The impact of a change in EC legislation on the combustion of municipal solid waste

– Interim report –

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Summary

Municipal Solid Waste (MSW) combustion has been discussed intensively over the last two decades. As a result of this over the last five years changes in regulations, equipment and techniques used have come very rapidly. In Europe different countries have adapted these changes in different degrees and the overall situation is not clear.

At the moment the Commission of the European Community, DG XI is planning on revising the two directives on municipal solid waste combustion which were set up in 1989. Before doing this, however, the impact of such a revision on the present and future combustion facilities in Europe is to be determined. This is done in two steps:

a. Assessment of the present and future situation concerning municipal solid waste combustion facilities.
b. Technical and economical consequences for adapting existing and new municipal solid waste combustion facilities to a stricter (EC) directive.

In this interim report mainly the results of the first step are presented: a survey on MSW combustion facilities in Europe. The countries concerned in this survey are: Austria, Belgium, Switzerland, Germany, Denmark, Spain, France, Greece, Italy, Ireland, Luxembourg, Norway, The Netherlands, Portugal, Sweden, Finland and the United Kingdom.

Besides MSW combustion facilities also the amount and composition of the MSW in the different countries are reported as well as the percentage of this waste which is combusted. The present regulations considering MSW combustion and plans or expectations for the future were also taken into consideration.

Also a brief description of the state-of-the-art technology in MSW combustion is given.

In order to draw up the survey on the combustion facilities the figures had to be compiled from many sources as none of the sources supplied the information needed for a total survey. For Italy the information was vague as to which installations are and which are not in operation. For Italy and France the information concerning the applied flue gas cleaning in a number of installations was missing. This interim report is restricted to combustion facilities with a capacity of at minimum 3 tonnes per hour. The final report will consider the facilities with smaller capacities too.

Information about the plans for future combustion facilities is very vague as due to public opposition and the 'NIMBY'-syndrome (Not In My Back-Yard), the planning and realisation of a MSW combustion facility is a very long and tedious process.

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Table of contents

1 Introduction

Combustion of municipal solid waste (MSW) has been a 'hot' item for the last decade. Not only because it is a sensitive subject for public and politics but also because the techniques for MSW combustion have been changing rapidly during the last five years.

Ever since the discovery of PCDD/F (polychlorinated-dibenzo-para-dioxines and -furanes) in the flue gases of a an MSW combustion facility [Olie et al,1977] emission legislations have been set up and have been made stricter, requiring more advanced techniques and equipment for combustion and flue gas cleaning.

In 1989 the EC (Directorate General XI) set up two directives on the combustion of MSW. However, at this moment some European countries have national guidelines which are a lot stricter than the EC directive: e.g. Germany, The Netherlands and Austria. As these last three guidelines more resemble the emission levels of what today is possible with state-of-the-art technology than the EC directive, the EC plans to update the 1989 directives. The 1992 directive for hazardous waste combustion (HWC) [European Directives, 1992] serves as an example of what the new directive for MSW combustion will look like.

However, before such a new directive is introduced the EC wants to know the impact such a directive will have on the existing and new MSW combustion facilities. Therefore TNO Institute of Environmental and Energy Technology has been assigned a study to examine this impact.

The study roughly consists of two phases:
a. Assessment of the present and future situation concerning municipal solid waste combustion facilities.
b. Technical and economical consequences for adapting existing and new MSW combustion facilities to a stricter (EC) directive.

In this interim report mainly the results of the first step are presented: a survey on MSW combustion facilities in Europe (EC member countries plus Austria, Switzerland, Norway, Sweden and Finland).

First in chapter 2 some definitions are given which were used in interpreting the information on MSW and MSW combustion facilities. In chapter 3 an overview is given of the national and EC emission guidelines and directives. In chapter 4 the most relevant data are given for Europe (the total of the countries considered in this study). Detailed data per country are given in Appendix B. In chapter 5 a brief description of the state-of-the-art technology in MSW combustion is given for new MSW facilities. Finally in chapter 6 the final report is previewed.

2 Definitions and general remarks

2.1 The part of combustion in MSW treatment

In this study the amount of waste produced in a certain country is the amount after prevention but before recycling. Separately collected waste thus is included.

This produced amount of MSW is per country split up in four treatment schemes: combustion, landfill, recycling and composting.

The residues from combustion and composting are left out of consideration in this study. For example: if a certain amount of residue from combustion is landfilled this amount is not included in the figure for landfill.
This is done for two reasons:

- First of all it is not known precisely how much residue is generated and what is done with the residues from combustion or composting: in theory composted MSW is used as fertilizer whereas in practice it is often landfilled.
- The second reason is that residues from these processes are often considered chemical or special waste and therefore have to be landfilled on special sites, separately from regular MSW.

Confusion can occur if the total combustion capacity in a country is compared to the amount of MSW which is said to be combusted in that country. These figures come from different sources and mismatches in the comparison can be caused by several factors:

- **definition**: the waste which is combusted might not have the same composition as the MSW which is produced; sometimes not only MSW is combusted but also industrial waste, sewage sludge, etc. A clear example of this confusion is Denmark. If the total combustion capacity in Denmark is related to the amount of MSW, the outcome is that around 70% of the Danish MSW is combusted. However, in the Danish combustors also industrial waste and some other kinds of waste are combusted, so that actually 'only' 48% of the Danish MSW is combusted.
- **operating hours**: the design capacity in tonnes per hours is multiplied by an assumed number of hours in operation of 7,000 per year. In The Netherlands, however, the average is much higher: 7,500-8,000 hours per year, whereas in other countries installations sometimes are not run 24 hours a day but only in daytime shifts. In Germany and Switzerland it is very common to build an extra unit to ensure waste disposal. This means that a plant with four units has a theoretically maximum availability of 75% (circa 6600 hours per year). Differences in operating hours are also caused by differences in maintenance practices: e.g. is the boiler cleaned once a year or once every two years?
- **increasing heat of combustion**: the heating value of the MSW has increased considerably over the last two decades [Dirks, 1991]. Because combustion facilities are limited in the amount of heat which can be generated per time period this means that at a certain point the increase of heat content per kg MSW had to be compensated by a decrease of MSW throughput. This caused these installations to combust less MSW then according to design specifications [Dirks, 1991; Rijpkema et al, 1991].

2.2 Waste and waste fractions

The definition of Municipal Solid Waste considerably differs between the countries concerned in this study. In general, MSW includes household waste and bulky waste as well as comparable wastes from small commercial or industrial enterprises (often called trade waste), and market and garden residuals, which are collected and treated by or for the municipalities. In this study separately collected fractions, mostly paper and glass, are also counted to the total amount of MSW. In chapter 4 for each country the definition of MSW is given, if known.

The composition of MSW is determined by sorting analyses. This is mainly done by sieving and picking by hand.
Among the different countries there are differences in the sorting fractions. In this study the following fractions are chosen:
- Putrescibles/Fines
- Paper and Cardboard
- Plastic
- Glass
- Metals
- Textiles
- Miscellaneous combustibles
- Miscellaneous non-combustibles

Most sorting analyses result in a fraction fines, but because of different sieve diameters these fractions are not comparable. As a great part of the fines, however, consists of putrescibles (kitchen/yard waste, etc.), it is counted to that group in this study.

The fraction 'miscellaneous combustibles' consists of wood, leather, rubber etc. 'Miscellaneous non-combustibles' stands for minerals, stones, bones etc.

When a product consists of two or more fractions it is counted to the dominating fraction. This means that a waste item which is 70% textile and 30% plastics is considered to be 100% textile.

Apart from differences in the definitions used there is also great fluctuation in the composition of MSW due to differences in social conditions, living structure, geographical location and the season in which the waste is produced. This explains why even figures of one country can show considerable differences in the amount and composition of the waste which is generated.

Compositions reported in literature often do not mention the definitions along with the figures. This makes comparison very difficult. Especially if not all the figures which are of interest to this survey are taken into consideration in a literature source. The gaps in the information then has to be filled in with figures from other reports, with possible other definitions. Another problem with figures from literature are the so-called primary and secondary sources. Primary source actually analyse (fractions of) the waste whereas secondary sources copy or refer to the results of others. While copying definitions are lost or estimates are interpreted as truly measured. As primary sources are outnumbered by far by the secondary sources it requires an enormous effort to obtain good figures. This effort has been made for this study.

This report, which in fact also will be a secondary source, relies as far as possible on primary sources. However, these primary sources sometimes are relatively old and possibly outdated. If this appears to be the case or if no primary reference is available, an educated guess is made and reported. In all cases the way the figures are obtained is mentioned.

For all of the countries it was possible to obtain figures on the total amount and the composition of MSW. Information on MSW treatment schemes was not obtained for Greece and figures on future trends and expectations were often very fragmented, uncertain and not structured.

2.3 Information sources

In order to obtain information out of first hand a questionnaire with all kinds of questions on MSW combustion facilities, on MSW (amount, composition, treatment) and on future plans was send to all the environmental ministries of the involved countries. Most of them replied by filling in the form or by sending relevant reports, some forwarded the questions to experts, and some did not reply at all. Most of the answers concerned the combustion facilities.

Besides writing to the ministries also experts, if known, were contacted, per phone or per letter (fax). Also literature was searched for relevant information.

In the figures per country the main information sources per country are mentioned by references. Besides these references used in the text the reference list at the end of the report also contains references which are not directly referred to but which have been used in this study for background or general information.

The difficulty in gathering the information on combustion lies in the fact that information from one source never gave all the figures on the combustors of interest to this study. This was solved by combining information from different sources, which sometimes is very well possible and other times requires a lot of effort.

Special difficulties with the gathering of figures were encountered in Italy, where a lot of combustors are temporarily out of order and the total situation is not clear at the moment (different sources give contradictionary information).

3 Emission guidelines in Europe

Almost each country in Europe (considered in this study) has its own legislation concerning emissions from MSW combustion. These regulations, however, differ a lot from country to country, not only in emission limits, but also in the number of pollutants for which there are limits. Some regulations only set limits to the emissions of dust, HCl, HF and CO, whereas others also imply SO_2, NO_x, total organic carbon (TOC), heavy metals, PCDD/F (polychlorinated dibenzo-para-dioxines and -furans) as well as certain performance demands, other than emissions.

Table 3.1 gives an overview of the emission limits conform the different regulations existing in Europe. For comparison the latest EC directive on hazardous waste combustion has also been included. The values in this table are related to an oxygen concentration in the flue gases of 11 vol% (dry, at standard temperature and pressure (stp): 273 K, 101.3 kPa) except for Norway (10 vol% O_2) and Sweden (10 vol% CO_2). An oxygen concentration of 11 vol% is assumed to correspond with a CO_2 concentration of 9 vol%.

Most of the regulations also require certain conditions to be met for the flue gases after the last (combustion) air injection. For example the German regulation requires that the flue gases, after the last injection of (combustion) air remain at a temperature of at least 850 °C and a concentration of 6 vol% O_2 (dry, at stp) for at least 2 seconds. This is meant as a sort of guarantee for destruction of combustible matter in the flue gases. What conditions are required is also mentioned in table 3.1.

Besides the limit values it is very important to specify the time period during which the measurements have to be averaged to meet the limit values. For example a limit value as a half hour average is more difficult to meet as the same value over a longer period of time (time to even out peaks). The remarks to the time basis for the limits are mentioned below per guideline.

Member countries of the European Committee have to comply with the EC-directive at minimum, but can have stricter limits. This is the case for Germany and The Netherlands.

Spain, France, Greece, Portugal, Ireland and Luxembourg do not have regulations of their own and only have the EC-directive to deal with. Belgium, Denmark, Italy and the United Kingdom have made small extensions to the EC-directive.

From the non-member countries Austria and Switzerland have stricter guidelines than the EC proposes. Norway and Sweden have comparable guidelines whereas Finland does not have a guideline but follows the EC-directive.

