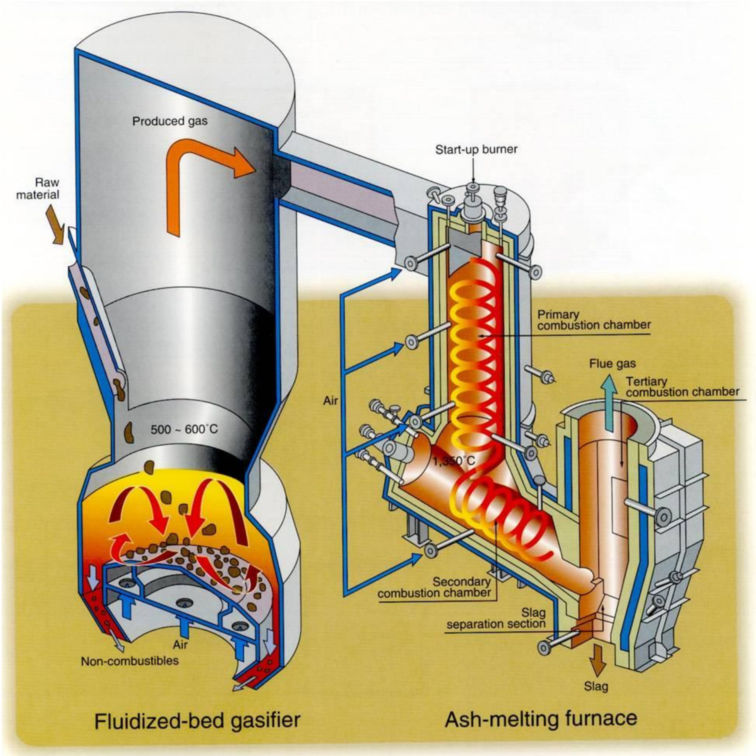
Figure 4.34: vonRoll / Hitachi RCP Process (without APC system)



Fluidised bed gasifiers are the second successful technology in Japan. The leader in this market is the Ebara TIFG Process which combines gasification in a revolving FB with a cyclone combustion chamber. A scheme of the gasification and combustion part of such plants is shown in Figure 4.35.

The gasification temperature is 500 - 600°C; the combustion takes place at 1,350 - 1,450°C. The combustion chamber is followed by a boiler and a conventional APC system. The gasification residues are ashes; those from the high temperature combustion are molten slags.

Figure 4.35: Scheme of the revolving FB gasifier and the cyclone combustion chamber of the Ebara TIFG Process

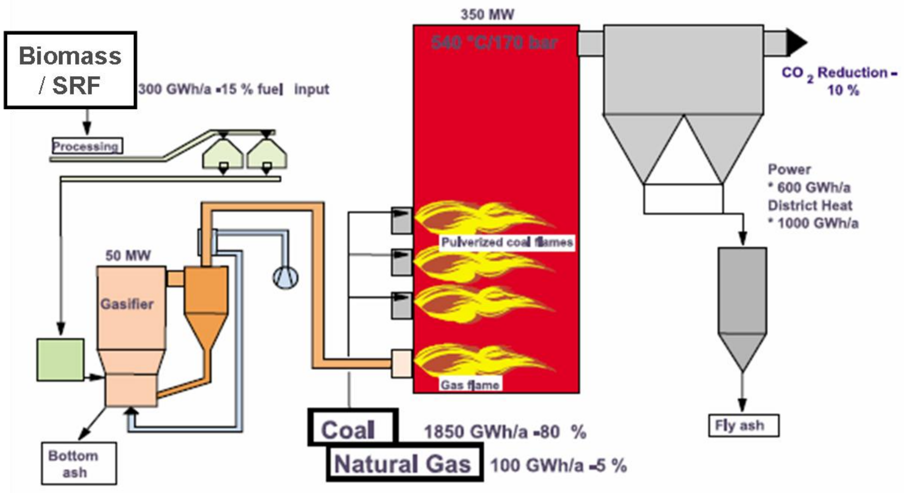


Ebara built 12 plants of this type in Japan, with 28 lines and a capacity of 3,100 t/d. The plants not only treat MSW, but also special waste fractions like automotive shredder residues (ASR) or waste plastics.

In Finland, a FB gasifier has been in operation for source-separated plastic-rich household waste in the city of Lahti [Nieminen 2005]. The plant no longer treats MSW due to the new Finnish air emission regulation. However, a new plant based on the same principle but equipped with an APC system is being proposed.

In Lahti, the synthesis gas is directly injected into the Kymijärvi coal and gas fired power plant. A scheme of the Lahti gasification / co-combustion system is shown in Figure 4.36.

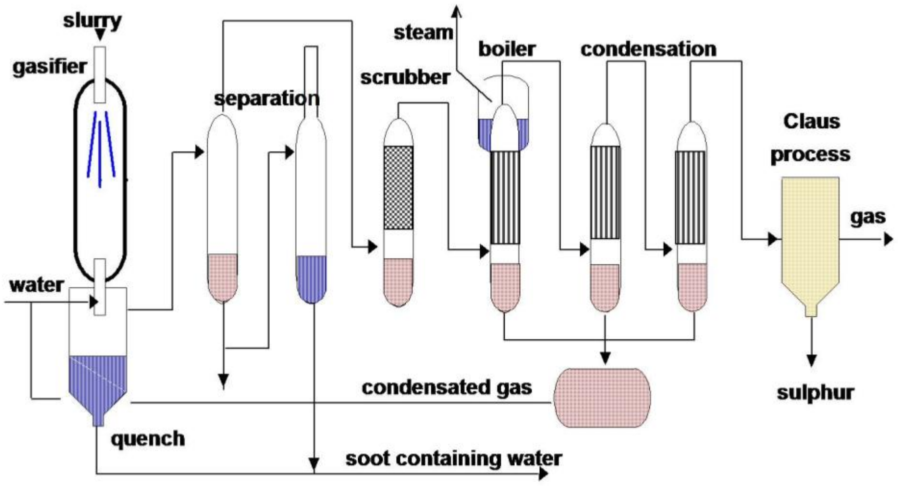
Figure 4.36: Flow diagram of the Lahti gasification / co-combustion system



The huge Schwarze Pumpe entrained flow gasification plant, originally built for lignite, has been in operation close to Cottbus in Germany. The plant gasified lignite and SRF produced from MSW; the synthesis gas was used for methanol production. The plant also had fixed bed gasifiers which partly also fed with SRF.

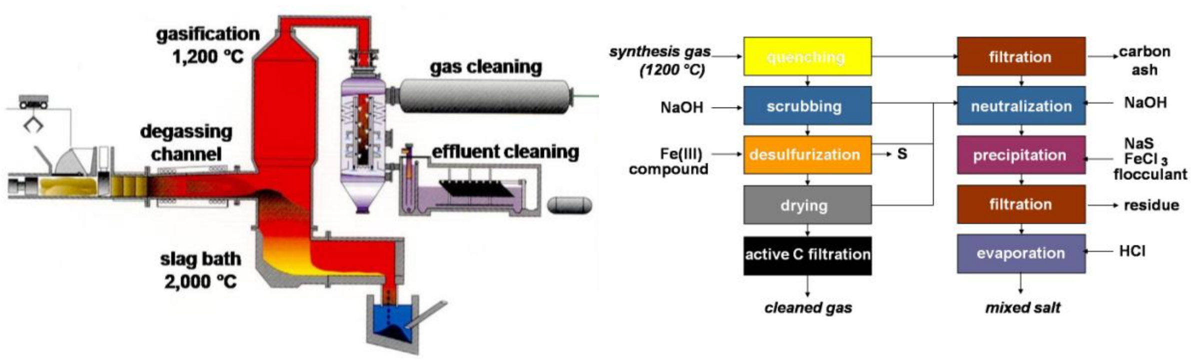
The whole plant had an annual throughput in the order of 300,000 - 350,000 t. It was shut down a couple of years ago due to financial problems. A flow diagram of the rather complex process is shown in Figure 4.37. The problem was the gas cleaning, which has high operational costs to meet the requirements of the methanol synthesis. A special challenge is the removal of sulphur compounds.

Figure 4.37: Flow diagram of the entrained flow gasifier plant at Schwarze Pumpe, Germany



Another complex process, based on degassing of the waste at elevated temperature, high temperature gasification (1,200°C), and residue melting (2,000°C) is the Thermoselect process [Stahlberg 1995]. The process aims for optimisation of energy and material recovery. The synthesis gas can either be used for methanol or other synthesis, it can drive a gas engine or it can be burnt. In case of synthesis, again, as in the case of Schwarze Pumpe, the gas cleaning results in high costs.

Figure 4.38: Flow diagram of the Thermoselect process (left) and scheme of the synthesis gas cleaning (right)

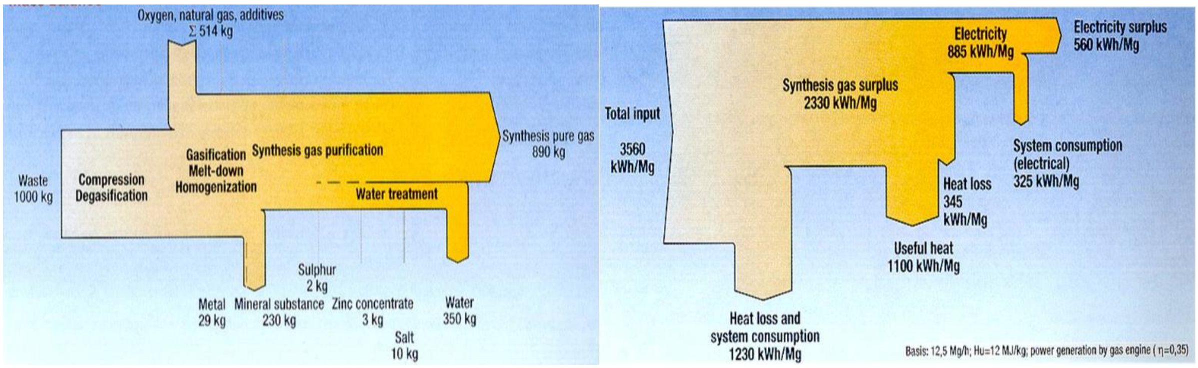


A flow diagram of the process is shown in the left part of Figure 4.38; the right part shows the multi-stage gas cleaning concept at the first German plant in Karlsruhe, which has, like other so-called novel processes, been shut down after a short operation time for financial reasons.

For the Karlsruhe plant, mass balances and energy balances have been published, but were, however, calculated before the plant started on the basis of results from pilot plant tests in Fondotoce, Italy. The balances are shown in Figure 4.39.

Since the Karlsruhe plant was equipped with a combustion chamber, the claimed 25% power efficiency was not achieved.

Figure 4.39: Mass (left) and energy balance (right) for the Thermoselect plant



The Japanese company Kawasaki, which is now part of JFE, took the licence from Thermoselect and built five plants with 12 lines and a total capacity of 1,725 t/d.

Architectural features

The Thermoselect plants are all built to a design by an Italian architect and have almost the same layout as can be seen in Figure 4.40, which shows the building of the mothballed plant in Karlsruhe and the first Japanese plant in Chiba, which is located on the premises of the Kawasaki steel works and began operation in 1999.

Figure 4.40: Thermoselect plant in Karlsruhe, Germany (left), and in Chiba, Japan (right)

Thermal treatment 4: pyrolysis

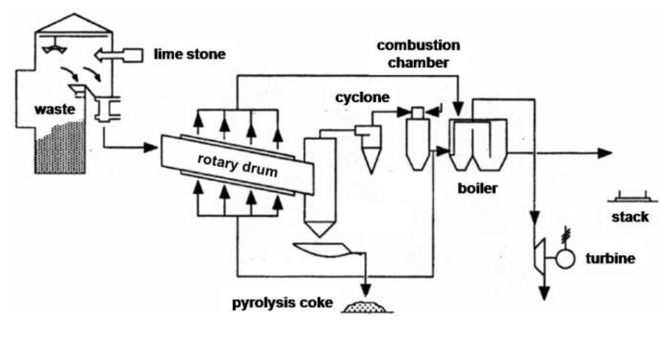
Technology	Pyrolysis in rotary drums / HT combustion of pyrolysis gas (and coke)
General concept	Pyrolysis of waste in an externally heated rotary drum, combustion of pyrolysis gas in high temperature combustion chamber Separation of pyrolysis coke from inert ash, in all but one plant burnt together with the pyrolysis gas
Status of commercialisation	First commercial plant operational in Burgau, Germany 11 plants with 22 lines and a total throughput of 2,360 t/d in Japan
Temperature	Pyrolysis: 400 - 500°C Combustion: 1,100 - 1,350°C
Size (per line) Size (per installation)	2.5 - 8.3 t/h 28,000 Mg/a - 140,000 t/a
Energy recovery	Boiler efficiency can be as high as in conventional combustion plants Power efficiency for one plant was reported to 15%

Pyrolysis reactors and flow diagrams

Pyrolysis of waste is applied in only a few commercial scale plants. The pyrolysis takes place in heated rotary drums at temperatures of approx. 450°C. The first commercial plant in Burgau, Germany, had an externally heated drum. Japanese plants, based on a Siemens patent, use a design with internal heating tubes (see inlet photo in the left part of Figure 4.42).

The Burgau pyrolysis plant, built in 1984 [Fichtel 1987], has a throughput of approximately 30,000 t/a and is, following a refurbishment in 2009, still in operation. Figure 4.41 shows the flow diagram of this plant (without APC system). The pyrolysis reactor is an externally heated rotary drum, the synthesis gas passes a cyclone and is then fed into a combustion chamber.

Figure 4.41: Flow diagram of the Burgau pyrolysis plant



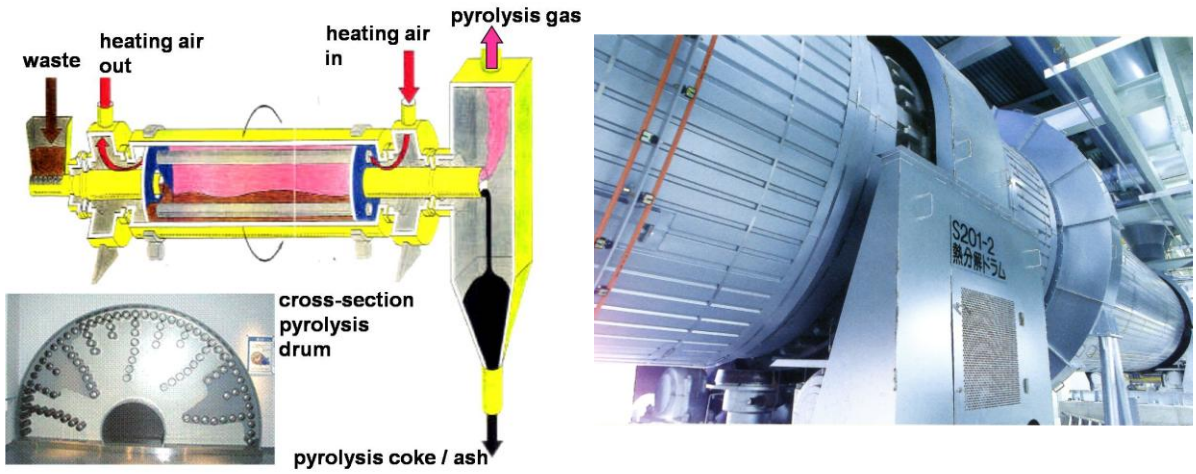
The plant is equipped with a heat recovery boiler and an APC system.