Some of the guidelines mentioned in table 3.1 have further regulations. These are mentioned briefly below.

Austria [Löffler, 1991]
The Austrian guideline also requires a CO/CO_2-ratio of 0.002.

Table 3.1 Emission guidelines for Municipal Solid Waste combustion in Europe (see text for explanation)

Component		A 1989	B 1982	CH 1991	D 1990	DK 1991	I	N	NL 1989	S	UK 1992	EC 1989 MSW	EC Haz. waste	Component
Dust	mg/Nm^3	15	100	10	10	30	30	10	5	20	30	30	5	Dust
HCl	mg/Nm^3	10	100	20	10	50	50	100	10	100	30	50	5	HCl
HF	mg/Nm^3	0.7	5	2	1	2	2	-	1	1	2	2	1	HF
SO_2	mg/Nm^3	50	-	50	50	300	300	300	40	200	300	300	25	SO_2
CO	mg/Nm^3	50	1000	50	50	100	100	100	50	100	100	100	50	CO
NO_x (as NO_2)	mg/Nm^3	100	-	80	200	-	-	-	70	400	350	-	-	NO_x (as NO_2)
TOC (as C)	mg/Nm^3	20	-	20	10	20	20	-	10	-	20	20	5	TOC (as C)
Heavy metals														Heavy metals
Hg	mg/Nm^3	0.05	-	0.1	0.05	-	-	0.1	0.05	0.03	0.1	0.2	0.05	Hg
Cd	mg/Nm^3	0.05	-	0.1	-	-	-	-	0.05	-	0.1	0.2	-	Cd
Hg+Cd	mg/Nm^3	-	-	0.1	-	0.2	0.2	-	-	-	-	-	-	Hg+Cd
Cd+Tl	mg/Nm^3	-	-	-	0.05	-	-	-	-	-	-	-	0.05	Cd+Tl
Pb	mg/Nm^3	-	-	1	-	1	-	-	-	-	-	-	-	Pb
Zn	mg/Nm^3	-	-	1	-	-	-	-	-	-	-	-	-	Zn
Pb+Zn+Cr	mg/Nm^3	2	-	-	-	-	-	-	-	-	-	-	-	Pb+Zn+Cr
Pb+Cr+Cu+Mn	mg/Nm^3	-	-	-	-	5	5	-	-	-	-	5	-	Pb+Cr+Cu+Mn
As+Ni	mg/Nm^3	-	-	-	-	1	-	-	-	-	-	1	-	As+Ni
As+Co+Ni	mg/Nm^3	0.5	-	-	-	-	-	-	-	-	-	-	-	As+Co+Ni
Tot.rest	mg/Nm^3	-	-	-	0.5	-	-	-	1	-	1	-	0.5	Tot.rest
PCDD/F	ng TEQ/Nm^3	0.1	-	-	0.1	-	4000 1)	2	0.1	0.1	1	-	0.1	PCDD/F
Conditions		11% O_2	11% O_2	11% O_2	11% O_2	11% O_2	11% O_2	10% O_2	11% O_2	10% CO_2	11% O_2	11% O_2	11% O_2	Conditions
Temperature	°C		800		850	850	950	800	850		850	850	850	Temperature
Residence time	s		1		2	2	2	1.5	2		2	2	2	Residence time
Oxygen conc.	vol%		6		6	6	6	-	6		6	6	6	Oxygen conc.

Sources:
Austria: Luftreinhalteverordnung (LRV 1989) [Löffler, 1991]
Belgium: capacity > 0.75 t/h [Jaubin, Wijs 1991]
Switzerland: Luftreinhalteverordnung [DK-Teknik, 1991, Löffler, 1991]
Germany: [17BImSchG, 1991]
Denmark: Emission limits for Waste combustion. Stat. Order 4th Jan. 1991 [Miljostyrelsen, 1991]
Italy: [Löffler, 1991]
Norway: [Pettersen, Nåmdal, 1992]]
Netherlands: [Besluit luchtemissies afvalverbranding, 1993]
Sweden: Solid waste management in Sweden, August 1990 [ISWA, 1991]
UK: Environmental Protection Act, Process Guidance Note IPR 5/3 [NMSO, 1992]
EC MSW [European Directives, 1989]
EC Hazardous waste combustion [European Directives, 1992]

1) ng/Nm^3, *not* expressed as TEQ

- no limit value
(blank) not known

ALL VALUES FOR DRY GASES AT 273 K
AND 101.3 kPa

Belgium [Jaubin, Wijs, 1991]
The present Belgian regulation also requires a greyness of the plume of less than 3 on Bacharach's scale and the following immission limits (half hour average):

- SO_2 0.1 mg/Nm^3
- HCl 0.1 mg/Nm^3
- HF 0.004 mg/Nm^3
- dust (< 10 μm) 0.1 mg/Nm^3

This year the Belgian government will adopt the EC-regulations. An exemption is proposed to be made for combustors with a capacity of more than 30 tonnes per hour. These will then have to comply with the German emission limits except for NO_x, which will have to be 100 in stead of 200 mg/Nm^3.

Germany [17.BImSchG, 1991]

- The emission of the remaining heavy metals which according to table 3.1 has to be less than 0.5 mg/Nm^3 is supposed to be the total of the emissions of: As, Sb, Pb, Co, Cr, Cu, Mn, Ni, V and Sn.
- The emission values given in table 3.1 are daily averages. Besides this also half hour averaged limits are set:
  - dust 30 mg/Nm^3
  - HCl 60 mg/Nm^3
  - HF 4 mg/Nm^3
  - SO_2 200 mg/Nm^3
  - NO_x 400 mg/Nm^3
  - TOC 20 mg/Nm^3

  For CO a one hour average of 100 mg/Nm^3 and a daily average of 50 mg/Nm^3 may not be exceeded. Also 90% of the CO-measurements in 24 hours have to be below 150 mg/Nm^3.
  Finally the values for heavy metals and PCDD/F are averaged on the sampling time used.
- This 17.BImSchG is valid for new installations. For existing installations the emission limits will be valid starting 01-03-1994. Exceptions can be made until 01-12-1996.
- Starting up and closing down of the combustor has to be done with auxiliary burners (not burning waste). Waste is only allowed in the combustion chamber if the temperature in the chamber is above 850 °C.
- MSW combustors are obliged to recover energy. If more than 0.5 MW of energy is produced in excess of the internal need for energy electricity has to be generated.
- The following parameters have to be monitored continuously:
  - the emissions of CO, dust, HCl, HF (not if HCl-cleaning is applied), SO_2 and NO_x;
  - the percentage O_2 in the flue gases;
  - the temperature of the flue gases in the required areas;
  - parameters needed for sensible operation (e.g. pressure, humidity and volume of the flue gases);
- If chemical waste is burned the required temperature is set at 1200 in stead of 850 °C.
- If only liquid wastes are burned the O_2-concentration must be above 3 instead of 6 vol%.

Denmark [Miljostyrelsen, 1991a]
- The values for dust and HCl are weekly averages. Besides that also daily averages are set: dust 40 mg/Nm^3 and HCl 65 mg/Nm^3. These values may be exceeded by up to 30%. For CO a one hour average of 100 mg/Nm^3 may not be exceeded. Also 90% of the CO-measurements (30 min. average) in 24 hours has to be below 150 mg/Nm^3. The other values are averaged on the sampling time used.
- CO, dust, HCl and the temperature have to be monitored on a continuous basis. The other components must be checked via sampling 6 times a year. If they comply with the limits each time this frequency drops to two times a year.

France
France has adopted the EC-guideline with one exception:
- Hg + Cd < 0.2 mg/Nm^3

Norway [Pettersen, Nåmdal, 1992]
The existing regulations for small plants (capacity < 2 tonnes per hour) only sets a limit to the dust emission: 100-250 mg/Nm^3 at 10 vol% O_2 (dry, stp) in the flue gases. These regulations will probably be sharpened in the near future:
- dust 30-100 mg/Nm^3
- HCl 100-200 mg/Nm^3
- Hg 0.1 mg/Nm^3
- CO 100 mg/Nm^3

The Netherlands [Besluit Luchtemissies afvalverbranding, 1993]
- This guideline is valid starting 21-2-1993 for new installations (started after 1-4-1990). Existing installations will have to comply with this regulation by 01-01-1995.
- The emission of the remaining heavy metals which according to table 3.1 has to be less than 1 mg/Nm^3 is supposed to be the total of the emissions of: As, Sb, Pb, Co, Cr, Cu, Mn, Ni, V, Se, Te and Sn.
- The emission limits set in table 3.1 are hourly averages, except for PCDD/F and the heavy metals.
- For the emission limit for Hg an exception can be made if a removal efficiency of 90% (for Hg) can be demonstrated. For this reason the concentration of Hg in the raw (= uncleaned) flue gases has to be measured also.
- Starting up and closing down of the combustor has to be done with auxiliary burners (not burning waste). Waste is only allowed in the combustion chamber if the temperature in the chamber is above 850 °C.
- The following parameters have to be monitored continuously:
  - the emissions of CO, dust, HCl, TOC, SO_2 and NO_x;
  - the percentage O_2 in the flue gases;
  - the temperature of the flue gases in the required areas.

  The emission of dust, heavy metals, HCl and HF have to be measured 4 times a year and of PCDD/F 2 times a year. For this each time three samples per chimney have to be taken.
- A combustion facility has to consist of two units at least to guarantee the continuity of the operation.
- Existing installations can get a PCDD/F exemption up to 0.5 ng TEQ/Nm^3 if it is proven that reaching 0.1 ng would require excessive investment.
- For existing installations the NO_x-limit of 70 mg/Nm^3 is a guidance value which they have to try to meet.

Sweden [Svenska Renhållningsverks-Föreningen,1991;Kuusisto,1992]
- The limits for dust and HCl are monthly averages, whereas the CO-limit is hourly averaged.
- For existing plants the limit for Hg is 0.08 mg/Nm^3 and for PCDD/F 2 ng/Nm^3.

United Kingdom [HMSO, 1992]
- This guideline came into effect in August 1992. New plants and substantially changed plants will have to comply with these regulations directly. Existing plants have until 1 December 1996 to comply with the limits. Starting 1 August 1992 existing plants only have one emission limit to comply with: 100 mg/Nm^3 total particulate matter.
- The emission of the remaining heavy metals which according to table 3.1 has to be less than 1 mg/Nm^3 is supposed to be the total of the emissions of: As, Pb, Cr, Cu, Mn, Ni and Sn.
- For PCDD/F the emission limit is 1 ng TEQ/Nm^3; the operators, however, are urged to reduce this emission as far as possible with an aim of 0.1 ng TEQ/Nm^3.
- The process should not give rise to an offensive smell noticeable outside the premises where the process is carried on.
- During normal operation, including start-up (with 5 minutes delay) and shut-down emissions should be free from visible smoke.
- Starting up and closing down of the combustor has to be done with auxiliary burners (not burning waste). Waste is only allowed in the combustion chamber if the temperature in the chamber is above 850 °C.
- The limits set in table 3.1 are valid for non-continuous monitoring. If they are continuously monitored 95% of the hourly averages should not exceed the emission value in table 3.1. The peak hourly average should not exceed 1.5 times the emission value.
- For CO a one hour average of 100 mg/Nm^3 may not be exceeded. Also 95% of the CO-measurements (10 minutes averages) taken in 24 hours have to be below 150 mg/Nm^3.
- For existing installations with a capacity > 6 tonnes per hour the conditions (850 °C, 2 seconds, 6 Vol% O_2) will have to be implemented by 1 December 1996, or at the latest when the furnaces are replaced. The other installations (capacity < 6 tonnes per hour) have until 1 December 1995 to comply with the following conditions: 850 °C and 6 Vol% O_2 for a sufficiently long time.