Towards the end of the 1980s, the German company Siemens started the development of a similar system, the Siemens Thermal Recycling Plant, which used a rotary drum with internal heating tubes for pyrolysis. In this process the pyrolysis gas was to be fed directly into a combustion chamber. On top of that the pyrolysis coke was separated from the mineral residue fraction and also burnt together with the gas.

Siemens built a full-scale technical plant of the process in Fürth, Germany. However, failures in the drum sealing and clogging of the gas transfer line caused the closure of the plant during its commissioning phase. Siemens withdrew from the market.

Two Japanese companies, MES and Takuma took licenses and brought the process to the Japanese market. The MES system is called R21 Process. The 3.1 m wide and 23 m long pyrolysis drum of this process is shown in the right part of Figure 4.42.

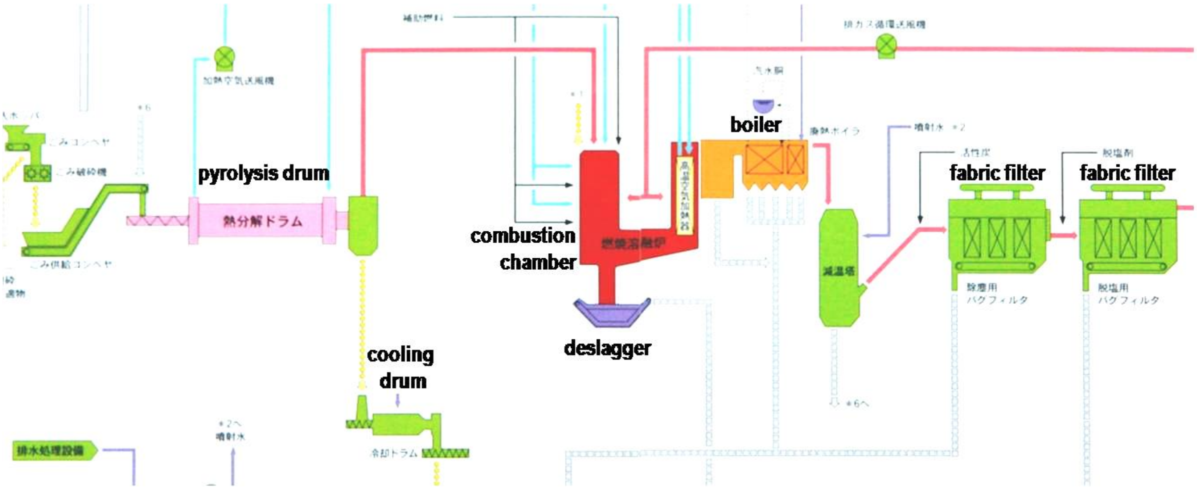
Figure 4.42: Scheme (left) and picture (right) of the rotary pyrolysis drum of the MES R21 Process



The pyrolysis temperature is 450°C, and the residence time 1 - 2 h. At the backend of the pyrolysis drum, the gas is extracted and fed directly into a combustion chamber where it is burnt at 1,350°C.

The solid residues pass a magnetic and eddy currant separation step for metal recovery and an air classifier for separation of the pyrolysis coke from the mineral residues. The coke is burnt together with the gas; the mineral fraction is either land filled or used as aggregate.
A simplified flow diagram of the MES R21 Process is illustrated in Figure 4.43.

Figure 4.43: Simplified flow diagram of the MES R21 Process



The process offered by Takuma is almost identical to the R21 Process.

MES built seven plants in Japan with 15 lines and a total capacity of 1,840 t/d; Takuma built another four plants with seven lines and a capacity of 518 t/d.

Architectural Features

Whereas MES used well-designed architecture for the R21 plants, the only picture that was found for a Takuma plant shows a pure industrial setup.

The plant in Toyahashi is the biggest MES R21 plant, with two lines, 200 t/d each. The plant became operational in 2004. The other MES plant is located in Koga city on Kyushu Island. It started operation in 2003 and has two lines with a throughput of 130 t/d each.

Figure 4.44: Three plants for pyrolysis with HT combustion in Japan

MES R21 plant Toyahashi

MES R21 plant Koga

Takuma pyrolysis plant

Mechanical and biological treatment (MBT) of MSW

Technology	MBT
Is the technology commercial?	Established technology in many parts of Europe and the world[21]. It is seen as an option for treatment for residual MSW remaining after recovery of source segregated wastes. MBT can contribute to the diversion of waste from landfill and increase recycling and/or energy recovery. However, it is an intermediate treatment technology and viable end-use or disposal options may still be needed for many of outputs of MBT.
General concept	Combination of mechanical and biological plant in various configurations, designed to improve recycling, biologically stabilise waste and produce residues appropriate to end markets or stabilised for disposal in landfill.
Size	50,000 to 500,000 t/a
Energy recovery	Through combustion of combustible residues, commonly know as refuse derived fuel (RDF), if composed of a simple fraction of the residual waste or solid recovered fuel (SRF), if the material has undergone significant processing. This can be in co-combustion (e.g. in cement kilns), in co-firing (in power stations equipped to meet incineration emission limits) or in purpose built facilities. MBT with anaerobic digestion as the biological treatment also produces biogas as energy recovery.
Temperature of incineration	Depends on how the RDF/SRF produced is combusted.

What is MBT?

MBT *partially* processes MSW by mechanically removing parts of the waste and by biologically treating others, so that the residual fraction is small, stable and more suitable (than MSW) for a number of possible applications. MBT is neither a single technology nor a complete solution to waste treatment, but is a generic term describing biological and mechanical process elements that are combined in a wide variety of ways to meet a range of objectives (Juniper 2005). The main reasons for using MBT would be to reduce the amount and environmental impact of landfilling residual waste, by improved resource recovery through increased recycling, producing a residue that is combustible and can be used as a fuel, and stabilising any residuals that are landfilled.

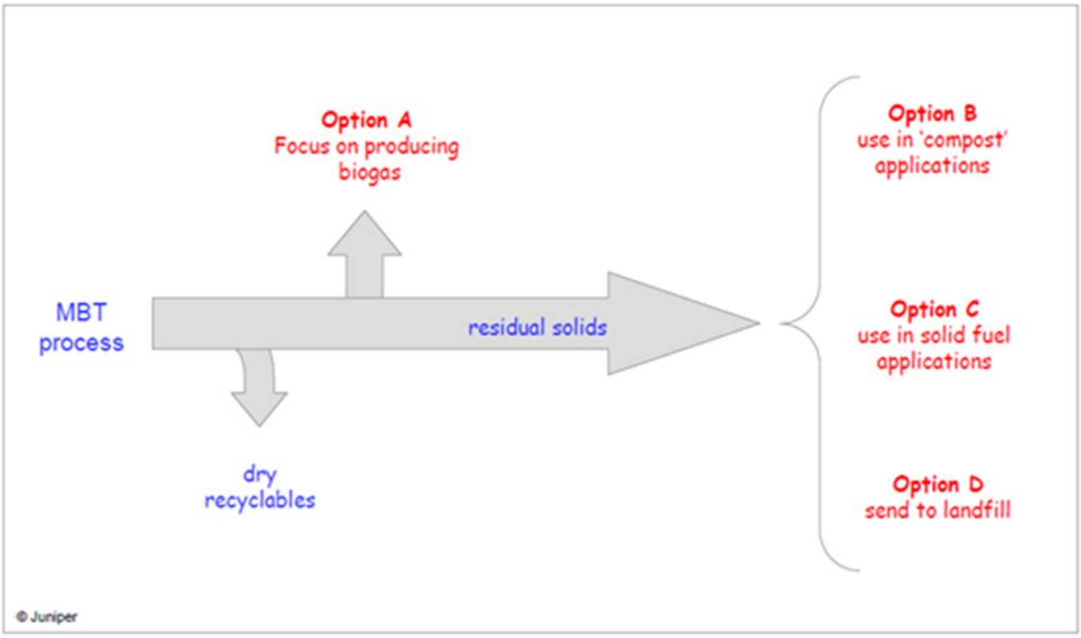
MBT systems vary in complexity and functionality, but generally they have a sorting and materials recovery facility that is integrated with a form of biological treatment, either composting or anaerobic digestion. Some MBT processes result in residues comprised of mixtures of combustible materials (e.g. plastics, textiles, wood, dried biomass) that cannot be recycled, but have a relatively high (for waste) calorific value and are therefore suitable for combustion. Frequently, such residues are called refuse derived fuel (RDF) if prepared from the simple separation of combustibles from the feedstock or solid recovered fuel (SRF) if the processing has been more extensive to derive a defined fuel product. These solid products may then be used as fuel in energy from waste plants that may involve incineration, gasification or pyrolysis.

[21] There are for example plants in operation in the UK, Germany, Austria, Italy, France, Spain, Israel, Australia, USA and the Netherlands.

Several generic MBT configurations may be identified, all of which may have variants capable of producing fuels for energy recovery. This section discusses these generic MBT configurations and how they may be applied for energy generation.

Figure 4.45 summarises the main options for MBT, focusing on the outputs.

Figure 4.45: The four main options for (integrated) MBT. Source: Juniper (2005)



Six generic MBT configurations are generally used:

- MBT with RDF production and composting.
- MBT with RDF production and anaerobic digestion.
- MBT with anaerobic digestion and recovery of recyclable fractions
- MBT with biodrying for SRF production.
- MBT with rapid composting and recovery of recyclable fractions
- MBT with biostabilisation.

Virtually all MBT configurations recover valuable metals at some stage of the process. Many may also recover glass and other non-metal inerts, such as stones and ceramics which may be used as aggregates. This section does not consider these further, but concentrates on processes relevant to energy generating. The key differences with regard to MBT configurations for energy are the fate of the plastics, dry biodegradable waste (paper, card, wood, textiles) and wet putrescible biodegradable wastes (kitchen and garden waste).

An MBT system will typically comprise one or more mechanical steps and one or more biological steps. These operations may occur in any sequence giving rise to descriptions as BMT for biological mechanical treatment when a biological step is first. We make no distinction between MBT, BMT or any other configuration and consider them all as MBT.

Mechanical treatment steps

The mechanical treatment part of MBT involves extensive processing of the waste, during which the waste particle size may be reduced, and/or waste separated into various fractions, which may be based on particle size by screens or on specific characteristics of the waste components, e.g. ferrous metal removed by magnets. Its main goals are to sort and treat the waste by (a) removing recyclables, (b) removing materials unsuitable for biological treatment, (c) homogenising the physical and chemical properties of the remaining fraction.

There are a number of options available for mechanical treatment, but it typically includes manual removal of materials (bulky items, white goods, cardboard), bag breakers, manual and automatic removal of recyclable materials (paper, plastics, glass, aluminium, tin cans), screening, shredding, magnetic separation and mixing using conveyors, magnets, eddy current separators, drums, shredders, air knives, hammer mills, flays and other size reducing equipment, screening for different sized components and other tailor made systems. A report available from the UK's Environment Department, Defra (2005), describes each of these processes in more detail. The remaining fraction is mainly made of organic matter which can be biologically treated.

Biological treatment

In different MBT systems, the biological stage may be short or long, be aerobic or aerobic or both, be on a defined fraction or the whole waste. Composting may be defined as the aerobic biological decomposition (i.e. degradation in the presence of oxygen) of biodegradable organic matter under controlled conditions. Composting in MBT systems typically takes place in in-vessel systems, although final maturation of partially stabilised waste may be carried out in open windrows. Particle size, moisture, temperature and oxygen are determining factors for composting. The composting period may be short (1 - 2 weeks), where it is not necessary for the waste to be fully biostabilised or up to 12 weeks or more if a fully stabilised material is required. Anaerobic digestion in MBT systems typically biologically treat only the putrescible fraction and this is over a short period (15 - 20 days), which maximises the gas production rate from the readily biodegradable fraction of the waste. The digestate is not fully stabilised and may, in some cases, be further composted to produce a stabilised material.

What are the specific disadvantages and advantages of MBT with RDF/SRF technology?

Advantages	Disadvantages
Diversion from landfill	Need for a market for RDF/SRF
Increase in recycling	Chemical properties of RDF/SRF (Cl, heavy metals contents) pose technical challenges to operation and APC during incineration
RDF/SRF can be burnt in industrial boilers, providing they meet waste combustion emission limits Production of an energy carrier which can be used when and where needed	Combustion plant operators may need to invest in additional processing equipment to handle RDF/SRF. There may be considerable challenge to use in some combustion plant (e.g. coal power plant).
Once MBT plant is operating, it is an available and plentiful fuel source of RDF/SRF	Variable quality of RDF/SRF
	Market: RDF/SRF is in competition with cheaper fuels
	Disposal of other MBT outputs
	RDF quality may degrade in long term storage

What are the specific challenges and advantages of MBT with AD technology?

Advantages	Challenges
Diversion from landfill	Need for an acceptable disposal route for the digestate Whether or not the digestate can be used as biomass rich solid if dried as another fuel output
Increase in recycling	Odour emissions
Heat and power generation from the biogas may attract a premium price if it is eligible for support as part of national renewable energy support programmes	Comprehensive pre-treatment is necessary to avoid contaminants (plastics, etc) in the digester
Production of an energy carrier which can be used when and where needed	Gas handling, storage and clean-up required
	Requires skilled staff to operate digester
	Requires treatment of large quantities of water if wet AD process

MBT 1: MBT with RDF production and composting

This is shown as option C in Figure 4.45.

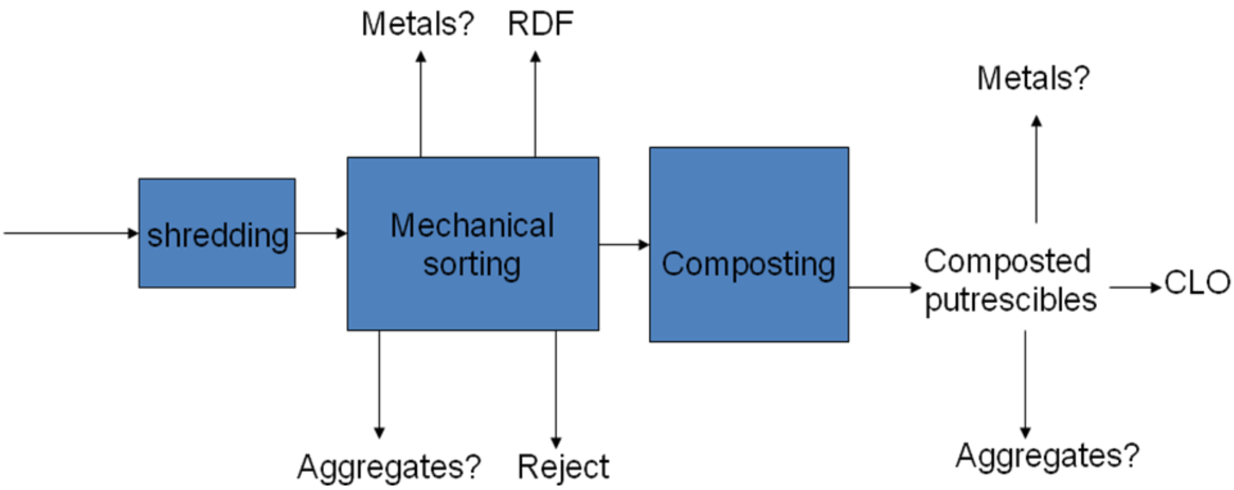
What are the main components of an MBT producing RDF?

Figure 4.46 shows a schematic representation of an MBT plant designed to produce a solid fuel residue, RDF. In a typical configuration, the incoming waste is shredded to some extent and the dry combustible fraction (plastics, paper, card, wood and textiles) are screened off from the bulk of the waste as the RDF. The RDF therefore comprises the driest and most combustible components of the waste as received. Depending on the composition of the feedstock, the RDF fraction may account for up to 40 - 60% of the input feedstock mass. The initial separation may also recover metals and aggregates as recyclable products.

The residue from this separation may then be composted for an extended period of several weeks to stabilise the residue for landfill. The stabilised material may be refined to produce a compost-like output (CLO), which may be used for land restoration under licence if it is of acceptable quality. This refining may generate additional recyclable materials, such as metals and aggregates. The total amount of these recyclables might be about 5 - 10% of the input mass.

There are options where the composted residue is dried during the composting stage and the composted material used as a low grade fuel. In the UK there are trends to examine the potential for refining the residue to derive a fuel with sufficiently high biomass content for this material to be considered as a bioenergy fuel for the Renewables Obligation, if removal of plastics is efficient.

Figure 4.46: Schematic of MBT with RDF production and composting (“?”) Represents optional processes where the materials recovery may change depending on the technology)



End use of the main RDF output of MBT

The RDF produced is typically of large particle size and low density with a net CV in the range of 10 - 14 MJ/kg, which is typically higher than the feedstock waste. Where and how RDF is used varies, but it is more commonly being considered as a fuel for power plants (i.e. co-incineration with fossil fuels, where the plants can meet WID emission limits) and in dedicated RDF combustion plants. The calorific value of this material is too low for use in cement kilns. RDF is not considered as a high grade fuel product and although the impurities are not often monitored, there seems no real barrier for its use in incineration or other thermal processes that would accept MSW.

It is worth mentioning that interest has been shown in innovative solutions for the use of RDF in other thermal processes, such as gasification and pyrolysis for the production of liquid fuels, as well as syngas.

The country where MBT has been used most extensively is Germany. Here, a number of options have been developed. One major issue facing the German plant operators has been the market for the RDF and the UK is currently in a similar position. Several planned MBT facilities currently in procurement also have to procure the associated RDF using EfW plant to ensure a market for the RDF.

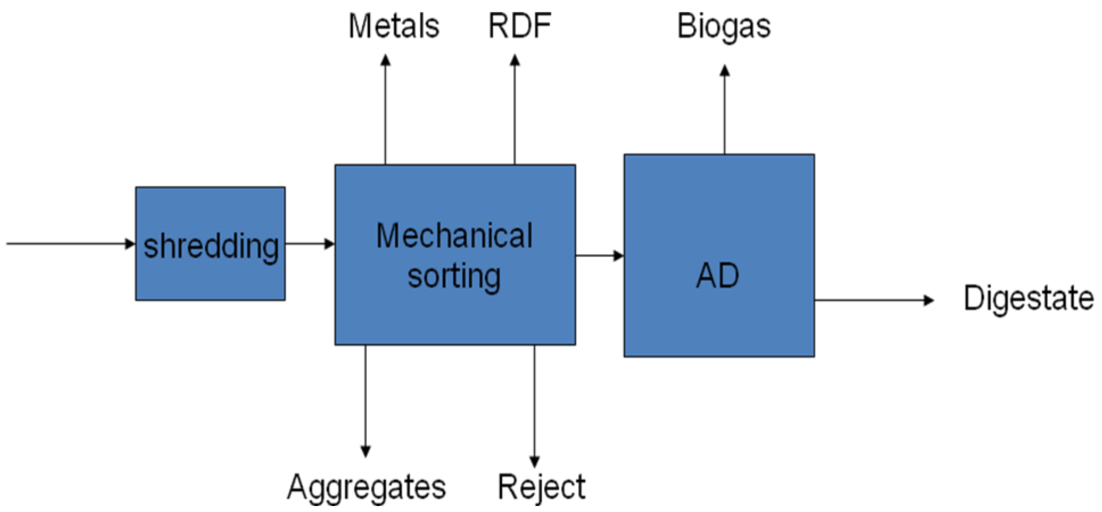
MBT 2: MBT with RDF production and anaerobic digestion (AD)

This MBT configuration is similar to the above in that there is the same initial mechanical step producing an equivalent RDF material, which also amounts to 40 - 60% of the input feedstock mass. The key difference is that the organic rich putrescible fraction is anaerobically digested rather than composted. This has the advantage of producing energy from both the dry combustible fraction as RDF and from the wet putrescible fraction as biogas. This MBT configuration is probably the most popular configuration being implemented in the UK, partly due to the promotion of AD by Defra in recent years. Shown as option A in Figure 4.45.

What are the main components of an MBT configured to produce biogas?

Figure 4.47 shows a schematic representation of an MBT plant configured RDF and biogas production.

Figure 4.47: Schematic of MBT with RDF production and anaerobic digestion



Biological treatment

In these MBT plants, the anaerobic digestion process involves the break down of the separated biodegradable matter (food and garden waste) by micro organisms in the absence of oxygen. In most MBT systems, the separated putrescible fraction undergoes an extensive preparation to remove inert material and sand from the AD feed. This is because these impurities may build up and block the tank stirrers or other movable parts or gas outlets. The end product of the biological process is a methane and carbon dioxide rich gas (usually called ‘biogas’) and an un-stabilised nutrient-rich solid digestate that could be used as a soil amendment in some soil restoration activities, or composted further to produce a stabilised compost for land restoration. The digestate may also be dried by waste heat from the biogas combustion and used as a low grade solid fuel. Unfortunately, in many cases, the markets for the digestate are not realised and the digestate may have to be landfilled,

Several different AD process configurations exist for the biological vessel (the anaerobic digester): they can be operated as batches or continuously, at mesophilic (30 - 40°C) or thermophilic (60 - 70°C) temperatures, at low (wet digestion) or high solids content (dry digestion) and with varying complexity (number of stages/vessels). The design of the plant will need to be suitable for the organic material that is digested, particularly the feedstock handling and transfer equipment. The typical composition of biogas is: methane, CH_4 50 - 75%; carbon dioxide, CO_2 25 - 50%; nitrogen, N_2 0 - 10%; hydrogen, H_2 0 - 1%; hydrogen sulphide, H_2S 0 - 3 Oxygen, O_2 0 - 2%. There are currently no gas quality standards specifically for biogas; however, given the deleterious minor constituents of raw biogas, such standards may be developed in the future. Safety standards are developed for land fill gas and sewage gas that are produced by the same microbial processes and it is likely that, as MBT including biogas becomes more common, such standards will be applied here as well. Further information on the use of anaerobic digestion in waste treatment is available from IEA Bioenergy Task 37, which examines the use of anaerobic digestion.

End use of the main output of this type of MBT

MBT is an intermediate treatment technology and a viable end-use is needed for biogas, the main output of the MBT presented here. The main alternatives for energy recovery from the biogas are:

- heat and electricity production with a engine or turbine (for higher quantities of biogas) for internal use (digester, buildings);
- supply of heat and/or electricity to the grid (biogas is a renewable energy carrier and its use may be supported in some countries);
- upgrading (removal of pollutants, especially H_2S) and concentration in order to be used as a vehicle fuel;
- upgrading to allow injection directly into the natural gas grid.

Solid residue

As indicated above, in addition to the production of biogas, the anaerobic digester also produces a solid humus-like material, which is termed 'digestate'. Currently, most MBT processes do not produce a digestate that can be sold commercially for compost or soil conditioning. However, if the digestate is treated after anaerobic digestion, then part of the residue may be post-composted to produce a soil conditioner, and a fluff high in calorific value and suitable as an RDF may also be produced.

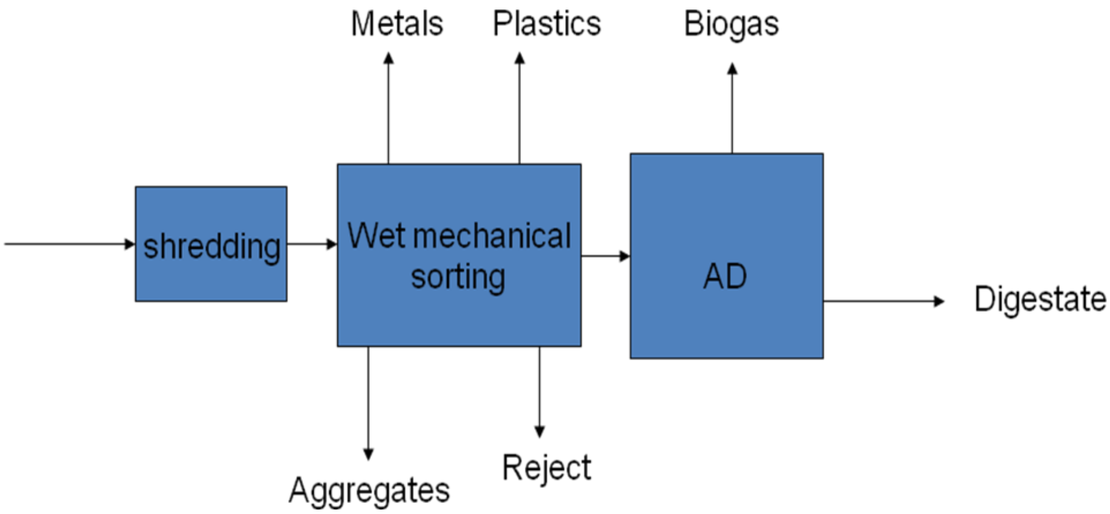
MBT 3: MBT with anaerobic digestion and recyclate production

This is an MBT configuration that differs significantly from the above AD concept and is a rarer and more novel approach. Plants exist in Israel and Australia and at least one plant is under construction in Scotland. In this design, the waste is first mixed with water and undergoes a mechanical wet separation process. During this separation process most of the biodegradable waste is macerated into a sludge and the recyclables, such as metals and plastics, are then removed and washed as clean recyclates. The remaining sludge is then AD treated.

The key difference is that the process produces all the plastic as a clean recyclate which can be recovered, although its use as a high CV fuel is possible. Also, the sludge for digestion contains the paper and card biomass as well as the putrescible food and green waste. Because of the presence of the less biodegradable paper and card, the biogas yield per tonne of organic matter is less than the conventional AD concept although, overall, more biogas is actually produced because the whole biodegradable fraction is sent to the AD stage.

As with other AD concepts, the digestate may be dried and used as a high biomass content fuel, or it may be applied to soil or composted prior to applying to soil in some soil restoration activities, if of suitable quality

Figure 4.48: Schematic of MBT with anaerobic digestion and recyclate production



MBT 4: MBT with biodrying and SRF production

In this MBT configuration, the waste is first shredded and then the whole waste is composted for a short period of 2 to 4 weeks. This composting is carried out using a forced aeration system where air is forced through the composting pile at a high rate. The combination of forced aeration and heat generated by the microbes as a result of their aerobic composting activity results in significant drying of the whole waste.

The biodried waste is then subjected to the main mechanical step which typically would produce a SRF fuel, recyclate metals and aggregates and a reject material for landfill. The solid fuel in this case is termed an SRF because it will have been derived from a more extensive processing than the RDF produced in the earlier discussed MBT configurations.

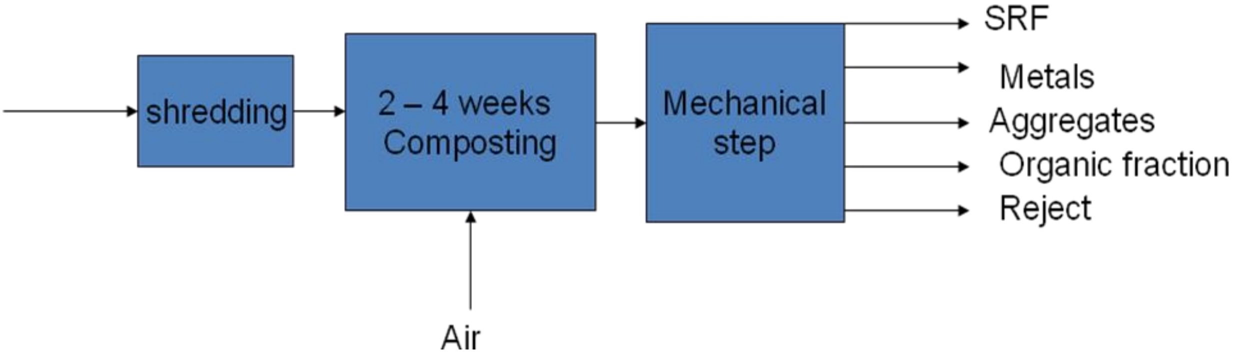
The biodried material may be processed to give several qualities of SRF. For example, it may be processed to yield an SRF with a high plastic to biomass ratio, which would have a corresponding high CV of 15 - 20 MJ/kg which would be suitable for use in cement kilns. However, the yield of this material would be low (20 - 30% of the feedstock mass). Some of the residue from such a process might be used as a lower grade solid fuel, as it would still consist of a dry biomass rich material. Alternatively, the biodried material may be processed into a larger yield of lower CV product where as much as 60% of the input feedstock may be delivered as an SRF with a CV in the range 10 - 15 MJ/kg.

Designation of the solid fuel product as an SRF, rather than a RDF, is beneficial as the SRF is considered as a more stable and tradable commodity. Various CEN standards have been developed to analysis and categorise the quality of SRF and a quality management system has been developed to compliment this to provide assurance of a consistent quality of the SRF as a tradable fuel. In the UK, SRF complying with the CEN standards may attract a full

2 ROCs for the biomass fraction if used in a certified CHP plant, which also provides a financial incentive for this product.

Several MBT plants are in operation in the UK with several more planned.