EC-directive MSW combustion [European Directives, 1989]
- The values in table 3.1 are directly valid for new installations with a capacity of more than 3 tonnes per hour. Installations with a capacity of more than 1 but less than 3 tonnes per hour have the following limits: dust 100 mg/Nm^3, HCl 100 mg/Nm^3, HF 4 mg/Nm^3, CO 100 mg/Nm^3 and TOC 20 mg/Nm^3. In addition the limits for heavy metals in table 3.1 apply. Installations smaller than 1 tonne per hour have the following limits: dust 200 mg/Nm^3, HCl 250 mg/Nm^3, CO 100 mg/Nm^3 and TOC 20 mg/Nm^3.
- Existing installations larger than 6 tonnes per hour have to comply with the values in table 3.1 starting 01-12-1996. Existing installations with a capacity of smaller than 6 tonnes per hour have to comply with the limits for new installations (see above) starting 01-12-2000. By 01-12-1995 the existing installations have to comply with the following limits:
  - capacity < 1 tonne/hour: CO 100 mg/Nm^3 and dust 500 mg/Nm^3;
  - capacity > 1 but < 6 tonnes/hour: CO 100 mg/Nm^3 and dust 100 mg/Nm^3.

- For existing installations the conditions 850 °C and 6 vol% O_2 for at least 2 seconds need only to be fulfilled from the moment the combustor is modernised.
- 90% of the CO-measurements in 24 hours have to be below 150 mg/Nm^3. For existing installations the CO-limit of 100 mg/Nm^3 is hourly averaged for installations larger than 1 tonne per hour and daily averaged for the smaller ones.
- New installations larger than 1 tonne per hour have to monitor the emissions of dust, CO and HCl and also the O_2-concentration and the temperature continuously. Heavy metals, HF, SO_2 and TOC are to be measured by sampling. Small installations (< 1 tonne per hour) have to monitor the emissions of dust, HCl and CO and the O_2-concentration by sampling. The frequency of the sampling is to be determined by the permitting authorities.
- Existing installations have to monitor dust, CO and O_2-concentrations continuously (> 1 tonne/hour) or by sampling (< 1 tonne/hour) starting 01-12-1995, until the requirements for new installations have to be met (see above).

EC-directive Hazardous waste combustion (HWC) [European Directives, 1992]

- This directive directly applies to new installations (starting 30-6-94). Existing installations (for which the first permit for operation was granted before 30-6-94) have until 30-6-97 to comply with this directive. Installations which will be definitely shut down before 30-6-99 and will not be operated for than 20,000 hours after 30-6-94 are exempted from the directive.
- The emission of the remaining heavy metals which according to table 3.1 has to be less than 0.5 mg/Nm^3 is supposed to be the total of the emissions of: As, Sb, Pb, Co, Cr, Cu, Mn, Ni, V and Sn.
- The emission values given in table 3.1 are daily averages. Besides this also half hour averaged limits are set:
  - dust 10 mg/Nm^3
  - HCl 10 mg/Nm^3
  - HF 2 mg/Nm^3
  - SO_2 50 mg/Nm^3
  - TOC 10 mg/Nm^3

  For CO a daily average of 50 mg/Nm^3 may not be exceeded. Also 95% of the CO-measurements (10 minutes average) in 24 hours have to be below 150 mg/Nm^3.

  Finally the values for heavy metals and PCDD/F are averaged on the sampling time used.
- The following parameters have to be monitored continuously:
  - the emissions of CO, dust, TOC, HCl, HF (not if HCl-cleaning is applied) and SO_2;
  - the temperature in the furnace;
  - the oxygen concentration, the pressure, the temperature and the water vapour of the flue gas;
- The heavy metal and PCDD/F emissions have to be measured periodically i.e. monthly.
- If halogenated waste is burned the temperature must be raised to at least 1200 °C.
- If only liquid wastes are burned the O_2-concentration must be above 3 instead of 6 vol%.

– Starting up and closing down of the combustor has to be done with auxiliary burners (not burning waste). Waste is only allowed in the combustion chamber if the temperature in the chamber is above 850 °C (or above 1200 °C in case of halogenated waste). The auxiliary burners must automatically come into operation if the temperature is below 850 (or in case of halogenated waste 1200) °C.
The waste feed is to be automatically stopped if the continuous measurements show that any emission limit value is exceeded due to malfunctioning of the flue gas cleaning system.

4 MSW combustion facilities in Europe

In this chapter the totals and averages of all the countries, considered in this study, are presented and compared. Data per country can be found in Appendix B. The comparison between countries must be made very carefully due to the (possible) differences in definitions of (parts of) the Municipal Solid Waste in the different countries. Where this plays an important role this will be commented upon shortly. In this study Europe stands for: the EC-member countries plus Austria, Switzerland, Norway, Sweden and Finland.

The survey presented refers to the situation in 1991. In the final report this will be updated.

4.1 Total amount of Municipal Solid Waste and the composition (putrescibles/paper/plastics/etc.) thereof generated in Europe per year

In this study Municipal Solid Waste is generally understood to be the total of:
- household waste;
- bulky waste;
- comparable wastes from small commercial or industrial enterprises;
- market and garden residuals;

as far as it is collected and treated by or for the municipalities. For some countries, however, the definition of MSW is slightly different.

In Europe a total population of 357 million people is living, producing a total of 140,880 ktonnes of Municipal Solid Waste per year. Per capita this is an amount of 395 kg per year. The total amount of MSW produced in each country is given in table 4.1 as well as the production per capita. Also the composition of the MSW per country is listed. A mean composition for the whole of Europe is given as a reference.

From table 4.1 it can be seen that the countries with relatively high standards of living also produce relatively more waste. An exception to this is formed by Austria, Germany and Sweden where on a basis of economy a higher amount of waste would be expected. In Germany and Sweden prevention of waste is relatively well established, whereas the low amount in Austria is known to be influenced by a difference in definition.

There are large differences in the composition of the MSW between the different countries; e.g. between Germany, Austria and Switzerland, countries which are expected to have comparable standards of living. Nevertheless in Germany 44% of the waste is putrescibles/fines and 24% is paper, whereas for Austria and Switzerland these fractions are equally represented at 30% (table 4.1).
Ireland, Greece, Portugal and Spain are high in putrescibles/fines, but for Italy the putrescibles/fines content is on average (for Europe) whereas for France the lowest content is reported, together with Norway. However, this might be influenced by some differences in definitions: France and Norway have the lowest content of putrescibles but also the highest content of miscellaneous. This suggests a difference in the definition of the fraction putrescibles/fines between the countries.

Table 4.1 Composition of Municipal Solid Waste per country in Europe
All figures consider total MSW per country

Country	Amount of MSW		Putrescibles/ fines	Paper	Plastic	Glass	Metals	Miscell (textiles incl.)
	k tonnes /yr	kg/capita	Wt%	Wt%	Wt%	Wt%	Wt%	Wt%
A	2,800	370	30	30	9	10	4	17
B	3,500	350	47	28	7	7	4	7
CH	3,700	550	30	31	13	7	6	13
D	25,000	410	44	24	7	9	6	10
DK	2,600	510	40	35	5	4	5	11
E	13,300	340	49	20	7	8	4	12
F	20,000	360	25	30	6	12	5	22
GR	3,150	310	53	18	7	3	4	15
I	17,500	300	40	22	7	8	3	20
IRL	1,100	310	55	20	10	3	3	9
L	180	480	47	28	7	7	4	7
N	2,000	470	25	32	7	4	4	28
NL	7,700	520	38	35	7	7	5	8
P	2,650	260	60	22	4	3	4	7
S	3,200	380	30	40	9	7	3	11
SF	2,500	500	30	40	6	4	3	17
UK	30,000	520	42	28	7	8	9	6
Europe	140,880	395	40	27	7	8	6	13
min-max[1)]		260-550	25-60	18-40	4-13	3-12	3-9	6-28

1) Minimum and maximum encountered, not based on standard deviation

4.2 Municipal Solid Waste treatment schemes (recycling, landfill, combustion)

All the MSW is disposed of in mainly 4 different ways: combustion, recycling, landfill and composting. The figures in this study do not include the treatment of residues from composting or combustion. For example: if a certain amount of residue from combustion is landfilled this amount is not included in the figure for landfill (see also chapter 2.1).

Table 4.2 gives an overview of how the waste is treated in Europe. The values for Europe serve as a reference and represent the average for the countries considered.

The (scarce) information available on Greece did not give evidence on any combustion, recycling or composting so it was assumed that all the MSW is landfilled.

From table 4.2 it is apparent that the Mediterranean countries (E, GR, I, P) have a relatively high level of landfill. The same goes for Ireland, the United Kingdom and Finland.

Furthermore the relatively high level of recycling in Spain and the relatively low level of recycling in Belgium, Luxembourg, France and Austria are noticeable.

Table 4.2 Treatment of Municipal Solid Waste per country in Europe
All figures (except amount) in Wt% of the total MSW per country

Country	Amount ktonnes/yr	Combustion	Landfill	Composting	Recycling
A	2,800	11	65	18	6
B	3,500	54	43	0	3
CH	3,700	59	12	7	22
D	25,000	36	46	2	16
DK	2,600	48	29	4	19
E	13,300	6	65	17	13
F	20,000	42	45	10	3
GR	3,150	0	100	0	0
I	17,500	16	74	7	3
IRL	1,100	0	97	0	3
L	180	75	22	1	2
N	2,000	22	67	5	7
NL	7,700	35	45	5	16
P	2,650	0	85	15	0
S	3,200	47	34	3	16
SF	2,500	2	83	0	15
UK	30,000	8	90	0	2
Europe	140,880	24	63	6	8

4.3 Overview existing Municipal Solid Waste combustors in Europe

In this interim report the small combustion facilities (< 3 tonnes/hour) are not taken into account. In the final report they will be integrated in the data.

In Europe there are 379 MSW combustors with a nominal capacity of at minimum 3 tonnes per hour in operation at the time. All together these combustors have a capacity (based on 7,000 hours of operation per year) of 41,134 ktonnes per year. If this is compared to the total amount of waste which is actually combusted in Europe (table 3.2: 140,880 ktonnes MSW, 24% combusted = 33,810 ktonnes combusted) there is a considerable difference (for explanation see chapter 2.2).

Table 4.3 shows in which country the combustors are located and how much of the total MSW they combust.

First of all it should be mentioned that the information on the Italian combustors is vague. The situation in Italy is very confusing and it is not clear which installations

are in operation and which are not. For this overview 37 combustors are assumed to be in operation.

In table 4.3 it can be seen that France owns the most combustion facilities by far (137). However, these 137 combustors are relatively small as they represent 36% of the number of combustors in Europe but only combust 25% of the total European MSW. On the contrary the installations in Germany and The Netherlands are relatively large: 12% (Germany) and 3% (The Netherlands) of the combustors combust respectively 27% and 7% of the European MSW. The average for The Netherlands is, however, largely influenced by the presence of the worlds largest MSW combustor: AVR Rotterdam, capacity 950 ktonnes/year.

Greece, Ireland and Portugal do not have MSW combustors.

Table 4.3 MSW combustors in Europe

Country	Number of combustors per country	% of total number of combustors in Europe [%]	Combustion capacity per country [ktonnes/yr]	% of total combustion capacity in Europe [%]
A	2	0.5	336	0.8
B	25	6.6	2,240	5.4
CH	30	7.9	2,860	7.0
D	47	12.4	11,230	27.3
DK	29	7.7	2,060	5.0
E	7	1.8	680	1.7
F	137	36.1	10,310	25.1
I	37	9.8	2,560	6.2
L	1	0.3	168	0.4
N	5	1.3	410	1.0
NL	10	2.6	2,800	6.8
S	17	4.5	1,770	4.3
SF	1	0.3	70	0.2
UK	31	8.2	3,640	8.8
Europe	379	100.0	41,134	100.0

In Europe most of the combustors recover energy from the flue gases (68% by number representing 83% of the MSW combustion capacity). Also this is very different per country. Surprisingly low is the energy recovery level in the United Kingdom. From comparing the percentages based on number of installations and amount of MSW processed it can be concluded that always the combustors which do recover energy are larger (in average) than the ones which do not.

Table 4.4 gives an overview of the level of energy recovery per country. The purpose of the recovered energy is mentioned in detail (as far known) in the following chapters per country. In general, however, the Scandinavian countries use a high percentage

of the recovered energy to produce hot water for district heating whereas the other countries mainly produce steam for electricity generation, with or without usage of the remaining energy.

Of course Greece, Portugal and Ireland are excluded from these table as they do not have any MSW combustion facilities.

Table 4.4 Level of energy recovery in the different countries in Europe

Country	Number of combustors per country	% of total number with energy recovery [%]	Combustion capacity per country [ktonnes/yr]	% of total capacity with energy recovery [%]
A	2	100	336	100
B	25	44	2,240	62
CH	30	77	2,860	90
D	47	100	11,230	100
DK	29	100	2,060	100
E	7	57	680	79
F	137	55	10,310	75
I	37	73	2,560	79
L	1	100	168	100
N	5	100	410	100
NL	10	90	2,800	97
S	17	100	1,770	100
SF	1	100	70	100
UK	31	19	3,640	29
Europe	379	68	41,134	83

Also the way the flue gases are cleaned differs a lot. In table 4.5 the flue gas cleaning used in Europe is showed. For this the installations which have scrubbers as well as dust removing equipment are only counted to the fraction with scrubbers. For a number of combustors in Italy and France the flue gas cleaning used is not known; they represent the fractions unknown in table 4.5. There are two combustors without flue gas cleaning: 1 in Spain and 1 in the United Kingdom.

Table 4.5 Extent of flue gas cleaning in MSW combustion facilities in Europe

Extent of flue gas cleaning	MSW combusted		Installations	
	ktonnes/ year	%	number	%
Flue gas cleaning:[1]				
- unknown	4,480	10.9	97	25.6
- none	60	0.1	2	0.5
- cyclone	800	1.9	18	4.7
- esp	14,590	35.5	121	31.9
- fabric filter	100	0.2	3	0.8
- dry scrubber	3,220	7.8	35	9.2
- semi-dry scrubber	6,208	15.1	30	7.8
- wet scrubber	11,650	28.3	73	19.3
Total	41,134	100.0	379	100.0
Extended flue gas cleaning:[1]				
- DeNOx	2,130	5.2	7	1.8
- active cokes	1,400	3.4	7	1.8

[1] Installations which have only a dust removal device and no scrubber are calculated under the dust removing device, installations which have both are calculated only under the scrubber. Most installations with scrubbers also have one of the mentioned dust removal systems. Installations which have dust removal devices, scrubbers and extended flue gas cleaning are counted to the scrubbers and are separately mentioned under the extended flue gas cleaning technique

From comparing the percentages based on number of installations and amount of MSW processed it can be concluded that on average the combustors:
- with no flue gas cleaning are relatively small;
- of which the flue gas cleaning system used is unknown are relatively small;
- which use just a fabric filter or just cyclones are relatively small;
- which use wet or semi-dry scrubbers or just an electrostatic precipitator are relatively large (on average);
- which use dry scrubbers are relatively small.

In table 4.6 where the use of scrubbers (total of wet, dry or semi-dry) is given per country also on the whole the combustors which use scrubbers are relatively large (on average). An exception is formed by The Netherlands and Belgium. For The Netherlands this will change soon because scrubbers are planned for all the installations which do not already have one.

Table 4.6 Extent to which scrubbers are used in the flue gas cleaning of MSW combustors per country

Country	Number of combustors per country	% of total number with scrubbers [%]	Combustion capacity per country [ktonnes/yr]	% of total capacity with scrubbers [%]
A	2	100	336	100
B	25	28	2,240	22
CH	30	47	2,860	54
D	47	100	11,230	100
DK	29	45	2,060	58
E	7	0	680	0
F	137	17	10,310	28
I	37	16	2,560	18
L	1	100	168	100
N	5	100	410	100
NL	10	60	2,800	25
S	17	82	1,770	94
SF	1	0	70	0
UK	31	0	3,640	0
Europe	358	39	40,050	53

4.4 Future perspectives for Municipal Solid Waste combustors: new combustors, retrofits, closing

As to combustion facilities there is a lot of uncertainty. Most countries have plans for extension of the combustion capacity but in a number of countries (among others Germany and The Netherlands) the opposition from the public and from environmental groups is getting so strong that plans are postponed or even cancelled. Even if there is in principle no opposition to new combustion plants there still are enormous difficulties in finding suitable locations ('NIMBY' = Not In My Back Yard). Also in politics new combustion facilities are not always popular subjects ('NIMEY' = Not In My Election Year).

However, the lack of other solutions (presently available) will make the construction of new MSW combustors inevitable. Especially because due to stricter regulations old combustors will be shut down. Others will be retrofitted with flue gas cleaning techniques or improved process control systems.

All countries (which have combustors) expect the combustion capacity to grow in the next two decades.

5 State-of-the-art MSW combustion technology

In this interim report the state-of-the-art technology in MSW combustion is briefly described. This will be done more extensively in the final report.

The system described is not the only sensible system possible, but it is one commonly accepted sensible system.

This description assumes mass-burn with energy recovery through steam production. The combustor is a moving grate type combustor, as this is seen as best suited for MSW combustion (at the moment). Also this type is most frequently used in Europe at the moment.

5.1 Pretreatment of MSW

The MSW is received in a bunker with a capacity of several days combustion capacity. Before it is fed to the combustor the big parts are removed and/or diminished in size. If possible the waste is mixed while it is stored in the bunker. The waste is fed through a funnel and arrives via a dosage system consisting of two hydraulic rams on the grate.

5.2 Grate type, furnace geometry, process control

The grate is either a forward or a reverse acting reciprocating grate and consists of several zones, each of which can be controlled separately (speed and air supply). In principle a rotary drum grate is also very well possible but the forward and reverse acting grates are preferred because of the better air distribution. Besides that the roller grate is only manufactured by one or two companies whereas there are more than 7 companies who manufacture a forward or a reverse acting grate.
The furnace is built in counterflow geometry. An intermediate flow or a parallel flow geometry is also possible. However, as it is expected that the heating value of the MSW will rise in future, problems with the furnace load are expected if a parallel flow geometry is used in combination with a forward or a reverse acting grate. So far only combinations of a parallel flow geometry with a rotary drum grate are known.
Because the forward and reverse acting grates are preferred also the counterflow geometry is preferred here.

A great part (ca. 40%) of the required combustion air is supplied through secondary air injectors. The total excess air ratio is 1.6-1.8. Experiments to decrease the excess air ratio using flue gas recycling are under execution at the moment.

The process is controlled by monitoring temperature, carbon monoxide and oxygen level, and all the flows including the steam production rate. The air supply to each zone of the grate can be varied as well as the ratio primary and secondary air. The supply is correlated to the monitored parameters. The primary air is preheated to 120-140 °C.

5.3 Boiler

A horizontal boiler is applied with (depending on the size of the boiler and the velocity of the flue gases) one, two or three empty drafts (radiation part) before the horizontal convective part. In this study the horizontal boiler is preferred over the vertical boiler due to the easier and cheaper cleaning of the convective tubes and the subsequent slightly longer lifetimes.

In the beginning of the radiation part the water tubes (in the walls) are shielded to keep the flue gas temperature at the required level for the required time. In the radiation part the flue gases are cooled to 600-700 °C, and in the convective part the temperature of the flue gases is further reduced to 200-250 °C. The tubes in the convective part are cleaned by automatic mechanical knocking systems.

Steam temperature is limited to around 400-450 °C due to increased corrosion problems at higher temperatures. If higher temperatures are required the steam can be heated up further outside the MSW combustor system with fossil (or other 'clean') fuels. To minimize erosion the flue gas velocity is kept below 5-7 m/s.

5.4 Flue gas cleaning system

The strictest emission guidelines (Germany, Austria, Netherlands, EC hazardous waste guideline) can be reached by using state-of-the-art flue gas cleaning techniques, but not without considerable effort.
In newly designed flue gas cleaning systems the following sequence of equipment is in principle often used:
- ESP;
- multi-staged wet scrubber with waste water evaporation;
- active cokes injection with fabric filter ('Flugstromadsorber');
- SCR-DeNOx (not necessary for EC HWC guideline).

This scheme is presented in figure 1. In figure 1 the waste water is evaporated because lately more and more often the permits given for MSW combustion demand zero discharge of waste water. Figure 2 gives the sequence if the waste water evaporation is included in the flue gas cleaning route.

Instead of the ESP a fabric filter is also possible, but it is more expensive and it needs more careful operation and maintenance. If further proof is found of PCDD/F-formation in ESPs at temperatures below 200 °C [Vogg,Merz, 1990] this could mean that the fabric filter is preferred over the ESP.

The dry and semi-dry scrubbing techniques are capable of reaching removal efficiencies for dust, HF and non-volatile heavy metals equal to the wet scrubber. For HCl, SO_2 and volatile heavy metals, however, the performances are not so good as for the wet system. The strictest regulations can hardly be met, and require a lot of adsorbent and consequently result in large amounts of residues [Reimann, 1992]. For this reason only smaller combustors might choose these techniques. Even existing (semi-)dry systems are now and then extended with a wet scrubber [Reimann, 1992].

The 'Flugstromadsorber' is often applied because of the low investment costs. Also the reduced risk of self-ignition because of the use of a mixture of active cokes with calciumhydroxide is a big advantage over the fixed bed technology. The circulating fluid bed technology is a good alternative to decrease the amount of contaminated residue at slightly higher investment costs.
Besides PCDD/F removal an important function of the active cokes technique is to remove the last remaining acid gases, dusts and heavy metals for two reasons. First to have a buffer towards the emission limits in case of changing loads or sudden malfunctioning of other parts of the cleaning system. Second to ensure a dust- and acid-free flue gas and thus to prolong the lifetime of an eventually following SCR-installation.
The fixed bed active cokes filter has relatively high investment costs and high consumption of active cokes (and subsequently a relatively large waste cokes stream). Therefore this technique will probably only be applied if very high removal efficiencies are required.

If there is no NO_x-limit like in the EC-directives no DeNOx-technique is necessary. If the NO_x-limit is set at 200 mg/Nm^3 it might be profitable to use SNCR because of the smaller investment and the easy operation. If the limit drops to 70 or 100 mg/Nm^3 SNCR needs high stoichiometric ratios of NH_3, which then requires extra NH_3-removing techniques. In that case SCR is often preferred.

5.5 Residue treatment

From the residues in general only the bottom-ash can be reused at the time. Before reuse the bottom-ash is crushed and iron scrap is removed. Several processes are under development to improve the quality to ensure disposal when the regulations are toughened. The bottom-ash which is not reused is landfilled, but because of the large amount (of bottom-ash) which is produced through MSW combustion great pressure (from the government) is executed to reuse as much as possible.

For fly-ash reuse is in fact not possible at the time: it is landfilled stacked in big bags ore fixated with cement or binder. Processes are under development to decrease the PCDD/F- and heavy metal content of the fly-ash prior to landfill, to reduce pollution risks due to leaching when landfilled. In future research will be executed to reuse fly-ash after treatment.

Flue gas cleaning residues are landfilled completely (often in big bags). At the time no processes are ready to treat the residues in order to improve landfill or reuse characteristics. Only the waste water of wet scrubbers can be used to produce concentrated hydrogen chloride, kitchen salt or gypsum. In most cases, however, the waste water is purified in a waste water cleaning process and released in the sewers or the water is evaporated and the remaining solids are landfilled.

Finally active cokes residues are combusted, until now in rotary kilns designed for chemical waste combustion. Other (combustion) options are under development.