Figure 4.49: Schematic of MBT with biodrying and SRF production



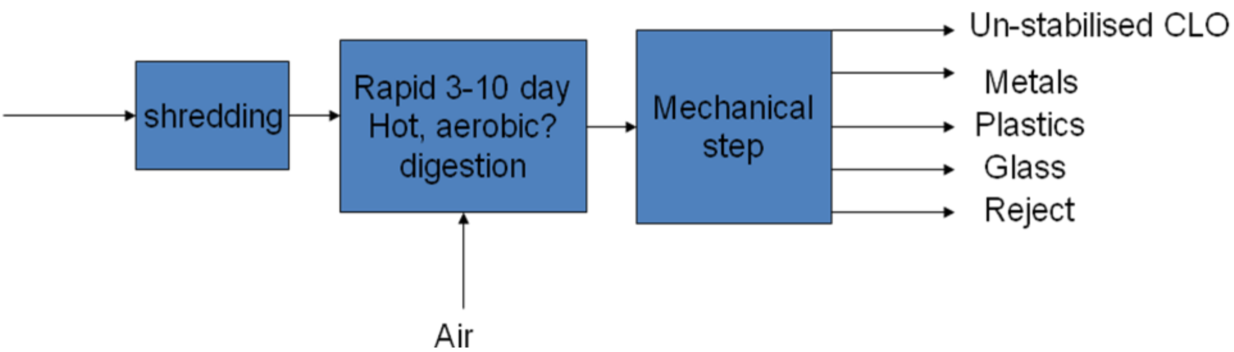
MBT 5: MBT with rapid composting and recyclate production

This MBT configuration is only applied in a few examples and consists of a very rapid initial composting phase at high temperatures for as short as six days in a reactor that mixes and churns the waste. The combination of mechanical attrition and rapid hot composting breaks the biodegradable matter down into a small particle sized fibre. This fibre is easily separated from the other waste components during subsequent mechanical processing.

Typically, the process would be designed to produce recyclates such as plastics, metals and glass and an organic rich biomass fibre. The fibre has a high biodegradability and requires further composting if it were to be considered for recycling to land. However, it may also be used as feedstock for AD or dried as biomass fuel. It might also be possible to use the plastics as a high CV fuel.

One supplier offers both the recyclate/compost option and the solid fuel option (with or without AD) option.

Figure 4.50: Schematic of MBT with rapid composting and recyclate production



MBT 6: MBT with biostabilisation

In the MBT with biostabilisation, the whole waste is composted for an extended period of several weeks to remove as much of the biodegradability of the waste as possible prior to landfilling the whole residue. In its original form this process provides minimal recyclate in the form of metals and perhaps some aggregate and plastic recovery, as these materials are more easily separated from the biostabilised waste. A few processes designed around this MBT configuration have been planned but with the increased cost of landfill due to the landfill tax increases, approaches are being considered to produce fuels from the biostabilised waste.

In this configuration, a high CV fuel might be produced from the separation of a plastic rich combustible fraction. It has also been proposed that a biomass fuel attracting maximum ROCs could be produced by refining the residue.

Whilst this is an unproven concept in the UK, it might have some attraction in that the biostabilisation would at least treat the waste for landfill and if opportunities for markets for fuel were realised, then the same MBT technology could be adapted to produce the fuels.

Figure 4.51: Schematic of MBT with biostabilisation

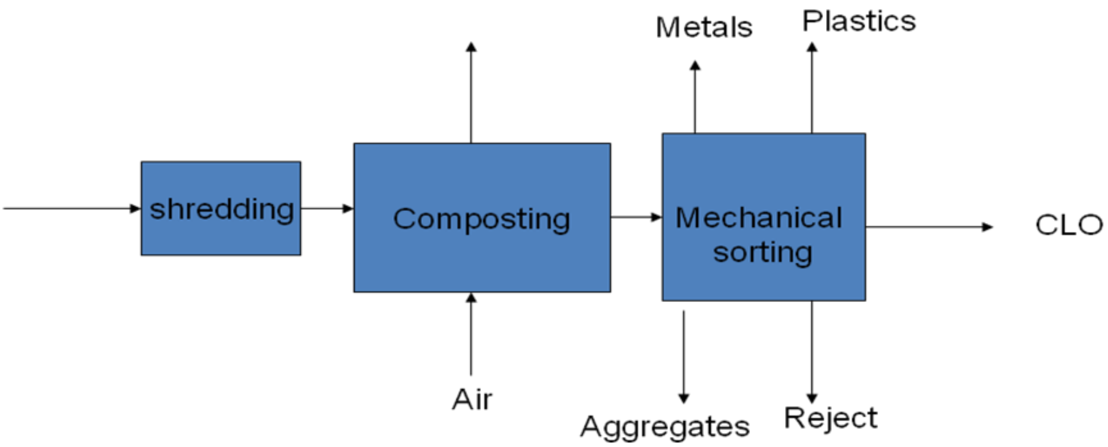


Table 4.7: Summary of main energy product streams from various MBT configurations

MBT generic design	RDF production	SRF production	Biogas energy by AD	Recyclables
MBT with RDF and composting	Yes - typically 40 - 60% of input	No	No	Yes - metals and aggregates
MBT with RDF and AD	Yes - typically 40 - 60% of input	No	Yes - from typically 40% of input	Yes - metals and aggregates
MBT with AD and recyclate	No - but recovered plastics might be used as fuel	No	Yes - from typically 60 - 70% of input	Yes - metals, aggregates and plastics
MBT with biodrying for SRF	No - solid fuel is SRF	Yes - amount and quality is controlled - typically 20 - 50% of input	No	Yes - metals and aggregates
MBT with rapid composting and recyclate	Not normally, but possible in some configurations	No	No	Yes - metals and aggregates
MBT with biostabilisation	Not normally, but possible in some configurations	No	No	Yes - metals, aggregates and plastics

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MSW incineration facilities worldwide

EU-27
Number of installations: about 420 (2008)
Total capacity: 200 Mt/y
Average capacity MSW incinerator: 200,000 t/y
Waste incineration market: 90% grate
Specific features: about 390 installations are to be found in the EU-15 countries

Japan
Number of installations: about 1,700 without energy recovery and 180 with energy recovery (the latter representing about 44% of the total capacity); the 400 largest installations represent about 73% of the total capacity (2004)
Total capacity (for the 1,880 installations): 70 Mt/y
Waste incineration market: about 80% grate (in number) and 7-8% FB (of the 400)
Specific features: about 75 of the approximately 120 gasification plants in the world are located in Japan (2008)

Canada
Number of installations: seven main (i.e. greater than 25 tpd capacity) – five with energy recovery and two without (2007)
Total capacity: 1.63 Mt/y
Specific features: 2% of the waste collected (residential and non-residential) are thermally treated and 76% are landfilled. The throughput is about 763 000 t/y, i.e. there is a large overcapacity

USA
Number of installations: 87 EfW plants in 25 states (2007)
Total throughput/capacity: 28.7 Mt/y, EfW are operated in excess of 90% (2007)
Specific features: (1) 1/5 of US MSW incinerators use RDF; (2) about half throughput is in the Northeast

China
Number of installations: about 47 (2009)
Total capacity: 11.2 Mt/y
Specific features: fast development (only 30 plants in 2002)

APPENDIX 1: NATIONAL PARTICIPANTS 2007 - 2009 (CONTACT DETAILS)

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Notice
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APPENDIX 2: STUDY TOUR OF JAPAN

Some observations on the operation of waste treatment technologies in Japan at the Task 36 meeting in Fukuoka, Japan, in November 2009.

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Introduction

Japan is one of the leading countries in advanced waste management. Because of its high population density and its geographic situation with limited space for landfilling, it has a long history of thermal treatment for minimising municipal solid waste (MSW) volume. Its first waste incinerator started operation in Tsuruga, Fukui prefecture, in 1893.

After sustained efforts in waste recycling during the last few decades and steady investment in thermal waste treatment technology, today almost no Japanese residual waste is disposed of without prior treatment. To save valuable space in landfills, Japan has also aimed for a long time to reduce ash volumes; many traditional waste incineration plants are equipped with special ash melting furnaces. This tradition led consequently to the implementation of novel processes which produce inherently molten slag.

As part of the current phase of IEA Bioenergy activity, Task 36 undertook a case study visit of Japan to obtain first hand information on the operation of such new technologies - which have not yet (due to reasons of cost or need) established in the markets of Task 36 member states.

Former Japanese members of Task 36 arranged visits of three different waste management centres, each of which takes care of the municipal solid waste of a number of municipalities in the vicinity of Fukuoka. Each centre comprises a pre-treatment stage, either for recycling or for RDF (refuse derived fuel, in parts of the world also called solid recovered fuel, SRF) production, and a thermal treatment facility.

- In Omuta, the Omuta Recycle Power Co. Ltd. operates a fluidised bed combustion plant which burns RDF, partly produced in an adjacent facility, partly coming from other production sites.

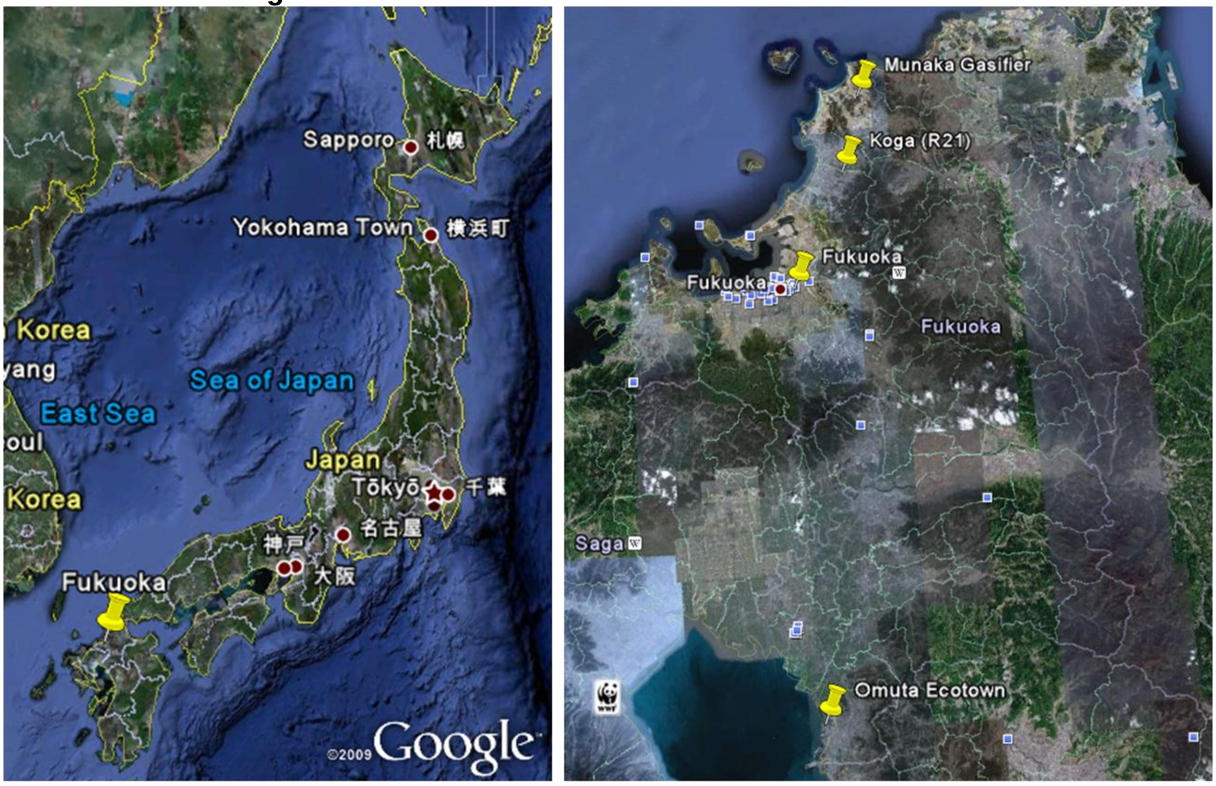
- Koga city has built a recycling plaza and a MES R21 system, a combination of rotary drum pyrolysis and high temperature combustion.

- The Munakata Eco Park consists of a recycling facility and a Nippon Steel shaft furnace gasification plant.

In all waste management centres, detailed information was provided about the structure of the waste management system, the applied technology, and partly about the investment and operational costs.

These visits took place on November 19 and 20 2009. The places visited during the meeting are marked in the map of Northern Kyushu, shown in Figure A2.1.

Figure A2.1: Map of Japan (left) and northern Kyushu (right) with places visited during the Task 36 meeting



Japanese waste management policy

Japan is a country with a high population density, high industrialisation, and very scarce space for landfilling. That is why Japan started early to regulate the management of waste and to try to reduce or even avoid its direct disposal.
The first waste law was enacted in 1971. This has been revised several times, the latest in April 2001, which includes regulations and standards provided for sustainable management and the establishment of suited facilities and service companies.

The driver for a permanent further development was the political will to convert Japan into a recycling-oriented society with the principle of the 3Rs as guideline:

- reduction;
- reuse;
- recycling.

Of initially strong influence were the legislative regulations in Germany, in particular the 1991 release of the Residential Waste Ordinance and the 1994 enacted Material Cycle and Waste Management Act in that country. Further drivers were the various EU Directives in this sector.

In 1993 and 1994, the Japanese government passed the basic Law for Environmental Pollution Control, the Environmental Protection Law and the Plan for Environmental Pollution Control. The latter one defined four fundamental principles for environmental policy and the role of government bodies in charge:

- circulation;
- co-operation;
- participation;
- international activity.

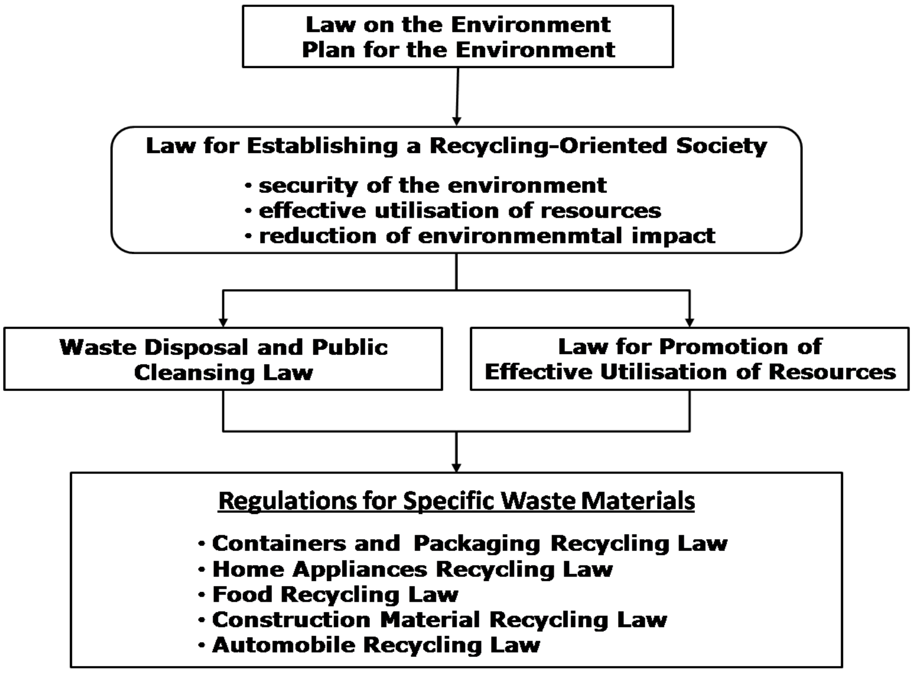
The main consequence was the adoption of the Law for Establishing a Recycling-Oriented Society in January 2001 with the following main objectives:

- reduce and control the disposal of waste;
- promote recycling;
- control the consumption of natural resources;
- reduce the environmental impact.