As the emissions to the air are to a great extent controlled now by the state-of-the-art, research is more and more focusing on residues (diminishing of the total amount and improving the quality for recycling and landfill).

6 Preview final report

In the final report first of all the survey will be extended with information on the combustion facilities in Europe with capacities less than 3 tonnes per hour. Furthermore the database will be updated and the present gaps in the information will be filled in as much as possible. (The presented data refer to 1991.)

Starting from the information on the state-of-the-art description (see chapter 5, which will be more extensively treated in the final report), it will be pointed out for the facilities found in the survey, what additional measures (flue gas cleaning and emission monitoring) will have to be taken for the existing plants to comply with the proposed directive on HWC (hazardous waste combustion) [European Directives, 1992]. One example per category of how an existing installation can reach the required emission limits will be given.

The measures taken to retrofit the existing installations which will be treated are given in table 6.1. No differences are made according to the capacity of the installations. Where two options are mentioned (dry and semi-dry scrubber), option 1 is not necessarily to be preferred to option 2.

Table 6.1 Measures per flue gas cleaning category to conform to the new emission limits as set in the legislation on HWC

Categories flue gas cleaning		ESP	wet scrubber	water evaporation	active coke filter[1)]	additive injection [1)]
without cleaning		X	X	X	X	
simple cleaning (only dust removal)			X	X	X	
dry scrubber	option 1 [2)]					X
	option 2 [3)]		X	X	X	
semi-dry scrubber	option 1 [2)]					X
	option 2 [4)]		X		X	
wet scrubber	one-stage[5)]		X	X	X	
	multi-stage with water discharge			X	X	
	multi-stage without water discharge				X	

1) With active cokes filter a combination of a reactor in which active cokes is injected and a subsequent bag filter is meant (German: 'Flugstromadsorber). Additive injection implicates that the bag filter is already present (from dry or semi-dry scrubber) and that only the ad- or absorbens is changed.
2) In this option it is assumed that through the addition of extra adsorbens (like active coke) the emission limits can be met
3) In this option it is assumed that the emission limits cannot be met through the addition of extra adsorbens; the existing dry scrubber needs to be replaced but the present dust removal system can be used again in the new system.
4) In this option it is assumed that the emission limits cannot be met through the addition of extra adsorbens; the existing semi-dry scrubber and the dust removal system can be used again in the new system, to evaporate the waste water from the wet scrubber.
5) A one-stage wet scrubber cannot reach the required emission limits. It is assumed that extension to a multi-staged wet scrubber is not possible, therefore it is replaced. The dust removal system can be used again in the new system.

In these measures NO_x-emission reduction (DENOX-systems) will not be included (as there is no emission limit on NO_x in the directive on HWC). It will be assumed that no emission monitoring equipment is present yet. Modifications of the furnace and/or the boiler are not included.

Apart from describing the measures required to conform to the directive on HWC, also the average costs of these additional measures will be calculated. In these costs (as a minimum) the same cost-items will be taken into account as in the example stated in the directive on HWC. The costs will be the total of investment and operation costs.

For installations with a capacity of less than 3 tonnes per hour these costs will be expressed as a function of annual operation time (continuous operation versus

daytime shifts). For non-continuous operation no extra costs relating to extra start-up and shut-down actions will be taken into account.

The costs will be the same for all the countries considered.

Finally for the different categories the realised emission reduction and the cost thereof per tonnes MSW combusted will be calculated. To determine the emission reduction realised the present emission will be estimated on a basis of average 'raw' (= uncleaned) flue gas composition and average performances of the presently used equipment. The present emission will be compared to the emission as given in the directive on HWC.

6.1 Designing new MSWC facilities

Starting from the information on the state-of-the-art description (see chapter 5, which will be more extensively treated in the final report), one example will be given of what flue gas cleaning system will be required for a new facility to conform to the emission limits in the proposed directive on the combustion of hazardous waste. The possibilities for such a system will be restricted to a 'wet' flue gas cleaning system (i.e. incorporating a wet scrubber) with or without discharge of waste water. No differences are made according to the capacity of the installations.

For several capacities (50, 100, 200 and 500 ktonnes/year) the costs per tonne of MSW burned will be estimated. Also the main basic assumptions which lead to these estimates will be stated clearly. In these estimated costs (as a minimum) the same cost-items will be taken into account as in the example stated in the directive on HWC.

The information on costs (and the assumptions under which they are valid) will be deducted from direct available TNO-expertise. The costs will be the same for all the countries considered.

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8 Authentication

Name and address of the principal
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Names of establishments to which part of the research was put out to contract

Date upon which, or period in which, the research took place
February 1992 - June 1993

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Appendix A

Figures

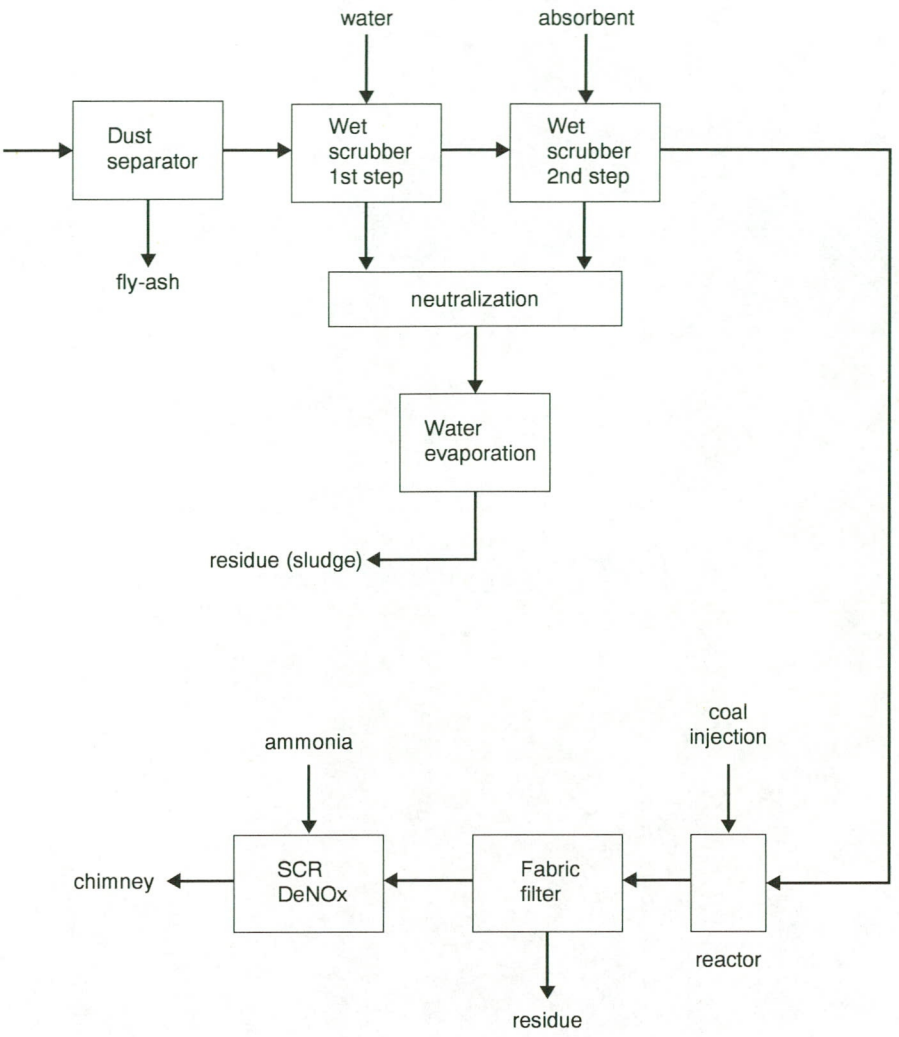

Figure 1 Block diagram of flue gas cleaning system with wet scrubber

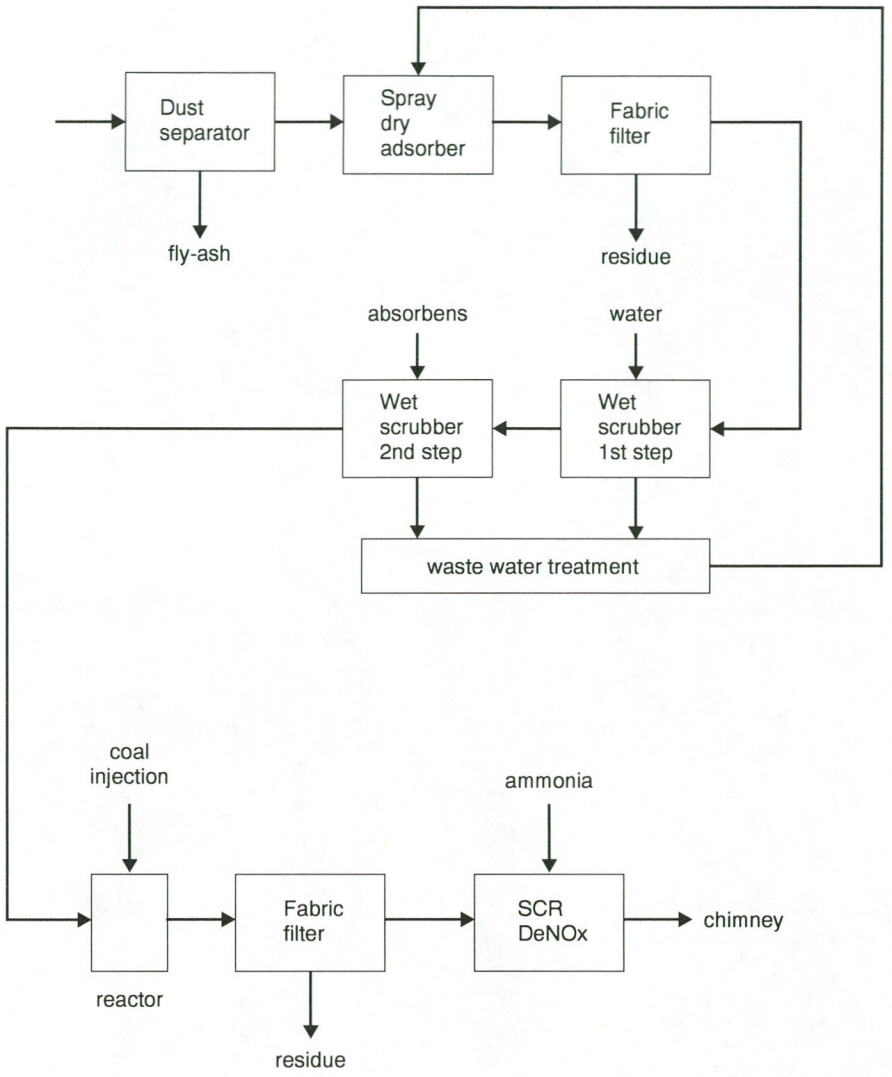

Figure 2 *Block diagram of flue gas cleaning system with wet scrubber, with evaporation of the waste water in a spray dry adsorber*

Appendix B Data per country

A Austria

Population: 7.6 million people
Total MSW: 2,800 ktonnes/year

Per capita: 370 kg/year

Table A.1 *Total amount and composition of Municipal Solid Waste generated in Austria per year (1990)*

Component	Amount	
	ktonnes/yr	% of total MSW
Putrescibles/Fines	840	30
Paper & cardboard	840	30
Plastic	250	9
Glass	280	10
Metals	110	4
Textiles	80	3
Miscellaneous	390	14
Total	2,800	100

Table A.2 *Municipal Solid Waste treatment per category in Austria (1990)*

Component	Municipal Solid Waste	
	ktonnes/yr	%
Recycling	170	6
Composting	500	18
Landfill	1,830	65
Combustion	300	11
Total	2,800	100

Existing MSW combustion facilities:
– capacity > 15 tonnes/hour 2

Table A.3 *Extent of energy recovery and flue gas cleaning in MSW combustion facilities in Austria*

Extent of energy recovery and flue gas cleaning	MSW combusted		Installations	
	ktonnes/ year	%	number	%
Energy recovery: – Yes – No	336	100	2	100
Total	336	100	2	100
Flue gas cleaning:[1)] – unknown – none – cyclone – esp – fabric filter – dry scrubber – semi-dry scrubber – wet scrubber	336	100	2	100
Total	336	100	2	100
Extended flue gas cleaning:[1)] – DeNOx – active cokes	336	100	2	100

1) Installations which have only a dust removal device and no scrubber are calculated under the dust removing device, installations which have both are calculated only under the scrubber. Most installations with scrubbers also have one of the mentioned dust removal systems. Installations which have dust removal devices, scrubbers and extended flue gas cleaning are counted to the scrubbers and are separately mentioned under the extended flue gas cleaning technique

New MSW combustion facilities:
– Wels: 1995 6.8 tonnes/hour

Sources

– OECD, 1991a+b
– PWMI, 1991
– Hodecek, 1989
– Vogel, 19??
– Gstraunhaler, Ringhofer, 1990
– Sema Group, 1991
– Thomé-Kozmiensky, 1985
– Löffler, 1991
– Lurgi, 19??
– VDI, 1992

B Belgium

Population: 9.9 million people
Total MSW: 3,500 ktonnes/year

Per capita: 352 kg/year

Table B.1 Total amount and composition of Municipal Solid Waste generated in Belgium per year (1990)

Component	Amount	
	ktonnes/yr	% of total MSW
Putrescibles/Fines	1,650	30
Paper & cardboard	980	30
Plastic	260	9
Glass	245	10
Metals	140	4
Textiles	70	3
Miscellaneous	175	14
Total	3,500	100

Table B.2 Municipal Solid Waste treatment in Belgium (1990)

Component	Municipal Solid Waste	
	ktonnes/yr	%
Recycling	100	3
Composting	0	0
Landfill	1,500	43
Combustion	1,900	54
Total	3,500	100

Existing MSW combustion facilities:
– 3 < capacity < 15 tonnes/hour 19
– capacity > 15 tonnes/hour 6

Table B.3 *Extent of energy recovery and flue gas cleaning in MSW combustion facilities in Belgium*

Extent of energy recovery and flue gas cleaning	MSW combusted		Installations	
	ktonnes/ year	%	number	%
Energy recovery:				
– Yes	1,390	62	11	44
– No	850	38	14	56
Total	2,240	100	25	100
Flue gas cleaning:[1)]				
– unknown				
– none				
– cyclone	70	3	2	8
– esp	1,670	75	16	64
– fabric filter				
– dry scrubber	150	7	3	12
– semi-dry scrubber				
– wet scrubber	350	16	4	16
Total	2,240	100	25	100
Extended flue gas cleaning:[1)]				
– DeNOx				
– active cokes				

1) Installations which have only a dust removal device and no scrubber are calculated under the dust removing device, installations which have both are calculated only under the scrubber. Most installations with scrubbers also have one of the mentioned dust removal systems. Installations which have dust removal devices, scrubbers and extended flue gas cleaning are counted to the scrubbers and are separately mentioned under the extended flue gas cleaning technique

New MSW combustion facilities:
- by 2010 all the existing installations will be shut down and replaced by 5 to 7 new large combustion facilities.

Sources
- OECD, 1991a+b
- PWMI, 1991
- Sema Group, 1991
- Jaubin, Wijs, 1991
- OVAM, 1989
- Lurgi, 19??
- Schleger, 1991
- Brussel, 19??
- OVAM, 19??
- Vandermeerschen, 1987

CH Switzerland

Population: 6.7 million people
Total MSW: 3,700 ktonnes/year

Per capita: 550 kg/year

Table CH.1 Total amount and composition of Municipal Solid Waste generated in Switzerland per year (1990)

Component	Amount	
	ktonnes/yr	% of total MSW
Putrescibles/Fines	1,110	30
Paper & cardboard	1,150	31
Plastic	480	13
Glass	260	7
Metals	220	6
Textiles	110	3
Miscellaneous	370	10
Total	3,700	100

Table CH.2 Municipal Solid Waste treatment per category in Switzerland (1990)

Component	Municipal Solid Waste	
	ktonnes/yr	%
Recycling	800	22
Composting	250	7
Landfill	450	12
Combustion	2,200	59
Total	3,700	100

Existing MSW combustion facilities:
– 3 < capacity < 15 tonnes/hour 22
– capacity > 15 tonnes/hour 8

Table CH.3 Extent of energy recovery and flue gas cleaning in MSW combustion facilities in Switzerland

Extent of energy recovery and flue gas cleaning	MSW combusted		Installations	
	ktonnes/ year	%	number	%
Energy recovery:				
– Yes	2,560	89	23	77
– No	300	11	7	23
Total	2,860	100	30	100
Flue gas cleaning:[1)]				
– unknown				
– none				
– cyclone				
– esp	1,310	46	16	53
– fabric filter				
– dry scrubber				
– semi-dry scrubber	50	2	1	3
– wet scrubber	1,500	52	13	43
Total	2,860	100	30	100
Extended flue gas cleaning:[1)]				
– DeNOx	250	9	2	7
– active cokes				

[1)] Installations which have only a dust removal device and no scrubber are calculated under the dust removing device, installations which have both are calculated only under the scrubber. Most installations with scrubbers also have one of the mentioned dust removal systems. Installations which have dust removal devices, scrubbers and extended flue gas cleaning are counted to the scrubbers and are separately mentioned under the extended flue gas cleaning technique

New MSW combustion facilities:
- Geneva 1993 unknown capacity
- Most plants will have scrubbers at the end of 1993

Sources

- OECD, 1991a+b
- PWMI, 1991
- Sema Group, 1991
- Thomé-Kozmiensky, 1985
- Bouscaren, Hollier, 1986
- Lurgi, 19??
- EVT, 19??
- VDI, 1992
- Nutec, 1992
- Schweiz, 1990a+b
- Simos, Maystre, 1988
- Larcher, 1990

D Germany

Population: 61.1 million people
Total MSW: 25,000 ktonnes/year

Per capita: 410 kg/year

Table D.1 Total amount and composition of Municipal Solid Waste generated in Germany per year (1990)

Component	Amount	
	ktonnes/yr	% of total MSW
Putrescibles/Fines	11,000	44
Paper & cardboard	6,000	24
Plastic	1,750	7
Glass	2,250	9
Metals	1,500	6
Textiles	500	2
Miscellaneous	2,000	8
Total	25,000	100

Table D.2 Municipal Solid Waste treatment per category in Germany (1990)

Component	Municipal Solid Waste	
	ktonnes/yr	%
Recycling	4000	16
Composting	500	2
Landfill	11,500	46
Combustion	9000	36
Total	25,000	100

Existing MSW combustion facilities:
– 3 < capacity < 15 tonnes/hour 9
– capacity > 15 tonnes/hour 38

Table D.3 Extent of energy recovery and flue gas cleaning in MSW combustion facilities in Germany

Extent of energy recovery and flue gas cleaning	MSW combusted		Installations	
	ktonnes/ year	%	number	%
Energy recovery:				
– Yes	11,230	100	47	100
– No				
Total	11,230	100	47	100
Flue gas cleaning:[1]				
– unknown				
– none				
– cyclone				
– esp				
– fabric filter				
– dry scrubber	1,180	11	7	15
– semi-dry scrubber	4,290	38	14	30
– wet scrubber	5,760	51	26	55
Total	11,230	100	47	100
Extended flue gas cleaning:[1]				
– DeNOx[2]	1,790	16	5	11
– active cokes	1,180	11	6	13

1) Installations which have only a dust removal device and no scrubber are calculated under the dust removing device, installations which have both are calculated only under the scrubber. Most installations with scrubbers also have one of the mentioned dust removal systems. Installations which have dust removal devices, scrubbers and extended flue gas cleaning are counted to the scrubbers and are separately mentioned under the extended flue gas cleaning technique

2) One small installation (35 ktonnes/year) applies active cokes adsorption also to reduce NO_x. This is not implied in the data for 'DeNOx' but only in the data for 'active cokes'.

New MSW combustion facilities:
- Bonn 1992 unknown capacity
- Burgkirchen 199?, 40 tonnes/hour, wet scrubber
- Schweinfurt 199?, 24 tonnes/hour, wet scrubber
- Berlin 199?, 8.5 tonnes/hour, wet scrubber
- Ulm 199?, 13 tonnes/hour, semi-dry and wet scrubber
- Plans for plants in Augsburg, Esslingen, Pirmasens, Velsen, Böblingen and Rems-Mürr

Sources

- OECD, 1991a+b
- PWMI, 1991
- Sema Group, 1991
- ISWA, 1991
- Barniske, 1989
- Wijdeven, 1991
- Volund, 19??
- VDI, 1992
- Hösel et al, 1991
- Bauer, Herrler, 1989

DK Denmark

Population: 5.1 million people
Total MSW: 2,600 ktonnes/year

Per capita: 510 kg/year

Table DK.1 Total amount and composition of Municipal Solid Waste generated in Denmark per year (1990)

Component	Amount	
	ktonnes/yr	% of total MSW
Putrescibles/Fines	1,040	40
Paper & cardboard	910	35
Plastic	130	5
Glass	100	4
Metals	130	5
Textiles	80	3
Miscellaneous		
combustibles	130	5
non-combustibles	80	3
Total	2,600	100

Table DK.2 Municipal Solid Waste treatment per category in Denmark

Component	Municipal Solid Waste	
	ktonnes/yr	%
Recycling	500	19
Composting	100	4
Landfill	750	29
Combustion	1,250	48
Total	2,600	100

Existing MSW combustion facilities:
– 3 < capacity < 15 tonnes/hour 24
– capacity > 15 tonnes/hour 5

Table DK.3 Extent of energy recovery and flue gas cleaning in MSW combustion facilities in Denmark

Extent of energy recovery and flue gas cleaning	MSW combusted		Installations	
	ktonnes/ year	%	number	%
Energy recovery: – Yes – No	2,060	100	29	100
Total	2,060	100	29	100
Flue gas cleaning:[1)] – unknown – none – cyclone – esp – fabric filter – dry scrubber – semi-dry scrubber – wet scrubber	 100 760 420 360 420	 5 37 20 18 20	 2 14 8 2 3	 7 48 28 7 10
Total	2,060	100	29	100
Extended flue gas cleaning:[1)] – DeNOx – active cokes				

1) Installations which have only a dust removal device and no scrubber are calculated under the dust removing device, installations which have both are calculated only under the scrubber. Most installations with scrubbers also have one of the mentioned dust removal systems. Installations which have dust removal devices, scrubbers and extended flue gas cleaning are counted to the scrubbers and are separately mentioned under the extended flue gas cleaning technique

New MSW combustion facilities:
- No new combustion facilities planned
- Closed down soon (1992/93): 5 plants with total capacity of 34.7 tonnes/hour (all in range 3-15 tonnes/hour)
- Closed down and rebuilt: 3 plants, total extra capacity: 16.5 tonnes/hour, 199?
- Extension 3 plants: total extra capacity: 7.3 tonnes/hour, 199?
- Aarhus: extended with 9.3 tonnes/hour, 199?
- Aalborg: extended with 12 tonnes/hour, 199?
- Amagerforbraending: extended with 12 tonnes/hour, 199?
- Nykobing: extended with 7 tonnes/hour, 1992

Sources

- Miljostyrelsen, 1989
- OECD, 1991a+b
- PWMI, 1991
- Sema Group, 1991
- ISWA, 1991
- DK-Teknik, 1991
- Miljostyrelsen, 1991a+b
- Warmer, 1992
- Tattersley, 1990
- Macdonald, 1991
- Elmlund, 1988