As mentioned above, the most important law following these regulations was the Waste Management Law in April 2001. For the initiation of a recycling-oriented society, another law is of equal importance, the Law for Promotion of Effective Utilisation of Resources, also issued in April 2001.

The new Waste Disposal and Public Cleansing Law from April 2001 promoted modern waste management in Japan to a great extent. Special laws for various waste materials like packaging waste, home appliances, food waste, construction waste and cars followed. A scheme showing the most important regulations in the waste management sector is depicted in Figure A2.2.

Figure A2.2: Framework of the Japanese waste management regulations



Although recycling has played a major role since the early 1990s, the new regulations pushed the source separation and respective collection of waste fractions, and all over the country new recycling facilities were built.

For saving landfill space and reducing the environmental impact, great efforts were also made to make combustible waste and recycling residues inert prior to their final disposal. Thermal processes have always been the technologies of choice for this treatment. Since the end of the 1990s, a preference for implementation of novel technologies can be recognised. Combined processes using gasification or pyrolysis followed by combustion have entered and partly - at least for smaller plants - conquered the market. This is for the time being a situation only found in Japan.

Omuta Waste Management Center

Waste management strategy

As mentioned above, in most big Japanese cities MSW used to be burnt. This was also the case in Omuta, Fukuoka Prefecture, a city approximately 60 km south of Fukuoka, where waste was incinerated since 1988 in a plant which was operated 16 h/d. Two problems caused a change in this practice:

- The disposal of bottom ash threatened to become a problem in the foreseeable future due to the limited lifetime of the available landfill.

- The dioxin emissions could not meet the new legislative regulations and the target of 5 µg[I-TE]/Mg of waste for the total dioxin emissions into all residue streams, exhaust-gases as well as all solid residues. This caste upgrading of the plant into doubt for technical and economical reasons.

It was decided to switch from incineration of mixed MSW to the production and combustion of (pelletized) RDF combined with extended recycling. The main advantages of RDF are its more stable calorific value and the option to store the material for at least six months.

To minimise dioxin formation in combustion plants for waste based fuels, continuous operation is mandatory. For economic considerations, a supply of more than 100,000 tonnes of MSW is needed to make the operation of an RDF plant viable. The average waste generation per inhabitant was approximately 1 kg/d, which meant that the 185,000 citizens of Omuta and its neighbouring city Arao, could not generate enough MSW for such a strategy.

Negotiation with municipalities in the wider vicinity identified 16 in Fukuoka Prefecture and 12 in Kumamoto Prefecture that had similar waste disposal problems and shared the preference for RDF production. These municipalities formed a consortium. It was decided to build seven RDF processing plants. The sites of these plants are allocated close to the local population centres to minimize the transportation of raw waste.

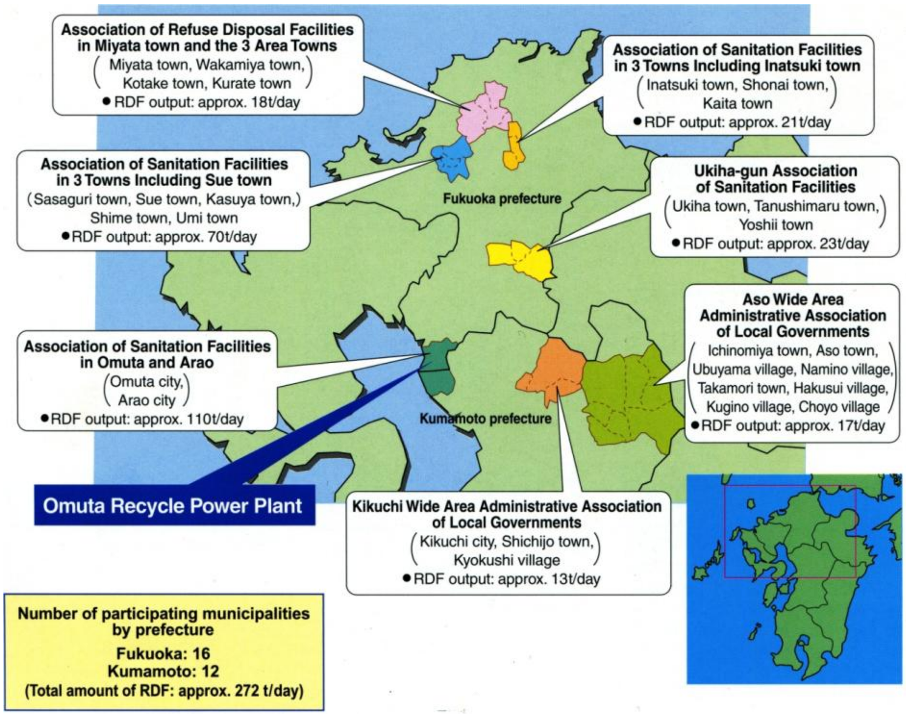
The seven processing plants send their RDF to a newly built central facility which uses fluidised bed combustion for power generation.

The participating municipalities and the locations and sizes of the respective facilities are shown in Figure A2.3.

The envisaged advantage of this strategy, apart from compliance with the new legislative dioxin regulations, was a significant extension of the lifetime of the ash landfill. Whereas the former Omuta waste incinerator produced in the order of 10,000 to 12,000 tonnes of bottom ash annually, the respective amount of the new RDF power plant was only 850 - 1,000 tonnes.

The RDF power plant and the RDF processing plant for the MSW of Omuta Arao were built in Omuta Ecotown. The Japanese government founded Omuta Ecotown, the fifth one in Japan, in 1998 on an area close to the coast line where, in former years, coal mining had taken place.

Figure A2.3: Distribution of the municipalities and the facilities processing RDF



The objectives of an Ecotown are to:

- create and foster environmental and recycling industries;
- enhance the conversion from a throwaway to a recycling society;
- promote the preservation of the regional environment;
- create new industries.

Figure A2.4: Location of Omuta Ecotown (left) and aerial view of the waste treatment facilities (right)

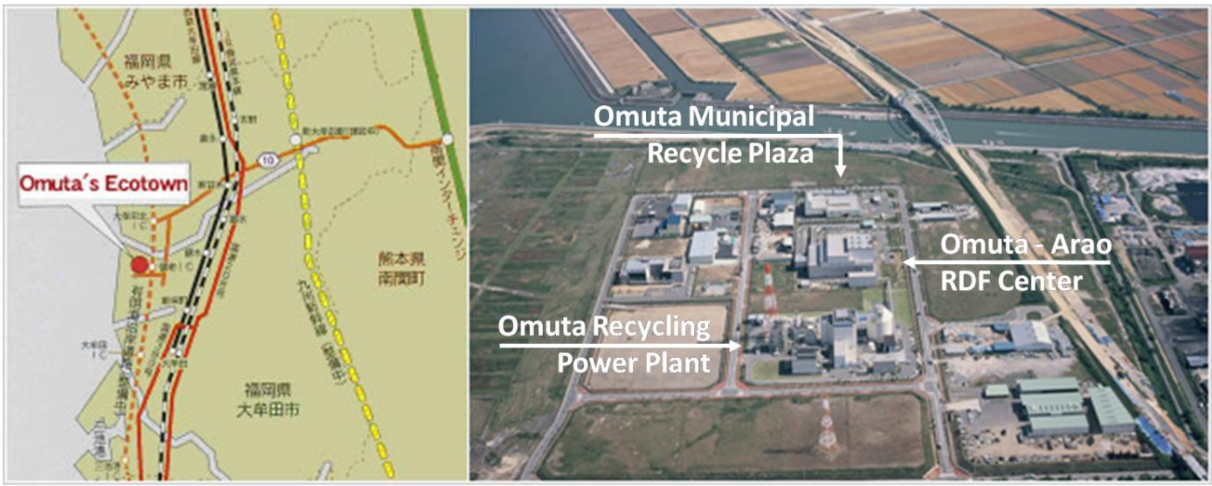


Figure A2.4 shows the location and an aerial view of Omuta Ecotown. The Omuta Recycling Power Plant, the Omuta-Arao RDF Center, and the Omuta Municipal Recycling Plaza are marked in the picture.

On the same site is situated the Omuta Ecosanc Center, a facility for citizen interaction and education, which has been set up in order to raise environmental awareness. It is integrated in the Environmental and Industrial Technology Research Center, which supports the development and planning of environmental and industrial technology. It also supports citizen and corporate activities related to the environment and industry.

The owner of the power plant is Omuta Recycle Power Co. which is owned and funded by Omuta City, Fukuoka Prefecture, and the Electric Power Development Co. Ltd.

The company is responsible for the organisation of the material and cash flow in the system. More detailed information on the functions and structure of Omuta Recycle Power Co. are shown in Figure A2.5.

Figure A2.5: Functions and structure of Omuta Recycle Power Co. Ltd.

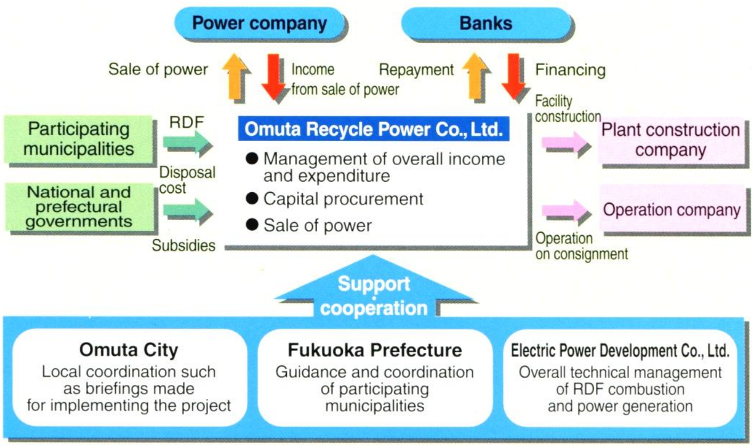
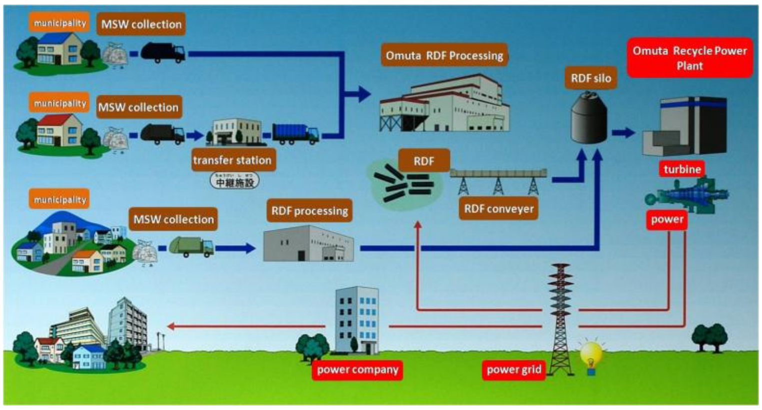


Figure A2.6: Flow scheme of the waste management system organised by Omuta Recycle Power Co. Ltd.



The scheme shown in Figure A2.6 illustrates the flow of materials in the waste management system organised by Omuta Recycle Power Co. Ltd. The Omuta city MSW is directly delivered by the waste collection cars to the tipping floor of the Omuta RDF Processing Plant (upper MSW collection line). The MSW of the neighbour city Arao - which belongs to another prefecture - is collected and brought to a transfer station from where it is transported by truck to the Omuta-Arao RDF Center (second MSW collection line from the top).

The other municipalities collect their waste and send it to local RDF processing plants from where the RDF is transported by trucks to the power plant.

The exported power is purchased by Electric Power Development Co. Ltd., one of the owners of Omuta Recycle Power Co. Ltd., and accounts for roughly 20% of the total power market of this company.

RDF production

Technology

The Omuta-Arao RDF Center built adjacent to the power plant produces RDF from the MSW of Omuta and Arao. The aerial view in Figure A2.7 shows this plant in the centre with the Omuta Recycle Power Plant in the left upper corner. Selected technical data of the RDF processing plant are compiled in Table A2.1.

Figure A2.7: Aerial view of the Omuta-Arao RDF Center

Table A2.1: Technical data of the RDF processing plant

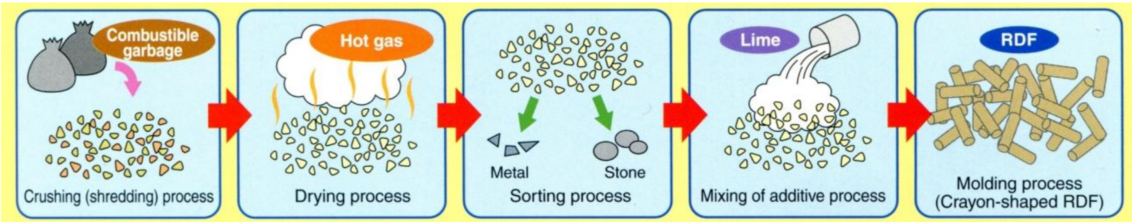
Typical MSW throughput	200 t/d
Typical RDF output	100 t/d
2008 MSW throughput	51,653 t
2008 RDF output	24,773 t
Operation time per day	16 h (on weekdays)
Number of shifts	2

The Omuta MSW is directly delivered by the waste collection cars to the waste pit of the plant; the waste from Arao gets there via a transfer station. The plant treats the combustible waste of 80,000 households, which means it gets in the order of 200 t of waste per day and produces up to 110 t of RDF.

The waste pit has a capacity for five days of MSW (see Figure A2.8). The MSW is treated according to the scheme for RDF processing shown in Figure A2.9. A crane feeds the material into a crusher from where it transferred into a 2.7 m wide and 11 m long drum dryer with an internal screw, heated by 500°C of hot air generated in a kerosene fired furnace. The dryer reduces the MSW moisture to 5 - 10%, typically to 8%.

Figure A2.8: Waste pit with raw MSW from Omuta and Arao (left) and the crane operator in action (right)

Figure A2.9: Basic processes in RDF processing facilities



The dried MSW passes through a magnetic and an eddy current separator for the removal of ferrous and non-ferrous metal scrap. The separators are followed by a second crusher and a drum sieve for size separation. The fine fraction undergoes a further magnetic and eddy current separation followed by an air separator where the combustible waste fraction is blown out. After the addition of slaked lime and intense mixing, this fraction is moulded to form pellets with a diameter of 15 mm and a length of 40 - 60 mm (see Figure A2.10).

Figure A2.10: RDF pellets produced in the Omuta RDF processing plant

The mass reduction achieved during the treatment is about 50%. In return, the lower heating value is raised from 7.6 - 12.7 MJ/kg of the raw MSW to 14.7 - 18.9 MJ/kg of the final product. The content of metallic and inert ingredients is significantly reduced; however, contaminants like chlorine or sulphur are concentrated, since these are almost totally carried in the RDF. The typical chlorine content of the RDF was said to be 1.6%. The inventory of biogenic energy in the material has been determined to approx. 55%.

These pellets are transported by a long belt conveyor to the RDF storage silo of the Omuta Recycle Power Plant. The conveyor can be recognised in the upper left corner of Figure A2.7 connecting the RDF processing plant and the silo.

Economy

Information on the economic data of the plant is listed in Table A2.2. According to these data, the treatment per tonne of MSW - without collection costs - is approx. 33,400 ¥ or 268 €. The treatment costs could be reduced if heat from the power plant could is used, but this is not currently practised.

Table A2.2: Economic data of the Omuta RDF processing plant for 2008

Categories	Costs in 1,000 ¥	Costs in 1,000 €
Total	1,724,178	13,846
Expenditures	479,959	3,854
Maintenance	343,119	2,649
Fuel	360,061	2,851
Electricity	188,670	1,515

RDF power plant

Technology

The Omuta Reycle Power Plant is located just north of the RDF processing plant. Figure A2.11 shows an aerial view; technical data of the plant are compiled in Table A2.3.

Figure A2.11: Aerial view of the Omuta Recycle Power Plant (left) and members of Task 36 on top of the RDF silo during the guided tour (right)

Table A2.3: Technical data of the Omuta Recycle Power Plant

Site area	24,700 m^2
Construction area	1,100 m^2
Construction	April 2001- December 2002
Type of furnace	Internally circulating fluidised bed
Number of lines	3
Design throughput of RDF	3x105 t/d
Combustion temperature	850 - 1,000°C
Boiler type	Single drum, natural circulation
Steam production	86.9 t/h
Steam pressure	8.14 MPa
Steam temperature	503°C
Power efficiency	>30%
Power generation capacity	20.6 MW
Plant availability	300 d/a

The RDF arrives either by conveyor belt from the adjacent Omuta RDF processing plant or by truck from the six other smaller processing plants, and is stored in the 32 m high silo seen in the lower right corner of the left photo in Figure A2.11 which takes up to 8,400 t of RDF.

RDF has to be stored under careful safety conditions. To prevent self ignition, the temperature in the silo should not exceed 40°C and the humidity of the RDF should be kept below 8%. Furthermore, to prevent dust explosion (which has already occurred in a few RDF silos) the O_2 concentration in the silo atmosphere is reduced to 10% by the addition of nitrogen. Therefore, a surveillance system is installed in the silo. Temperature as well as CO and O_2 are monitored. If critical parameters are detected, the atmosphere is made inert by flooding the silo with nitrogen.

Figure A2.12 shows the layout of the plant. The RDF processing plant is directly adjacent to the parking lot at the top of the diagram. The belt conveyor which transports the RDF from the processing plant to the RDF storage silo is not drawn in.

Figure A2.12: Layout of the Omuta recycle power plant

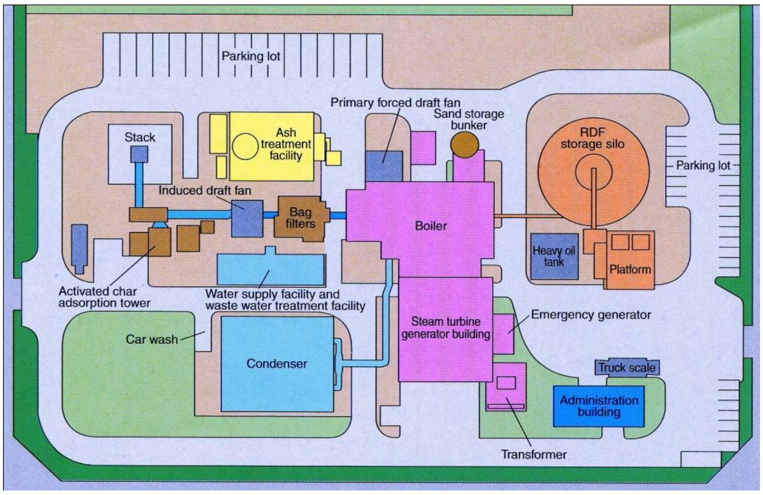
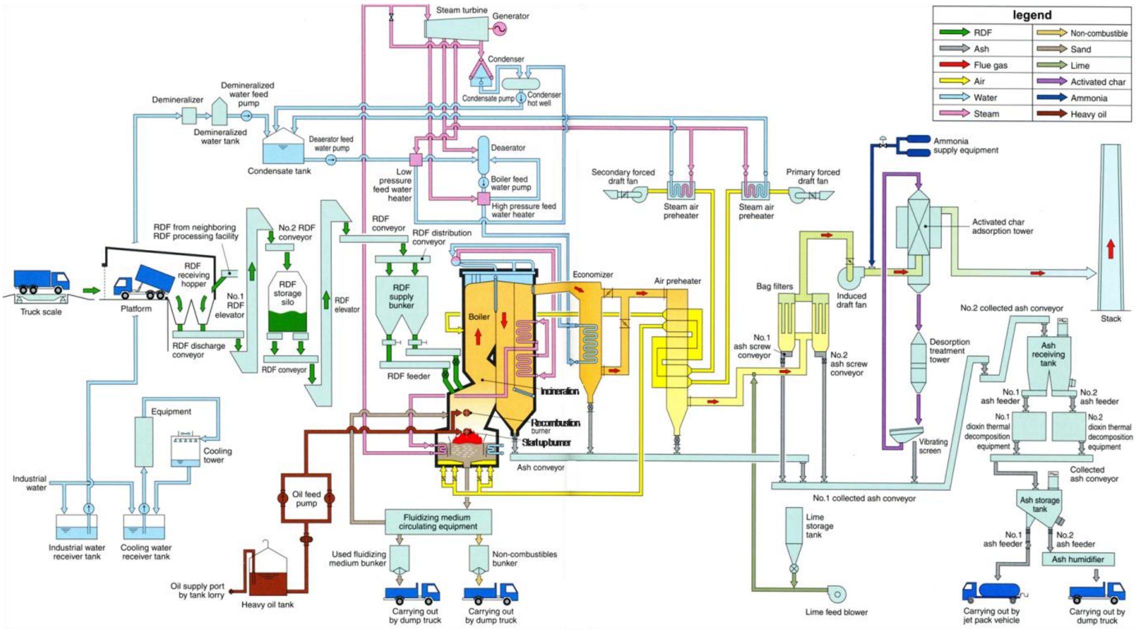
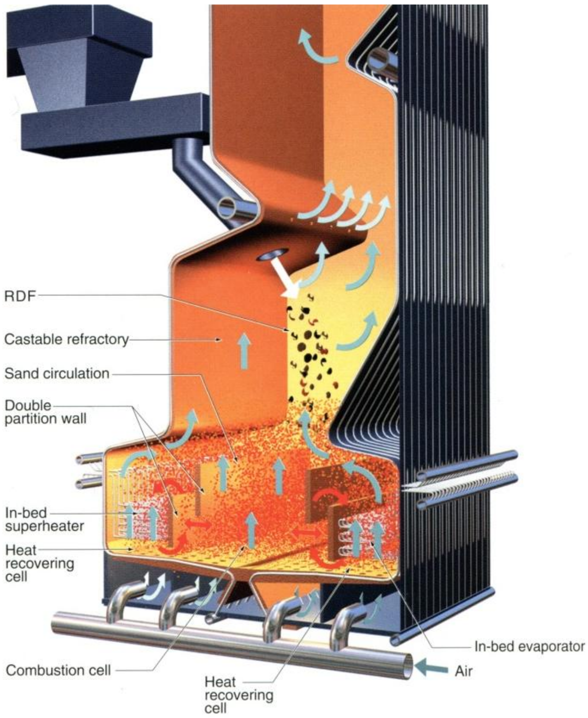


Figure A2.13: Flow diagram of the Omuta recycle power plant



The flow diagram of the power plant is depicted in Figure A2.13. The RDF is fed from the large storage silo via a smaller RDF supply bunker into the internal circulation fluidised bed-type furnace, built by Kawasaki Heavy Industries. Its design is similar to that of a revolving fluidised bed furnace (left diagram in Figure A2.14).

Figure A2.14: Scheme of the fluidised bed incinerator (left) and bottom ash (right)



Its rear wall is equipped with heat extraction (evaporator) tubes. Further evaporator tubes and the super-heater are integrated in the outer parts at the bottom of the fuel bed, where special cells are built in to reduce the gas and sand velocity and, with that, reduce the risk of tube erosion.

During start-up, the furnace is heated by burning oil until the temperature exceeds 500°C. The combustion temperature in the free board is 850 - 1,000°C. The legislative regulations require, like in the EU Incineration Directive, that the flue gas exceeds a temperature of 850°C for two seconds after the last air injection.

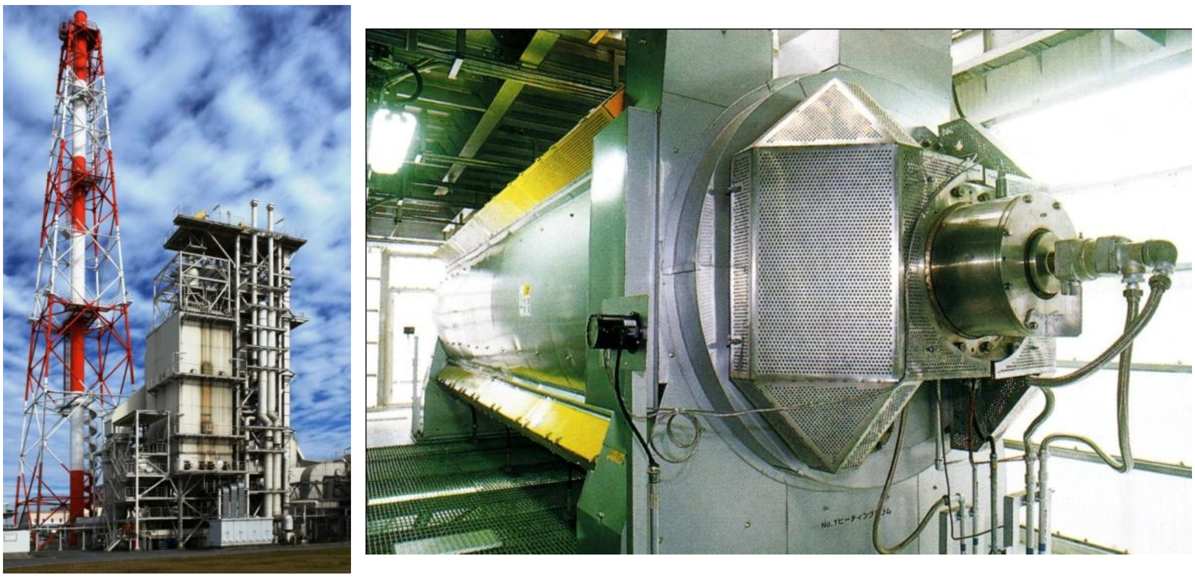
The temperature of the fuel bed inside the combustion zone is kept at 800°C, and in the heat recovery cells (where evaporator super-heater tubes are located), the temperature is approximately 600°C.

Bottom ash and sand are extracted at the base of the furnace. The material goes to a separation stage where sand is recovered. The ash (see right photo in Figure A2.14) has a fine particle size and the light colour indicates a rather good burnout. It is transported by truck to a cement plant.

The steam parameters of the boiler are rather high, with a pressure of 8.15 MPa and a temperature of 500°C. In relation to the high Cl inventory of the fuel of 1.6 wt%, the reported lack of boiler corrosion can be explained by the localisation of part of the evaporator and the super-heater. At the bottom of the fuel bed the HCl concentration of the gas flow should be low compared to that in the flue gas leaving the free board. The latter was reported to be in the order of 240 mg/m^2, a figure which seems too low, taking the Cl concentration of the RDF of 1.6 wt% into consideration.

The boiler is followed by an economiser and the air pre-heater. A conventional dry scrubbing system is installed downstream of the air pre-heater. Slaked lime is injected into the flue gas to capture the acid gases. The fly ash and the reaction products are separated by a fabric filter.

Figure A2.15: Charcoal filter tower (left) and Hagenmaier drum (right)



The cleaned gas passes through a fixed bed charcoal filter (see left photo in Figure A2.15) where organic pollutants are adsorbed. Furthermore, an upstream addition of ammonia facilitates NO_x reduction in the charcoal filter.

The oxygen concentration in the flue gas is typically 6 vol%. The air emission limits are listed in Table A2.4.

Table A2.4: Selected air emission limits of the Omuta recycle power plant (standardised to a CO_2 off-gas concentration of 14%) and of the EU Waste Incineration Directive (WID, daily average, standardised to 11 vol% O_2)

	Omuta Recycle Power Plant	WID
Dust	20 ppm	10
HCl	20 ppm	10
SO_2	20 ppm	50
NO_x	65 ppm	200
PCDD/F	0.1 ng[I-TE]/m^3	0.1 ng[I-TE]/m^3

Compared to the standards of the EU Incineration Directive, these limits are higher for dust and HCl and lower for SO_2 and NO_x. However, all emission standards are easily met. The regular check in 2008 resulted in dioxin emissions ranging, for the three lines, between 0.0002 and 0.002 ng[I-TE]/m^3.

To meet the Japanese target for the total export of dioxins into air and all other residue streams of 5 µg[I-TE]/t of RDF, the gas cleaning residues are treated in a Hagenmaier drum for thermal dioxin destruction. The material is kept at a temperature of 350 - 400°C for 0.5 h in inert atmosphere. A view of the Hagenmaier drum, which is widely used in Japanese waste incineration plants, is shown in the right photo of Figure 15.
The power plant is operated by 35 people. Five are employed by the Omuta Recycle Power Co. Maintenance and operation has been outsourced on the basis of annual contracts. Regular maintenance takes place three times a year and requires the work of approximately 100 workers.

The availability of the plant is in the order of 300 days per line. The total throughput of RDF in 2008 was approximately 80,000 t.

Economy

The plant economics have not fully been reported. According to the operator, 50% of the investment came from the government and 50% was contributed by the financial sector. The total construction costs amounted to 10.5 billion ¥ (≈ 84 million €); the depreciation time of the plant is 15 years, however, the interest on the loan was not disclosed.