E Spain

Population: 38.9 million people
Total MSW: 13,300 ktonnes/year

Per capita: 340 kg/year

Table E.1 Total amount and composition of Municipal Solid Waste generated in Spain per year (1990)

Component	Amount	
	ktonnes/yr	% of total MSW
Putrescibles/Fines	6,520	49
Paper & cardboard	2,660	20
Plastic	930	7
Glass	1,060	8
Metals	530	4
Textiles	270	2
Miscellaneous:		
combustibles	930	7
non-combustibles	400	3
Total	13,300	100

Table E.2 Municipal Solid Waste treatment per category in Spain (1990) [7, 16, 24, 27, 78]

Component	Municipal Solid Waste	
	ktonnes/yr	%
Recycling	1,700	13
Composting	2,200	17
Landfill	8,650	65
Combustion	750	6
Total	13,300	100

Existing MSW combustion facilities:
- 3 < capacity < 15 tonnes/hour 5
- capacity > 15 tonnes/hour 2

Table E.3 Extent of energy recovery and flue gas cleaning in MSW combustion facilities in Spain

Extent of energy recovery and flue gas cleaning	MSW combusted		Installations	
	ktonnes/ year	%	number	%
Energy recovery:				
– Yes	540	79	4	57
– No	140	21	3	43
Total	680	100	7	100
Flue gas cleaning:[1)]				
– unknown				
– none	20	3	1	14
– cyclone	120	18	2	29
– esp	540	79	4	57
– fabric filter				
– dry scrubber				
– semi-dry scrubber				
– wet scrubber				
Total	680	100	7	100
Extended flue gas cleaning:[1)]				
– DeNOx				
– active cokes				

[1)] Installations which have only a dust removal device and no scrubber are calculated under the dust removing device, installations which have both are calculated only under the scrubber. Most installations with scrubbers also have one of the mentioned dust removal systems. Installations which have dust removal devices, scrubbers and extended flue gas cleaning are counted to the scrubbers and are separately mentioned under the extended flue gas cleaning technique

New MSW combustion facilities:
- 6 new installations will be built with total capacity of 1640 ktonnes/year (approx. 220-240 tonnes/hour), 199?
- 5 locations are examined for feasibility

Sources
- OECD, 1991a+b
- PWMI, 1991
- Sema Group, 1991
- ISWA, 1991
- Spain, 1992
- Cadman, 1989

F France

Population: 56.2 million people
Total MSW: 20,000 ktonnes/year

Per capita: 360 kg/year

Table F.1 Total amount and composition of Municipal Solid Waste generated in France per year (1990)

Component	Amount	
	ktonnes/yr	% of total MSW
Putrescibles/Fines	5,000	25
Paper & cardboard	6,000	30
Plastic	1200	6
Glass	2400	12
Metals	1000	5
Textiles	600	3
Miscellaneous	3,800	19
Total	20,000	100

Table F.2 Municipal Solid Waste treatment per category in France (1990)

Component	Municipal Solid Waste	
	ktonnes/yr	%
Recycling	600	3
Composting	2,000	10
Landfill	9,000	45
Combustion	8,400	42
Total	20,000	100

Existing MSW combustion facilities:
- 3 < capacity < 15 tonnes/hour 109
- capacity > 15 tonnes/hour 28

Table F.3 Extent of energy recovery and flue gas cleaning in MSW combustion facilities in France

Extent of energy recovery and flue gas cleaning	MSW combusted		Installations	
	ktonnes/ year	%	number	%
Energy recovery:				
– Yes	7,730	75	75	55
– No	2,590	25	62	45
Total	10,310	100	137	100
Flue gas cleaning:[1)]				
– unknown	3,270	32	76	55
– none				
– cyclone	330	3	9	7
– esp	3,830	37	29	20
– fabric filter				
– dry scrubber	340	3	6	4
– semi-dry scrubber	1,340	13	12	9
– wet scrubber	1,170	11	5	4
Total	10,310	100	137	100
Extended flue gas cleaning:[1)]				
– DeNOx				
– active cokes				

1) Installations which have only a dust removal device and no scrubber are calculated under the dust removing device, installations which have both are calculated only under the scrubber. Most installations with scrubbers also have one of the mentioned dust removal systems. Installations which have dust removal devices, scrubbers and extended flue gas cleaning are counted to the scrubbers and are separately mentioned under the extended flue gas cleaning technique

New MSW combustion facilities:
– no information available

Sources
– OECD, 1991a+b
– PWMI, 1991
– Sema Group, 1991
– ISWA, 1991
– France, 1990
– Bouscaren, Houllier, 1986
– EVT, 19??
– Schleger, 1991
– Souet, 1990

GR Greece

Population: 10.0 million people
Total MSW: 3,150 ktonnes/year

Per capita: 310 kg/year

Table GR.1 Total amount and composition of Municipal Solid Waste generated in Greece per year (1990)

Component	Amount	
	ktonnes/yr	% of total MSW
Putrescibles/Fines	1,670	53
Paper & cardboard	570	18
Plastic	220	7
Glass	100	3
Metals	130	4
Miscellaneous (textiles incl.)	470	15
Total	3,150	100

No information is available to us on the composite
No information on treatment schemes in Greece.
No MSW combustion facilities at present.
No MSW combustion facilities planned.

Sources

– OECD, 1991a+b
– PWMI, 1991
– Sema Group, 1991
– ISWA, 1991
– Papachristou, 1988
– Greece, 1991
– Moussiopoulos, 1992

I Italy

Population: 57.5 million people
Total MSW: 17,500 ktonnes/year

Per capita: 300 kg/year

Table I.1 *Total amount and composition of Municipal Solid Waste generated in Italy per year (1990)*

Component	Amount	
	ktonnes/yr	% of total MSW
Putrescibles/Fines	7,000	40
Paper & cardboard	3,850	22
Plastic	1,230	7
Glass	1,400	8
Metals	520	3
Miscellaneous textiles incl.)	3,500	20
Total	17,500	100

Table I.2 *Municipal Solid Waste treatment per category in Italy (1990)*

Component	Municipal Solid Waste	
	ktonnes/yr	%
Recycling	500	3
Composting	1,200	7
Landfill	13,000	74
Combustion	2,800	16
Total	17,500	100

Existing MSW combustion facilities:
- 3 < capacity < 15 tonnes/hour
- capacity > 15 tonnes/hour

Table I.3 *Extent of energy recovery and flue gas cleaning in MSW combustion facilities in Italy*

Extent of energy recovery and flue gas cleaning	MSW combusted		Installations	
	ktonnes/ year	%	number	%
Energy recovery:				
– Yes	2,030	79	27	73
– No	530	21	10	27
Total	2,560	100	37	100
Flue gas cleaning:[1)]				
– unknown	1,210	47	21	57
– none				
– cyclone				
– esp	895	35	10	27
– fabric filter				
– dry scrubber	100	4	2	5
– semi-dry scrubber				
– wet scrubber	355	14	4	11
Total	2,560	100	37	100
Extended flue gas cleaning:[1)]				
– DeNOx				
– active cokes				

[1)] Installations which have only a dust removal device and no scrubber are calculated under the dust removing device, installations which have both are calculated only under the scrubber. Most installations with scrubbers also have one of the mentioned dust removal systems. Installations which have dust removal devices, scrubbers and extended flue gas cleaning are counted to the scrubbers and are separately mentioned under the extended flue gas cleaning technique

New MSW combustion facilities:
– no information available

Sources
– OECD, 1991a+b
– PWMI, 1991
– Sema Group, 1991
– ISWA, 1991
– Italy, 1990
– Fraja Frangipane, 19??
– Sim, 1988

IRL Ireland

Population: 3.5 million people
Total MSW: 1,100 ktonnes/year

Per capita: 310 kg/year

Table IRL.1 Total amount and composition of Municipal Solid Waste generated in Ireland per year (1990)

Component	Amount	
	ktonnes/yr	% of total MSW
Putrescibles/Fines	610	55
Paper & cardboard	220	20
Plastic	110	10
Glass	30	3
Metals	30	3
Textiles	30	3
Miscellaneous	70	6
Total	1,100	100

Table IRL.2 Municipal Solid Waste treatment per category in Ireland (1990)

Component	Municipal Solid Waste	
	ktonnes/yr	%
Recycling	35	3
Composting	0	0
Landfill	1,065	97
Combustion	0	0
Total	1,100	100

No MSW combustion facilities at present.
No MSW combustion facilities planned.

Sources

- OECD, 1991a+b
- PWMI, 1991
- Sema Group, 1991
- Schoenberg, 1991
- Ireland, 1992

L Luxembourg

Population: 0.4 million people
Total MSW: 180 ktonnes/year

Per capita: 480 kg/year

Table L.1 Total amount and composition of Municipal Solid Waste generated in Luxembourg per year (1990)

Component	Amount	
	ktonnes/yr	% of total MSW
Putrescibles/Fines	85	47
Paper & cardboard	50	28
Plastic	13	7
Glass	13	7
Metals	7	4
Textiles	4	2
Miscellaneous	9	5
Total	180	100

Table L.2 Municipal Solid Waste treatment per category in Luxembourg (1990)

Component	Municipal Solid Waste	
	ktonnes/yr	%
Recycling	4	2
Composting	2	1
Landfill	39	22
Combustion	135	75
Total	180	100

Existing MSW combustion facilities:
– capacity > 15 tonnes/hour 1

Table L.3 *Extent of energy recovery and flue gas cleaning in MSW combustion facilities in Luxembourg*

Extent of energy recovery and flue gas cleaning	MSW combusted		Installations	
	ktonnes/ year	%	number	%
Energy recovery: – Yes – No	168	100	1	100
Total	168	100	1	100
Flue gas cleaning:[1)] – unknown – none – cyclone – esp – fabric filter – dry scrubber – semi-dry scrubber – wet scrubber	168	100	1	100
Total				
Extended flue gas cleaning:[1)] – DeNOx – active cokes				

1) Installations which have only a dust removal device and no scrubber are calculated under the dust removing device, installations which have both are calculated only under the scrubber. Most installations with scrubbers also have one of the mentioned dust removal systems. Installations which have dust removal devices, scrubbers and extended flue gas cleaning are counted to the scrubbers and are separately mentioned under the extended flue gas cleaning technique

New MSW combustion facilities:
– no changes in existing situation foreseen

Sources
– OECD, 1991a+b
– PWMI, 1991
– Sema Group, 1991
– Eickmann, 1992
– EVT, 19??
– Kirsch, 19??

N Norway

Population: 4.2 million people
Total MSW: 2,000 ktonnes/year

Per capita: 470 kg/year

Table N.1 Total amount and composition of Municipal Solid Waste generated in Norway per year (1990)

Component	Amount	
	ktonnes/yr	% of total MSW
Putrescibles/Fines	500	25
Paper & cardboard	640	32
Plastic	140	7
Glass	80	4
Metals	80	4
Textiles	40	2
Miscellaneous:		
combustibles	280	14
non-combustibles	240	12
Total	2,000	100

Table N.2 Municipal Solid Waste treatment per category in Norway (1990)

Component	Municipal Solid Waste	
	ktonnes/yr	%
Recycling	140	7
Composting	100	5
Landfill	1,330	67
Combustion	430	22
Total	2,000	100

Existing MSW combustion facilities:
– 3 < capacity < 15 tonnes/hour 4
– capacity > 15 tonnes/hour 1

Table N.3 Extent of energy recovery and flue gas cleaning in MSW combustion facilities in Norway

Extent of energy recovery and flue gas cleaning	MSW combusted		Installations	
	ktonnes/ year	%	number	%
Energy recovery: – Yes – No	410	100	5	100
Total	410	100	5	100
Flue gas cleaning:[1)] – unknown – none – cyclone – esp – fabric filter – dry scrubber – semi-dry scrubber – wet scrubber	410	100	5	100
Total	410	100	5	100
Extended flue gas cleaning:[1)] – DeNOx – active cokes				

1) Installations which have only a dust removal device and no scrubber are calculated under the dust removing device, installations which have both are calculated only under the scrubber. Most installations with scrubbers also have one of the mentioned dust removal systems. Installations which have dust removal devices, scrubbers and extended flue gas cleaning are counted to the scrubbers and are separately mentioned under the extended flue gas cleaning technique

New MSW combustion facilities:
– two permits for combustion facilities have been granted, but no decisions on size, location, etc. have been made yet.