The plant receives a gate fee of 9,500 ¥ (≈ 76 €) per tonne of RDF burnt, which amounts to 760 million ¥ (6.1 million €) per year. Revenue also comes from the electric power sold. The plant receives 8 ¥/kWh (≈ 6.4 €cent), which is rather high compared to European countries. Based on a mean lower RDF heating value of 16 MJ/kg and a net power efficiency (taking the self-consumption into account) of 25%, a power export of approximately 1,100 kWh per tonne of burnt RDF can be calculated. This would result in a profit of roughly 9,000 ¥ (≈71€), which almost the same as the gate fee of the RDF.

From these figures, the total disposal costs of the combustible MSW (excluding collection and most likely transport) can be estimated. The expenditure for the conversion of 1 tonne MSW into 0.5 tonnes of RDF is 33,400 ¥ (≈270 €), and the combustion of this RDF needs another 4,800 ¥ (38.5 €).

These figures summarise to approximately 38,000 ¥ (310 €) per tonne, a level which is high compared to the average disposal costs in Europe. According to the latest OECD statistics, the share of burnable MSW in Japan amounts to approx. 74%. The expenses needed for the recycled waste and the costs for collection and eventual separation have not been reported.

Koga City Waste Management Centre

Waste management strategy

Koga city in Fukuoka Prefecture is located approximately 20 km north-east of Fukuoka with approximately 60,000 inhabitants. The MSW of Koga city and three neighbouring cities is managed by the Koga City and One City, Four Towns Waste Treatment Co-operation. This organisation set up two waste management centres, each comprising a recycling plaza and a thermal waste treatment plant. Both centres are operated by Genkai Environmental Association.

The first centre visited was the one close to Koga city which uses an R21 system built by Mitsui Engineering & Shipbuilding Co. Ltd. for thermal treatment. A view of the centre is shown in Figure A2.16.

Figure A2.16: View of the Koga city waste management centre

The cities collect recyclable and combustible waste separately. All fractions end up in one of the waste management centres, the recyclables at the recycling plaza and the combustible waste in the thermal treatment plant.

The photo of the complex shows it is a good example of the design of waste management facilities. Many of these plants can rightly be called iconic.

This endeavour for an exciting architecture and pleasant facade painting is followed up with a thorough layout of the interior. All plants attach great importance to visitor friendliness. Clean and bright corridors are built in for good access to and view upon the implemented technology.

The aim of such visitor friendly facility is not to impress experts, like the members of Task 36, but to inform local citizens about the objectives, technology, and execution of waste treatment. Many plants like this one have special rooms, playgrounds, and exhibitions to inform school children about modern waste management and its importance for a recycling-oriented society.

Koga R21 plant

Technology

The R21 technology chosen for thermal treatment of burnable MSW in Koga was initially invented by the German company Siemens as Thermal Recycling Process and licensed in 1991 to MES. The first full scale plant in Germany failed, but MES was successful in building six plants in Japan and an order from Korea two years ago.

The R21 technology combines drum pyrolysis and high temperature combustion of the pyrolysis products gas and coke in a combustion chamber.

Technical data of the plant are compiled in Table A2.5. The scheme of the process is shown in Figure A2.17, a 3D chart taken from a MES presentation.

Table A2.5: Technical data of the Koga R21 plant

Construction	November 2000 - March 2003
Number of lines	2
Throughput	2 x 130 t/d
Availability	300 d/a per line
Diameter of rotary drum	3.1 m
Length of rotary drum	23 m
Pyrolysis residence time	1 - 2 h
Pyrolysis temperature	450°C
Air temperature in heating pipes	520°C
Combustion temperature	1,300°C
Steam pressure	4 MPa
Steam temperature	400°C
Power generation capacity	4.5 MW
Own/recycling plaza consumption	1.8/0.7 MW
Power for sale	≈ 2 MW
Pit for APC residue storage	1,770 m^2 / 11,505 m^3

The R21 process treats the combustible waste of Koga city, as well as the residues from the recycling facility. The waste bunker is 15 m deep and has a storage capacity of five days. A crane feeds the waste into a shredder where its maximum size is reduced to 20 mm. A screw conveyor transports the shredded material into the internally heated 3.1 m wide and 23 m long rotary drum.

The drum is sealed to prevent access of air and to establish an almost oxygen free atmosphere. The temperature inside the drum is 450°C, and the residence time of the waste is in the order of 1 - 2 hours. A picture of the drum is seen in the left part of Figure A2.18.

Figure A2.17: Flow diagram of the MES R21 process

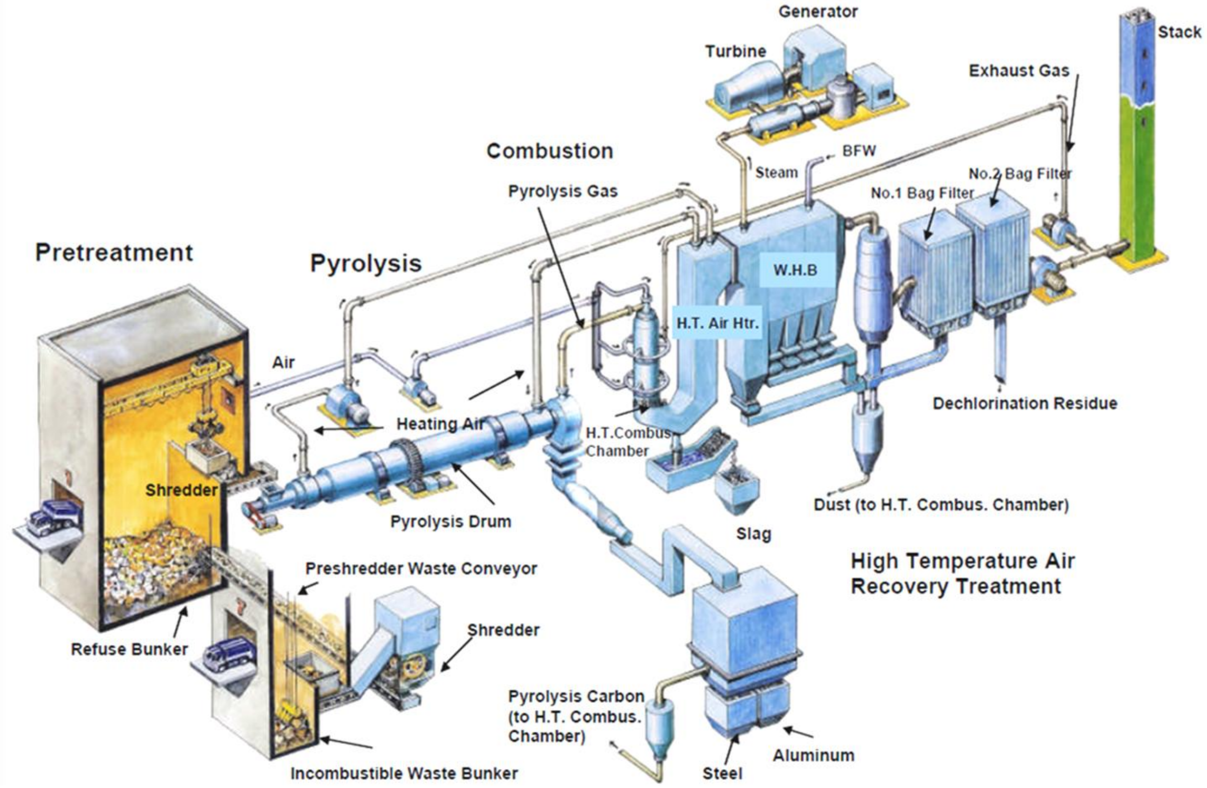
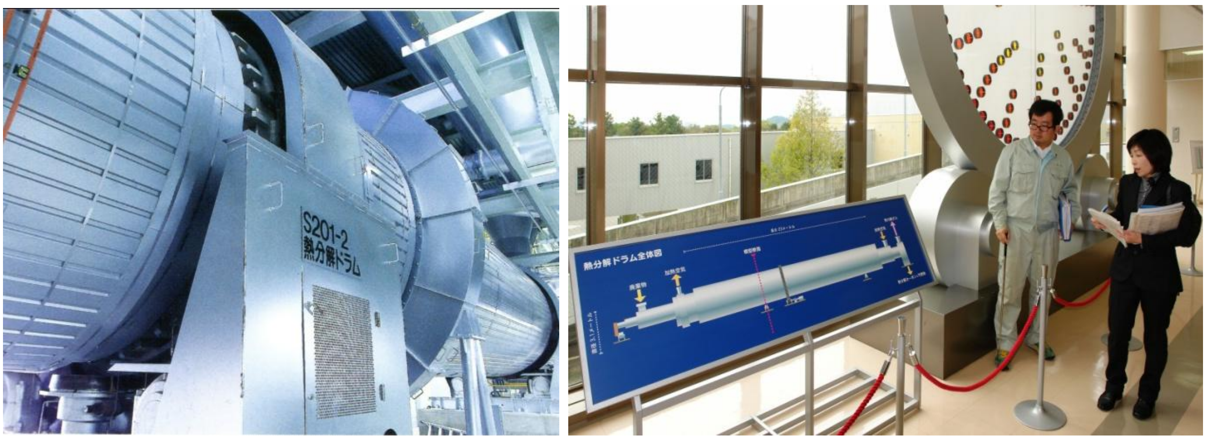


Figure A2.18: Photo of the pyrolysis drum (left) and of the operator explaining the function of the drum (right, with a full scale cross-section of the drum in the background)



The right photo in the same figure shows the operator of the plant explaining the function of the drum with the help of a chart in the foreground. A cross section of the drum partly seen in the background visualises the complex design of the internal heating tubes. The heating medium is air heated up in the first pass of the boiler.

The pyrolysis process transforms the waste into pyrolysis gas, the typical composition of which is compiled in Table A2.6 and a solid residue consisting of pyrolysis coke, inert matter, and metal scrap.

Table A2.6: Main species and their typical concentration in pyrolysis gas

Species	Concentration
O_2	0 vol%
CO	30 vol%
CO_2	20 - 40 vol%
H_2	15 vol%
CH_4	15 vol%

Species	Concentration
C_nH_m	5 vol%
NH_3	20 - 100 ppm
HCN	1 50 ppm
SO_2	<100 ppm
H_2S	>1,000 ppm

The solid residues are discharged to a drum where they are cooled down to approx. 80°C and are then transferred to a sorting stage equipped with a magnetic separation for ferrous and an eddy current separation for non ferrous metals recovery. The residual fraction passes an air separator to blow the pyrolysis coke out. This carbonaceous material is pneumatically transported into the high temperature combustion chamber; the inert residue can be utilised as aggregate in asphalt or concrete applications.

The pyrolysis gas is transferred to the high temperature combustion chamber (see Figure A2.19) where it is burnt together with the pyrolysis coke at a temperature of approx. 1,300°C.

Figure A2.19: High temperature combustion chamber

The liquid slag from the high temperature combustion chamber is quenched with water. The leaching of heavy metals out of this slag is very low; the material can be utilised the same way as the inert residues from the pyrolysis process.

The hot flue gas leaving the combustion chamber enters the heat recovery system. In the first pass, air is heated which serves as an energy source for the pyrolysis drum, the following part is a conventional boiler with generation of steam of 400°C and 4 MPa which feeds a turbine. The electric power is sold to a local power distribution company.

The first stage of the air pollution control (APC) system is a fabric filter for removal of the fly ashes. Since this filter is labelled as a dioxin removal stage, it is assumed that activated carbon is injected in the cylindrical container seen between the boiler and the first filter in Figure A2.17.

For acid gas cleaning, Neutrec® technology is installed. This is a dry process, invented by Solvay, which uses freshly ground $NaHCO_3$ as a reagent for abatement of acid gases. The process guarantees compliance with the emission standards of the plant, which are listed in Table A2.7. As can be seen these are significantly higher than those of the Omuta RDF combustion plant (compare Table A2.4).

Table A2.7: Selected air emission limits of the R21 plant (standardised to a CO_2 off-gas concentration of 14%)

	Emission limit
Dust	20 mg/m^3
HCl	100 ppm
SO_2	100 ppm
NO_x	100 ppm
PCDD/F	0.05 ng[I-TE]/m^3

The main advantage of the Neutrec® process is its stoichiometry of almost 1, which compensates the higher operation costs by the small amount of residues. The reaction products NaCl and Na_2SO_4 account for about 95% of these residues, and the remaining 5% consist of other salts, including heavy metal ones.

The APC residues are stored in bags of 600 kg each in a roofed concrete pit with an area of 1,770 m^2. The pit volume of 11,505 m^3 allows the storage of residues accumulated during 15 years of operation. There is a good chance that heavy metal recovery and recycling of the alkali salts (offered in Europe by Solvay) will be economically attractive in the future.

Economy

The investment for the plant was approx. 13 billion ¥ (≈ 104 million €). The depreciation time and conditions have not been reported, however, it can be expected that the time is 15 years as for comparable facilities in Japan.

The operator quoted 10,000 ¥ (≈ 80 €) as treatment costs of one tonne of waste in the R21 plant. It can be expected that this is rather the gate fee than the real treatment costs since it is close to the 9,500 ¥ reported for the fee to be paid by the community in Omuta. The sum includes most likely the revenues from sales of power and metals.

The price of electric power can be expected to be in the same order of magnitude as in Omuta, which is 8 ¥/kWh (≈ 6.4 €cent). The total income per tonne of waste, however, is much lower due to the lower electrical efficiency, which, should, in accordance with the turbine capacity,, reach approx. 15%.

Using a lower MSW heating value of 10 MJ/kg, the generation of electric power should be approximately 420 kWh/Mg. Since only around 45% of the generated power are sold, this would mean an income of approx. 1,500 ¥ (≈ 12 €) per tonne.

If an additional profit of 1,000 - 2,000 ¥ (≈ 8 - 16 €) from the sale of metal scrap would be considered, the total treatment costs per tonne of waste in the R21 plant should be in the order of 13,000 ¥ (≈ 105 €). This sum is low compared to 18,500 ¥ (≈ 150 €) calculated for the combustion of one tonne of RDF in the Omuta Recycle Power Plant.

Koga city recycling plaza

Technology

The recycling plaza is located in the same building as the R21 plant and can be seen in the background of Figure A2.16. Technical data of the plant and main materials treated in the plant are compiled in Table A2.8. The list of treated materials may not be complete.

Table A2.8: Technical data of the recycling plaza and treated materials

Building area	2,750 m^2
Throughput	48 t/d
Operation time per day	5 h (on weekdays)
Accepted and recycled materials	
metal scrap, cans	aluminium and steel
glass	white, green, other cullet
paper etc.	paper, paper carton, board
plastics	esp. PET bottles, PS foam trays
bulky waste	
hazardous MSW	dry batteries, fluorescent tubes

The first step in the plant is the sorting of the incoming waste into material specific fractions which is, to a great extent, done manually. High-tech processes such as NIR (near infrared) systems for separation of different plastic species or coloured glass are also applied. The separated and practically uniform materials undergo further treatment such as shredding, grinding, pelletizing, or compacting, depending on the specification of the final products.

Bulky waste also ends up on the tipping floor where it is first hand sorted, than passed through a metal separation stage. Burnable residues are shredded and sent to the R21 plant.

Glass is sorted into white, green, and different-coloured cullet. White and green glass is sold to glassworks; the residual cullet is used for the production of glass foam.

Polystyrene is melted and moulded into pellets, paper and paper board is baled, soft drink bottles are partly shredded, and partly sold as complete bottles on pallets.

The recycling plaza was not in operation during the visit. The various treatment steps were demonstrated by the operator of the R21 plant using charts on the walls of the bright and wide aisles.

Figure A2.20 gives examples of charts explaining the workflow applied for recycling of the various materials. In most cases, the waste items and the final products of the respective processes are displayed below the charts.

Figure A2.20: Explanation of recycling methods by the operator of the R21 plant and recycled materials ready for sale: overview of all processes (top left), sorting and baling of waste paper (top right), baled paper (bottom left), recycled composite containers and PET bottles (bottom right)

Aluminium cans are of paramount importance due to the high aluminium price. The cans are compacted to form kinds of ingots as shown in Figure A2.21.

Figure A2.21: Compacted aluminium cans

Like in Omuta where a facility for interaction and education was built, the Koga centre houses an exhibition of waste materials as well as recycled items. The left photo in Figure A2.22 shows the entrance to the exhibition of recycled materials. This area is mainly installed to educate children. In an attached workshop they can explore what can be done with, and what can be produced from waste materials.

Figure A2.22: Entrance to the exhibition rooms (left) and women producing decorative items from waste (right)

The right photo has been taken during a course where women produced decorative items from waste.

The way the recycling processes, their efficiencies, and their products were presented can be looked upon as exemplary. The members of Task 36 were deeply impressed by the efforts the operators and the local decisions makers spent to establish not only a well functioning waste management system, but also to spread the message of the value of recycling among the citizens.

Economy

For the total construction costs of the Koga city waste management centre, a sum of approx. 20 billion ¥ (≈ 160 million €) was stated. Taking the investment for the thermal part of 13 billion ¥ into account, that leaves about 7 billion ¥ (≈ 56 million €) investment for the recycling plaza, including the information and education facilities.

Detailed information about the operational costs was not available. Only data on the revenues from the sold metals were announced. The price of aluminium was 97 ¥/kg and that of iron was 27 ¥/kg.

Munakata Eco Park

Waste management strategy

The Munakata Eco Park is the second centre set up by the Koga and One City, Four Towns Waste Treatment Co-operation and is also operated by Genkai Environmental Association. It is located in Munakata, Fukuoka prefecture, approx. 12 km north-east of the Koga city centre and, like that one, is a combination of a recycling plaza and a thermal treatment plant under one roof. Like in Koga city, there is also a recycling information/exhibition and education centre integrated in the administration building for public relations.

The objectives to set up the centre were the same as those reported above. The main drivers were:

- shortage of landfill space;
- the new Japanese legislative regulations for establishing a recycling-oriented society;
- problems with dioxin emissions in the former waste combustion facilities.

Hence, recycling became the number one solution for reducing the amount of waste for disposal and thermal treatment, using alternative processes for making the residues inert and reducing the volume of the residual combustible waste.

The waste collection system with separation of burnable and recyclable waste is the same as described above for the Koga centre.

The technology chosen for thermal treatment was gasification, which offers another route for minimising dioxin formation and reduces the volume of waste to be disposed of significantly by producing molten slag. The slag has, due to its leaching stability, a high potential for utilisation as secondary building material.

The selected process was the Nippon Steel gasifier, a combination of shaft furnace gasification based on steel blast furnaces and high temperature combustion. A photo of the gasification plant is shown in Figure A2.23.

Figure A2.23: View of the Nippon Steel gasification plant at Munakata Eco Park

The decision to establish Munakata Eco Park was made at the end of the 1990s; construction started in February 2001, and was completed in June 2003. The basic data concerning the layout of the waste treatment centre are compiled in Table A2.9.

Table 9: Layout of the Munakata Eco Park

Lot area	150,000 m^2
Recycling plaza building	4,043 m^2
Gasification plant building	5,359 m^2
Disposal area for gas cleaning residues	1,470 m^2
Exhibition and administration building	981 m^2

Nippon Steel gasification plant

Technology

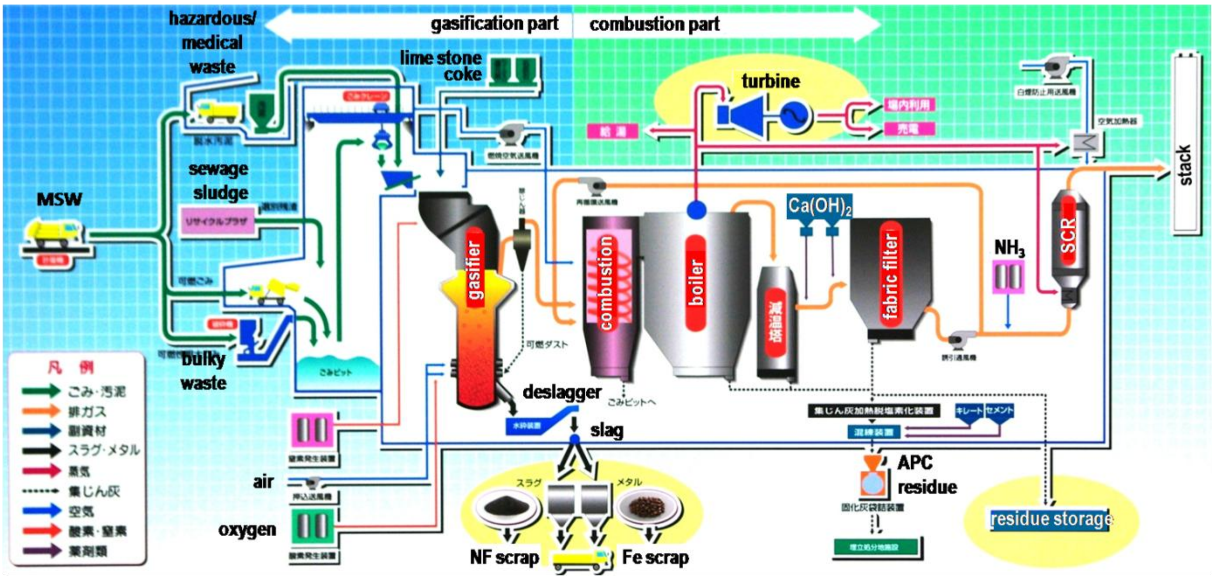
The shaft furnace technology used for thermal treatment of combustible waste is by far the most applied gasification process in Japan, but hardly known outside the country. It was developed during the early 1990s by Nippon Steel, based on its experiences with shaft furnaces used in its steel works. Meanwhile, all over Japan, 15 plants with 52 lines and an accumulated capacity of almost 2,750 t/d are in operation. The technical data of the local Nippon Steel gasification plant are compiled in Table A2.10.

Table A2.10: Technical data of the Nippon Steel gasification plant

Design waste throughput	44,000 t/a
Number of lines	2
Design waste throughput per line	80 t/d
Design coke throughput	61 kg/t of waste
Waste throughput in 2008	32,177 t
Coke throughput in 2008	1,954 t
Design operation time	240 d/a per line
Operation time furnace 1 in 2008	183 d
Operation time furnace 2 in 2008	202 d
Both furnaces in operation	28 d
Waste humidity	50 - 55%
Gasification residence time	4 h
Gasification temperature	300 1,000°C
Oxygen in gasification air	36 vol%
Combustion temperature	≈ 940°C
Steam pressure	4 MPa
Steam temperature	400°C
Power generation capacity	2.4 MW
Typical power generation	1.2 MW
Power sold in 2008	722 MWh

The flow diagram of the plant is shown in Figure A2.24.

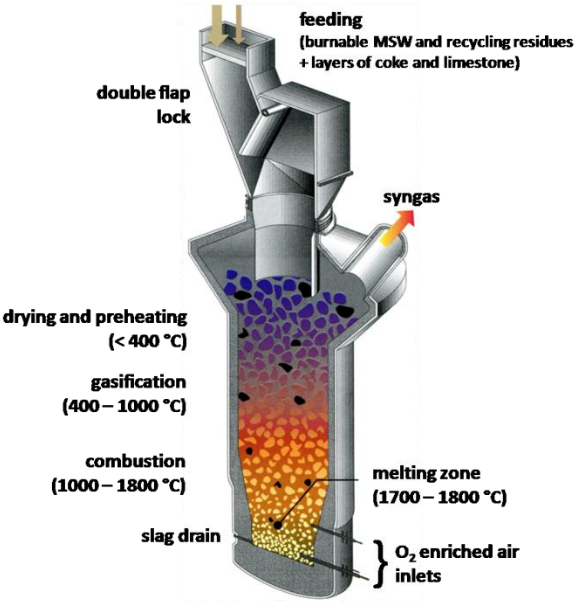
Figure A2.24: Flow diagram of the Nippon Steel process



The burnable MSW is delivered by truck to the bunker. Coarse waste passes through a shredder for size reduction. Dried sewage sludge is mixed in from a waste water treatment plant. A crane takes the waste mix to the top of the gasification furnace. Hazardous and medical waste is stored in a separate small silo from where it is also fed into the furnace.

For better control of the gasification process a small amount of approx. 0.6% of coke is added to the waste in layers. For conditioning of the slag, as well as for capture of some sulphur, lime stone is added. A scheme of the furnace with indication of the different reaction zones is shown in Figure A2.25.

Figure A2.25: Scheme of the gasification furnace



The waste enters the furnace via a double flap lock which ensures a tight separation of the furnace atmosphere from the environment. Oxygen enriched air (36 vol%) is blown into the furnace through four nozzles at the lower part; through another six nozzles higher up, air is injected.

The energy for the gasification process is delivered by the combustion of residual carbon at 1,000 - 1,800°C in the lower part of the furnace. This high temperature causes melting of the slag which is drained through an outlet at the bottom of the furnace. A discharge of liquid slag is shown in Figure A2.26.

Figure A2.26: Discharge of liquid slag from furnace 2

The slag of the gasifier is quenched in the water of the deslagger. After separation of ferrous and non-ferrous metals, it is used as construction material. The metal fractions are sold. The ferrous scrap is mainly used as counterweight material for cranes, dredgers or other machinery.

The gasification takes place in a temperature range between 400 and 1,000°C above the combustion zone. The hot syngas leaves the furnace after heating the mix waste, coke, and lime stone. Its main components are CO with 15 - 20 vol% and H_2 with 2 - 5 vol%. The calorific value of the gas is in the order of 6.7 MJ/m^3.

In a cyclone directly behind the gas outlet, coarse fly ashes are removed and are fed back into the furnace; the gas is then burnt in a cyclone combustion chamber at a temperature of approx. 940°C.

The natural circulation boiler cools the flue gas down to 160°C. The steam of 400°C and 4 MPa, serves for power production and heating purposes. Most of the energy is used in the gasification plant and in the recycling plaza, only a small fraction of the generated electric power is exported (compare 0).

For air pollution control, dry scrubbing with injection of slaked lime ($Ca(OH)_2$ into the flue gas is applied. The APC residues are stored in bags in a roofed concrete pit built on the premises of the Eco Park (see Figure A2.27). The pit volume of 9,340 m^3 allows the storage of residues accumulated during five years. The aim is for heavy metal recovery from the material in the future.

Figure A2.27: Pit for storage of APC residues

The last stage of the flue gas cleaning is a SCR system with ammonia injection into the reheated flue gas. The air emission limits of the plant are compiled in Table A2.11. These limits are with the exception of dioxins lower than those of the R21 plant in Koga city and with the exception of dust and NO_x higher than those of the Omuta RDF combustion plant.

Table A2.11: Selected air emission limits of the Nippon Steel gasification plant (standardised to a CO_2 off-gas concentration of 14%, bdl = below detection limit, * July 2009)

	Emission limit	Emission November 2009
Dust	10 mg/m^3	< 1
CO	30 ppm	< 1
HCl	50 ppm	18
SO_2	50 ppm	2
NO_x	50 ppm	19
PCDD/F	0.1 ng[I-TE]/m^3	0.000046 ng[I-TE]/m^3

The table contains emission data measured for furnace 2 - which was the only one in operation - in November 2009, the month of the visit. The sampling for dioxin emission control was performed in July 2009. The reported figures document the easy compliance of the plant with the emission standards.

The plant is operated by 28 people - 16 working in 4 shifts, 12 during the day in 2 shifts. These people are employed by the operation company. In addition and as a kind of controlling/auditing process, 3 ‘officers’ of the municipality are permanently working in the plant.

Recycling plaza

Technology

The amount of non burnable waste processed in the recycling plaza is listed in Table A2.12, together with the accepted and recycled waste materials. The latter ones are, in principle, the same as in the Koga city recycling facility.

Table A2.12: Technical data of the recycling facility and treated materials

Total throughput	40 t/d
Recyclable waste throughput	22 t/d
Non burnable waste throughput	18 t/d
Operation time	5 h/d (on weekdays)
Accepted and recycled materials	
metal scrap, cans	iron, aluminium,
glass	white, brown, other cullet
paper etc.	paper, paper carton, board
plastics	esp. PET bottles, PS foam trays
non burnable waste	
bulky waste	

The treatment methods, too, are almost the same with sorting, crushing, pelletizing etc. The sorting is mainly done manually and manual sorting is typically a dirty and unforgiving (human) working activity, however, it was surprising to see the clean working areas where the sorting took place in the facility (see Figure A2.28).

Figure A2.28: Hand sorting of recyclable waste

To a great extent, manually performed sorting and recycling requires a number of employees. The sorting is done by 11 employees and another 11 operate the recycling processes. For assistance, maintenance and other activities, another 4 workers are present.

Economy

The data supplied on the economic facts are not complete and to some extent it was not clear whether they are describing the entire complex or are valid for single facilities only.

The construction costs of the Eco Plaza were indicated as 15 billion ¥ (≈ 120.5 million €) and the annual costs are 1 billion ¥ (≈ 8 million €).

A specific number was given for the thermal treatment, which is 20,000 ¥/t (≈ 160 €/t) and - as said - more expensive than incineration in grate furnaces in Japan. There is not much income from the small sale of electric power which resulted in a profit of 563 million ¥ (≈ 45,000 €) only. These figures allow the calculation of the power price which is 7.8 ¥ (≈ 6.2 €cent) -similar to Omuta.

Considering the 2008 throughput of the gasification plant of approx. 32,000 tonnes, the operation costs of the gasification plant amounted to approx. 645 million ¥ (≈ 5.2 million €), which leaves 355 million ¥ for the operation of the recycling facility.

Since this plant operates on weekdays only, it can be estimated that it has an annual throughput of approximately 10,000 tonnes. Hence the recycling costs should be in the order of 35,000 ¥ (≈ 280 €) per tonne, a rather high sum if the figures supplied are accurate.