Sources
– OECD, 1991a+b
– PWMI, 1991
– Sema Group, 1991
– ISWA, 1991
– Pettersen, Namdal, 1992
– Lurgi, 19??
– Norway, 1990a+b
– Götaverken, 19??

NL The Netherlands

Population: 14.8 million people
Total MSW: 7,700 ktonnes/year

Per capita: 520 kg/year

Table NL.1 Total amount and composition of Municipal Solid Waste generated in The Netherlands per year (1990)

Component	Amount	
	ktonnes/yr	% of total MSW
Putrescibles/Fines	2,930	38
Paper & cardboard	2,700	35
Plastic	540	7
Glass	540	7
Metals	390	5
Textiles	150	2
Miscellaneous:		
combustibles	310	4
non-combustibles	150	2
Total	7,700	100

Table NL.2 Municipal Solid Waste treatment per category in The Netherlands (1990)

Component	Municipal Solid Waste	
	ktonnes/yr	%
Recycling	1,200	16
Composting	350	3
Landfill	3,450	45
Combustion	2,700	35
Total	7,700	100

Existing MSW combustion facilities:
– 3 < capacity < 15 tonnes/hour 4
– capacity > 15 tonnes/hour 6

Table NL.3 Extent of energy recovery and flue gas cleaning in MSW combustion facilities in The Netherlands

Extent of energy recovery and flue gas cleaning	MSW combusted		Installations	
	ktonnes/ year	%	number	%
Energy recovery:				
– Yes	2,720	97	9	90
– No	80	3	1	10
Total	2,800	100	10	100
Flue gas cleaning:[1)]				
– unknown				
– none				
– cyclone				
– esp	2,090	75	4	40
– fabric filter				
– dry scrubber	80	3	1	10
– semi-dry scrubber				
– wet scrubber	630	23	5	50
Total	2,800	100	10	100
Extended flue gas cleaning:[1)]				
– DeNOx				
– active cokes				

[1)] Installations which have only a dust removal device and no scrubber are calculated under the dust removing device, installations which have both are calculated only under the scrubber. Most installations with scrubbers also have one of the mentioned dust removal systems. Installations which have dust removal devices, scrubbers and extended flue gas cleaning are counted to the scrubbers and are separately mentioned under the extended flue gas cleaning technique

New MSW combustion facilities:
- Amsterdam-West, 1993, 765 ktonnes/year, semi-dry scrubber
- Alkmaar, 1995, 55.5 tonnes/hour, wet scrubber
- Extension AVR Rotterdam with 27 tonnes/hour, 1993
- Extension for 2 plants: total extra capacity 230 ktonnes/year
- Closing down: 2 in 1993: 1 * 52.5 and 1 * 64 tonnes/hour, 1 in 1995: 12 tonnes/hour
- Wet scrubber for AVR and ROTEB Rotterdam, 1993
- 5 new combustors planned before the year 2000: total capacity 2350 ktonnes/year.

Sources

- OECD, 1991a+b
- PWMI, 1991
- Sema Group, 1991
- ISWA, 1991
- TNO 1992
- Wijdeven, 1991
- RIVM, 1989
- Brasser, 1990
- The Netherlands, 1989
- Beusekom, 1991
- Nagelhout et al, 1989
- Folmer, 19??

P Portugal

Population: 10.3 million people
Total MSW: 2,650 ktonnes/year

Per capita: 260 kg/year

Table P.1 *Total amount and composition of Municipal Solid Waste generated in Portugal per year (1990)*

Component	Amount	
	ktonnes/yr	% of total MSW
Putrescibles/Fines	1,590	60
Paper & cardboard	580	22
Plastic	110	4
Glass	80	3
Metals	110	4
Miscellaneous (textiles incl.)	190	7
Total	2,650	100

Table P.2 *Municipal Solid Waste treatment per category in Portugal (1990)*

Component	Municipal Solid Waste	
	ktonnes/yr	%
Recycling	0	0
Composting	400	15
Landfill	2,250	85
Combustion	0	0
Total	2,650	100

No MSW combustion plants at present.
No information available on new plants planned.

Sources
- OECD, 1991a+b
- PWMI, 1991
- Sema Group, 1991
- Warmer, 1989
- Cadman, 1989

S Sweden

Population: 8.5 million people
Total MSW: 3,200 ktonnes/year

Per capita: 380 kg/year

Table S.1 Total amount and composition of Municipal Solid Waste generated in Sweden per year (1990)

Component	Amount	
	ktonnes/yr	% of total MSW
Putrescibles/Fines	960	30
Paper & cardboard	1,280	40
Plastic	260	9
Glass	220	7
Metals	100	3
Textiles	60	2
Miscellaneous	290	9
Total	3,200	100

Table S.2 Municipal Solid Waste treatment per category in Sweden (1990)

Component	Municipal Solid Waste	
	ktonnes/yr	%
Recycling	500	16
Composting	100	3
Landfill	1,100	34
Combustion	1,500	47
Total	3,200	100

Existing MSW combustion facilities:
- 3 < capacity < 15 tonnes/hour 11
- capacity > 15 tonnes/hour 6

Table S.3 *Extent of energy recovery and flue gas cleaning in MSW combustion facilities in Sweden*

Extent of energy recovery and flue gas cleaning	MSW combusted		Installations	
	ktonnes/ year	%	number	%
Energy recovery:				
– Yes	1,770	100	17	100
– No				
Total	1,770	100	17	100
Flue gas cleaning:[1]				
– unknown				
– none				
– cyclone				
– esp				
– fabric filter	100	6	3	18
– dry scrubber	950	54	8	47
– semi-dry scrubber				
– wet scrubber [2]	720	41	6	35
Total	1,770	100	17	100
Extended flue gas cleaning:[1]				
– DeNOx				
– active cokes	220	12	1	6

1) Installations which have only a dust removal device and no scrubber are calculated under the dust removing device, installations which have both are calculated only under the scrubber. Most installations with scrubbers also have one of the mentioned dust removal systems. Installations which have dust removal devices, scrubbers and extended flue gas cleaning are counted to the scrubbers and are separately mentioned under the extended flue gas cleaning technique

2) Included is one installation which has a wet scrubber as well as a dry scrubber. This installation is not calculated under dry scrubber

New MSW combustion facilities:
— Extension of the Goteborg combustor with 105 ktonnes/year

Sources

- OECD, 1991a+b
- Haley, 1990
- PWMI, 1991
- Hagenmaier, 1989
- Sema Group, 1991
- Thomé-Kozmiensky, 1985
- Svenska, 1991
- ISWA, 1991
- VDI, 1992
- Gotaverken, 19??
- RVF, 1990
- Bergström, 1989

SF Finland

Population: 5.0 million people
Total MSW: 2,500 ktonnes/year

Per capita: 500 kg/year

Table SF.1 Total amount and composition of Municipal Solid Waste generated in Finland per year (1990)

Component	Amount	
	ktonnes/yr	% of total MSW
Putrescibles/Fines	750	30
Paper & cardboard	1,000	40
Plastic	150	6
Glass	100	4
Metals	80	3
Miscellaneous (textiles incl.)	430	17
Total	2,500	100

Table SF.2 Municipal Solid Waste treatment per category in Finland (1990)

Component	Municipal Solid Waste	
	ktonnes/yr	%
Recycling	375	15
Composting	0	0
Landfill	2,075	83
Combustion	50	2
Total	2,500	100

Existing MSW combustion facilities:
– 3 < capacity < 15 tonnes/hour 1

Table SF.3 Extent of energy recovery and flue gas cleaning in MSW combustion facilities in Finland

Extent of energy recovery and flue gas cleaning	MSW combusted		Installations	
	ktonnes/ year	%	number	%
Energy recovery: – Yes – No	70	100	1	100
Total	70	100	1	100
Flue gas cleaning:[1)] – unknown – none – cyclone – esp – fabric filter – dry scrubber – semi-dry scrubber – wet scrubber	70	100	1	100
Total	70	100	1	100
Extended flue gas cleaning:[1)] – DeNOx – active cokes				

1) Installations which have only a dust removal device and no scrubber are calculated under the dust removing device, installations which have both are calculated only under the scrubber. Most installations with scrubbers also have one of the mentioned dust removal systems. Installations which have dust removal devices, scrubbers and extended flue gas cleaning are counted to the scrubbers and are separately mentioned under the extended flue gas cleaning technique

New MSW combustion facilities:
- Pori, 1993/4, 34-60 ktonnes/year
- Helsinki, 199?, 400-600 ktonnes/year (uncertain)

Sources
- OECD, 1991a+b
- PWMI, 1991
- Sema Group, 1991
- Kuusisto, 1992
- Ojala, 1991
- Finland, 1987
- Finland, 1992

UK United Kingdom

Population: 57.2 million people
Total MSW: 30,000 ktonnes/year

Per capita: 520 kg/year

Table UK.1 Total amount and composition of Municipal Solid Waste generated in the United Kingdom per year (1990)

Component	Amount	
	ktonnes/yr	% of total MSW
Putrescibles/Fines	12,600	42
Paper & cardboard	8,400	28
Plastic	2,100	7
Glass	2,400	8
Metals	2,700	9
Textiles	1,200	4
Miscellaneous:		
combustibles	300	1
non-combustibles	300	1
Total	30,000	100

Table UK.2 Municipal Solid Waste treatment per category in the United Kingdom (1990)

Component	Municipal Solid Waste	
	ktonnes/yr	%
Recycling	600	2
Composting	0	0
Landfill	27,000	90
Combustion	2,400	8
Total	30,000	100

Existing MSW combustion facilities:
– 3 < capacity < 15 tonnes/hour 16
– capacity > 15 tonnes/hour 15

Table UK.3 Extent of energy recovery and flue gas cleaning in MSW combustion facilities in the United Kingdom

Extent of energy recovery and flue gas cleaning	MSW combusted		Installations	
	ktonnes/ year	%	number	%
Energy recovery:				
– Yes	1,040	28	6	19
– No	2,610	72	25	81
Total	3,640	100	31	100
Flue gas cleaning:[1)]				
– unknown				
– none	40	1	1	3
– cyclone	180	5	3	10
– esp	3,420	94	27	87
– fabric filter				
– dry scrubber				
– semi-dry scrubber				
– wet scrubber				
Total	3,640	100	31	100
Extended flue gas cleaning:[1)]				
– DeNOx				
– active cokes				

1) Installations which have only a dust removal device and no scrubber are calculated under the dust removing device, installations which have both are calculated only under the scrubber. Most installations with scrubbers also have one of the mentioned dust removal systems. Installations which have dust removal devices, scrubbers and extended flue gas cleaning are counted to the scrubbers and are separately mentioned under the extended flue gas cleaning technique

New MSW combustion facilities:
- London, 400 ktonnes/year, 1994?
- London, 1200-1500 ktonnes/year, 199?
- Leeds, 300 ktonnes/year, 199?
- Isle of Man, 24 ktonnes/year, 199?
- Portsmouth, 300 ktonnes/year, on old site
- Birkenhead, 18 ktonnes/year, 1994
- Approx. 20 of the 31 combustion facilities will close down before 1996
- Plans for combustors in Derby and Birmingham on old sites

Sources

- Patel, 1991
- OECD, 1991a+b
- PWMI, 1991
- Clayton et al, 1991
- Sema Group, 1991
- ISWA, 1991
- Warmer, 1992
- Cooper, 19??